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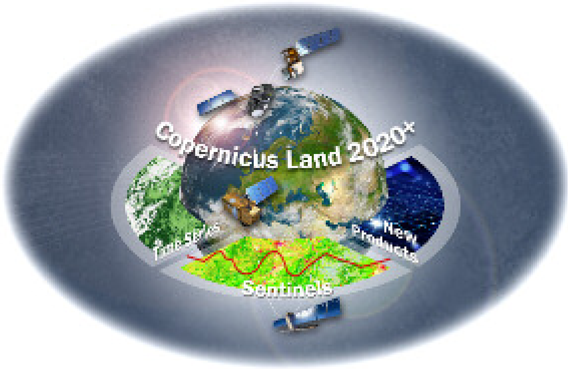
ECoLaSS

Evolution of Copernicus Land Services based on Sentinel data



D17.1

"D52.1a - Report on Candidates for Operational Roll-out"

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Applicable Documents

ID	Document Name / Issue Date
AD01	Horizon 2020 Work Programme 2016 – 2017, 5 iii. Leadership in Enabling and Industrial Technologies – Space. Call: EO-3-2016: Evolution of Copernicus services. Issued: 13.10.2015
AD02	Guidance Document: Research Needs Of Copernicus Operational Services. Final Version issued: 30.10.2015

ID	Document Name / Issue Date
AD03	Proposal: Evolution of Copernicus Land Services based on Sentinel data. Proposal acronym: ECoLaSS, Proposal number: 730008. Submitted: 03.03.2016
AD04	Grant Agreement – ECoLaSS. Grant Agreement number: 730008 – ECoLaSS – H2020-EO-2016/H2020-EO-2016, Issued: 18.10.2016
AD05	D3.1a – D21.1a - Service Evolution Requirements Report (Issue 1). Issued: 09.08.2017
AD06	D11.1 – D41.1a - Prototype Report: Time Series-derived Indicators and Variables (Issue 1). Issued: 10.08.2018
AD07	D12.1 – D42.1a - Prototype Report: Consistent HR Layer Time Series/Incremental Updates (Issue 1). Issued: 23.07.2018
AD08	D13.1 – D43.1a - Prototype Report: Improved Permanent Grassland (Issue 1). Issued: 17.07.2018
AD09	D14.1 – D44.1a - Prototype Report: Crop Area and Crop Status Parameters (Issue 1). Issued: 10.08.2018
AD10	D15.1 – D45.1a - Prototype Report: New LC/LU Products (Issue 1). Issued: 03.08.2018
AD11	D16.2 – D51.1b - Stakeholder Consultation Report (Issue 2). Issued: 20.07.2018

EXECUTIVE SUMMARY

The Horizon 2020 (H2020) project, "Evolution of Copernicus Land Services based on Sentinel data" (ECoLaSS) addresses the H2020 Work Programme 5 iii. Leadership in Enabling and Industrial technologies - Space, specifically the Topic EO-3-2016: Evolution of Copernicus services. ECoLaSS will be conducted from 2017–2019 and aims at developing and prototypically demonstrating selected innovative products and methods for future next-generation operational Copernicus Land Monitoring Service (CLMS) products of the pan-European and Global Components. This will contribute to demonstrating operational readiness of the finally selected products, and shall allow the key CLMS stakeholders (i.e. mainly the Entrusted European Entities (EEE), EEA and JRC) to take informed decisions on potential procurement of the next generation of Copernicus Land services from 2020 onwards.

To achieve this goal, ECoLaSS will make full use of dense time series of Sentinel-2 and Sentinel-3 optical data as well as Sentinel-1 Synthetic Aperture Radar (SAR) data. Rapidly evolving scientific as well as user requirements will be analysed in support of a future pan-European roll-out of new/improved CLMS products, and the transfer to global applications.

This Deliverable **D17.1: "D52.1a - Report on Candidates for Operational Roll-out"** is based on the technical developments and subsequent prototype implementations that have been achieved for each candidate in Task 3 and Task 4 of the project. In WP31–35, methods applying high volume data processing of mainly Sentinel-1 and -2 time series were developed, and in WP41–45, these methods have been used to develop and analyse the resulting prototypes in the thematic fields of Indicators and Variables, Imperviousness, Forest, Grassland, Agriculture and New LC/LU Products, which are described in detail in the respective WP reports.

This deliverable provides a benchmarking evaluation of all developed prototypes in the ECoLaSS project phase 1 under different benchmarking criteria, in order to identify the most cost-efficient, most urgently needed, technologically most advanced product(s). The assessment concludes to three prototypes being most promising to be mature for future CLMS implementation 2020+ ("Incremental IMD Change", "Improved Grassland Status Layer at 10m", and "Incremental Forest Change"), five prototypes showing high potential for roll-out as operational CLMS product 2020+ (Improved IMD Status Layer at 10m", "Improved IMD Status Layer at 10m", "New Crop Mask Status Layer at 10m", "New Crop Type Status Layer at 10m" and "Crop Grownth Condition"), and four prototypes needing additional research to become mature enough due to still being in an experimental phase ("CLC Evolution", "Crop Emergence Date Map", "Generic Landcover Metrics" and "Multi-Annual Trends and Potential Change").

Section 1 of this document provides a general introduction to the benchmarking process. The procedure and selected benchmarking criteria are explained in Section 2. Section 3 presents an overview on the candidates to be benchmarked and the planned evolution for phase 2. The benchmarking itself is described in Section 4. Each candidate is rated according to relevant technical, political and financial criteria in order to identify the most suitable products and methods to be further developed in project phase 2. A conclusion and outlook is finally presented in Section 5.

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Abbreviations

CAP	Common Agricultural Policy
CLC	Corine Land Cover
Cl_green	Chlorophyll Index Green
CLMS	Copernicus Land Monitoring Service
Cl-red_edge	Chlorophyll Index RedEdge
CoV	Coherence value
DG AGRI	Directorate-General for Agriculture and Rural Development
DIAS	Data and Information Access Service
DIFF	difference value
DLT	Dominant Leaf Type
DS	Downstream
EAGLE matrix	matrix of the EIONET Action Group on Land monitoring in Europe containing basic components of LC/LU/characteristics of landscape
EC	European Commission
ECoLaSS	Evolution of Copernicus Land Services based on Sentinel data
EEA	European Environmental Agency
EEE	Entrusted European Entities
ENFIN	European Network of Forest Inventories
EO	Earth Observation
EU-Hydro	Pan-European Layer on River networks, water bodies and drainage systems
EVI	Enhanced Vegetation Index
FCC	Forst Cover Change
GRA	High Resolution Layer Grassland
GSAA	Geospatial Aid Application
H2020	Horizon 2020
HRL	High Resolution Layer
HR	High Resolution
IACS	Integrated Agricultural Control System
IMC	Imperviousness Change
IMD	Imperviousness Degree
InVeKoS	Integriertes Verwaltungs- und Kontrollsystem
IPR	Infrared Percentage Ratio
IRS	Indian Remote Sensing (satellite)
ITT	Invitation To Tender
JRC	Joint Research Centre
LC/LU	Land Use/ Land Cover
LISS	Linear-Imaging Self-Scanning System (onboard of IRS-1A satellite)
LPIS	Land Parcel Identification System
Ls	Landsat (satellite)
LUCAS	Land Use and Coverage Area frame Survey
MCARI	Modified Chlorophyll Absorption in Reflectance Index
MAX	Maximum value
MEAN	Mean value
MIN	Minimum value
MMU	Minimum Mapping Unit
MMW	Minimum Mapping Width
MPA	Maximum Phenological Activity
MR	Medium Resolution
MTCI	MERIS Terrestrial chlorophyll index
NBR	Normalized Burn Ratio
NFIs	National Forest Inventories

NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NDMI	Normalized Difference Moisture Index
NDRE	Normalized Difference RedEdge
NLC	New Land Cover layer
NNIR	Sentinel-2 - Short Wavelength Infrared - B8a
OA	Overall accuracy
OSAVI	Optimized Soil-Adjusted Vegetation Index
OSM	Open Street Map
PA	Producers's accuracy
PPI	Plant Phenology Index
REP	Red-Edge Position Linear Interpolation
R&D	Research & Development
RF	Random Forest
SAR	Synthetic Aperture Radar
SAVI	Soil-Adjusted Vegetation Index
STD	standard deviation value
SVM	Support Vector Machine classifier
SW	Software
WaW	(High Resolution Layer) Water and Wetness
SWIR	Short Wave Infrared
TCARI	Transformed Chlorophyll Absorption Reflectance Index
TCB	Tasseled Cap Brightness
TCC	Tree Cover Change
TCD	Tree Cover Density
TCG	Tasseled Cap Greenness
TCW	Tasseled Cap Wetness
UA	User's accuracy
VHR	Very High Resolution
VI	Vegetation index
WBS	Work Breakdown Structure
WP	Work Package
WPD	Work Package Description

1 Introduction

The aim of WP 52 "Candidates for Operational Roll-out" is to benchmark the investigated new/improved Copernicus Land products developed and prototypically implemented in the Tasks 3 and 4, in terms of their overall readiness for future operational implementation. This is deemed to provide direct benefit to the operational Copernicus Land Monitoring Service, helping to ensure its state-of-the-art also from 2020 onwards. The WP 52 activities commenced after T_0+12 and are/will be conducted largely in parallel with the prototype development and implementation of the Task 4 WPs, throughout the two project phases.

Benchmarking is an industrial process to objectively compare methodologies/products in terms of pre-defined criteria, in order to identify the most cost-efficient, most urgently needed, technologically most advanced, etc. method(s) or product(s). The benchmarking process will determine which prototypes shall finally become candidates for operational roll-out, and which ones will need further research and development. The actual benchmarking method and the related criteria will be elaborated by WP 52 and provided to EC for approval upfront its application.

The selection of benchmark criteria during the project will be undertaken in close consultation with the EC from (i) the H2020 Work Programme 2016-2017, *5iii. Leadership in Enabling and Industrial Technologies – Space*, and the Guidance Document *Research Needs of Copernicus Operational Services* associated with the addressed Call *EO-3-2016: Evolution of Copernicus services*, (ii) further service evolution requirements voiced by users, as will be collected by WP 21, (iii) additional recommendations gathered in the stakeholder consultation process undertaken by WP 51, (iv) external findings from other sources that might become available during the course of the project (such as e.g. from the *GIO/Copernicus Land Monitoring Service: Validation of Products* project, the *High Resolution Layer 2015* production, or the *High Resolution Layers 2018 ITT*, and (v) further criteria which were expressed by EC, the project reviewer, EEA or JRC at project Kick-Off, at later review meetings or project meetings.

The present deliverable *D52.1 Report on Candidates for Operational Roll-out* contains in a clear and transparent manner: (i) a complete documentation of all benchmarking criteria, (ii) an overview of the developed prototypes in the ECoLaSS project phase 1 that are to be benchmarked, as well as (iii) a documentation of the obtained results, i.e. the resulting candidate products for operational roll-out.

Results of this benchmarking will feed directly into WP 53 "Integration Plan into the Copernicus Service Architecture" and, moreover, into Task 3 and Task 4 developments of the second project phase as well as the second round of stakeholder consultations as part of WP 51.

2 Benchmarking Process

In the following two sections, the benchmarking process is described. The benchmarking and its aim and main parameters are explained in section 2.1, and the benchmarking criteria applied to the prototypes are presented in section 2.2.

2.1 Definition of the Benchmarking Process

Benchmarking is an industrial process to objectively compare methodologies/products in terms of pre-defined criteria, in order to identify the most cost-efficient, most urgently needed, technologically most advanced, etc. method(s) or product(s). Consequently, the benchmarking will be conducted in this project by the two industrial partners GAF and SIRS, who have a proven-track experience in operational Copernicus Land services, related methods and requirements. In order to avoid any bias, they shall follow the strict principle that the experts conducting the benchmarking will be fully independent from the teams developing and implementing the methods and prototypes in Tasks 3 and 4.

The benchmarking process will determine which prototypes shall finally become candidates for operational roll-out, and which ones will need further research and development.

2.2 Selection of Benchmarking Criteria

The selection of benchmark criteria was undertaken in close consultation with the EC. Several information sources have been evaluated in order to derive appropriate criteria to compare the performance of the prototypes. Important data sources were the H2020 Work Programme 2016-2017, *5iii. Leadership in Enabling and Industrial Technologies – Space* and the Guidance Document *Research Needs of Copernicus Operational Services* associated with the addressed Call *EO-3-2016: Evolution of Copernicus services* that were analysed, as these documents provide the guideline for the ECoLaSS service evolution needs. Secondly, service and product requirements as voiced by users and as collected by WP 21 as well as additional recommendations gathered in the stakeholder consultation process undertaken by WP 51 were considered. These suggestions have been evaluated and realised by the prototypes whenever possible and technically feasible. Furtheron, findings from other projects like e.g. from the *GIO/Copernicus Land Monitoring Service: Validation of Products* project, the *High Resolution Layer 2015* production, or the *High Resolution Layers 2018 ITT* were taken into account. Finally, criteria expressed by EC, the project reviewer, EEA or JRC at project Kick-Off or at later review meetings or project meetings have been included. From this selection process, the following benchmark criteria appear imperative and have finally been chosen for the benchmarking process:

- representing a **long-term service evolution challenge,** rather than becoming likely part of "regular" service maintenance and enhancement efforts covered already by the current tasks delegated to the EEEs through the Copernicus work programme and funding until 2020 (e.g. in the latest Copernicus 2015 projects and upcoming Copernicus calls 2018);
- maintaining a sufficient level of **complementarity with respect to the Copernicus portfolio,** and alignment to the **current and upcoming Copernicus Land service environment's overall logic and setup**;
- answering to identified **high-priority evolution needs** (as e.g. listed in the *Guidance Document*) in response to known shortcomings;
- having **political support** (e.g. from EEEs side);
- respecting the border between **Copernicus core services** and **downstream (DS) services**;
- being based on the **latest scientific state of the art**;
- providing **appropriate timing**, which will allow that R&D results will become available in a sufficiently timely manner in order to support an informed stakeholder discussion, thus enabling smooth integration into the calendar of future operational Copernicus Land Monitoring service procurements;
- providing overall **technical maturity**;
- **operational feasibility** in terms of adequate (future) availability of:

  - (i) required EO/in-situ input data,
  - (ii) data processing and handling capacities, as well as
  - (iii) related hardware/software solutions and processing infrastructure;
- reaching a **high level of automation**, thus avoiding undue efforts and costs for manual interaction;
- providing convincing evidence of **service roll-out potential to pan-European level**;
- showing a good trade-off between expected costs and information gain by means of a **positive cost/benefit analysis**;
- availability of a **proper documentation** of methods and product/service specifications;
- **non-limiting conditions** for making the results (including IPR) available to the EEEs, their contractors and service providers, for use and exploitation. It is assumed that this wil be non-limiting in any case, therefore it is not included in the evaluation.

Based on these criteria, a transparant and comparable investigation of all phase 1 products and services was carried out. Each prototype and methodology was verified impartially to find out which candidates are best suited for a future service evolution. Five threshold levels (++, +, o, -, - -) were used to determine the degree of conformity (level of satisfaction or relevance) with the respective benchmarking criteria.

The benchmarking was performed by experts on the field that were not directly involved in the production of the products/services in order to guarantee a non-biased rating. To avoid misunderstandings during the evaluation, a detailed explanation was provided with examples for positive and negative rating, which is listed below in Table 1.

Table 1: Explanation of benchmarking criteria

Criteria	Explanation for evaluation of the respective criteria
Long-term evolution	(+) Candidate is not yet part of the HRL2018 ITT (-) Candidate is already part of the HRL2018 ITT
Portfolio complementarity	(+) Candidate generates an additional/added value to the existing Copernicus portfolio (-) Candidate is already existing in the HRL2018 portfolio
Answering identified needs	(+) the candidate refers to (i) the Task 2 user needs, or (ii) the user needs are known from current developments (-) the development was not mentioned by users or is not part of any relevant Copernicus documentation
Political support	(+) Candidate has political support (e.g. from EEE side) (-) Candidate is lacking political support or requirements
Respecting core vs. DS	(+) Candidate is far away from a possible downstream service (-) Candidate is close to a downstream service
State of the art/Innovation	(+) Candidate is produced following the scientific-technical state of the art (-) Candidate is lagging behind the scientific-technical state of the art
Maturity/Timing	(+) Candidate can be established until end 2020 (-) Candidate will not be mature until end of 2020
Adequate EO availability	(+) Adequate EO data are available to produce the respective candidate (-) Adequate EO data are not available as needed to produce the respective candidate

Adequate in-situ availability	(+) Adequate in-situ data are available to produce this the respective candidate (-) Adequate in-situ data are missing/not available as neededto produce the respective candidate
Processing capacity (platform, SW)	(+) Technical infrastrucuture (e.g. DIAS) is at place to produce the candidate (-) Technical infrastructure for candidate production is missing
Automation level	(+) Candidate can be produced with high automation level (-) Manual work or intermediate interactions are required to establish candidate
Pratically proven roll-out potential	(+) Roll-out potential has been proven on prototype sites and prototype has worked well (-) Prototype been proven on prototype sites and turns out to have less roll-out potential
Cost/ benefit (forecast)	(+) Effort/costs are low and and outcome is high (o/+) Effort/costs are high and outcome is high as well (-) Effort/costs are high and outcome is low. Cost means the costs of a service under operational conditions (including infrastructure costs, manpower, data, developments, etc.).
Documentation	(+) Adequate documentation is exisiting (in terms of ECoLaSS report and deliverables) (-) Adequate documentation is missing or does not give the full picture of the prototype

3 Overview of Prototypes to be Benchmarked

Chapter 3 provides the basis for the benchmarking evaluation in Chapter 4. Therefore, first the service evolution requirements as gained from the work in WP 21 are stated and amended with an explanation on the level and contents – if and how they were taken up in the first phase of the ECoLaSS prototype production (section 3.1). In the following, a description of each candidate prototype is provided, focussing on its input data, prototype sites, methodology, results, and further plans in ECoLaSS phase 2 (section 3.2). Thereafter, a table summarizing and comparing the specifications of the High Resolution Layers 2015 production, the High Resolution Layers 2018 ITT and the ECoLaSS prototypes of phase 1 is provided (section 3.3).

3.1 Service Evolution Requirements for Prototypes

This section presents a table (see Table 2) distilled from the WP 21 Service Evolution Requirements Report with focus on the pan-European and global prototypes as developed in ECoLaSS. The local component is included in requirements analysis but not scope of the ECoLaSS prototype development.

Table 2: Service evolution requirements taken up in ECoLaSS

Product Group	Requirement	Taken up in ECoLaSS prototypes Yes Partially No	Comment on how the requirement is addressed in ECoLaSS
HRL in general	Higher temporal resolution/more frequent updates: from current 3-yearly update cycle to shorter (e.g. yearly) updates, depending on the HRL product.	Yes	ECoLaSS targets yearly incremental update layers for Forest and Imperviousness (phase 1+2) as well as grassland (phase 2).
HRL in general	Higher temporal frequency of spatially partial (yearly) updates: Regular (yearly) updates solely regarding changes.	Yes	ECoLaSS targets yearly incremental update layers for Forest and Imperviousness (phase 1+2) as well as for Grassland (phase 2). The yearly incremental update layer is a change layer focussing only on changes in that period.
HRL in general, especially GRA and WET/WaW	Developments towards dynamic HRL products.	No	Dynamic HRL products are for the moment out of scope from a technical processing/data availability point of view.
HRL in general	Yearly alert by change detection only.	Yes	The yearly incremental update layer is a change layer focussing only on changes in that period.
HRL in general	Shortened production time: Increased timeliness of availability of the products	Yes	The highly automated approach in ECoLaSS as well as the increasing density of available sensors should enable shorter production times of future CLMS products.
HRL in general	Change from largely mono-temporal classification to time series analysis and multi-sensor analysis shall be further fostered, including SAR data where possible.	Yes	The approach in ECoLaSS is purely focussed on the application of dense S1 and S2 time series.

HRL in general	Increased product quality is expected through the use of time series data as input.	Yes	Requirements related to thematic accuracy are minimum the same as for the previous HRL products or higher in ECoLaSS, whilst and running a more automated approach. Effects of cloud cover and seasonal effects can be better filtered out through the time series approach.
HRL in general	Current spatial resolution of 20m is described as appropriate for European applications ; development towards higher spatial resolution is required – taking into account technical and sensor constraints in case quality can be maintained.	Yes	All ECoLaSS prototoypes are produced with 10m resolution scale, except the change/incremental update products of phase 1 which are in 20m spatial resolution (otherwise artificial artefacts are introduced due to the previous HRL 2015 products at 20m which are basis for the incremental update and change layers).
HRL in general	More continuously scaled products, such as the current Imperviousness Density (IMD) or Tree Cover Density (TCD)	Partially	WP 41 on indices/variables provides generic temporal/seasonal statistics. In ECoLaSS phase 2 an improvement of IMD and TCD products are targeted.
Continental and Local Component products	Spatial resolution that regularly allows retrieving objects with a 0.25 ha or 0.5 ha Minimum Mapping Unit.	Yes	ECoLaSS products are produced by testing different MMUs for certain products, whereas other products are not considering an MMU and the output is on pixel level.
All pan-European products	Towards more generic products – such as biophysical parameters – also on pan-European scale.	Partially	WP 41 on indices/variables provides generic temporal/seasonal statistics. Biophysical parameters are momentarily still subject to the Global Component products.
All pan-European products	Legend information should be consistent and be provided in several formats (ArcGIS, QGIS, CSV).	Yes	Legend information consistent to the existing CLMS products is applied in ECoLaSS, output in several formats does not need testing but can be done for future products without any problems.
All pan-European products	All existing products should be consolidated, quality controlled and consistently provided in the next releases. A thorough (external) validation should be performed before product release.	Partially	The ECoLaSS prototypes are quality controlled inside the consortium and are provided in a consistent manner. The aspect of external validation is taken up as a suggestion to the EEEs for future products.
All pan-European products	Provision of a “Flag-Layer” would be of help, in order to provide pixel-based geolocated quality information to the users.	Partially	Selected ECoLaSS prototypes contain flag layers (e.g. number of images used for production which can be useful to conclude to a lower reliability of the product due to strongly cloud affected areas in S2).
HRL in general	Current requirements of ~85/90% accuracy should be maintained as well when applying automated updates based on time series, which is acknowledged to be a challenge.	Partially	The time-series based ECoLaSS approaches for generating the HRL status layers result in products with improved thematic quality. A challenge are product updates where accuracies are still not in the range required.
HRL in general	Ensuring backward compatibility of HRL time series especially in view	Partially	EColaSS considers the existing HRL products and takes care of data compatibility where possible. However,

	of time series for change monitoring.		changes of technical specifications sometime hamper data comparability (e.g. change of MMU, change of spatial resolution).
HRL in general	Better harmonisation and stream-lining between global and pan-European components. Users are fully clear about the differences and commonalities of the respective products.	Partially	ECoLaSS approaches include other HRLs for data harmonization and aim to minimize product overlaps.
HRL in general	Provision of detailed product specifications.	Yes	ECoLaSS has extensive reporting and documentation obligations, which include product specification sheets of the same contents and layout as the operational Copernicus HRLs.
HRL in general	More sophisticated product presentation and visualisation in an online viewer would be of high value for users.	No	This requirement is acknowledged and communicated to the EEEs, but is not within the scope of ECoLaSS.
HRL Imperviousness	A comparable HRL product to the HRL 2015 with 10m spatial resolution and 3-year update frequency would be interesting in case it becomes operational; it should be regularly updated	Yes	ECoLaSS products are developed at 10m spatial resolution. Update frequency targeted for HRL IMP in ECoLaSS is 1 year.
HRL Imperviousness	Better match with statistical data in industrial and traffic areas.	Partially	This requirement is partially addressed through the improved resolution of S2 and the fact that the road network is now better captured. Industrial areas were already included as part of the Imperviousness product as long as they included a substantial proportion of impervious areas.
HRL Imperviousness	The legend information should be consistent/transferable to CLC and MAES.	Partially	The imperviousness product is mainly a land cover product, but there is already a coirrespondence between the imperviousness degree definition and CLC classes.
HRL Forest	Tree species: Shifts between extensive and intensive management and loss of habitats.	No	An idea of a tree species product was conceptualized in ECoLaSS, but cannot be realized on larger scales due to missing adequate field data to produce such a prototype.
HRL Forest	Texture (tree rows, shapes) or discrimination of plantation forests vs. other types.	No	Whereas different texture parameters are generally thinkable, the discrimination of plantations from other types is only possible by inclusion of highly adequate in-situ data (e.g. LPIS data).
HRL Forest	General (improvement of) or cooperation with National Forest Inventories (NFIs) and/or the European Network of Forest Inventories (ENFIN) for product validation purposes.	No	An improvement of the cooperation with National Forest Inventories (NFIs) and/or the European Network of Forest Inventories (ENFIN) would be desired from the consortium, and efforts in this direction are planned to be undertaken in project phase 1.

HRL Grassland	Longer time series of HR optical satellite data (e.g., SPOT/IRS/ Landsat, etc.) to derive long-term trends of changes. A yearly change would not necessarily be required, but a trend/tendency towards regional changes/losses would be of interest.	Partially	Long-term changes including historical time-series are not considered within the focus of ECoLaSS, but short-term changes including regional changes/losses are taken into account.
HRL Grassland	Seasonal instead of static infor-mation; phenology parameters, e.g. the timing and frequency of (i) changes or (ii) cutting/grazing would be of relevance. Grassland information should include the management practice.	Partially	ECoLaSS addresses phenological parameters by applying specific indices/variables/stataistics (phase 1 & 2). Cutting frequencies are not addressed by the project.
HRL Grassland	A yearly update that would allow for quantifying areas and changes (losses).	Yes	ECoLaSS addresses the change detection of grasslands in the second phase of the project.
HRL Grassland	Separation between grassland and cropland (+ change/conversion).	Yes	As no HRL Agriculture is available so far, ECoLaSS addresses the differentiation of grasslands and croplands by computing new crop mask prototypes.
HRL Grassland	Separation between (i) species-rich (extensively used) and therefore relevant for biodiversity and (ii) species-poor (intensively used) and managed grassland (+change/conversion);	Yes	Intensively/extensively used grassland will be investigated in the second phase of the ECoLaSS project.
HRL Grassland	A differentiation amongst different types of species-rich grassland habitats, based on land use type, altitude and latitude, hydrology, geology and soil quality (although it is recognised that this probably is an unreachable objective unless in a dedicated downstream service).	Partially	As ECoLaSS works in different test sites, different grassland habitats will be investigated. Intensively and extensively used grassland will be investigated in the second phase of the ECoLaSS project which will include the aspect of species richness.
HRL Grassland	Identification of pressures on grassland areas (e.g. intensification, extensification, abandonement, transformation).	No	The time scale for the testing/prototyping in ECoLaSS is too short to allow concise consclusions on pressures. The issues of intensively and extensively managed grassland classification is, however, addressed.
HRL Grassland	There would be an identified improvement potential through the use of LPIS data which are currently mostly not openly available.	Partially	As far as availbale, LPIS data are used for the ECoLaSS project. However, not for all ECoLaSS test/prototype sites LPIS data are accessible. The methodology developed for grassland is therefore not dependend on these input data sets. In the framework of a potential future Agricultural Layer, ECoLaSS is in contact with DG AGRI and EEA and continuously tries to create awareness on the added value of making LPIS data Europe-wide available.
HRL Grassland	Use of different parameter combinations to derive intensive and extensive of grassland	Yes	Intensively/extensively used grassland will be investigated in the second phase of the ECoLaSS project.

	management for large-area trends in the EU.		
HRL Water and Wetness	Potential enlargement of the product's scope towards wetland habitats, biodiversity and soil protection.	No	The HRL WaW are not in line with the ECoLaSS developments. The definition of the HRL WaW significantly differs from the other HRLs, making use of continuous optical and radar based observations over seven consecutive years.
HRL Water and Wetness	Further parameters such as water quality (pesticides, hot spot areas) or flood mapping.	No	The HRL WaW are not in line of the ECoLaSS developments. The mentioned further parameters are not in line with the current Copernicus portfolio.
CLC+	Improved resolution of 0.5 ha MMU instead of 25ha.	Yes	With the use of S2 data sets in ECoLaSS, the spatial resolution could be improved. The approach selected did not apply a fixed MMU but works with the spatial resolution of 10m of the input data.
CLC+	First implementation of the EAGLE matrix.	Partially	So far, the CLC+ trials have focused on a preliminary nomenclature not compatible with the EAGLE matrix, but this will be addressed in the second phase of the project.
CLC+	CLC+ shall be harmonized with the Local Component products and duplication of work shall be avoided.	No	The work has so far focused on prototype areas to evaluate the feasibility of the CLC+ approach and the complementarity with the local component products has not yet been assessed.
New pan-European LC/LU products: CLC+	The HRLs and the CLC+ product should complement each other. Preferentially, the whole portfolio should be complementary, easy to understand, and usable in combination.	Yes	Whenever possible the HRLs were included as part of the CLC+ protorype workflow
New pan-European LC/LU products: Agriculture	Arable land/agriculture: Crop status and crop monitoring; estimations of biomass & yield.	Yes/partially	ECoLaSS has a strong focus on testing and prototyping for a potential future Copernicus agricultural layer. The main topics are a European crop mask and crop type layer. Moreover, more experimental prototypes have been generated in African sites on (i) crop growth conditions and (ii) crop emergence date. Biomass and yield is not within the scope of the project or CLMS portfolio.
New pan-European LC/LU products: Agriculture	Capturing the phenology as well as the crop types (different classes)	Yes/partially	The main focus of the ECoLaSS agricultural developments is on crop mask and crop type mapping. The phenological information is used for classification in terms of temporal statistics. Moreover, more experimental prototypes have been generated in

			African sites on (i) crop growth conditions and (ii) crop emergence date.
New pan-European LC/LU products: Agriculture	Similar spatial resolution (20m) as for the HRLs		ECoLaSS focusses on 10m resolution for development of a potential future Agricultural product, therefore enhances this requirement.
New pan-European LC/LU products: Agriculture	Also a dynamic product with updates on a yearly or intra-yearly basis (e.g. more frequent products to capture crop rotations) would be of interest. Especially in case of product availability with a 3-yearly update frequency, agricultural dynamics would otherwise not be captured.	Yes/partially	ECoLaSS includes testing of different time intervals for capturing winter crops, all crops as well as late spring crops. However, since a future Copernicus layer targets a single product the emphasis is on evaluating the quality and accuracy of the different tests and choosing the recommended product. The 3-yearly update frequency is right away changed into a 1-yearly update frequency.
New pan-European LC/LU products: Agriculture	Incremental in-season crop specific masks, crop area estimates and crop status monitoring.	Partially	ECoLaSS includes testing of different time intervals for capturing winter crops, all crops as well as late spring crops. However, since a future Copernicus layer targets a single product the emphasis is on evaluating the quality and accuracy of the different tests and choosing the recommended product. Crop area and status is the main focus of the prototype, crop monitoring (in terms of a dynamic product) is beyond the scope of ECoLaSS.
New pan-European LC/LU products: Agriculture	LPIS or IACS/InVeKoS data would be very useful, but are currently restricted in their accessibility	Yes	This is recognized as one of the main issues for a European-wide crop type mapping. ECoLaSS is in contct with DG AGRI and EEA and continuously tries to create awareness on the added value of making LPIS data Europe-wide available. The ECoLaSS crop mask, however, is produced independently of LPIS data.
New pan-European LC/LU products: Agriculture	CAP Management	No	This is beyond the scope of ECoLaSS and is covered by other projects and European initiatives.
New pan-European LC/LU products: Agriculture	Connection with the Integrated Agricultural Control System (IACS), i.e. for setting up a digital dossier of a farm, and collect information at farm level through GSAA (Geospatial Aid Application).	No	This is beyond the scope of ECoLaSS and is covered by other projects and European initiatives.
New pan-European products: Phenology	Phenology: Phenology derivatives such as start, duration and end of season; plant phenology index (PPI), using medium to high resolution data.	Partially	In ECoLaSS several new prototypes of various indicators and variables are tested, among them a products on phenology and vegetation monitoring called the Maximal Phenological Activity (MPA) layers, which go into the direction of a potential future phenology layer. A further prototype on crop emergence date provides a prototype for a

			phenological parameter exemplified on crops.
New pan-European products: Phenology	Ensure compliance between the related HR and MR products (thematic overlap with the Global Component)	No	The Copernicus global land portfolio offers a great number of different products, wheras the ECoLaSS prototypes focus on specific indices and variables of potential use for the pan-European component.
New pan-European products: Phenology	It was mentioned that the Phenology Layer should serve as basis for other products, e.g. yield estimation	Partially	The application of the prototypes on indicators and variables (or part of the methods or processing) to serve as basis for other products is explored in phase 2 of ECoLaSS.
New pan-European products: Snow and Ice	Snow and ice: Permanent snow and ice cover monitoring. According to the results of the Snow and Ice Monitoring User Consultation Workshop held on 7th of July 2018, a harmonised cross-border data set is currently lacking and was requested by the Member States through the Copernicus Committee and the Copernicus User Forum to be included in the Copernicus Land Monitoring Service.Such a product is envisaged to focus on on high resolution data, tailored to the specific needs of the pan-European community.	No	A new potential layer on Snow and Ice is not within the scope of ECoLaSS.
Global component: Biophysical variables	Expansion of the current and stable Global Land portfolio by Sentinel-2	No	Biophysical variables are beyond the scope of the ECoLaSS project. ECoLaSS focusses on thematic services fro Sentinel-2 and -1 data.
Global component: Biophysical variables	Adaption of processing chains to Sentinel-3, calibration between sensors and the development of a long time series is also a priority	No	Biophysical variables are beyond the scope of the ECoLaSS project. Sentinel-3 was only meant to be a complementary data source to Sentinel-2 in the ECoLaSS project. With Sentinel-3b still being in the commissioning phase there is no added value of using only Sentinel-3a.
Global component: new thematic products	Forest, Water, or Imperviousness (human settlement mapping (GHSL)) are potentially foreseen for the Global Component evolution.	No	These are already existing products for which there is no further need for development within ECoLaSS.

3.2 Description of Prototypes

This section contains a description of all prototypes under evalutation, developed as part of Task 4. These prototypes are spread among the following topics: Imperviousness as part of WP 42 (section 3.2.1), Forest as part of WP 42 (section 3.2.2), Grassland as part of WP 43 (secton 3.2.3), Agriculture as part of WP 44 (section 3.2.4), New LC/LU Products as part of WP 45 (section 3.2.5), and Indicators and Variables as part of WP 41 (section 3.2.6).

3.2.1 Improved Imperviousness Prototypes

The prototypes for IMP are based on the existing HRL2015 IMP product definitions with further improvements taking into account the user requirements, that have been addressed as follows:

- **Input data:** Use of one-year coverage only, from optical (combination of S-2A and S-2B) and SAR (combination of S-1A and S-1B) data for 2017, to head towards a yearly update
- **Production:** Improved level of automation for faster production, related to the latter point
- **Product definition:** Improved thematic accuracy; full use of the spatial resolution of S-1 and S-2 sensors, from 20 to 10m; refined change detection to capture the omission of the previous layers – expected with such improvement on spatial resolution – for the change layer;
- **Methodology:** Integration of SAR data into the time series analysis, in particular to tackle the issue of cloud coverage.

<u>**Two prototypes**</u> have been developed as part of the WP 42: an **improved imperviousness binary mask (IMP) status layer at 10 m**, and an **incremental change layer** between the HRL2015 status layer at 20m resolution and the new status layer for 2017 at 10m resolution, forcing the production of the change layer at 20m. The respective sites used for testing and demonstration are listed in Table 4 below.

Table 3: Demonstration sites for the imperviousness prototypes

Prototype Forest – Demonstration Sites					
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***
Countries	*Sweden*	*Germany, Austria, Switzerland*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*
Biogeographic Region	*Boreal*	*Continental, Alpine*	*Atlantic, Continental*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterranean, Continental, Alpine*
Phase 1				X	
Phase 2		X		X	X

<u>**IMPROVED IMPERVIOUSNESS BINARY MASK (IMP) BASED ON A COMPUTATION OF THE IMPERVIOUSNESS DEGREE (IMD):**</u>

This layer is already well integrated into the HRL portfolio, but for the year 2017, a 10m spatial resolution has been produced over the South-West site in Phase I, while a new iteration with the same characteristics over the same site will be produced in Phase II as well as over the Central site and the South-East site.
As **input data**, S-1 and S-2 time series were used to create the layer both spanned from January 2017 to November 2017. **Ancillary data** from Open Street Map, the HRL 2015 and Google Earth have been incorporated in the processing chain. **Temporal statistics** have been computed for the SAR time series based on the polarization bands VV and VH, from which monthly means and yearly maximum, minimum, mean and standard deviation have been derived. For the optical time series, the yearly maximal NDVI as well as the Haar attribute profiles and the results of a Soble filtering have been computed based on all spectral bands. An automated **supervised classification using active learning** has produced the initial built-up mask for 2017 based solely on S-2 datasets. An attempt at merging those results with S-1 classifications using **SVM algorithms** has led to a degraded result. Therefore, SAR data has been set aside for the 2017 production, whose producer s accuracy (PA) reached 92.37% and user s accuracy (UA) 85.07% without any manual enhancement.

In **Phase 2,** further investigations are undertaken to enhance the results and the efficiency of the classifiers. A multi-sourcing approach will be explored with not only one sensor, Sentinel-2, but also other sensors including Sentinel-1. New metrics related to the SAR time series could be introduced to this end.

THE IMPERVIOUSNESS CHANGE (IMC) LAYER:

This layer is well integrated into the HRL portfolio. In Phase 1, a first improvement on the spatial resolution has been undergone from 100 m to 20 m over the South-West site, while a new iteration will be produced in Phase 2 for the sites South-West, Central and South-East to demonstrate the transferability of the automated production. The change detection procedure has been refined as well.
The **datasets used for change detection** were the IMP 2015 layer and the IMP 2017. The dataset applied for the **calibration** has been produced using photo-interpretation done with Google Earth. A **reclassification** of the change stratum based on spatial statistics and probability map led to the creation of the pixel-based change layer for 2015-2017.

In **Phase 2**, it is envisioned to apply this change detection procedure to generate a new change layer that will quantify the loss or gain in imperviousness degree, between 2017 and 2018.

3.2.2 Improved Forest Prototypes

The prototype for forest is based on the exisiting HRL2015 Forest product definitions and aims at delivering improved production concepts and enhanced products while considering various user requirements regarding the input EO/ancillary data base applied, the speed of HRL production and enhanced forest data characteristics. In detail, the following requests have been addressed:

- **Input Data:** Use of complete Sentinel-2A+B and Sentinel-1 time series instead of applying a limited temporal EO data coverage of pre-selected, best-suited EO data scenes;
- **Production:** Improved level of automation to allow a faster production and shorter monitoring intervals (e.g. for future yearly incremental updates);
- **Product definition**: Improved thematic classification accuracy; enhanced status layer's spatial detail from 20m spatial resolution to 10m and product definitions respectively; refined change detection approach to identify both increase and decrease of forest areas;
- **Methodology**: Application of an integrated SAR/optic time series data analysis to benefit from the multi-sensor characteristics and ability for gap filling of clouds.

Based on these requirements, **two prototypes** have been developed related to the HRL Forest as part of WP 42: an **improved DLT status layer at 10m** and an **incremental forest cover change layer**. Please see Table 4 for further information on the sites produced in phase 1 and 2.

Table 4: Demonstration sites for the forest prototypes

Prototype Forest – Demonstration Sites					
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***
Countries	*Sweden*	*Germany, Austria, Switzerland*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*
Biogeographic Region	*Boreal*	*Continental, Alpine*	*Atlantic, Continental*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterranean, Continental, Alpine*
Phase 1	X				
Phase 2	X	X			X

PROTOTYPE ON IMPROVED DLT STATUS LAYER AT 10M:

The methodology designed for the forest prototypes is able to process SAR Sentinel-1 and optical Sentinel-2 as **input data sets**. In the first project phase however, only optical Sentinel-2 data of the reference year 2017 have been applied, while an extension to Sentinel-1 data is planned for the second phase of the project. A total of 90 Sentinel-2A+B images acquired from 15-March to 15-August 2017 have been investigated (10 m geometric resolution) and a number of **auxiliary data sets** have been utilized for sampling design and validation to produce the prototype. In-situ data used were mainly the HRL2015 data (Imperviousness Degree, Dominant Leaf Type, Grassland, Water and Wetness) and VHR_IMAGE_2015, D2_MG2b_ECOL_011a (Archive_standard_Optical_VHR1).

The **automated approach** designed for an improved DLT status layer production uses spatio-temporal input features and an new automated reference sampling application. As most important features, the indices BRIGHTNESS, IRECI (inverted red-edge chlorophyll index), NDVI and NDWI (Normalized Difference Water Index) have been calculated within the period mid-March to mid of August and applied in the classification process. However, best results in terms of classification accuracy and lowest processing time could be achieved by using features from the spring period. The **Supervised Random Forest Classifier** has been selected as classification algorithm for prototype production. The results achieved provided an overall thematic accuracy of 96.75%. Producer's and User's accuracies for the two leaf type classes are in a range of 86-98% and exceed the minimum requirements of 90%. The approach demonstrated the potential for an almost fully automatic DLT status layer generation at 10m spatial resolution and without manual enhancement, the successful improvement of the classification workflow and the higher degree of automation in the classification process.

PROTOTYPE ON INCREMENTAL UPDATES:

A **map-to-map change detection** approach has been selected for this prototype to ensure continuity with the precursor HRL products. The Incremental Update layer or "Forest Cover Change (FCC)" layer compares the HRL2015 and HRL2017 products to detect areas of forest loss. Due to the very short time interval between the two masks (2015 vs. 2017), the layer concentrated on negative changes (loss). A MMU of 3ha was applied to the final map to focus on real forest loss. The results provided an overall accuracy of 96.73%, a producer s accuracy for forest loss of 81.90% and respective user's accuracy of 56.6%.

Further investigations in phase 2 will focus on the following tasks:
- integration of Sentinel-1 SAR data (i) to fill cloud-related data gaps in the DLT status layer, (ii) to test the effort/value of integrating SAR, and (iii) to increase the accuracy of detected forest losses of the change product
- assess full comparability and update feasibility based on 20m/10m products for both time stamps (2015 – 2017 and 2017 – 2018)
- improvement of the MMU
- include Tree Cover Density (TCD) and respective change layers/analyse update feasibility
- validate transferability of the approach to different geographic conditions and seasonal patterns, including testing of further time features.

3.2.3 Improved Grassland Prototypes

The prototype for grassland aims at improving the existing HRL2015 Grassland mask. The investigations focused thereby on various grassland product and production aspects: the use of EO input data, the data analysis approaches, the automation of processes and the development of new products which are of great interest for users. The main requirements addressed during testing and prototype are summarized below:

- **Input Data:** Full use of complete Sentinel-2A+B and Sentinel-1 time series; provide a seamless, wall-to-wall product where data gaps due to cloud cover have been maximally reduced;

- **Production:** Improved level of automation of processes to accelerate processing time;
- **Product definition:** Improved thematic classification accuracy (user s, producer s, overall accuracy); improve 20m spatial resolution to 10m and MMU of 1 ha
- **New products:** Investigate a future change detection and a further grassland discrimination between e.g. intensively managed (frequently cut grassland) and extensively managed (more natural, extensively used or grazed grassland);
- **Methodology:** Design a fully integrated SAR/optical time series analysis approach to benefit from the multi-sensor characteristics.

Based on these requirements, **one prototype** on **improved permanent grassland identification** has been developed as part of WP 43 and tested on a selection of sites that were presented in Table 5.

Table 5: Demonstration sites for the grassland prototypes

Prototype Grassland – Demonstration Sites					
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***
Countries	*Sweden*	*Germany, Austria, Switzerland*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*
Biogeographic Region	*Boreal*	*Continental, Alpine*	*Atlantic, Continental*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterranean, Continental, Alpine*
Phase 1			X		
Phase 2		X	X		X

IMPROVED PERMANENT GRASSLAND IDENTIFICATION

As **input data** sets, full Sentinel-1 and Sentinel-2 data archives have been chosen. From SAR archives, the polarisations VV/VH were best-suited for that task and therefore selected from the database.
Additionally, specific **in-situ data** necessary for training and validation purposes have been applied, namely visually controlled LUCAS point data, LPIS Data (where available) and VHR Data from the Data Warehouse.

The **methodological approach** designed uses a multi-sensor data integration where a fusion on pixel level is applied by stacking different S-1/S-2 features into one dataset. This stack is afterwards utilized as input for the classification approach. Various optical and SAR features have been tested from which the following proved to be the most promising:

- optical annual indices applied: CI_green, CI_red_edge; EVI, MCARI_705_740, MTCI, NBR, NDMI, NDRE1, NDRE2, NDVI, OSAVI_705_740, REP, SAVI, TCB, TCG, TCW, TCARI
- optical annual features applied: median, mean, maximum, minimum and standard derivation
- Seasonal optical median composites derived from the optical reflectance bands: the bands GREEN, NNIR and SWIR are more promising to differentiate between grassland and non-grassland than the other S-2 bands.
- Annual statistical SAR features selected: MIN, MAX, MEAN, STD, CoV, DIFF

Moreover, specific **time windows** have been investigated. The research showed, that the spring season (March-April), late summer (July – August) and autumn (September-October) seasons are found to be important to contribute to the grassland/cropland discrimination.

Based on these input features and time windows, a selection of **test cases** was defined and classified using the **Supervised Random Forest Classifier**:

- SAR + seasonal features,
- SAR + VI (Vegetation Index) + seasonal features,

- SAR + OPT + seasonal features,
- SAR + OPT + VI + seasonal features

The **most promising results** over all test cases could be achieved combining annual statistical multi-temporal filtered SAR features in combination with annual and seasonal optical features from March-April, July-August and September-October and annual vegetation indices. The overall thematic accuracy reached was 90.86% (Producer s accuracy grassland 77.25%, User s accuracy grassland 78.60%, Producer s accuracy non-grassland 94.45%, User s accuracy non-grassland 94.02%).

Further investigations to be targeted in phase 2 will focus on the following requirements:

- determine the optimal combination of features and indices derived from the optical as well as SAR dense time series at the biogeographical region level
- improve thematic accuracy
- Focus on further curve fitting and outlier-detection (e.g. selected features like e.g. greenness vs. brightness) for approach to optimally utilize the information content of temporal trajectories
- Signature anomaly detection related to agriculture and grassland
- distinguish between intensively/extensively managed grassland
- Comparative analysis to distinguish different types of grasslands and different grassland management intensities
- Improvement of MMU from 1 ha to 0.5 ha
- Test approaches to derive grassland change between two status layers or as an incremental update.

3.2.4 New Agriculture Prototypes

The prototype for agriculture is a new product that is not yet present in the HRL 2015 portfolio or part of the HRL 2018 ITT. User requirements have been gathered throughout the runtime of the ECoLaSS project which showed that there is a great interest in an agricultural HRL product, however, there are no clear requirements yet from user or stakeholder side on the specifications of such a product. The ECoLaSS prototypes consist of **crop mask** and **crop type maps** and were produced for 2 European sites: “Central” and “West” (from which the “West” demo site was further split into a Belgian and French part due to the nature of different time frames of reference data availability), and for an African demo site in Mali (see Table 5). The main requirements that are being addressed are as follows:

- **Input Data:** Complete Sentinel-1 and Sentinel-2 time series of the year 2017 (Central; West: Belgian part), full time series of Sentinel-2 for 2016 (West: French part); as well as Sentinel-2 time series of the year 2017 (Mali).
- **Production:** High level automation for the classification;
- **Product definition:** New status layers Crop Mask and Crop Type Map for a potential implementation in the frame of future HRLs on pixel level at 10m spatial resolution;
- **Methodology:** Design a fully integrated SAR/optical time series analysis approach to benefit from the multi-sensor characteristics.

Based on these requirements, **two prototypes** have been developed related to a potential future HRL Agriculture as part of WP 44: a **crop mask status layer at 10m** and an **crop type status layer at 10m**. See Table 6 for further information on the sites produced in phase 1 and 2.

Table 6: Demonstration sites for the agriculture prototypes

	Prototype Grassland – Demonstration Sites						
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***	***MALI***	***SOUTH-AFRICA***
Countries	*Sweden*	*Germany, Austria, Switzerland*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*	*Mali*	*South-Africa*
Biogeographic Region	*Boreal*	*Continental, Alpine*	*Atlantic, Continental*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterranean, Continental, Alpine*	*Mali*	*South-Africa*
Phase 1		X	X			X	
Phase 2		X	X			X	X

CROP MASK AND CROP TYPES

As the Agriculture Prototypes have been produced in three different sites of which one has been additionally divided into two parts, both the **input** and the **in-situ data** (used for training and validation purposes) differ depending on the location.
Due to the fact that relevant LPIS in-situ data for the French part of the West site were only available for the reference year 2016 on short-term notice, the used Sentinel-2 data are restricted to 2016 as well. Only derived spectral indices were used in combination with their temporal statistics to feed into the classifier, in order to restrict the huge volume of data for the time series. Since no SAR images covering this time window had been foreseen to be used in ECoLaSS, and a complete re-processing of the raw archive of S-1 images was deemed too time-consuming at that stage, the process only used optical data from 2016.
For the Belgian part of the West site however, the relevant LPIS data were available for 2017 so the used satellite data time series refers to the period from January 3rd to November 15th 2017. Regarding the Sentinel-2 time series the used bands are 3-8 and 11-12. Besides the optical data also SAR (Sentinel-1) data for the same period have been taken into account, namely the polarizations VV and VH.

The classification for the Central site is also based on both Sentinel-2 and Sentinel-1 data for the year 2017. Regarding the optical data the bands 2-8 and 11-12 were used for the classification and from the SAR data the relevant polarizations were also VV and VH.

Regarding the Mali site a combination of Sentinel-2 and Landsat-8 data of 2017 was used for the classification whereas SAR data was not taken into consideration. Since there is no appropriate dataset like the LPIS in Europe available for that site a team of field operators collected geotrace (polylines) and identified and encoded the crop type as well as the relative position of the field with regards to the geotrace. This data collection was used for validation and training purposes.

The chosen **classification algorithm** for all the agriculture prototypes is the **Random Forest Classifier** based on different time features (spectral and temporal) calculated on a multitemporal set of input data.

In the classification of the Belgian part of the West site optical indices (NDVI, NDWI, brightness) have been calculated in addition to the spectral Sentinel-2 bands B3-B8 and B11-B12. Regarding the Sentinel-1 input data backscattering was included. The time period considered most useful is from January to December 2017 in 2-monthly time steps.

For the French part of the West site, whose area exhibits a strong mix of cropland and intensive grasslands, NDVI, NDWI and brightness have been computed for each date, as well as their temporal statistics, among which the various percentile, the standard deviation and the median for example, over 3 periods covering 3 months each.

For the Central site, the time features have been both derived from the whole period covered by the input dataset as well as from specific time steps during this period. In order to reduce financial and timely efforts the number of time features has been reduced to a set of most relevant ones additionally by applying a forward feature selection. For the Central site the most important features are mainly derived from optical data (mostly related to the NDVI and NDWI) which were calculated over the whole period.

In contrary to the European sites the input data for the Mali site is Landsat-8 and Sentinel-2. The classification algorithm follows the Sen2Agri-system, which is based on a weighted linear interpolation performed in a first step. Afterwards 10 spectral bands of Sentinel-2 as well as the NDVI, NDWI, and brightness are calculated and used for the classification.

The classification **results** for the crop type classification within the West site (French part) have an overall accuracy of 77% with a PA of 46-96% and an UA of 49-96%. For the West site (Belgian part) the OA is approx. 92%. Regarding the Central site the OA is at 89% with an UA of 21-95% and a PA of 46-98%. The accuracies in the Mali site amount to an overall accuracy of 64-66% depending on the stratum (southern stratum, northern stratum).

Further improvements which are planned to be addressed within the second project phase are the following:

- Definition of a European classification key (~15-20 classes) which is meaningful and applied onto all the European prototype sites
- Testing of different time intervals for deriving crop types, i.e., from March until May (having winter crops in place), from March until July (having all crops in place), from March to October (covering the whole main growing season).
- Including SAR data also in the Mali and South African sites, as well as in the French part of the West site.
- Adding SAR coherence feature to the testing and determining if there is an added value or increase in accuracy, despite of the decreased spatial resolution of coherence products.

3.2.5 New LC/LU Prototypes

The prototypes for new LC/LU products are more related to the potential evolution of the CLC datasets. User improvements required were taking into account, since the 2018 ITT is not released yet, and they can be listed as follow:

- **Input data:** Use of one-year coverage only, from optical data (combination of S-2A and S-2B) for 2017, to head towards more frequent updates;
- **Production:** Improved level of automation for faster production, related to the latter point; Harmonization between pan-European and global layers (for which MRLC are envisioned)

One prototype was developed for the WP 45: a **new land cover (NLC) layer at 10m**, with 7 classes (grassland, cropland, forest, water, urban area, bare soil and natural grassland) – but that should be modified in Phase II in order to take into account the latest recommendations of CLC+ workshops. For further information on the sites produced in phase 1 and 2, see Table 7.

Table 7: Demonstration sites for the new land cover prototypes – 3rd site: to be determined later

Prototype Forest – Demonstration Sites					
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***
Countries	*Sweden*	*Germany, Austria, Switzerland*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*
Biogeographic Region	*Boreal*	*Continental, Alpine*	*Atlantic, Continental*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterranean, Continental, Alpine*
Phase 1				X	
Phase 2		X		X	

NEW LAND COVER (NLC) LAYER AT 10M

The NLC layer is a new product that could or could not be integrated in the HRL portfolio, however, it should pave the way for the potential evolution of the CLC+ dataset.

In Phase 1, a status layer at 10 m was produced on the South-West site. For Phase II it is planned to produce a second iteration, with an expanded set of classes and at the same spatial resolution over the same site, as well as a layer over the Central site, and on one of the African sites. Depending on the 2018 ITT requirements for CLC+, a change layer over the South-West site could be envisioned as well.
Optical-only datasets were used as **input data** sets, based on S-2 images from January 2017 to November 2017, that was split into 3-month periods. Additional **ancillary datasets** such as Open Street Map (OSM), EU-Hydro, 2015 HRLs (Water and Wetness, TCD, IMD), as well as the CLC2012 and the LPIS 2016 for agricultural inputs have been utilized.

Temporal and spectral features (NDVI, NDWI, brightness index and their maximum, minimum, mean, standard deviation as well as 10^{th}, 25^{th}, 75^{th}, 90^{th} percentiles for 3-month periods) were derived from the optical S-2 images and fed into a **random forest classifier**, while the ancillary data serve as a hard skeleton basis regarding permanent objects in the landscape, and a soft skeleton, created using a large scale mean shift segmentation for persistent objects. After merging the results, a majority filter has been applied to smooth the map. The thematic accuracies ranges from 82.39% to 99.98% for the PA, and from 89.35% to 97.52% for the UA following the various classes.

Improvements in Phase 2 are planned to be focused on adapting the prototype to the most recent nomenclature specifications, the integration of S-1 datasets in the processing chain, and on the potential creation of a change layer over the South-West site between 2017 and 2018.

3.2.6 New Prototypes on Indicators and Variables

Four experimental prototypes have been developed related to Indicators and Variables as part of WP 41: Crop growth condition, Crop Emergence Date Map, Generic Land Cover Metrics and Multi-annual trends & potential change. See Table 8 for further information on the sites produced in phase 1 and 2.

Table 8: Demonstration sites for the new prototypes on indicators and variables

	Prototype Indicators and Variables – Demonstration Sites						
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***	***MALI***	***SOUTH-AFRICA***
Countries	*Sweden*	*Germany, Austria, Switzerland*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*	*Mali*	*South-Africa*
Biogeographic Region	*Boreal*	*Continental, Alpine*	*Atlantic, Continental*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterranean, Continental, Alpine*	*Mali*	*South-Africa*
Phase 1			X				X
Phase 2		X	X				X

Crop growth condition

The Crop Growth condition is one of the four phenological prototypes focussing on agriculture. It aims at displaying the individual crop growing cycle and development of the plants, as well as farming management practices by comparing the profiles of the LAI index for three different crop types (winter barley, winter wheat, maize) at the test site in Belgium during the season of 2017 with those of the local average. The deviation of the 2017 LAI-gradient towards the average LAI-gradient reveals a shifting of the growing cycle for that year.

Input data set: This prototype relies on Sentinel-2 time series of 2017, focussing on the most important time slots within the growing cycle of the crop types. This is week 9 to week 31 (27/02/2017 - 06/08/2017) for winter barley and winter wheat and week 18 to week 43 (17/04/2017 - 29/10/2017) for maize.

Production: In this specific case, the LAI is actually a GAI being not limited to the one-sided green leaf area per unit ground surface – as it is usually the case – but taking into account that in the case of cereals, the whole plant shows photosynthetic activity. The LAI/GAI is calculated with the BVnet algorithm with reflectance values deriving from the ProSail radiative transfer model. This model uses the Sentinel-2 bands at 10 m and 20 m-resolution except the blue band (B2) and the B8 due to its overlap with B7 and B8a.

Method: The method aims at retrieving important growing parameters per crop, per period and per parcel to get a detailed profile of the crop development by applying the following steps:

- Identification of crop types at parcel level with the help of LPIS data
- Verification of the LAI profiles for winter barley, winter wheat and maize at parcel level with the local average profile
- Retrieving growing conditions per crop type, i.e. crop development in terms of earliness, maximum, maturity and management aspects such as time for sowing and harvesting.

Improvement: This product allows to identify local marginal behaviour along the season in terms of crop growth cycle, crop development or management practices by depicting quantitative anomaly derived from the comparison between the LAI profiles of each field with its surrounding ones.
The analysis of the individual development of crops within one growing season supports an accurate classification respectively the differentiation between crop types as well as between agricultural areas and other vegetation cover. Additionally, the accurate monitoring of the growing phase, starting with time of sowing, the sprouting of the plants, growing, growing peak, maturing, ending up with harvesting could support the selection of suitable time slots for EO data and thus reducing the amount of data.

The results of the crop growth condition prototype at the Belgium test site revealed a shift of 2-3 weeks for the beginning of the growing cycle within the year 2017 (compared to the local average) and proves thus quite promising.

Phase II will see the exploitation of the full potential of S-1 time series in addition to optical data.

Crop Emergence Date Map

The Crop Emergence Date Map is an agricultural indicator layer providing information about the crop status at the field level. It responds to the growing demand of farmers to get detailed and realtime phenological parameters and thus more information on the development of their seeding, of germination and expected yield of their crops in times of variable climate conditions. The emergence date as an important parameter is subject to high inter-annual variability.
The aim of this prototype is

- To provide early-season information first phonological stages of maize, such as sprouting and first leaf development
- To offer operational implementation
- To allow further generalization of the method

Parameters for this layer have been calculated in an agricultural area at the demo site in Free State, Southern Africa, with Sentinel-2 time series for 2016 and 2017, focussing on the growing season of maize, from 1st of October until end of April. Due to late launch of S-2B, only S-2A data were available.

Production:
The pre-processing followed the already proven standards (see WP32), using MACCS algorithm, which is embedded within the open-source Sen2-Agri operational system due to its better cloud screening capabilities in comparison to Sen2Cor.
Several Indices such as NDWI, vegetation proxies like NDVI, MSAVI, FAPAR and others, as well as hue time series have been calculated basing on the Sentinel-2A 10m-resolution data in order to identify potential candidates for estimating the emergence date as precise as possible. Long-term Vis mean, yearly Vis, NDVI ratios have been analysed in terms of performance. Several band combinations have been tested to identify best practices for detecting sparse vegetation in humid as well as in dry areas avoiding at the same time potential interferences through soil properties.
In a second step, several detection methods have been tested, p. e. the application of thresholds (testing different time metrics, p. e. threshold intersection, highest slope, inflection point, maximum value, base logistic value), moving windows, function fitting or model fitting. The objective of testing these candidates was to identify the ideal combination of index and method.
The identification of the sprouting and the leaf development – in brief: the emergence date - of the plants complies with the phenological stages defined according to the classification systems from the BBCH (Biologische Bundesanstalt and Bundessortenamt und Chemische Industrie). Presupposition within this classification system: a phenological stage is reached at the point where at least 50% of the plants fulfill the criteria of that stage.

Method:
The relative threshold method has been identified as the most suitable in terms of performance and robustness and has then be applied to the demo site. Linking a phenological event with the crossing of certain values in the VI profile. In combination with the NDVI, basing on S-2 Red (B4) and NIR (B8a) bands, and the MSAVI, the relative threshold, behaving dynamic and variable with changing land cover, soil and solar angle, provides an estimation of the emergence date with about 10 days accuracy.
The benchmarking of indices and methods was based on detailed ancillary data at parcel level. With a large reference dataset collected on the ground, provided by ARC, PIECES and an insurance company, UCL had detailed data sets about crop type and cultivar, crop density, agricultural practices, weed management,

planting windows as well as datasets of point observations on farms, parcels, report date, phonological status at time of the observation, estimated emergence date at its disposal in order to calibrate and validate the results of the methodological approach.

Improvement:
Farming conditions at the demo site of Free State are quite challenging. Due to environmental and climate factors as well as to management decisions on farm level (crop variety, crop rotation, input availability, etc.) time slots for the stages reveal high annual variability. The date of crop emerging is highly dependent on a sufficient supply with water, favouring temperature, nutrients and sunlight. The demo site being quite heterogeneous in terms of these limiting factors, the production of these phenological parameters gets challenging.
Given these background, the results of the combination of NDVI, MSAVI and a flexible threshold are promising for an accurate estimation of crop emergence of maize. The validation showed an already satisfactory performance with a 10 day accuracy. The extension of the data base, especially the exploitation of both, S-2A and S-2B time series within the upcoming phase II will make the approach more accurate and results more reliable. The results for maize are most likely to be generalized to other crop types.

GENERIC LAND COVER METRICS OR MAXIMAL PHENELOGICAL ACTIVITY (MAP)

The prototype developed for the test site West has been drafted using Landsat-8 time series as **input data sets**. Unfortunately, 2017 was a very cloudy year, leading to a very limited number of exploitable Sentinel-2 images. Therefore Landsat-8 series, ordered by months and spanning from July 2013 to December 2017, were used to simulate a dense S-2A and B time series.

Production:
A **Maximal Phenological Activity (MPA)** layer, which is proposed as one of the potential Generic Land Cover Metrics to explore to support the production/analysis of more advanced products such as HRLs or other LC products was produced. Its concept has been detailed in the report (AD06).
Those layers constitute new products related to **phenology and vegetation monitoring**, and can be listed as:

- A pixel-based regroupment of the **maximum monthly NDVI** into 30 classes, based on the start, peak, end, and length of the phenological season -;
- Four reclassified layers representing the following phenological characteristics: the start of the season, the peak of the season, the length and the end of the season.

Those first products were created over the demonstration site West in Phase 1, and it is planned to extend the study to the Central site, as well as to one of the African sites in Phase 2.

Methodology: To derive the new products, the maximum NDVI was computed for each month and irrespective from the year. Then, an unsupervised classification was carried out, with roughly 30 classes. The winter months (starting from November to February) have been excluded from the investigation. However, the validation step is still missing, and this prototype was not deemed mature enough to be submitted.

Improvement: For the second phase of the project, further improvements could be envisioned:

- use of S-2 datasets for the year 2018,
- calculate NDVI on a bi-monthly basis in order to refine the phenological classes;
- validate the datasets in order to compute the thematic accuracies and deliver the prototype.

MULTI-ANNUAL TRENDS & POTENTIAL CHANGE

The experimental prototype on multi-annual trends and potential change aims at improving those HRL focusing on vegetation, such as grassland and forest by exploiting additional information provided by radar data. The basic idea is to identify the characteristic seasonal and long-term annual trends for certain vegetation types (such as grasslands, broadleaved and coniferous forest, various crop types) in order to differentiate them more accurately and to remove misclassification. These trends base upon dense time series of Sentinel-1 data of the years 2015, 2016 and 2017 for the testsite in Belgium, covering ascending and descending imagery. In phase I, the first prototype derives from sigma naught backscattering. The recent results being promising but baring certain limitations, the production in phase II will prefer the flattened gamma naught coefficient for overcoming misclassification caused by speckle, shadowing and topographically induced effects.

Production:
After pre-processing the full time series of Sentinel-1 IW GRD data for the years 2015, 2016 and 2017, 9 key temporal statistics have been calculated. In terms of growing phase, the seasons of March-April-May, June-July-August and of September-October-November have proved to be of large interest. Therefore a first calculation covered these seasons, an additional calculation based on the whole years of 2015, 2016 and 2017. These key temporal statistics are the backscattering temporal maximum, minimum, mean, median, standard deviation as well as the 5th, 10th, 90th and 95th percentile.

Methodology:
For each class of the HRL (broadleaved and coniferous forest and grassland), the key temporal statistics showed specific statistical distributions in terms of seasonal and annual trends. By applying thresholds, these statistical distributions can reveal potential changes on pixel level. Pixel values ranging within a certain threshold will be confirmed being correctly classified, pixel outside the threshold might be either real change or candidate for updating the classification and improving the HRL.

Improvement:
Referring to grasslands, considering multi-annual trends support the differentiation between grasslands and cropland. Using predominantly optical data, at certain growing stages, grassland and cropland or even grassland and recently afforested areas show very similar spectral characteristic whereas in a long-term perspective, grasslands and crop areas show different behavior.
Concerning the HRL Forest, the multi-annual trend provides the detection of misclassified forest and helps to differentiate between real changes and misclassification.

Further testing in phase II is needed to
- analyse potential deviations of the backscatter values of pixels within a certain HRL over time and space, and
- to understand to which extent these method would still be suitable for larger areas and areas comprising different biogeographic regions

3.3 Comparison of HRL Products 2015, new ITT 2018 and ECoLaSS Prototypes

This section provides a comparative overview of the specifications of the HRL 2015 production, the HRL 2018 ITT, and the prototypes developed in phase 1 of the ECoLaSS project. Specifications on input data, reference year, geometric resolution, MMU, MMW, thematic classes, format, thematic accuracy and applied methodology are compared for the already existing HRL products Imperviousness, Forest and Grassland, for which improved prototypes are suggested by ECoLaSS.

Table 9: Comparison of Technical Specifications for the Imperviousness Status Layer (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for IMPERVIOUSNESS Status Layer			
	HRL2015	**HRL2018**	**ECoLaSS**
Input Data	IRS-P6/Resourcesat-2 LISS-III, SPOT 5 and Landsat 8	Sentinel-1/-2, IMAGE2018 VHR	Sentinel-1/-2
Reference Year	2015 +/- 1 year	2017 and 2018	2017 (2018 in second project phase)
Geometric resolution	20m x 20m	10m x 10m	10m x 10m
MMU	20m	10m	10m
MMW	20m	10m	10m
Thematic Classes	Thematic classes: 0: all non-impervious areas 1-100: imperviousness values 254: unclassifiable 255: outside area	Thematic classes: 0: all non-impervious areas 1-100: imperviousness values 254: unclassifiable 255: outside area	Thematic classes: 0: all non-impervious areas 1-100: imperviousness values 254: unclassifiable 255: outside area
Format	GeoTIFF	GeoTIFF	GeoTIFF
Thematic accuracy	Minimum 90% user's / producer's accuracy	Minimum 90% user's / producer's accuracy	90% user's / producer's accuracy
Applied methodology	Supervised classification of built-up/non built-up areas with subsequent visual improvement of classification results and derivation of degree of imperviousness based on continuous multi-temporal seasonal image composites (see Technical Specifications of HRL2015 product).	tbd	Application of supervised machine learning methods.

Table 10: Comparison of Technical Specifications for the Imperviousness Change Layer (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for IMPERVIOUSNESS Change Layer			
	HRL2015	**HRL2018**	**ECoLaSS**
Input Data	IRS-P6/Resourcesat-2 LISS-III, SPOT 5 and Landsat 8	Sentinel-1/-2, IMAGE2018 VHR, IRS-P6/Resourcesat-2 LISS-III, SPOT 5 and Landsat 8	Sentinel-1/-2
Reference Year	2012 - 2015	2015 and 2018	2015/16 – 2017 (2018 in second project phase)
Geometric resolution	20m x 20m	20m x 20m	20m x 20m
MMU	20m	20m	20m
MMW	20m	20m	20m
Thematic Classes	Thematic classes (3 years): 0-99: decrease (0 = 100% decrease, 99 = 1% decrease) 100: stable built-up 101-200: increase (101 = 1% increase, 200 = 100% increase) 201: stable non built-up 254: unclassifiable 255: outside area	8 thematic classes (3 years): 0: unchanged areas with imperviousness degree of 0 1: new cover - increased imperviousness density, zero IMD at first reference date 2: loss of cover - decreasing imperviousness density, zero IMD at second reference date 10: unchanged areas, IMD>0 at both reference date 11: increased imperviousness density, IMD>0 at both reference date 12: decreased imperviousness density, IMD>0 at both reference date 254: unclassifiable in any of parent status layers 255: outside area	8 thematic classes (yearly): 0: unchanged areas with imperviousness degree of 0 1: new cover - increased imperviousness density, zero IMD at first reference date 2: loss of cover - decreasing imperviousness density, zero IMD at second reference date 10: unchanged areas, IMD>0 at both reference dates 11: increased imperviousness density, IMD>0 at both reference dates 12: decreased imperviousness density, IMD>0 at both reference dates 254: unclassifiable in any of parent status layers 255: outside area
Format	GeoTIFF	GeoTIFF	GeoTIFF
Thematic accuracy	90% user's / producer's accuracy of derived IMD changes	90% user's / producer's accuracy of derived IMD changes	90% user's / producer's accuracy for derived IMD changes
Applied methodology	To derive the Imperviousness 2012-2015 layers, the respective IMD status layers	tbd	The change based on HRL IMD 2017 resampled to 20m and IMD 2015 from HRL

	are subtracted from each other after considering a rule based adaptation of the historical layers. The classified change is derived by aggregating the IMD change values in specified change classes. The final result are raster datasets of imperviousness degree change including change values from -100 to 100 and raster datasets of classified imperviousness change including defined classes as unchanged areas, new cover, loss of cover, and imperviousness degree increase and decrease (see Technical Specifications of HRL2015 product).		2015; direct subtraction of the 20m imperviousness values; spatial filtering to take into account the different specifications; conversion of the derived change layer into a 'classified change' layer. Continuous change values are thematically aggregated into the defined change classes.

Table 11: Comparison of Technical Specifications for the Forest Status Layer (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for FOREST Status Layer (Dominant Leaf Type)			
	HRL2015	**HRL2018**	**ECoLaSS**
Input Data	Sentinel-2, Landsat 8, SPOT-5, ResourceSat-2, HR_IMAGE_2015	Sentinel-1/-2 (Landsat)	Sentinel-2
Reference Year	2015 +/- 1 year	2017 and 2018	2017 (2018 in second project phase)
Geometric resolution	20m x 20m	10m x 10m	10m x 10m
MMU	20m	20m	10m
MMW	20m	20m	10m
Thematic Classes	5 thematic classes: 0: all non-tree covered areas 1: broad leaved trees 2: coniferous trees 254: unclassifiable (no satellite image available, or clouds, shadows, or snow) 255: outside area	5 thematic classes: 0: all non-tree covered areas 1: broad leaved trees 2: coniferous trees 254: unclassifiable (no satellite image available, or clouds, shadows, or snow) 255: outside area	5 thematic classes: 0: all non-tree covered areas 1: broadleaved trees 2: coniferous trees 254: unclassifiable (no satellite image available, or clouds, or shadows) 255: outside area
Format	GeoTIFF	GeoTIFF	GeoTIFF
Thematic accuracy	Minimum 90% user's / producer's accuracy for both, broadleaved and coniferous class	Minimum 90% user's / producer's accuracy for both of broadleaved / coniferous class	Minimum 90% user's / producer's accuracy
Applied methodology	Supervised classification and manual enhancement.	tbd	Random Forest (RF) based classification; application of spatio-temporal input features capturing important time series properties and patterns.

Table 12: Comparison of Technical Specifications for the Forest Change Layer (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for FOREST Change Layer (Tree cover change)			
	HRL2015	**HRL2018**	**ECoLaSS**
Input Data	Sentinel-2, Landsat 8, SPOT-5, ResourceSat-2, HR_IMAGE_2015	Sentinel-1/-2 (Landsat 8, SPOT-5, ResourceSat-2, HR_IMAGE_2015)	Sentinel-2
Reference Year	2012 (+/- 1 year) to 2015 (+/- 1 year)	2015-2018	2015/16 – 2017 (2018 in second project phase)
Geometric resolution	20m x 20m	20m x 20m	20m x 20m
MMU	1 ha (25 pixels) for detected changes; plus additional 1 ha (25 pixels) boundary filter	20m	3 ha
MMW		20m	
Tree cover density threshold	30%		
Thematic Classes	Dominant Leaf Type Change (3 years): 0: unchanged areas with no tree cover 1: new broadleaved cover - increased tree cover density 2: new coniferous cover - increased tree cover density 3: loss of broadleaved cover - decreased tree cover density 4: loss of coniferous cover - decreased tree cover density 10: unchanged areas with tree cover 11: increased broadleaved cover density 22: increased coniferous cover density 33: decreased broadleaved cover density 44: decreased coniferous cover density 120: broadleaved changed to coniferous 210: coniferous changed to broadleaved 254: unclassifiable in any of parent status layers 255: outside area	Tree Cover Change Mask (3 years): 0: unchanged areas with no tree cover 1: new tree cover 2: loss of tree cover 10: unchanged areas with tree cover Dominant Leaf Type Change (3 years): 0: unchanged areas with no tree cover 1: new broadleaved cover - increased tree cover density 2: new coniferous cover - increased tree cover density 3: loss of broadleaved cover - decreased tree cover density 4: loss of coniferous cover - decreased tree cover density 10: unchanged areas with tree cover 120: broadleaved changed to coniferous 210: coniferous changed to broadleaved	Forest Cover Change mask (yearly): 0: all non-tree covered areas in 2015 10: unchanged tree cover in 2015 11: forest regrowth (not relevant for this implementation of the TCC) 12: forest loss 254: unclassifiable (no satellite image available, or clouds, or shadows) 255: outside area

		254: unclassifiable in any of parent status layers 255: outside area	
Format	GeoTIFF	GeoTIFF	GeoTIFF
Thematic accuracy	85% per biogeographic region	90% user's / producer's accuracy of derived changes	80-85% overall accuracy
Applied methodology	The layer is derived by dedicated GIS operations of the primary status layers Tree Cover Density and Dominant Leaf Type for both time steps. The layer has a "noise" filter applied to address geometric, radiometric as well as phenological differences between the reference years 2012/2015 using a 30% density threshold and a 1 ha boundary filter. Changes in the tree cover extent and leaf type are indicated, if the difference between TCD 2012 and 2015 products is exceeded by the defined significance threshold of 30%, whilst considering a Minimum Mapping Unit of 1 ha (see Technical Specifications of the HRL2015 product).	tbd	Comparison of a pre- and post-change tree cover mask by map-to-map change detection.

Table 13: Comparison of Technical Specifications for the Grassland Status Layer (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for GRASSLAND Status Layer			
DATA SET	**HRL2015**	**HRL2018**	**ECoLaSS**
Input Data	Sentinel-1/-2, Landsat	Sentinel-1/-2, Landsat	Sentinel-1/-2,
Reference Year	2015 +/- 1 year	2017 and 2018	2017 (2018 in second project phase)
Geometric resolution	20m x 20m	10m x 10m	10m x 10m
MMU	1 ha	10m	1 ha
MMW		10m	
Thematic Classes	4 thematic classes: 0: all non-grass areas 1: grassy and non-woody vegetation 254: unclassifiable (no satellite image available, or clouds, shadows, or snow) 255: outside area	4 thematic classes: 0: all non-grass areas 1: grassy and non-woody vegetation 254: unclassifiable (no satellite image available, or clouds, shadows, or snow) 255: outside area	4 thematic classes: 0: all non-grass areas 1: Grassy and non-woody vegetation 254: unclassifiable (no satellite image available, or clouds, or shadows) 255: outside area
Format	GeoTIFF	GeoTIFF	GeoTIFF
Thematic accuracy	85% per biogeographic region	85% per biogeographic region	85% overall
Applied methodology	Automated iterative image segmentation of the pre-selected image data base; semi-automatic land cover classification with supervised and unsupervised elements; rule-based intersection of optical and SAR-based grassland classification results and bare soil masks to derive the final grassland mask (see Technical Specifications of the HRL2015 product).	Full use of Sentinel-1/2 data base; semi-automatic land cover classification with supervised and unsupervised elements; application of time-series analysis.	Multi-sensor data integration; multi-temporal SAR and optical metrics; multi-seasonal features; application of machine learning algorithms (Random Forest).

Table 14: Comparison of Technical Specifications for the Grassland Change Layer (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for GRASSLAND Change Layer			
DATA SET		**HRL2018**	**ECoLaSS**
Input Data		Sentinel-1/-2, Landsat	Sentinel-1/2
Reference Year		2014/15/16 and 2018	tbd
Geometric resolution		20m x 20m	tbd
MMU		20m	tbd
MMW		20m	tbd
Thematic Classes		6 thematic classes (3 years): 0: all non-grass areas 1: new grassland 2: loss of grassland 10: unchanged grassland in both years 254: unclassifiable (no satellite image available, or clouds, shadows, or snow) 255: outside area	Thematic classes (yearly): tbd
Format		GeoTIFF	GeoTIFF
Thematic accuracy		tbd	tbd
Applied methodology		tdb	tbd

4 Benchmarking Results of Candidate Products

The following chapter describes the benchmarking of the various ECoLaSS services and products of Phase 1 and the subsequent selection of candidates that are ready for a future operational implementation. The benchmarking procedure with an explanation of the benchmarking criteria has been presented in chapter 0. An overview of the benchmarking evulation for all prototypes is presented in section 4.1 and Table 15. The particular rating per prototype and an explanation of the most important rating results are documented in section 4.2. This information was afterwards used to identify gaps in the service and product evolution and to reformulate related development needs for Phase 2, which are described in section 3.2 for each prototype. Chapter 4 closes with a summary on the candidates that are already described to be mature for roll-out and a selction of products that require further research and development. This information leads over to WP 53 which is documented in the Deliverable *D53.1a - Integration Plan into Copernicus Service Architecture (Issue 1)*.

4.1 Overview of the Benchmarking Evaluation Results

The results of the benchmarking analysis are compiled in Table 15. A qualitative evaluation has been applied, ranking from:

- very satisfactory/relevant/applicable (++)
- satisfactory/relevant/applicable (+)
- neutral (o)
- not satisfactory/relevant/applicable (-)
- not at all satisfactory/relevant/applicable (- -)

Moreover, an overall score for each prototype has been calculated by applying between five (for the rating ++) and one (for the rating - -) points to each of the benchmarking criteria.
The highest overall scores could be retrieved for the prototypes “Incremental IMD Change”, “Improved Grassland Status Layer at 10m”, and “Incremental Forest Change” which can therefore be concluded to be the overally most promising candidates for future roll-out as operational CLMS products 2020+.

These most promising prototypes were closely followed by “Improved IMD Status Layer at 10m”, “Improved IMD Status Layer at 10m”, and “New Crop Mask Status Layer at 10m”. A little further behind are the “New Crop Type Status Layer at 10m” and “Crop Grownth Condition”. These five prototypes show potential for implementation as future CLMS products 2020+.

The least points were retrieved for the prototypes “CLC Evolution”, “Crop Emergence Date Map”, “Generic Landcover Metrics” and “Multi-Annual Trends and Potential Change”, which are interpreted not yet to be mature enough for a roll-out as future operational CLMS products 2020+.

Phase 2 of the ECoLaSS project will address and improve all of the abovementioned prototypes in a second round, which will conclude to a final evaluation of the roll-out potential of the prototypes as future operational Copernicus Land product 2020+.

Table 15: Benchmarking evaluation of candidates for operational roll-out in project phase 1

	Service/product candidate	long-term evolution	portfolio comple-mentarity	answering identified needs	political support	respecting core vs. DS	State of the art/Innovation	Maturity/ Timing	adequate EO availability	adequate in-situ availability	processing capacity (platform, SW)	Automation level	pratically proven Roll-out potential	Cost/ benefit (forecast)	Documen-tation	Overall score
WP 42 Imperviousness incremental update	improved IMD status layer at 10m	-	o	+	++	++	+	++	++	+	++	++	+	+	+/++	59,50
	incremental IMD change	++	+	++	++	++	++	+	+	o	++	+	+	+	+/++	61,50
WP 42 Forest incremental update	improved DLT status layer at 10m	-	o	+	++	++	+	++	++	+	++	+	+	+	+/++	58,50
	incremental forest cover change	++	+	++	++	++	o/+	+	+	o	++	+	+	+	+/++	60,00
WP 43 Improved Grassland	Improved Grassland status layer at 10m	o	o	++	++	++	+	++	++	+	++	+	+	+	+/++	60,50
WP 44 New Agriculture product	New crop mask status layer at 10m	++	++	++	-	++	++	o	++	-	++	+	+	+	+/++	58,50
	New crop type status layer at 10m	++	++	++	-	++	++	o	++	--	++	+	o	+	+/++	56,50
WP 45 New Products	CLC evolution	+	+	++	+	++	++	o	++	o	o	o	-	+	+	54,00
WP 41 Time series indicators	Crop growth condition	++	+	+	o	o	++	+	++	--	++	++	+	+	+	56,00
	Crop Emergence Date Map	++	+	o	o	o	++	o	+	--	++	+	+	+	+/++	52,50
	Generic Land Cover Metrics	++	+	+	+	+/++	+	-	+	o	++	o	-	+	o	51,50
	Multi-annual trends & potential change	++	+	o	o	+/++	+	-	++	o	++	o/+	-/o	+	o	51,50

++	very satisfactory/relevant/applicable
+	satisfactory/relevant/applicable
o	neutral
-	not satisfactory/relevant/applicable
--	not at all satisfactory/relevant/applicable

4.2 Detailed Evaluation of Prototypes

This section contains the evaluations of the benchmarking for all prototypes developed as part of Task 4. These prototypes mirror the described prototypes in section 3.2: Imperviousness as part of WP 42 (section 4.2.1), Forest as part of WP 42 (section 4.2.2), Grassland as part of WP 43 (section 4.2.3), Agriculture as part of WP 44 (section 4.2.4), New LC/LU Products as part of WP 45 (section 4.2.5), and Indicators and Variables as part of WP 41 (section 4.2.6).

The most important negative and positive evaluations as presented in section 4.1c are explained in more detail in the following sub-sections.

4.2.1 Improved Imperviousness Prototypes

IMPROVED IMD STATUS LAYER AT 10M

For the product "Improved IMD status layer at 10m", the HRL2018 ITT published in July 2018 has set new benchmarks by requiring improved spatial resolution (10m) and MMU (10m) for the status layer, which has already been envisioned for the ECoLaSS prototype. The status layer has reached full maturity within this Horizon 2020 project, and few evolutions are anticipated in the second project phase, thus the negative rating regarding "long-term evolution" (-). It should also be mentioned that the binary mask is rated neutral as for its "portfolio complementarity" (o) since it is already present in it (HRL 2015 production as well as HRL 2018 ITT). The production of the status layer is close to full "automation level" (++), "maturity/timing" (++), "state-of the art" (++), "well documented" (+/++), and the "roll-out potential" (+) has already been proven. Summarizing various above-mentioned evaluations and considering the very high overall evaluation score, the continuation of this product is highly recommended.

INCREMENTAL IMD CHANGE AT 20M

As for the product "Improved IMD status layer at 20m", the HRL2018 ITT required improved technical specifications including a spatial resolution at 20m (and a MMU of 20m) for the change layer in order to compare the previous status layer at 20m for 2015 with the newly produced status layer for 2017 at 10m – this had already been envisioned for the ECoLaSS prototype. The status layer is mature (+) within ECoLaSS, but further evolutions are anticipated, in particular related to a version of the change layer using a degree of imperviousness as starting point, instead of a binary mask as it is the case at the moment. Due to the small amount of surface related to changes in urban areas, the "in-situ data availability" (o) is quite scarce, hence the neutral rating, which is important in particular for the validation step. The procedure for the creation of the change layer, based on the current status layer and the previous update is still being refined at the moment, using "well-documented" (+/++) "state-of-the-art" technics (++), however, it should be mentioned that this process is close to full automation (+). The incremental change product fully complies to user requirements (++), complements the portfolio of the Copernicus Imperviousness products (+) and enjoys political support (++). With a very high overall score and due to all the above mentioned evaluations, the continuation of this product is highly suggested.

4.2.2 Improved Forest Prototypes

IMPROVED DLT STATUS LAYER AT 10M

The HRL DLT product is a mature (++) product. Adequate Earth observation (++) and in-situ data (+) as well as processing platforms (++) are in place enabling a satisfactory level of automation for the status layer production (+) at a good cost-benefit ratio (+). Service evolution regarding spatial resolution (10m) and MMU which have been part of the ECoLaSS prototype development, are already realized within the new HRL2018 product description leading to a negative rating concerning "long-term evolution" (-). The neutral grad for portfolio complementary (o) reflects the fact that the ECoLaSS product does not add new aspects to the exisiting HRL2018 product definition. Documentation of the product is available (+/++) and roll-out potential (+) is fully met. In summary, there is no doubt in continuing with this product, mirrored by the high overall score.

INCREMENTAL FOREST COVER CHANGE

Incremental updates are a suitable extension of the existing HRL Forest portfolio (+) and highly supported by political decision-makers (++) as they answer the requirements of different user groups (++). Service evolution in ECoLaSS phase 1, however, has not yet reached the desired degree of technical excellence. State-of-innovation can be improved (o/+) and technical evolution of forest cover changes will therefore be the main focus of phase 2. In the last years, the EO data base for change detection has highly improved (++) due to the availability of S-1 and S-2 time series and the development of respective cloud-based image-processing capacities (++). For that reason, level of automation (+), roll-out-potential (+) and cost/benefit forecast (+) are rated positive, anticipating as well that the prototype can be established until 2020. Regarding up-to-date in-situ data (o) that contain near-term LC changes, no suitable data sources are available so far and probably will not be available in the future as data collection is costly. Summarizing various criteria and considering the very high overall evaluation score, the continuation of this product is highly supported.

4.2.3 Improved Grassland Prototypes

IMPROVED GRASSLAND STATUS LAYER AT 10M

For the product "Improved grassland status layer at 10m", the HRL2018 ITT published in July 2018 has set new benchmarks by requiring improved spatial resolution (10m) and MMU (10m) for the status layer. Both specifications have been relevant criteria for the ECoLaSS grassland product. However, as the HRL status layer has not yet reached maturity and further improvements are required, the benchmark criteria on "long-term evolution" (o) and "portfolio complementarity" (o) were rated as neutral. Further, automation of processes and thematic quality of the product is at a good status with still some room for improvement, which is why the categories "state-of-the art" (+) and "level-of-automation" (+) have a moderately positive rating. Concerning "user needs" (++), the ECoLaSS grassland product fully answers the identified requirements and achieves high political support due to its relevance for nature conservation programs (e.g. Natura 2000) or the CAP reform. "Processing capacities" (++) and "EO data availability" (++) are fully ensured enabling a high positive rating for "Maturity/Timing" (++). The same applies to the availability of "in-situ data" (+), "roll-out potential" (+), "cost/benefit ratio" (+) or "level of documentation" (+/++) which are all assessed as existing or fulfilled. Summarizing all categories, the benchmarking for the "Improved grassland status layer at 10m" is positive with a very high overall score and supports a continuation of the product.

4.2.4 New Agriculture Prototypes

NEW CROP MASK STATUS LAYER AT 10M

The product "New crop mask status layer at 10m" is a newly conceptualized prototype which is not yet part of the HRL 2015 production or HRL 2018 ITT. Same as for the beforementioned "improved" HRL products, the spatial resolution was set to 10m. Both, "long-term evolution" (++) and "portfolio complementarity" (++) was rated very relevant since an Agricultural HRL layer is not yet part of the HRL 2018 ITT but is the most apparent product to be included 2020+, and therefore also highly complementary with the current Copernicus portfolio. Concerning "user needs" (++), the ECoLaSS grassland mask answers multiply voiced requirements for an Agircultural HRL in the future, and is clearly not a downstream service, therefore the "core versus downstream" (++) criteria is evaluated very satisfactory. However, the specifications for such a product are not yet defined, therefore "political support" (-) is set to not satisfactory. Being according to the "state of the art/state of innovation" (++), the product however was rated neutral in terms of fulfilling "maturity/timing" (o). In terms of technical criteria, "adequate EO data" (++) is rated very satisfactory taking into account Sentinel-1 and -2 time series, as well as "processing capacity" (++). The perhaps biggest non satisfactory criteria is the "adequate availability of in-situ data" (-

), which is connected to a European-wide non-availability of adequate data, such as LPIS. However, ECoLaSS found a way to produce the crop mask prototypes independent of LPIS data, which however, involved some manual sampling. Therefore, the "automation level" (+) and "cost/benefit ratio" (+) is satisfactory but not very satisfactory. The "documentation" (+/++) has been rated satisfactory and is still to be amended in project phase 2. The "practically proven roll-out potential" (+) was satisfactory in the ECoLaSS project phase 1, however, there is still room for improvement to be tested in phase 2. In summary, the benchmarking for a crop mask product with a high overall score suggests to go ahead with the product.

NEW CROP TYPE STATUS LAYER AT 10M

Likewise as the previous crop mask product, the product "New crop type status layer at 10m" is a newly conceptualized prototype which is not yet part of the HRL 2015 production or HRL 2018 ITT, and targets a 10m spatial resolution and the around 15-20 most meaningful crop types in Europe. All ratings are the same as for the crop mask, besides the criteria on "adequate in-situ availability" (- -) due to this prototype being highly dependent on detailed Europe-wide reference data such as LPIS, which are only availably for some European, countries but not for others. Training of the algorithms as well as validation with respect to detailed crop type mapping would not be possible in those countries that do not provide their LPIS data. This is connected to the "practically proven roll-out potential" (o) set neutral and therefore less than for the crop mask mapping. Likewise as for the crop mask prototypes, there are very positive ratings for "long-term evolution" (++), "portfolio complementarity" (++), "user needs" (++), "core versus downstream" (++) and "state of the art/state of innovation" (++), "adequate EO data" (++), and "processing capacity" (++). The "automation level" (+) and "cost/benefit ratio" (+) is satisfactory, and the "documentation" (+/++) has been rated satisfactory, still to be improved and in project phase 2. In summary, with a high overall score the benchmarking for a crop type product clearly indicates to proceed with the product in phase 2, despite of political support or user requirements being not clear at this stage.

4.2.5 New LC/LU Prototypes

CLC EVOLUTION

For the evolution of CLC products, the overall benchmarking is positive in terms of portfolio complementarity (+), users requirement (++), state-of-the-art (++) or availability of adequate EO data (++), for example. However, a few setbacks are still present, in correlation with the various steps of possible evolution that have been envisioned. The CLC+ nomenclature has undergone several modifications, slightly restraining the maturity (o) of the prototype and it should be noted that the last version of this nomenclature, in particular the introduction of a class for "mosses and lichens"will be quite challenging to tackle in Phase II, hence the neutral rating for the availability of in-situ data (o) and the automation level (o) of the processing chain. The potential roll-out (-) of the prototype remains in negative rating for the moment, but this is expected to change at the end of the second project phase. Showing one of the lower overall scores and with maturity/timing (o) still not being clear, the prototype is suggested to go ahead into the second project phase where an updated nomenclature will be applied.

4.2.6 New Prototypes on Indicators and Variables

CROP GROWTH CONDITION

The product "Crop Growth Condition" provides a new potential agriculture indicator layer about the crop status at the field level in relation to the neighborhood crops. This prototype is an additional layer not yet produced and therefore presents possible long-term evolution (++) towards 2020+, and possibly high portfoliot complementarity (+).The boundary between core and downstream service (o) is not yet known. The state-of the art (++) rating is evaluated very positive. The prototype is mature for automation (++) and processing capacities (++) are efficient as well as EO data availability (++), and it can be distributed in a timely manner at the country scale. Nevertheless, it requires either the availability of LPIS data or a confident Crop Mask/Type Layer to be able to identify the parcels and their crop type resulting in the category "adequate in-situ availability" (- -) having a negative rating. Concerning "user needs" (+), it is not clear yet if the product answers the requirements of end users and whether or not it will get political support (o) due to its novelty. Therefore the "roll-out potential" (+) is seen satisfactory as well as existing documentation (+). In summary, the benchmarking for the "Crop Growth Condition" is positive with the highest overall score among the experimental new prototypes, which supports a continuation of the product.

Crop Emergence Date Map

The product "Crop Emergence Date" provides another new agriculture indicator layer about the crop status at the field level. This prototype is an additional layer not yet produced in the Copernicus Services and therefore presents possible long-term evolution (++) towards 2020+ while showing potentially high portfolio complementarity (+). The boundary between core and downstream service (o) is not yet known. The state-of the art (++) rating is evaluated very high, EO data availability is sufficient (+) and the automation level (+) can be improved but is at a good status. The neccessity to get LPIS data or a confident Crop Mask/Type Layer to be able to identify the parcels and their crop type means that we rated the category "adequate in-situ availability" (- -) as negative. Concerning "user needs" (o), this information is relevant for the production of agriculture products and the monitoring of food security in developing countries, though no clear user requirements have been voiced. Political support (o) is not yet known resulting in a neutral rating. Overall, the roll-out potential (+) is seen positive and respective documentation (+) is existing. In summary, the benchmarking for the "Crop Emergence Date Map" is positive with a lower overall score due to some still unknown aspects, but supports a continuation of the product.

Generic Land Cover Metrics

This type of product has been recurrently required by users (+) at pan-European scale. There is a clear need for such generic products in the Copernicus related offers which is reflected by the positive rating for the categories "long-term evolution" (++), "portfolio complementarity" (+), "answering identified needs" (+) and "state of the art" (+). However, during project phase 1, this prototype was deemed not mature enough (-) and therefore was not handed over as deliverable. This fact arises from the still open question of accuracy assessment. The new layer has not been validated, since there is currently no similar operational product for comparision. Hence the negative rates related to the maturity/timing (-) and to roll-out potential (-), although adequate EO data (o) and related processing capacities (++) are available. In-situ data (o) such as the LPIS could be used, but they will require further work to derive elements related to the growing season, all the while not being available at a pan-European scale (rating "o"). This should be further explored and documented in project phase 2.The flagging of events such as start, end or peak of season is still done manually – yet the rest of the process is automated, hence an "o" rating regarding automation. Though the overall score and benchmarking evaluates this prototype of not yet mature, it has been decided to carry on with it in ECoLaSS phase 2 and re-evaluate it at the end of project phase 2.

Multi-annual trends & potential change

The prototype "Multi-annual trends & potential change" has been developed during project phase 1 as a generic product providing information on areas potentially affected by change. The method relies on the detection of marginal behaviour of the statistical metrics computed from S-1 time series. As it is not known up to now, if this type of product would be "answering user needs" (o) and/or would have "political support" (o), these categories have a neutral rating. However, as such a product is not part of the ITT 2018, but would provide an added value to the current portfolio, the "long-term evolution" (++) and "portfolio complementarity" (+) have been rated as strongly and moderately positive, respectively. Despite it is following the scientific-technical state of the art (+), (moderately positive rating) the "level of automation" (o) as well as "documentation" (o) of the prototype is not yet mature and adequate enough and therefore, were rated as neutral. Furthermore, the prototype has not been validated up to now due to insufficient availability of in-situ data (o). However, the density of the S-1 time series and therefore EO data availability (++) is very interesting and highly sufficient and rated as strongly positive, as the processing capacity (++), the signal sensitivity to various elements other than change would require developing additional filters.

Against this background and the testing on only one demo site so far, the roll-out potential is not yet proven (-/o) with a slightly negative rating, and has to be further evaluated within the second project phase.

5 Conclusions and Outlook

This deliverable provides a benchmarking evaluation of all developed prototypes in the ECoLaSS project phase 1 under different benchmarking criteria, in order to identify the most cost-efficient, most urgently needed, technologically most advanced, etc. product(s).

This assessment concludes to three prototypes being most promising to be mature for future CLMS implementation 2020+ (“Incremental IMD Change”, “Improved Grassland Status Layer at 10m”, and “Incremental Forest Change”), five prototypes showing high potential for roll-out as operational CLMS product 2020+ (Improved IMD Status Layer at 10m”, “Improved IMD Status Layer at 10m”, “New Crop Mask Status Layer at 10m”, “New Crop Type Status Layer at 10m” and “Crop Grownth Condition”), and four prototypes needing additional research to become mature enough due to still being in an experimental phase (“CLC Evolution”, “Crop Emergence Date Map”, “Generic Landcover Metrics” and “Multi-Annual Trends and Potential Change”).

In project phase 2 of ECoLaSS will address and improve all of the abovementioned prototypes in a second round, which will conclude to a final evaluation of the roll-out potential of the prototypes as future operational Copernicus Land product 2020+.