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ECoLaSS

Evolution of Copernicus Land Services based on Sentinel data

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Consortium Partners

No.	Participant Organisation Name	Short Name	City, Country
1	GAF AG	GAF	Munich, Germany
2	Systèmes d'Information à Référence Spatiale SAS	SIRS	Villeneuve d'Ascq, France
3	JOANNEUM RESEARCH Forschungsgesellschaft mbH	JR	Graz, Austria
4	Université catholique de Louvain, Earth and Life Institute (ELI)	UCL	Louvain-la-Neuve, Belgium
5	German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Weßling	DLR	Weßling, Germany

Contact:

GAF AG
Arnulfstr. 199 – D-80634 München – Germany
Phone: ++49 (0)89 121528 0 – FAX: ++49 (0)89 121528 79
E-mail : copernicus@gaf.de – Internet : www.gaf.de

Disclaimer:

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	Name, Function	Date	Signature
Author(s):	Katharina Schwab (GAF) Regine Richter (GAF) Markus Probeck (GAF) Linda Moser (GAF) Kathrin Schweitzer (GAF) Christophe Sannier (SIRS) Sophie Villerot (SIRS) Antoine Masse (SIRS) Jolan Wolter (UCL) Annekatrin Metz-Marconcini (DLR)	28.11.2019	K. Schwab
Review:	Markus Probeck (GAF)	23.12.2019	M. Probeck
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2.1	07.02.2020	52	Revision based on reviewer's recommendations at Final Review Meeting, comprising major updates throughout chapter 4, a new Annex 1, moderate updates to chapter 5 and Executive Summary, as well as minor updates to chapter 1, sections 3.2.1-3.2.5 and Tab. 13.

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
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	D11.2 – D41.1b - Prototype Report: Time Series-derived Indicators and Variables (Issue 2). Issued: 24.12.2019
AD07	D12.1 – D42.1b - Prototype Report: Consistent HR Layer Time Series/Incremental Updates (Issue 2). Issued: 03.12.2019
AD08	D13.1 – D43.1b - Prototype Report: Improved Permanent Grassland (Issue 2). Issued: 05.12.2019
AD09	D14.2 – D44.1b - Prototype Report: Crop Area and Crop Status Parameters (Issue 2). Issued: 20.12.2019
AD10	D15.2 – D45.1b - Prototype Report: New LC/LU Products (Issue 2). Issued: 31.12.2019
AD11	D16.4 – D51.1d - Stakeholder Consultation Report (Issue 4). Issued: 31.10.2019

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 is being conducted from 2017–2019 and aims at developing and prototypically demonstrating selected innovative products and methods as candidates for future next-generation operational Copernicus Land Monitoring Service (CLMS) products of the pan-European and Global Components. ECoLaSS assesses the operational readiness of such candidate products and eventually suggests some of these for implementation. This shall enable the key CLMS stakeholders (i.e. mainly the Entrusted European Entities (EEE) EEA and JRC) to take informed decisions on potential procurement as (part of) the next generation of Copernicus Land services from 2020 onwards.

To achieve this goal, ECoLaSS makes full use of dense time series of High-Resolution (HR) Sentinel-2 optical and Sentinel-1 Synthetic Aperture Radar (SAR) data, complemented by Medium-Resolution (MR) Sentinel-3 optical data if needed and feasible. Rapidly evolving scientific developments as well as user requirements are continuously analysed in a close stakeholder interaction process, targeting a future pan-European roll-out of new/improved CLMS products, and assessing the potential transferability to global applications.

This second and final issue of the Deliverable **D17.2: "D52.1b - Report on Candidates for Operational Roll-out"** assesses the technical developments and subsequent prototype implementations achieved for each candidate product in Task 3 and Task 4 of the project. In the WPs 31–35, methods applying high volume data processing of mainly Sentinel-1 and -2 time series were developed, and in the WPs 41–45, these methods have been used to develop and analyse the resulting prototypes in the thematic fields of Indicators and Variables, High Resolution Layers (HRLs) on Imperviousness, Forest, Grassland and Agriculture/Crops as well as New LC/LU Products, which are described in detail in the respective WP reports.

After 3 years of intense user needs assessment and stakeholder interaction and two complete cycles of technical development, testing, prototyping and quality assessment, this report provides the final benchmarking results of all developed products and assessed prototypes in the ECoLaSS project. It is applying a range of relevant benchmark criteria, in order to identify the most cost-efficient, most urgently needed, technologically most advanced, … product(s) to qualify for being finally put forward as most promising candidates for future new implementation in the 2020+ CLMS operational product portfolio.

The assessment concludes with the duly elaborated recommendation of five candidate products, which are being found most mature and best-fitting for a near-future implementation as part of the CLMS operational service portfolio 2020+, i.e.: Incremental (yearly) IMD Change, Incremental (yearly) Tree Cover Loss, Grassland Use Intensity, Crop Mask Status Layer (10m), and Crop Type Status Layer (10m). Whereas the first three products would complement existing HRL product groups, the two latter could constitute the basis for a new HRL Crops, as foreseen in the Copernicus Work Programme 2020. It is worth noting that the latter three product recommendations go along with a recommendation to the European and Member State stakeholders and decision makers to improve the respective in-situ data availability. By the project end of ECoLaSS, all five of these products are in the planning for operational implementation, which confirms the project's findings. In turn, ECoLaSS provides the scientific basis, product specifications, methodological descriptions and various well documented and validated prototypes in the most relevant European bio-geographic regions, giving ample proof of the products' operational feasibility.

Two further candidate products have been found very relevant for a next-stage operational implementation in 2021 (HRL Combined Layer) or as additional component to complement the upcoming HR Vegetation Phenology and Productivity product group (Crop Growth Condition). Three prototypes have been finally assessed to still benefit from additional developments to become mature enough for operational roll-out (Crop Emergence Date Map, Generic Land Cover Metrics and Multi-Annual Trends and Potential Change). The latter may also qualify as some sort of a downstream service.

Beyond these assessed new product candidates, it should be highlighted that further five products have meanwhile already found their way into the operational CLMS portfolio (i.e. the HRLs 2018 and the CLC+

Backbone), which can be considered a great success and proof that ECoLaSS has been assessing and promoting the right topics. These meanwhile-operational products comprise the Improved IMD Status Layer at 10m, the Imperviousness Built-Up Area, the Improved DLT Status Layer at 10m, the Improved Grassland Status Layer at 10m, and the CLC evolution (i.e. CLC+ Backbone) product, all of which are being operationally implemented by industrial consortia with ECoLaSS project partners' leading involvements.

This report is structured as follows: 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. The benchmarking itself is described in Section 4. Each candidate is rated according to relevant technical, political and financial criteria. A conclusion and outlook is finally presented in Section 5.

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Abbreviations

CAP	Common Agricultural Policy
CI_green	Chlorophyll Index Green
CI-red_edge	Chlorophyll Index RedEdge
CLC	CORINE Land Cover
CLC+	CORINE Land Cover + (next generation)
CLMS	Copernicus Land Monitoring Service
CORINE	Coordination of Information on the Environment
CoV	Coherence value
CUF	Copernicus User Forum
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	EIONET Action Group on Land monitoring in Europe
EC	European Commission
ECoLaSS	Evolution of Copernicus Land Services based on Sentinel data
EEA	European Environmental Agency
EEA39	the 33 EEA member and cooperating countries, plus the 6 Western Balkan States
EEE	Entrusted European Entities
EIONET	European Environment Information and Observation Network
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
HR	High Resolution
HRL	High Resolution Layer
HR VPP	High Resolution Vegetation Phenology and Productivity (Layer)
IACS	Integrated Agricultural Control System
IMC	Imperviousness Change
IMCC	Imperviousness Change Classified
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
MAX	Maximum value
MCARI	Modified Chlorophyll Absorption in Reflectance Index
MEAN	Mean value
MIN	Minimum value
MMU	Minimum Mapping Unit

MMW	Minimum Mapping Width
MPA	Maximum Phenological Activity
MR	Medium Resolution
MS	(EEA39) Member State
MTCI	MERIS Terrestrial chlorophyll index
NBR	Normalized Burn Ratio
NFIs	National Forest Inventories
NDMI	Normalized Difference Moisture Index
NDRE	Normalized Difference RedEdge
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
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
R&D	Research & Development
REP	Red-Edge Position Linear Interpolation
RF	Random Forest
SAR	Synthetic Aperture Radar
SAVI	Soil-Adjusted Vegetation Index
STD	standard deviation value
SVM	Support Vector Machine classifier
SW	Software
SWIR	Short Wave Infrared
TCARI	Transformed Chlorophyll Absorption Reflectance Index
TCB	Tasseled Cap Brightness
TCD	Tree Cover Density
TCG	Tasseled Cap Greenness
TCL	Tree Cover Loss
TCM	Tree Cover Mask
TCW	Tasseled Cap Wetness
UA	User's accuracy
VHR	Very High Resolution
VI	Vegetation index
WaW	(High Resolution Layer) Water and Wetness
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 Monitoring Service 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 from 2020 onwards. The WP 52 activities commenced after T_0+12 and were 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 determines which prototypes are finally suggested as candidates for operational roll-out, and which ones will need further research and development, possibly beyond the project context of ECoLaSS. The actual benchmarking method and the related criteria have been elaborated by WP 52 and reviewed by the EC.

The selection of benchmark criteria during the project has been undertaken primarily 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 collected by WP 21, (iii) additional recommendations gathered in the stakeholder consultation process undertaken by WP 51, (iv) external findings from other sources that have 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* and the *High Resolution Layers 2018* initial production phase, 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 *D52.1b Report on Candidates for Operational Roll-out* contains in a clear and transparent manner: a complete documentation of the benchmarking process and all benchmarking criteria (chapter 2), an overview of the developed prototypes throughout the ECoLaSS project (chapter 3), as well as a detailed documentation of the obtained benchmarking results (section 4.1) and a respective interpretation, including recommendations which of the candidate products are suggested for operational roll-out (section 0). Finally, chapter 5 provides some conclusions and an outlook.

Results of the benchmarking as undertaken in this report have fed directly into the WP 53's *"Integration Plan into the Copernicus Service Architecture"*.

2 Benchmarking Process

In the following two sections, the benchmarking process is described. The benchmarking and its aims and main parameters are explained in section 2.1, and the benchmarking criteria applied to the prototypes developed, tested and demonstrated in ECoLaSS 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 was 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 followed the strict principle that the experts conducting the benchmarking were fully independent from the teams developing and implementing the methods and prototypes in Tasks 3 and 4.

The benchmarking process has finally determined which prototypes shall be suggested as candidates for operational roll-out, and which ones will need further research and development, possibly beyond the project context of ECoLaSS.

2.2 Selection of Benchmark Criteria

The selection of benchmark criteria was undertaken considering several information sources and aspects, in order to derive appropriate criteria for comparing the performance of the prototypes. Important data sources were the H2020 Work Programme 2016-2017, *5iii. Leadership in Enabling and Industrial Technologies – Spac*e 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 were 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 as well as the first phase of the *High Resolution Layers 2018* production 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 and 2018 reference year projects and upcoming Copernicus calls);
- maintaining a sufficient level of **complementarity with respect to the (existing and near-future upcoming) Copernicus Land portfolio,** and alignment with the **current and upcoming Copernicus Land service environment's overall logic and setup**;
- answering to identified **high-priority evolution needs** in response to known current shortcomings;
- having **political support** (e.g. from EEEs and Member States (MS) 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 the R&D results of ECoLaSS 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 (near-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** (as given by the prototypes mapped in ECoLaSS);
- 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 (from ECoLaSS);
- **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, as all ECoLaSS results are being made openly and freely available, therefore it is not included in the evaluation.

Based on these criteria, a transparant and comparable investigation of all phase 1+2 products and services was carried out. Each prototype and method was verified impartially to find out which candidates are best suited for a future service evolution. Five benchmark levels (++, +, o, -, - -) were used to determine the degree of conformity (level of satisfaction or relevance) with the respective benchmarking criteria, or if needed, intermediate grades.

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

Table 1: Explanation of benchmarking criteria (examples)

Criteria	Explanation for evaluation of the respective criteria
Long-term evolution	(+) Candidate is not yet part of the HRLs 2018 (-) Candidate is already part of the HRLs 2018
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 and proven 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 and MS side) (-) Candidate is lacking political support
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 could be operationally procured 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 the respective candidate for the entirety of the targeted roll-out area (e.g. EEA39) (-) Adequate in-situ data are missing/not available as needed to produce the respective candidate
Processing capacity (platform, SW)	(+) Technical data access/processing/storage infrastrucuture (e.g. DIAS) is in place to produce the candidate (-) Technical infrastructure for candidate production is missing or inadequate
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 in ECoLaSS prototype sites and prototype has worked well (-) the Prototype has proven problematic in the ECoLaSS prototype sites and therefore turns out to have less roll-out potential
Cost/ benefit (forecast)	(+) Effort/costs are low 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 reports 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 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 and results (section 3.2). Thereafter, a table summarizing and comparing the specifications of the High Resolution Layers 2015 production, the High Resolution Layers 2018 and the ECoLaSS prototypes 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 has been 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 targeted 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 targeted yearly incremental update layers for Forest and Imperviousness (phase 1+2) as well as for Grassland (phase 2).
HRL in general, especially GRA and WET/WaW	Developments towards dynamic HRL products.	No	Dynamic HRL products are 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 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 frequency of available sensor acquisitions will 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 has been 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	Thematic accuracy has increased through use of the time series, whilst enabling a more automated approach. Effects of cloud cover and seasonal effects can be better filtered out through the time series approach.

HRL in general	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 prototypes are produced with 10m Sentinel 1/2 spatial resolution, except the change/incremental update products 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 WP 43, grassland use (mowing) intensity product has been successfully demonstrated [AD08].
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. A range of Vegetation Indices and biophysical variables, particularly for vegetation phenology and productivity monitoring, are upcoming with the new HR Vegetation Phenology and Productivity (HR VPP) Layer 2018 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. External validation is applied as a standard since 2015 by an independent validation consortium contracted by the EEA.
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 such accompanying flag layers (e.g. number of images used for production, which can be useful to assess the reliability of the product, e.g. affected by frequently 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 typically not easily and uniformly in the range required for all products and in a large-scale fashion.
HRL in general	Ensuring backward compatibility of HRL time series especially in view	Partially	ECoIaSS considered the existing HRL products and took care of data compatibility where possible. However,

	of time series for change monitoring.		changes of technical specifications sometimes 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	The methods applied in ECoLaSS included data harmonization between continental component products, aiming to minimize thematic product overlaps.
HRL in general	Provision of detailed product specifications.	Yes	ECoLaSS is provising extensive reporting and documentation, which includes 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. However, all prototypes produced within ECoLaSS are made available in a Viewing Service accessible via the project webpage (www.ecolass.eu). This requirement will be fully taken up in the upcoming update of the Copernicus Land portal, which is currently being tendered by the EEA to industrial implementation[1]
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 have been 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 correspondence between the imperviousness degree definition and CLC classes. The EAGLE nomenclature will potentially serve in the future as harmonisation standard.
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.

[1] Open Call for Tenders EEA/DIS/R0/19/016 (closed 18/12/2019)

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. forest inventory 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 generally have been desired from the consortium.
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/statistics (phase 1 & 2). In phase 2, layers on use intensity and mowing events were produced in three European sites, but could not be fully validated due to a lack of reference data.
HRL Grassland	A yearly update that would allow for quantifying areas and changes (losses).	Yes	ECoLaSS addressed the change detection of grasslands in the second phase of the project. Yealy updates appear possible, though probably not very meaningful due to the small quantity of annual change.
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 Crops is suggested for operational implementation in 2020.
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 was investigated and successfully demonstrated 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 were investigated. Intensively and extensively used grassland was investigated in the second phase of the ECoLaSS project, which has a certain correlation with 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. The mentioned pressures are investigated as part of the EEA's operational CLMS Hotspot Monitoring of grassland rich Natura2000 sites.
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 were used for the ECoLaSS project. However, not for all ECoLaSS test/prototype sites LPIS data were accessible. The methodology developed for grassland is therefore not dependent on these input data sets. In the framework of a potential future HR Crop 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 grassland management for large-area trends in the EU.	Yes	Intensively/extensively used grassland was investigated in the second phase of the ECoLaSS project.
HRL Water and Wetness	Potential enlargement of the product's scope towards wetland habitats, biodiversity and soil protection.	No	The HRL WaW is 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. However, a further enrichment of the HRL WaW product (e.g. by retrieval of true 'wetland' areas) had been announced as an option for future product evolution by the EEA in the CUF.
HRL Water and Wetness	Further parameters such as water quality (pesticides, hot spot areas) or flood mapping.	No	The HRL WaW is not in line with 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. The operational implementation of the CLC+ Backbone product has just recently been awarded to an industrial consortium coordinated by one of the ECoLaSS project partners.
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 was addressed with an early version of the CLC+ nomenclature in the second phase of the project. It will be operationally implemented as part of the upcoming CLC+ Backbone in 2020+.

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. It will be part of the operational CLC+ Backbone implementation in 2020+.
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 used as supporting datasets in the CLC+ prototype workflow. This will be similar in the operational CLC+ Backbone production, where also complemetarity between the products is being aimed at.
New pan-European LC/LU products: Agriculture	Arable land/agriculture: Crop status and crop monitoring; estimations of biomass & yield.	Yes/partially	ECoLaSS had a strong focus on testing and prototyping for a potential future Copernicus agricultural (HRL Crop) layer. The main topics were a European crop mask and crop type layer. Moreover, more experimental prototypes have been generated in European and African sites on (i) crop growth conditions and (ii) crop emergence date. Biomass and yield is not (yet) within the scope of the project or the pan-European 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 European and African sites on (i) crop growth conditions and (ii) crop emergence date. Phenology will be part of the operational HR VPP, contracted by EEA in Dec. 2019 to a VITO led team.
New pan-European LC/LU products: Agriculture	Similar spatial resolution (20m) as for the HRLs	Yes	ECoLaSS focusses on 10m resolution for development of a potential future Agricultural (HRL Crop) product, therefore exceeds 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.	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 should be 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	See above. Crop area and status is the main focus of the prototype. Intra-seasonal 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 contact 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 product on phenology and vegetation monitoring called the Maximal Phenological Activity (PHL) layers, which go into the direction of a potential future phenology layer. A further prototype on crop emergence date (EMD) provides a prototype for a phenological parameter exemplified on crops. The HR VPP phenology products have been contractec to be operationally implemented from 2020 onwards.
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, whereas the ECoLaSS prototypes focus on specific indices and variables of potential use for the pan-European component. The pan-European CLMS component will benefit from an own phenology product from 2020 onwards.
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 was 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	No	A new potential layer on Snow and Ice is not within the scope of ECoLaSS, but meanwhile implemented by a consortium coordinated by Magellium as operational service part of the CLMS since 2019.

	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.		
Global component: Biophysical variables	Expansion of the current and stable Global Land portfolio by Sentinel-2	No	Global-level biophysical variables are beyond the scope of the ECoLaSS project. ECoLaSS focusses on thematic services for 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	Global-level 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 and 2018 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 2017/2018, 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, evolution 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; production of a built-up layer for 2018
- **Methodology:** Integration of SAR data into the time series analysis, in particular to tackle the issue of cloud coverage.

Two prototypes have been developed as part of the WP 42: an **improved imperviousness degree (IMD) 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. In phase 2, the number of **protoptypes** implemented could be raised to **three**. Besides the change of the reference year from 2017 to 2018 (change detection for the period 2017-2018), they also comprise the the built-up layer. The respective sites used for testing and demonstration are listed in Table 4 below.

Table 3: Demonstration sites for the imperviousness prototypes

Prototype Imperviousness – 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 Imperviousness Degree (IMD) Status Layer at 10m

The HRL Imperviousness is already well integrated into the operational HRL portfolio, but for the year 2017, a 10m spatial resolution has been produced over the South-West site in phase 1, while a new iteration with the same characteristics over the same site was produced in phase 2 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 layers spanned from January-November 2017 and January-November 2018, respectively. **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 of 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. For the prototypes produced during phase 2, both sensors (S-1 and S-2) were included in the classification. The overall accuracies range between 97.03-99.11%.

Incremental Imperviousness Degree Change Layer

In phase 1, a first improvement on the spatial resolution has been undertaken from 100 m to 20 m over the South-West site, while a new iteration was produced in phase 2 for the sites South-West (2017/2018 at 10m), Central and South-East (both 2015/2018 at 20m) 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 HRL IMP 2015 layer and the IMP 2017/2018. 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 as well as for 2017-2018. An OA of 98.37-99.68% could be reached.

IMPERVIOUSNESS BUILT-UP AREA (IBU)

The Built-up layer is a binary mask, distinguishing between built-up and non-built-up areas. This thematic layer is part of the operational HRLs 2018 and is based on optical **input data** (S-2) only, from which biophysical variables (NDVI, Pantex and textural features) are derived. Open Street Map and the European Settlement Map serve as **ancillary data** sets. The classification algorithm is the same as for the other Imperviousness-related prototypes - the Random Forest Classifier. The accuracies of the prototypes for the reference year 2018 range between 98.64 and 99.45%.

3.2.2 Improved Forest Prototypes

The prototype for forest is based on the exisiting HRL2015 and 2018 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-1A+B 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 during project phase 1: an **improved DLT status layer at 10m** and an **incremental tree cover loss layer**. Based on the findings of phase 1, **three prototypes** were implemented in three different demonsites: an **improved DLT status layer at 10m** (for the reference year 2018), the **tree cover density at 10m (2018)** and an **incremental tree cover loss layer** (2017-2018). 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

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 was undertaken in the second phase of the project. A total of 3,946 Sentinel-1A+B images and 946 Sentinel-2A+B images acquired between March and September (for both reference years 2017 and 2018) have been investigated (10 m geometric resolution) for three demonstration sites. In addition, a number of **auxiliary data sets** have been utilized for sampling design and validation to produce the prototypes. In-situ data used were mainly the HRL2015 data (Imperviousness Degree, Dominant Leaf Type, Grassland, Water and Wetness) and VHR_IMAGE_2015, VHR_IMAGE_2018 and 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 a 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/mid-September 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% (NO 2017). The method could be transferred successfully to different geographic regions and led to OAs between 92.78-97.8% (SE, NO, CE) for the reference year 2018. The approach demonstrated the potential for an almost fully automatic DLT status layer generation at 10m spatial resolution without manual enhancement. Further, the successful improvement of the classification workflow and the higher degree of automation in the classification process could be achieved. Following the recommendations from the reviewer, the Tree Cover Density was produced for the reference year 2018 for all sites as well.

INCREMENTAL TREE COVER LOSS

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 "Tree Cover Loss (TCL)" layer compares the HRL2015 (being based mostly on 2016 Sentinel-2 input imagery) and the ECoLaSS Tree Cover Masks for 2017/2018 to detect areas of forest loss and thereby assess the full comparability and incremental update feasibility based on 10m products. Due to the very short time interval between the masks (2015/16 vs. 2017 vs. 2018), the layer concentrates on negative changes (losses) only. A final MMU of 1 ha is applied. The results provided an overall accuracy of 96.73% (demo site North: 2017) and 94.34-96.81% (demo sites Sweden, North, Central: 2018).

3.2.3 Improved Grassland Prototypes

The prototype for grassland aimed 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 prototyping are summarised 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, a prototype on **improved permanent grassland identification** has been developed as part of WP 43 for the reference year 2017. For the year 2018, the methodological approach could not only be transferred to two other European demo sites (see Table 5) but also a layer on incremental change at 10m could be produced. Furthermore, a layer on the **grassland use intensity at 10m** was implemented.

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 GRASSLAND STATUS LAYER AT 10M

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, including detailed curve fitting and outlier detection analyzing them towards their temporal trajectories. The final set of features used for the prototype generation comprises both, optical and SAR derived features, with optical being predominant.
Moreover, specific **time windows** have been investigated including not only the full coverage of the respective reference year, but also site-specific intermediate steps to derive developments during the early/late spring period. Using different time windows is crucial for a good distinction between grassland and agricultural land cover.
The Random Forest Classifier was chosen as being most suitable for the prototype production. The product's MMU of formerly 1ha (phase 1) could be improved to 0.05ha in phase 2. The initial overall thematic accuracy was 90.86% (WE phase 1) and could be increased to over 98%. In the other sites, the OA ranges between 91. 5 and 96.63%. For all sites listed in Table 5, status layers for the years 2017 and 2018 were produced, building the basis for a change layer. In addition to the time step 2017-2018, the change layer was also calculated for the period 2015-2018, using the existing HRL Grassland 2015.

GRASSLAND USE INTENSITY (GRU) AT 10M

The Grassland Use/Mowing Intensity at 10m is depicting the use intensity based on the previously developed grassland status layer at 10m. For all the areas classified as grassland in the binary mask, the amount of mowing events is derived using optical **input data** (Sentinel-2). As **in-situ data** the IACS dataset was used, where available. This was only the case in Austria, where the specific information about mowing events is included. Even though the data would have been available for Southern Germany or Belgium as well, it could not be integrated in the classification due to missing information on the topic. This is also the reason why a validation was not possible. Nevertheless, **two** different **approaches** were applied to derive the number of mowing events in the three different sites: one is based on the Kalman filter, the other on NDVI time series.

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.[2] 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 uniformly agreed 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 the African demo sites in South Africa (2017 only) and Mali (both 2017 and 2018) (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 and 2018 (Central; West: Belgian part), full time series of Sentinel-2 for 2016 and 2017(West: French part); as well as Sentinel-2 time series of the year 2017/2018 (Mali).
- **Production:** High level of 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 Agriculture/Crops– Demonstration Sites							
Site	***NORTH***	***CENTRAL***	***WEST***	***SOUTH-WEST***	***SOUTH-EAST***	***MALI***	***SOUTH-AFRICA***
Countries	*Sweden*	*Germany, Austria, Switzer-land*	*Belgium, France*	*France, Spain*	*Greece, Bulgaria, Macedonia, Serbia*	*Mali*	*South-Africa*
Biogeo-graphic Region	*Boreal*	*Continen-tal, Alpine*	*Atlantic, Continen-tal*	*Atlantic, Alpine, Mediterranean, Continental*	*Mediterra-nean, Conti-nental, Alpine*	*Mali*	*South-Africa*
Phase 1		X	X			X	
Phase 2		X	X			X	X

[2] A new HRL Crops is mentioned in the final Copernicus Work Programme 2020, as part of the pan-European CLMS component, although the tergeted reference year (2018 or 2021) remains unclear.

NEW CROP MASK (CRM) AND CROP TYPES (CRT) AT 10M

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 and 2017, respectively, on short-term notice, the used Sentinel-2 data are restricted to 2016/2017 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 2016/2017.
For the **Belgian** part of the **West** site however, the relevant LPIS data were available for 2017/2018 so the used satellite data time series refers to the period from January 3rd to November 15th 2017 and March 1st to Novemer 30th 2018, respectively. 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 years 2017/2018. 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 and 2018 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 in the frame of the IER improvement of the Sen2Agri campaign. This data collection was made available to ECoLaSS and served for validation and training purposes.
For the production of the prototype over the **South African** site S-2 and Landsat-8 data covering the whole growing season for the reference year 2017 were used. In addition, field data collected by the Western Cape Department of Agriculture for 2017 were used as reference/training data.
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.
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 windows 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. The final feature set comprises features from both S-1 and S-2 from all time periods. Within this feature set S-2 derived features predominate those derived from S-1. Regarding the time windows, the period from mid July to mid October shows the hightest number of selected features. Depending on the cloud cover of the specific part of Europe, the CRM could theoretically be calculated by using optical data only whereas the thematic accuracy of the CRT is highly benefitting from the combined use of S-1 and S-2.
In contrast to the European sites the input data for the **Mali** and **South Africa** 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.
One major focus for the second round of prototype production was the definition of a common European classification key (~15-20 crop classes) which is meaningful and applied to all the European prototype sites.

As a basis the LUCAS and LPIS classes as well as the EUROSTAT classification key served as a basis. The classification **results** for the crop type classification within the **West** site (**French** part) have an overall accuracy of 77%. For the **West** site (**Belgian** part) the OA is approx. 92%. Regarding the **Central** site the OA is at approx. 82%.
The stratum-specific overall accuracies of the crop type maps in the **Mali** site amount to 54-63% whereas the OA of the CRT produced over the **South Africa** site is at 80%.

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 towards CLC+. User requirements as collected by ECoLaSS were taken into account. The CLC+ Backbone operational implementation ITT was only released in late July 2019, therefore could not be fully considered any more for the already mapped prototyps. Considered requirements for the ECoLaSS CLC+ prototype can be listed as follows:

- **Input data:** Use of one-year coverage only, from optical data (combination of S-2A and S-2B) for 2017/2018, to head towards more frequent updates; combination of HRLs 2015 with CRM 2017 (where available);
- **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);

Two prototypes were developed for the WP 45:

1. a **new land cover (NLC) layer at 10m**, with 7 classes in phase 1 (grassland, cropland, forest, water, urban area, bare soil and natural grassland), that were modified to 9-11 classes in phase 2 of the project, taking into account the recommendations made during CLC+ workshops and other exchange meetings with stakeholders in view of the upcoming operational CLC+ specifications (which turned out to request 12 basic land cover classes).

2. a **combined HR Layer**, integrating the HRLs 2015 and – where available – the Crop Mask results from phase 1. 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

Prototype New Land Cover – 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	

CLC EVOLUTION (CLC+ BACKBONE) AT 10M

In Phase 1, a status layer at 10 m was produced on the South-West site. However at the time of Phase I, the final CLC+ specifications were not known. For Phase 2, the final specifications of the CLC+ Backbone became available and could be considered for its implementation in the Southwest site as well as the Central site, but this required a substantial revision of the methodology developed during phase 1 for the raster classification but especially for the hardbone / softbone production.

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 CLC2018 and the LPIS 2017 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 were implemented to focus on adapting the prototype to the CLC+ specifications as provided as part of the CLC+ Backbone tender documents issued over Summer 2019. As a result a new prototype was produced over the southwest site and efforts were dedicated to the production of the softbone based on an automated segmentation approach. A second prototype based on the same methodology was also produced over the Central site to confirm the validity of the approach..

HRL COMBINED LAYER

The HRL Combined Layer is a complementary product, integrating the existing **HRLs 2015** (Water and Wetness, Imperviousness, Grassland and Forest; Small Woody Features are not yet available at full pan-European extent and would also not fit due to their VHR nature). In addition, the **Crop Mask 2017**, that forms an outcome of phase 1 in ECoLaSS, was included, where available.
This prototype was implemented in three European sites: Central, West and South-West. The final rasters with a spatial resolution of 20m depict for each pixel the amount of overlapping HRLs/CRM and give details on which layers are overlapping.

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			X

<u>CROP GROWTH CONDITION</u>

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 seasons of 2017 and 2018 with those of the local average. The deviation of the LAI-gradient towards the average LAI-gradient reveals a shifting of the growing cycle for the respective year.

Input data set: This prototype relies on Sentinel-2 time series of 2017 and 2018, respectively, focussing on the most important time slots within the growing cycle of the crop types.

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. In the second project phase the focus was laid on the definition on a more informative threshold separating the respective categories in order to define 5 classes corresponding to very poor, poor, medium, good, very good.

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.

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.
Parameters for this layer have been calculated in an agricultural area at the demo site in Free State, South Africa, with Sentinel-2 time series for 2016 and 2017, focussing on the growing season of maize and sunflowers, 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 were 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 were 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.
Method:
The relative threshold method was identified as the most suitable in terms of performance and robustness. In combination with the NDVI, based on S-2 Red (B4) and NIR (B8a) bands, and the MSAVI, the relative threshold, behaving dynamically 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, 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 were available 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. Given this background, the results of the combination of NDVI, MSAVI and a flexible threshold are promising for an accurate estimation of crop emergence of the analysed crop types.

Generic Land Cover Metrics or Maximal Phenelogical Activity (PHL)

The phase 2 prototypes developed for the test sites West, Central and South-West were produced using Sentinel-2 time series as **input data** sets in contrast to the prototype created for the West site in the first project phase, where the limited availability of cloud free S-2 data led to the additional use of Landsat-8 time series.
Production:
A **Maximal Phenological Activity (PHL)** layer, which is proposed as one of the potential Generic Land Cover Metrics 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.

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 is still an open question.

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 to 2019, 4 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. These key temporal statistics are the backscattering temporal maximum, minimum, mean and standard deviation.

Methodology:
For each class of the HRL (broadleaved and coniferous forest and grassland), the key temporal statistics showed characteristic statistical distributions in terms of seasonal and annual trends. By applying thresholds, these statistical distributions can reveal potential changes on pixel level but also highlight pixels which are more distant from the class mean. Pixel values ranging within a certain threshold are confirmed as 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.

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

This section provides a comparative overview of the specifications of the HRL 2015 production, the new HRL 2018 production, and the prototypes developed within 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)	2018 (- 1 year)	2017 and 2018
Geometric resolution	20m x 20m	10m x 10m	10m x 10m
MMU	N/A	N/A	N/A
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	Minimum 90% user's/producer's accuracy
Applied methodology	Supervised classification of Sealed/non sealed 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).	Similar procedure than previously with full use of S2 time series	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 – 2017/18
Geometric resolution	20m x 20m	20m x 20m	20m x 20m
MMU	N/A	N/A	N/A
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	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 are	Thematic classes (yearly): 0-99: decrease (0 = 100% decrease, 99 = 1% decrease) 100: Sealed in both years (stable built-up) 101-200: increase (101 = 1% increase, 200 = 100% increase) 201: Non-sealed in both years (stable non built-up) 254 unclassifiable in any of parent status layers 255: outside are
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 of derived IMD changes
Applied methodology	To derive the Imperviousness 2012-2015 layers, the respective IMD status layers 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	Similar procedure than previously with full use of S2 time series	Similar procedure than for 2015, but with full use of S2 and S1 as complement with texture based classification and Random Forest

	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).		

Table 11: Comparison of Technical Specifications for the Built-Up Mask (HRL2015, HRL2018, ECoLaSS)

Technical Specifications for IMPERVIOUSNESS Built-Up Mask			
		HRL2018	**ECoLaSS**
Input Data	**N/A**	Sentinel-1/-2, IMAGE2018 VHR	Sentinel-1/-2
Reference Year		2018	2018
Geometric resolution		10m x 10m	10m x 10m
MMU		N/A	N/A
MMW		10m	10m
Thematic Classes		4 thematic classes: 0: non built-up 1: built-up 254: unclassifiable 255: outside area	4 thematic classes: 0: non built-up 1: built-up 254: unclassifiable 255: outside area
Format		GeoTIFF	GeoTIFF
Thematic accuracy		Minimum 90% user's/producer's accuracy	Minimum 90% user's/producer's accuracy
Applied methodology		Extraction of Texture Attributes based on MASADA toolbox from JRC and with Random Forest Classification	Extraction of Texture Attributes based on MASADA toolbox from JRC with Random Forest Classification

Table 12: 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-1/-2
Reference Year	2015 +/- 1 year	2018	2017/2018
Geometric resolution	20m x 20m	10m x 10m	10m x 10m
MMU	N/A	N/A	N/A
MMW	20m	10m	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 and coniferous class	Minimum 90% user's/producer's accuracy for all status layers
Applied methodology	Supervised classification and manual enhancement.	Random Forest (RF) based classification; application of spatio-temporal input features capturing important time series properties and patterns. The leaf type classification is combined with the Tree Cover Mask (see below) to derive the final DLT product.	Random Forest (RF) based classification; application of spatio-temporal input features capturing important time series properties and patterns. The leaf type classification is combined with the Tree Cover Mask (see below) to derive the final DLT product.

Table 13: 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	• 2018: Sentinel-1/-2 • 2015: Landsat 8, SPOT-5, ResourceSat-2, HR_IMAGE_2015 • Reference DB for change calibration (sampled in loss and gain strata)	Sentinel-1/-2
Reference Year	2012 (+/- 1 year) to 2015 (+/- 1 year)	2015-2018	2017/2018
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	1 ha	3/1 ha (Phase 1/2)
MMW		20m (Boundary filter of 1 pixel to account for geometrical imprecisions)	
Tree cover density threshold	30%	N/A	N/A
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	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 2: new coniferous cover 3: loss of broadleaved cover 4: loss of coniferous cover 10: unchanged areas with tree cover 12: potential change among dominant leaf types	Tree Cover Change mask (yearly): 0: unchanged areas with no tree cover 10: unchanged tree cover 11: new tree cover (not relevant for this implementation of the TCL) 12: loss of tree cover 254: unclassifiable (no satellite image available, or clouds, or shadows) 255: outside area

	254: unclassifiable in any of parent status layers 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).	An initial change layer is derived through map-to-map change detection. Loss and gain strata are sampled to distinguish real loss/gain from commission/omission in one of the input reference years. Based on this sample the probability thresholds are adjusted to correct potential biases. If this is still insufficient to reduce the amount of false positive changes to a sufficiently accurate level a re-classification is performed using supervised learning and the production imagery from the respective reference year. In a final step a boundary filter and the MMU is applied to account for geometric inaccuracies.	Comparison of a pre- and post-change tree cover mask by map-to-map change detection.

Table 14: 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 and 2018
Geometric resolution	20m x 20m	10m x 10m	10m x 10m
MMU	1 ha	0.03 ha (3 pixel)	1 ha/0.05 ha (Phase 1/2)
MMW	20m	10m	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	Minimum 85% overall accuracy
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).

4 Benchmarking Results of Candidate Products

This chapter describes the benchmarking of the various ECoLaSS services and products of Phase 1+2 and the subsequent selection of candidates that are recommended for a future operational implementation from 2020 onwards. The benchmarking procedure with an explanation of the benchmarking criteria has been presented in section 2.2. An overview of the benchmarking evaluation for all prototypes is presented in section 4.1. The particular rating per prototype and an explanation of the most important rating results are documented in section 0. The respective sub-sections (4.2.1-4.2.6) comprise a summary of the candidate services that are considered mature for roll-out and a selection of products that require further research and development. This information leads over to the work of WP 53, which is documented in the Deliverable *D53.1b - Integration Plan into Copernicus Service Architecture (Issue 2)*.

It should be noted that after the first project phase, the first benchmarking outcome (cf. Annex 1) had also been used to identify gaps in the service and product evolution and to support re-focussing related development needs for Phase 2, which is accordingly described in the respective section 3.2 of each ECoLaSS prototype report (AD06-10).

4.1 Overview of the Benchmarking Evaluation Results

The results of the final benchmarking analysis of candidate services/products are presented in Table 16.[3] 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 (- -)

Also intermediate values (such as +/++) are allowed to enable further fine-grading of the relative differences between the candidate prototypes.

In order to correctly derive the “Final ranking” overall scores from these qualitative ratings, , scores between 1 and 5 have been assigned, as shown in Table 15.

Table 15: Translation of qualitative benchmark grades into quantitative scores

Benchmark grade		Score
++	very satisfactory/relevant/applicable	5
+/++		4.5
+	satisfactory/relevant/applicable	4
o/+		3.5
o	neutral	3
-/o		2.5
-	not satisfactory/relevant/applicable	2
--/-		1.5
--	not at all satisfactory/relevant/applicable	1

The ”Final ranking” for each prototype is then calculated as the arithmetic mean of points scored over all validly applied benchmark criteria, recoded into the qualitative ranking scale as shown in Table 15.

[3] The intermediate benchmarking results of the first ECoLaSS project phase are given in Annex 1, as a reference.

The final ECoLaSS benchmarking has been undertaken considering the latest status of all ECoLaSS prototype developments and demonstrations. It encompasses those 11 candidates, which have not yet entered into the operational Copernicus domain, including the three new prototypes “Imperviousness Built-Up Area” (WP 42), “Grassland Use Intensity” (WP 43) and “HRL Combined Layer” (WP 45), which have all been added in the second project phase in response to upcoming new user requirements.

Compared to the phase 1 benchmarking results (Annex 1), the situation has evolved: Altogether, the obtained overall final benchmarking scores have increased, since many developments have taken place in ECoLaSS since. In terms of top-ranked products, the “Incremental IMD change” and “Incremental FO cover change” products remain in the group of most promising products (overall score +/++) for roll-out as future operational Copernicus Land products 2020+. Additionally, three further products have stepped up to the highest achieved “+/++” category: the newly assessed “Grassland Use Intensity”, the “New Crop mask status layer 10m” and the “New crop type status layer 10m”, which all have been rated as mature for implementation and receiving significant stakeholder support. By the project end of ECoLaSS, all five of these products are in the planning for operational implementation, which confirms the project’s findings. In turn, ECoLaSS provides the scientific basis, product specifications, methodological descriptions and various well documented and validated prototypes in the most relevant European bio-geographic regions, giving ample proof of the products’ operational feasibility.

Therefore, the three products resulting with the next-best overall “+” score, i.e. the “HRL Combined Layer” (WP 45), the “Crop Growth Condition” (WP 41) and the “Generic Land Cover Metrics” (WP 41), are all considered very relevant for a next-stage operational Copernicus service implementation, either in a second implementation round from 2021+, as complementary component added to existing products, or potentially as a downstream service, see detailed recommendations in the following section 0.

In addition to the above discussed candidates for future operational implementation, Table 17 shows benchmarking results for those prototypes, which do not require further implementation planning, as they have already become operational during the lifetime of the ECoLaSS project, and are currently already being implemented as operational products of the pan-European CLMS component. This comprises all improved HRL-related products with 10m spatial resolution (investigated in WP 42+43), which have each been ranked with the highest obtained category “+/++”. The same applies to the “CLC evolution” prototype developed in WP 45 in view of the operational implementation of the CLC+ Backbone about to start in early 2020. Since these products have already reached operational status, the three benchmark criteria “long-term evolution”, “portfolio complementarity” and “political support” are obsolete and have therefore not been applied in this case (cf. Table 17). The clear recommendation from ECoLaSS is to maintain these products as integral part of the operational Copernicus product portfolio.

Table 16: Final benchmarking evaluation of candidates for operational roll-out

	Service/product candidate	long-term evolution	portfolio complementarity	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	practically proven roll-out potential	Cost/benefit (forecast)	Documentation	Final ranking
WP 42 Imperviousness incremental update	Incremental IMD change	++	+/++	++	++	++	++	+	+	o	++	+	+	+/++	+/++	+/++
	Imperviousness Built-Up Area	-	-	+/++	+	+/++	+	+	+	+	++	+	+	+	+/++	+
WP 42 Forest incremental update	Incremental tree cover loss	++	+/++	++	++	++	+	+	+	o	++	+	+	+/++	+/++	+/++
WP 43 Improved Grassland	Grassland use intensity	++	++	++	++	+/++	++	o	+	-	++	o/+	o/+	+/++	+/++	+/++
WP 44 New Agriculture product	New crop mask status layer at 10m	++	++	++	+	++	++	+	++	-/o	++	+	+	++	+/++	+/++
	New crop type status layer at 10m	++	++	++	+	++	++	o/+	++	-	++	+	o	+/++	+/++	+/++
WP 45 New Products	HRL combined layer	+	+	o	o	o/+	o	+	o	*N/A*	++	+	++	++	+/++	+
WP 41 Time series indicators	Crop growth condition	+	o/+	+	o	o	++	+	++	-	++	++	+	+	+/++	+
	Crop Emergence Date Map	+	o/+	o	o	o	++	o	+	-	++	+	+	+	+/++	o/+
	Generic Land Cover Metrics	+	o/+	+	+	+	+	-	+	o	++	o	+	+	+/++	+
	Multi-annual trends & potential change	+	o/+	o	o	+	+	-	++	o	++	o/+	+	+	+/++	o/+

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

Table 17: Benchmarking evaluation of investigated prototypes which have meanwhile entered the operational Copernicus service domain

	Service/product candidate	answering identified needs	respecting core vs. DS	State of the art/Inno-vation	Maturity/ Timing	adequate EO availability	adequate in-situ availability	processing capacity (platform, SW)	Automation level	practically proven roll-out potential	Cost/ benefit (forecast)	Documen-tation	Final ranking
WP 42 Imperviousness incremental update	Improved IMD status layer at 10m	+	++	+	++	++	+	++	++	+	+	+/++	+/++
WP 42 Forest incremental update	Improved DLT status layer at 10m	+	++	+	++	++	+	++	++	+	+	+/++	+/++
WP 43 Improved Grassland	Improved Grassland status layer at 10m	+	++	+	++	++	+	++	+	+	+	+/++	+/++
WP 45 New Products	CLC evolution	++	++	++	+	++	+/++	++	+	+	+	+/++	+/++

++	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 provides a detailed interpretation of the above benchmarking results (section 4.1) obtained for all products and prototypes developed as part of Task 4, excluding those which have already entered into the operational domain meanwhile. 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 benchmarking findings, obtained in both, phase 1 and phase 2 as presented in section 4.1, are explained in more detail in the following sub-sections.

4.2.1 Improved Imperviousness Prototypes

INCREMENTAL IMD CHANGE AT 20M

As for the product "Improved IMD status layer at 10m", the HRL2018 ITT required improved technical specifications including a spatial resolution at 20m for the change layer in order to compare the previous status layer at 20m for 2015 with the newly produced status layer for 2018 at 10m – this had already been envisioned for the ECoLaSS prototype. The status layer is mature (+) within ECoLaSS and further evolutions have been made during phase 2, 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 used to be the case. This led to a better evaluation of the "cost/benefit (forecast)" from formerly (+) to (+/++).

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" techniques (++), however, it should be mentioned that this process is close to full automation (+). The incremental change product fully complies to user requirements (++) and enjoys political support (++). Since the methodological approach was further improved during phase 2, the complementary function of the IMD change layer towards the CLMS imperviousness products is considered even higher now at the project's end. Therefore, the ranking slightly increased (from (+) to (+/++)).

With a very high overall score and due to all the above mentioned evaluations, the uptake of this product into the operation CLMS portfolio as of 2020+ is highly suggested, with a yearly update frequency.

BUILT-UP LAYER AT 10M

The newly implemented product "Built-up layer at 10m" is one of the new layers required within the HRLs 2018. As it is already part of the upcoming update, it is considered not being relevant as a long-term evolution (-) nor being a relevant new part of the portfolio (-), since it is already part of it. As could be documented within WP 21 and the related deliverables already, this prototype is answering to user's/stakeholder's needs/requirements (+/++). It is rather seen as a core service element than a downstream service (+/++) and it has a satisfactory level of "political support" (+), as well as "innovation" (+), "maturity" (+), and "automation level" (+). The availability of "processing platforms" capable of dealing with the production of the Built-up layer is very satisfactory (++). The status of documentation is between satisfactory/very satisfactory (+/++), since the full documentation within ECoLaSS is not finalized yet.

With a satisfactory (+) overall score, the product is considered suited to be maintained and further developed as part of the existing operational CLMS portfolio.

4.2.2 Improved Forest Prototypes

INCREMENTAL TREE COVER LOSS

Incremental updates are considered 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 (++). Throughout the project's lifetime, the portfolio complementarity even slightly increased (+/++). Service evolution in ECoLaSS phase 1, however, had not yet reached the desired degree of technical excellence. After completion of phase 2, where the technical evolution of forest cover changes was on of the main focus areas, the state-of-innovation could be improved from neutral/satisfactory (o/+) to satisfactory (+).

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 by 2020. Due to the overall increase of automation level that was tackled as a main topic in phase 2, the cost/benefit forecast could be slightly raised (+/++). Regarding up-to-date in-situ data (o) that contain near-term LC changes, no suitable data sources (besides VHR imagery) are consistently available so far and probably will not be available in the future, as respective data collection would be costly.

Summarizing the various criteria and considering the very high overall evaluation score (+/++), the continuation of this product as part of the operation CLMS portfolio 2020+ is highly recommended, at a yearly update frequency (at least for forest losses).

4.2.3 Improved Grassland Prototypes

GRASSLAND USE INTENSITY AT 10M

The newly demonstrated layer on “Grassland Use Intensity at 10m”, which is seen to exhibit a very high potential for “long-term evolution” (++), is not yet part of the HRLs 2018, but the decision on whether such layer will be produced within this frame is still open. There is a respective option foreseen as part of the HRL Grassland 2018 service contract. Therefore, the “political support” is very high at the moment (++), since the product shows a very high “portfolio complementarity” (++) and definitely answers the “user needs” (++) and shows a high level of innovation (++).

Some questions are still seen in the “automation level” (o/+) as well as the “practically proven roll-out potential” (o/+). This is mainly caused by the fact that “adequate in-situ data” (-) are not consistently available, i.e. LPIS/IACS data containing the necessary information about mowing events. Due to the scarcity of adequate reference data, it is not easy to perform validations. Therefore, the prototype is rated neutral (o) in terms of “maturity/timing”. All in all, the overall score is very high (+/++), which indicates a high potential and interest for operational roll-out.

The product is therefore recommended to form part of the future CLMS portfolio 2020+. Particularly the reference data situation will however have to be further investigated.

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 2018. Like for the beforementioned “improved” HRL products, the spatial resolution was set to 10m. Both, “long-term evolution” (++) and “portfolio complementarity” (++) were rated very relevant, since a Crop HRL layer is not yet part of the HRL 2018, but is the most apparent “missing” product which should be included in the HRL portfolio 2020+, and therefore also highly complementary with the current Copernicus portfolio. Concerning "user needs" (++), the ECoLaSS cropland 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, particularly the Member State support remains currently still unclear and the specifications for such product are not yet commonly agreed, therefore "political support" (-) was set to not satisfactory in the first round of benchmarking undertaken in phase 1. After the second round of prototype implementation, the overall interest in the operational implementation has increased, evidenced by the inclusion of a respective HRL Crops in the Copernicus Work Programme 2020, which leads to an increase in "political support" (+) as well. Although being "state of the art/state of innovation" (++), the product had been rated only neutral in terms of fulfilling "maturity/timing" (o) after the production of the first prototype in phase 1. During phase 2, however, the technical development and maturity level has overall increased (+). In terms of technical criteria, the EO data availability is rated as very satisfactory (++), taking into account Sentinel-1 and -2 time series, and the same goes as well for the "processing capacity" (++). The most critical non satisfactory criterion is the "adequate availability of in-situ data" (-), which is connected to the non-European-wide availability of adequate reference data, such as LPIS. For that reason, ECoLaSS found a way to produce the crop mask prototypes independently of LPIS data,which involved some manual sampling and led to an adjusted ranking in phase 2 (-/o). Accordingly, the "automation level" (+) is satisfactory but not very satisfactory. The "cost/benefit ratio" was initially valued as satisfactory (+). Because of the improvements made during the second iteration and the related more efficient production, the ranking has been adjusted to very satisfactory (++). The "documentation" (+/++) is considered mature. The "practically proven roll-out potential" (+) was overall regarded satisfactory.

In summary, the benchmarking for the new crop mask status layer product resulted in one of the highest overall scores, suggesting to go ahead with the product as part of the operational CLMS portfolio 2020+ in any case.

NEW CROP TYPE STATUS LAYER AT 10M

Like 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 2018, and targets the 15-20 most meaningful crop types in Europe at a 10m spatial resolution. Most ratings are the same as for the crop mask, just some marks tend to be a bit lower. One of the limitations is 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/regions. 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 will have to be considered when deciding on a potential operational implementation. Consequently, this fact is also connected to the only neutral to satisfactory mark for "maturity" (o/+) and the "practically proven roll-out potential" (o).

Like for the crop mask prototype, the otherwise 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 the "documentation" (+/++) have been rated satisfactory/very satisfactory. Thanks to the good basis established during phase 1, the "cost/benefit ratio" (+) could be raised to satisfactory/very satisfactory (+/++). The "political support" has been rated satisfactory (+), since, despite the slightly unclear Member State support situation for a respective pan-European product, a new HRL Crops is included in the Copernicus Work Programme 2020.

In summary, with a very high overall score (+/++), the benchmarking result for the crop type product clearly suggests to proceed with the product for implementation as part of the operational CLMS portfolio. It has to be noted though that particularly the in-situ data availability will have to be improved in collaboration with the Member States, and agreement on common product specifications (particularly the depth of the class nomenclature) will have to be reached on European level.

4.2.5 New LC/LU Prototypes

HRL COMBINED LAYER

The HRL combined layer at 20m spatial resolution is based on already existing products/prototypes, namely the HRLs 2015 and the ECoLaSS Crop Masks. This is the reason why the "availability of adequate in-situ data" is not applicable here, since none are directly necessary. It is not existing in the CLMS portfolio up to now, which led to a satisfactory ranking in the category "long-term evolution" as well as "portfolio complementarity" (both +). On the other hand, the related "user needs" are not very explicit, thus this criterion is rated neutral (o), which is same for the "political support" and the "state of the art / innovation" (both o). One further potential issue is the service nature as such, which is a bit closer to downstream applications than others, hence a neutral-satisfactory mark (o/+).

The "processing capacities" (++) however, are in place, and the "practical proven roll-out potential" (++) has even been rated the highest from all assessed prototypes, since there are hardly any external dependencies and the roll-out potential has been fully proven in ECoLaSS. Furthermore, the product exhibited a satisfactory automation level and maturity (both +) and a good documentation (+/++) together with an excellent "cost/benefit" forecast (++), since the combination of the high quality HRLs does neither require a high amount of man power, nor time-consuming pre-processing of e.g. raw EO data.

The overall satisfactory score (+) indicates that it would be worthwhile to consider an operational implementation of the product in the future operational CLMS context, probably for a second round of implementations in 2021+. This would also fit well with the next (3-yearly) reference year 2021 for the HR Layers.

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 neighbourhood crops. This prototype is an additional layer not yet produced and therefore still presents possible long-term evolution (+) towards 2020+, an intermediate portfolio complementarity (o/+). The boundary between core and downstream service (o) is not yet known, but the product is by its nature a bit less generic than others. 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 is considered satisfactorily mature and timely (+), as well as having an adequate cost-benefit expectation (+).

Nevertheless, it requires either the availability of LPIS data or a very reliable Crop Mask/Type Layer, to be able to identify the parcels and their crop type. Therefore, in the category "adequate in-situ availability" a negative rating (-) has been assigned. However, the second iteration and the thereby improved derivation of both crop mask and crop type map have led to an increase of this criterion from the first phase (where it had still been rated - -). Concerning "user needs" (+), it is not fully clear yet if the product answers the requirements of a sufficient number of end users and whether or not it will get political support (o) due to its novelty. Based on the practical experience gatherd with the prototype implementation in the ECoLaSS demonstration sites, the "roll-out potential" (+) is seen satisfactory, as well as the existing documentation, which could be further improved by the final prototype report delivered within ECoLaSS (+/++).

In summary, the benchmarking for the "Crop Growth Condition" is positive with a high overall score (+) among the experimental new prototypes, which supports a continuation of the product in a future operational CLMS context – possibly as part of the HR VPP products or an associated downstream service.

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 represents a possible long-term evolution (+) towards 2020+ while showing potentially neutral to high portfolio complementarity (o/+). The boundary between core and downstream service (o) is not yet known, anyway also this product is by its nature a bit less generic than others. The state-of the art (++) rating and the availability of the required processing capacity (++) are 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 highly reliable Crop Mask/Type Layer, to be able to identify the parcels and their crop type, means that the category “adequate in-situ availability” had been rated very negative in the first benchmarking assessment (- - in Phase 1). However, the developments made during phase 2 regarding the cropland classification (both mask and types) enabled a slight improvement of this criterion (- in Phase 2). 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 so far. Political support (o) is not yet known, resulting in a neutral rating. Overall, the roll-out potential (+) is seen positive and respective documentation has been improved during phase 2 (+/++).

In summary, the benchmarking for the "Crop Emergence Date Map" is neutral to positive (o/+) with a lower overall score due to some still unknown aspects and not fully reached maturity (o), but supports at least a future further development and investigation 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 offerings, which is reflected by the positive rating for the categories “long-term evolution” (+), answering identified needs” (+), political support (+) and “state of the art” (+). However, during project phase 1, this prototype had been deemed not mature enough and therefore no prototype was provided as deliverable. There had particularly been, and still are, open question related to the product’s accuracy and its assessment. The new layer has not been validated, since there is currently no similar operational product for comparision, but may be in the course of 2020, when the first results of the HR Vegetation Phenology and Productivity become available. Hence the negative rates related to the maturity/timing (-), although adequate EO data (+) 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”). The automation level is still mixed, hence a “o” rating. By its nature, the product leans more towards the core service derfinition (+) and the practical roll-out potential has manwhile been proven through prototype products in ECoLaSS (+). Bersides a satisfactory documentation (+/++), the cots-benefit outlook appears positive. Although the overall score results at (the lower end of) satisfactory (+), the limited technical maturity (-) and the likely partial overlap with the upcoming operational HR VPP product (therefore portfolio complementarity: o/+) suggest that this product may not be a primary candidate for operational rollout in 2020+ and may benefit from further development.

MULTI-ANNUAL TRENDS & POTENTIAL CHANGE

The prototype “Multi-annual trends & potential change” has been developed in ECoLaSS 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 HRLs 2018, but would provide an added value to the current portfolio, the “long-term evolution” (+) and “portfolio complementarity” (o/+) have been rated as neutral to positive. Despite it is following the scientific-technical state of the art (+), (moderately positive rating) the “level of automation” (o/+) was rated as neutral.

Furthermore, the prototype has not been validated up to now due to insufficient availability of in-situ data (o), hence also the negative mark on “maturity/timing” (-). However, the density of the S-1 time series and therefore EO data availability (++) is highly sufficient and rated as strongly positive, as well 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 in phase 1, the roll-out potential could not be proven in phase 1 (-/o). In phase 2, this issue was tackled and a second site was chosen (Central) for proving the roll-out potential. Therefore, the respective rating has been increased in Phase 2 (+). Since the documentation in ECoLaSS was carried out on a high level, the final score for “documentation” (+/++) of the prototype is rated positive.

In summary, the the overall benchmarking score for the "Multi-annual trends and potential change" is neutral to positive (o/+) due to some yet unsolved questions, but is considered to support a continuation of the product development, possibly as some sort of downstream service.

5 Conclusions and Outlook

After 3 years of intense user needs assessment and stakeholder interaction and two complete cycles of technical development, testing, prototyping and quality assessment, this report provides the final benchmarking results of the developed products and assessed prototypes in the ECoLaSS project. It is applying a range of relevant benchmark criteria, in order to identify the most cost-efficient, most urgently needed, technologically most advanced, … product(s) to qualify for being finally put forward as most promising candidates for future new implementation in the 2020+ CLMS operational product portfolio.

The assessment concludes with the duly elaborated recommendation of five candidate products, which are being found most mature and best-fitting for a near-future implementation as part of the CLMS operational service portfolio 2020+, i.e.: Incremental (yearly) IMD Change, Incremental (yearly) Tree Cover Loss, Grassland Use Intensity, Crop Mask Status Layer (10m), and Crop Type Status Layer (10m). Whereas the first three products would complement existing HRL product groups, the two latter could constitute the basis for a new HRL Crops, as foreseen in the Copernicus Work Programme 2020. It is worth noting that the latter three product recommendations go along with a recommendation to the European and Member State stakeholders and decision makers to improve the respective in-situ data availability. By the project end of ECoLaSS, all five of these products are in the planning for operational implementation, which confirms the project's findings. In turn, ECoLaSS provides the scientific basis, product specifications, methodological descriptions and various well documented and validated prototypes in the most relevant European bio-geographic regions, giving ample proof of the products' operational feasibility.

Two further candidate products have been found very relevant for a next-stage operational implementation in 2021 (HRL Combined Layer) or as additional component to complement the upcoming HR Vegetation Phenology and Productivity product group (Crop Growth Condition). Three prototypes have been finally assessed to still benefit from additional developments to become mature enough for operational roll-out (Crop Emergence Date Map, Generic Land Cover Metrics and Multi-Annual Trends and Potential Change). The latter may also qualify as some sort of a downstream service.

Beyond these assessed new product candidates, it should be highlighted that further five products have meanwhile already found their way into the operational CLMS portfolio (i.e. the HRLs 2018 and the CLC+ Backbone), which can be considered a great success and proof that ECoLaSS has been assessing and promoting the right topics. These meanwhile-operational products comprise the Improved IMD Status Layer at 10m, the Imperviousness Built-Up Area, the Improved DLT Status Layer at 10m, the Improved Grassland Status Layer at 10m, and the CLC evolution (i.e. CLC+ Backbone) product, all of which are being operationally implemented by industrial consortia with ECoLaSS project partners' leading involvements.

As already stated at the beginning of this report, the outcomes of this benchmarking serve as major input for WP53 and the second issues of the related reports. Therefore, the promoted products exhibiting the highest overall benchmarking scores are analysed in detail in view of the potential roadmap towards their integration into the Copernicus service architecture, in the report ***D18.2:D53.1b - Integration Plan into Copernicus Service Architecture (Issue 2)***.

It has to be noted that these final results of the benchmarking procedure as carried out towards the project end of ECoLaSS in late 2019, show a snapshot of the current status of the technological developments and Copernicus service landscape evolution. Since the evolution in this field is highly dynamic, it is clear that the coming years will bring about a range of new developments and information needs, and the same kind of assessment will for sure look very different in two or three years' time. In this regard, and considering the overall very successful results achieved within the ECoLaSS project, it is highly recommended to continue with this sort of project setup in the future. This will allow to monitor the most up-to-date developments, to obtain the maximum benefit from the continuously increasing amounts of EO data, to enhance the competitiveness of the European research & development as well as downstream service industry and to ultimately support Copernicus stakeholders and decision makers to take informed decisions on the future of the Copernicus Land Monitoring services and products.

ANNEX 1: ECoLaSS Phase 1 Benchmarking evaluation of candidates for operational roll-out

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

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