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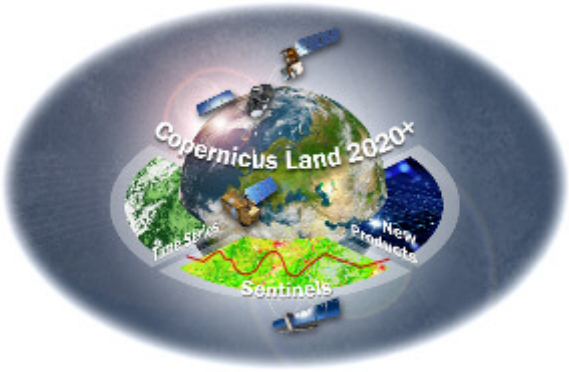
ECoLaSS

Evolution of Copernicus Land Services based on Sentinel data



D4.2

"D22.1b – EO and other data requirements Report (Issue 2)"

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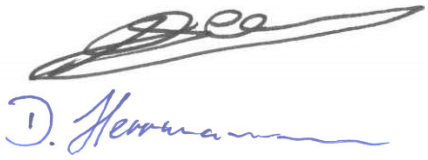
Author(s):	Christophe Sannier (SIRS) Sophie Villerot (SIRS) David Herrmann (GAF) Linda Moser (GAF) Katharina Schwab (GAF) Amelie Lindmayer (GAF)	22.01.2019	
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AD03	Proposal: Evolution of Copernicus Land Services based on Sentinel data. Proposal acronym: 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	D3.1 – D21.1a - Service Evolution Requirements Report, Issue 1.0, Issued: 09.08.2017
AD06	D11.1 – D41.1a - Prototype Report: Time Series-derived Indicators and Variables, Issue 1.0. Issued: 10.08.2018
AD07	D12.1 – D42.1a - Prototype Report: Consistent HR Layer Time Series/Incremental Updates, Issue 1.0. Issued: 23.07.2018
AD08	D13.1 – D43.1a - Prototype Report: Improved Permanent Grassland, Issue 1.0. Issued: 17.07.2018
AD09	D14.1 – D44.1a - Prototype Report: Crop Area and Crop Status Parameters, Issue 1.0. Issued: 10.08.2018
AD10	D15.1 – D45.1a - Prototype Report: New LC/LU Products, Issue 1.0. Issued: 03.08.2018
AD11	D17.1 – D52.1a - Report on Candidates for Operational Roll-out, Issue 1.0. Issued: 21.12.2018
AD12	D18.1 – D53.1a - Integration Plan into Copernicus Service Architecture, Issue 1.0. Issued: 23.12.2018
AD13	D18.3 – D53.2a – White Paper on Copernicus Land Evolution, Issue 1.0. Issued: 23.12.2018
AD14	Technical Note – Proposed substitutes for Sentinel-3 data, Issue 1.0. Issued: 04.12.2018
AD15	GMES Initial Operations / Copernicus Land monitoring services – Validation of products: EU-Hydro validation Report (GIO_EU_HYDRO_2012_Validation_Report_1_1), Issue 1.1, Issued 09.06.2017. Available at: https://land.copernicus.eu/user-corner/technical-library/eu-hydro-validation-report/view
AD14	State of Play Report – Geospatial Reference Data, issued Dec. 2017, available at: https://insitu.copernicus.eu/state-of-play/

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 or other optical data if needed. 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 Deliverable "**D22.1b – Assessment of EO and other Data Requirements**" analyses the data requirements of Copernicus Land services of the continental and global component, for mid-term (2018) and long-term (2020+) evolution.

The comprehensive assessment of Copernicus Land Service evolution requirements as undertaken by ECoLaSS needs to consider specifically also EO and other data requirements, in order to make sure that the general requirements expressed as part of WP 21 "Assessment of Service Evolution Requirements" [AD05] are realistic and can be supported by a sustainable provision of relevant input data, to ensure the service operational conditions in the near and more distant future. Therefore, the objectives of the WP 22 are to:

- Assess currently available EO, reference and in situ data and their usability for the evolution of Copernicus Land Services
- Follow and analyse the evolution of new and upcoming satellite/sensors
- Define data requirements relevant for future Copernicus Land services 2020+

This "EO and other data requirements report" constitutes the second issue of the WP22 main deliverable. It takes into account the experiences made in the first implementation of the new/improved next-generation Copernicus Land service candidates in a range of demonstration sites, as well as the most recent exhaustive collection of user requirements as documented by the outcomes of WP21. This second issue represents the final consolidation of the EO and other data requirements as collected by ECoLaSS. Several conclusions on the operability of the prototypes envisioned in the first phase can already be drawn – in particular, the S-2 and S-1 time series datasets have proven to be a strong basis for shorter incremental updates of the current CLMS products and it is expected in the second phase to be reinforced by the further complementary time series use of S-1 data.

A detailed review of the status of Copernicus EO and other data was made outlining the shortcomings of the current provision and the consequence this might have for future services. An assessment of the current and future offering in terms of EO data was made including the Sentinel constellation based on available documentation and the assessment of future mission evolution was also done primarily based on the participation in relevant meetings. This was contrasted to the needs identified as part of WP21 to assess any critical gaps and potential mitigation measures as outlined below:

- There is still a lack of a reliable geometric reference dataset which is not fully supporting the use of the Copernicus VHR dataset for calibration and validation of the thematic classification associated with the production of HRL at pan-European level. This could be resolved e.g. by

improving the quality of the pan-European DTM and/or by developing a reliable VHR reference based on one of the VHR coverages and making use of available orthophoto coverages from MS.

- The specifications of the upcoming VHR_IMAGE_2018 data with 2-4 m spatial resolution will pose a limitation in terms of information content and discriminability of landscape features.
- The level of pre-processing for S-2 imagery is currently inadequate thus hampering the development of automated processing chains based on dense time series. Updates of the pre-processing tools available are expected in the future, without further explicit date.
- Alternatives to the cloud mask provided by Sen2Cor, such as MAJA pre-processing or a customised cloud mask, have proven to be viable, as outlined in WP32.
- Newer candidate products such as phenological layers and crop type layers could benefit more from the deeper integration of S-1 images into the processing chain, in particular to mitigate the occurrence of cloud cover, which will be further tested in the second project phase of ECoLaSS.
- At the time of this report's writing, the products of S-3 were still under review in order to improve their quality and robustness. The densification of the time series of optical data from S-2 will be done in the framework of ECoLaSS by using PROBA-V data in the meantime.
- Maintaining the quality of historic HR/VHR EO data collections and improving access thereto may become of increasing importance. Recent examples at European level suggest there may be a trend to consider retrospective monitoring approaches, to extend the time series of EO based LC/LU assessment and change analyses also into the past, allowing comprehensive and informed policy decisions.

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

- Although a higher-precision DEM for Europe may be procured by ESA in the course of 2019, it will come too late to support a better geometric consistency of the upcoming VHR_Image_2018 dataset. However, future generations of Copernicus services may greatly profit from it.
- Supporting in situ data for training and validation of thematic data are not homogeneous across the EEA-39 countries.
- One of the more obvious examples is that of LPIS which could provide reliable training and validation data for the production of HRL grassland and a future crop layer, but its availability at pan-European level is far from complete despite the INSPIRE Directive. This would require further support and Strengthening of the Copernicus In-situ Component to improve the access to high quality reference and in-situ data for the Copernicus Services.
- The use of LUCAS dataset will be further explored in the second ECoLaSS phase as a basis for a crop mask layer.

The analysis of critical gaps and the provision of mitigation measures does not end in the final WP22 report. Rather it will be re-assessed at the end of the project through WP52 and WP53 Deliverables, which tackle the issues of feasibility of each prototype for future operational implementation.

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Abbreviations

AGDC	Antarctic Glaciological Data Center
ALOS	Advanced Land Observing Satellite
AMI	Active Microwave Instrument
AOD	Aerosol Optical Depth
AOI	Area Of Interest
AOT	Aerosol Optical Thickness
ASAR	Advanced Synthetic Aperture Radar
ASTER-GDEM	Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model
AVNIR	Advanced Visible and Near-Infrared Radiometer
AWiFS	Advanced Wide Field Sensor
BGIS	Ball Global Imaging System
CASC	China Aerospace and Science Corporation
CAVIS	Clouds Aerosols Vapors Ice and Snow
CCM	Copernicus Contributing Mission
CCME	Copernicus Contributing Mission Entity
CDED	Canadian Digital Elevation Data
CLC	CORINE Land Cover
CLMS	Copernicus Land Monitoring Services
CNES	Centre National d'Études Spatiales/National Centre for Space Studies
CORDA	Copernicus Reference Data Access
CORINE	Coordination of Information on the Environment
COSMO	COnstellation of small Satellites for the Mediterranean Observation
C-SAR	C-band Synthetic Aperture Radar
CSCDA	Copernicus Space Component Data Access
DAP	Data Access Portfolio
DEM	Digital Elevation Model
DMC	Daily Imaging Capability
DSM	Digital Surface Model
DTM	Digital Terrain Models
DWH	Data Warehouse
EC	European Commission
ECoLaSS	Evolution of Copernicus Land Services based on Sentinel data
EDRS	European Data Relay Satellite
EEA	European Environment Agency
EEE	Entrusted European Entities
EIONET	European Environment Information and Observation Network
ENVISAT	ENVironment SATellite
EO	Earth Observation
EROS	Earth Resources Observation and Science (Center)
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ESDB	European Soil Database
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper Plus
ETRS89-LAEA	European Terrestrial Reference System 1989 - Lambert Azimuthal Equal-Area
EU	European Union
EU-DEM	European Union Digital Elevation Model over Europe
EUNIS	European University Information Systems
EW	Extra-Wide Swath Mode
FAO	Food and Agriculture Organization

FOC	Full Operational Capacity
FOR	Forest layers
FP7	Seventh Framework Program
FUA	Functional Urban Area
GCP	Ground Control Point
GEDI	Global Ecosystem Dynamics Investigation
GeoTIFF	Georeferenced Tagged Image File Format
GEZ	Global Ecological Zones
GFSAD30	Global Food Security-Support Analysis Data at 30 m
GHCN	Global Historical Climatology Network
GIO	GMES Initial Operations
GIS	GeoEye Imaging System
GISC	GMES in-situ Coordination
GLWD	Global Lakes and Wetlands Database
GMES	Global Monitoring for Environment and Security
GPCC	Global Precipitation Climatology Centre
GRA	Grassland layers
ha	Hectare
HD	High-Definition
HH	Horizontal transmit/Horizontal receive (polarization)
HiRAIS	High Resolution Advanced Imaging System
HiRI	High-Resolution Imager
HLOP	High Level Operations Plan
HR	High Resolution
HRG	High-Resolution Geometrical
HRL	High Resolution Layer
HRS	High-Resolution Stereoscopic
HRVIR	High-Resolution Visible and Infrared sensor
HV	Horizontal transmit/Vertical receive (polarization)
ID	Identifier
IMD	Imperviousness Density
IMP	Imperviousness layers
INSPIRE	Infrastructure for Spatial Information in Europe
IPF	Instrument Processing Facility
IRS	Indian Remote-Sensing Satellite
ISMN	International Soil Moisture Network
ISRO	Indian Space Research Organization
ISS	International Space Station
IW	Interferometric Wide Swath Mode
JAXA	Japan Aerospace Exploration Agency
JRC	Joint Research Centre
LC	Land cover
LIDAR	Light Detection And Ranging
LISS	Linear Imaging Self-Scanning Sensor
LMR	Low Resolution Mode
LPIS	Land Parcel Identification Systems
LS	Landsat
LST	Land Surface Temperature
LU	Land Use
LUCAS	Land Use/Cover Area frame statistical Survey
MAES	Mapping and Assessment of Ecosystems and their Services
MAP	Maximal Phenological Activity
MBRSC	Mohammed Bin Rashid Space Center

MEP	Mission Exploitation Platform
METI	Ministry of Economy, Trade and Industry of Japan
MGRS	Military Grid Reference System
MIR	Mid InfraRed
MMU	Minimum Mapping Unit
MODIS	Moderate Resolution Imaging Spectroradiometer
MPC	Mission Performance Center
MR	Medium Resolution
MS	Multi-Spectral
MWIR	Mid Wavelength InfraRed
N/A	Not Available
N2K	Natura2000
NAOMI	New AstroSat Optical Modular Instrument
NIR	Near-InfraRed
NISAR	NASA-ISRO Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
NRC	National Reference Centers
NSIDC	National Snow and Ice Data Center
NUTS	Nomenclature of territorial units for statistics
OLCI	Ocean and Land Color Instrument
OLI	Operational Land Imager
OSA	Optical Sensor Assembly
OSM(F)	OpenStreetMap (Foundation)
PA	Producer´s Accuracy
PAN	Panchromatic
PDGS	Payload Data Ground Segment
PICES	Producer Independent Crop Estimate System
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
PROBA-V	PRoject for On-Board Autonomy–Vegetation
R&D	Research and Development
REIS	RapidEye Earth Imaging System
REMA	Reference Elevation Model of Antarctica
RISAT	Radar Imaging Satellite
RMSE	Root Mean Square Error
RSIS	Ramsar Sites Information Service
S-1	Sentinel-1
S-2	Sentinel-2
S-3	Sentinel-3
SAOCOM	Satélite Argentino de Observación Con Microondas/Argentine Microwaves Observation Satellite
SAR	Synthetic Aperture Radar
SARM	SAR Mode
SIASGE	Sistema Italo Argentino de Satélites para la Gestión de Emergencias/Italian-Argentine System of Satellites for Emergency Management
SLIM6	Surrey Linear Imager Multispectral 6 channels
SLSTR	Sea and Land Surface Temperature Radiometer
SM	Strip Map Mode
SPOT	Satellite Pour l'Observation de la Terre/Satellite for observation of Earth
SRAL	Sentinel-3 Ku/C Radar Altimeter
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wavelength Infrared
SYN	Synergy
TIR	Thermal Infrared

TM	Thematic Mapper
TP	Tie Point
URL	Uniform Resource Locator
UK	United Kingdom
US	United States
USGS	United States Geological Survey
VGT	Vegetation
VHR	Very High Resolution
VH	Vertical transmit/Horizontal receive (polarization)
VIS	Visible
VITO	Vlaamse Instelling voor Technologisch Onderzoek
VNIR	Visible and Near InfraRed
VV	Vertical transmit/Vertical receive (polarization)
WFS	Web Feature Service
WMS	Web Map Service
WMTS	Web Map Tile Service
WP	Work Package
WPD	Work Package Description
WV	Wave-Mode
WV	Water Vapour
WV	WorldView
WWF	World Wide Fund for Nature

1 Introduction

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

To achieve this goal, ECoLaSS will make full use of dense time series of Sentinel-1 (S-1) Synthetic Aperture Radar (SAR) data and Sentinel-2 (S-2) optical data – Sentinel-3 (S-3) was foreseen as a potential complement for the S-2 time series, however, as of the time of the redaction of this report, the selection of suitable S-3 products was not operational. Rapidly evolving scientific as well as user requirements will be analysed in support of a future pan-European roll-out of new/improved Copernicus Land Monitoring Service products, and the transfer to global applications.

The comprehensive assessment of Copernicus Land Service evolution requirements as undertaken by ECoLaSS needs to consider specifically also EO and other data requirements, in order to make sure that the general requirements expressed as part of WP 21 "Assessment of Service Evolution Requirements" [AD05+06] are realistic and can be supported by a sustainable provision of relevant input data, to ensure the service operational conditions in the near and more distant future. Therefore, the objectives of the WP 22 are to:

- Assess currently available EO, reference and in situ data and their usability for the evolution of Copernicus Land Services
- Follow and analyse the evolution of new and upcoming satellite/sensors
- Define data requirements relevant for future Copernicus Land services 2020+

This present Deliverable D4.2: "**D22.1b – EO and other data requirements Report (Issue 2)**" is the second issue of the "WP 22 – EO and other Data Requirements" main Deliverable, and takes into account the experiences made in the first implementation of the new/improved next-generation Copernicus Land services in several ECoLaSS demonstration sites and the outcomes of WP21 of Phase 1 and Phase 2 in terms of user requirements. It is part of Task 2: "Consolidation of Copernicus Land Evolution Requirement". The main objective of this Task is to collect, update and consolidate the functional and technical evolution requirements of existing and upcoming services for the Copernicus Land Monitoring Service (CLMS) beyond 2020, both of the Continental and Global CLMS Component.

The assessment of EO and other data requirements as outcome of WP 22 forms part of the basis for the developments to be implemented within the ECoLaSS project, e.g. the methodological developments (Task 3), prototype demonstrations (Task 4), user consultation/feedback, as well as the identification of candidates for future operational roll-out and their integration potential in future (2020+) Copernicus Land services (Task 5). The dependencies of WP 22 with the relevant other WPs/Tasks of the ECoLaSS project are visualised in Figure 1:

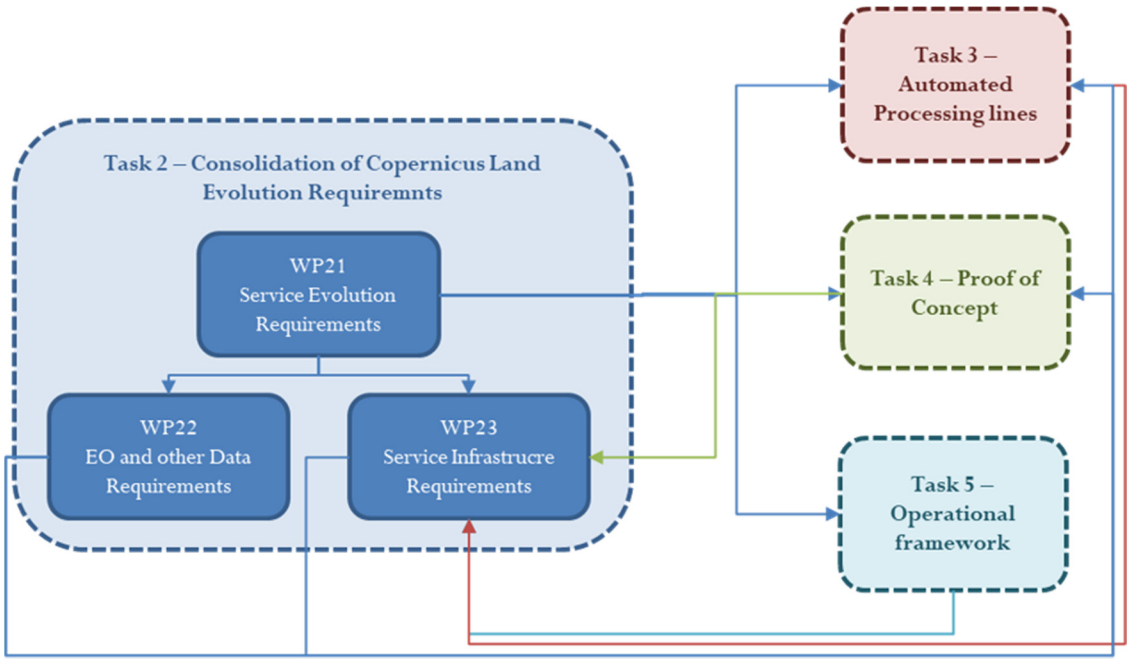


Figure 1: Schematic dependencies and information flows between the main ECoLaSS implementation Tasks

Based on the experiences from the GMES Initial Operations (GIO) stage between 2011 and 2014 (i.e. still in the pre-Sentinel era), EO data availability had been identified a major bottleneck for operational service implementation by the EEA. This is of relevance for future evolution of the Copernicus Land Monitoring services on pan-European level -see also Dufourmont (2015), and Langanke and Dufourmont (2015)-, which are being addressed in ECoLaSS: Acquisition of EO data for HR Layer production had been somewhat disconnected from service provision with: **i)** no continuous satellite image acquisition system (only two HR coverages per reference year, based on CCM data), **ii)** lack of timely availability of initial contiguous image coverages, **iii)** very long range of image acquisition (4 years, from 2011 to 2014) for complete coverage (EEA-39).

Issue **i)** had already been improved for the Copernicus Land High Resolution Layer (HRL) 2015 production, by the use of initial S-2 time series for the production of four HRLs, S-1 time series for 2 HRLs, and additional data such as from Landsat-8 etc. for four HRLs. Concerning issue **ii)** such time series enable a faster timely availability of the data which are no longer restricted to 1-2 complete coverage acquisitions per reference year; the problem, however, persists for a contiguous image coverage of Very High Resolution (VHR) data. Regarding issue **iii)** there had still been a long range of image acquisition necessary for the HRL reference year 2015 with still only restricted Sentinel time series availability (3 years from 2014 to 2016).

As for the global component, most products were deducted from SPOT VEGETATION imagery. There is an ongoing increase of the spatial resolution of some of the products from 1 km to 333 m / 100 m (PROBA-V only, since S-3 products that were deemed relevant to densify the S-2 time series are not operational for the second phase). In addition, some S-2 based products similar to the HRLs are currently under development to be applied at global level (AD 05 and corresponding second Issue).

A second iteration of the **user requirements analysis** was performed as part of **WP 21** (second Issue). There is a general recognition that users are increasingly interested in the Copernicus (Sentinel) satellite data themselves rather than in derived thematic services, which was repeatedly mentioned by most of the (institutional) user organisations. There is an increasing tendency that users are aiming to build up own processing facilities and acquire according staff. This represents a real paradigm change as compared to the past, where most institutional users found it technically too difficult and economically not worthwhile to invest in such, and were – if using remote sensing data at all – rather relying on commercial service providers' capacities. In terms of spatial resolution, the 20m of derived HRL 2015 products has proven sufficient for some users, but not for others which would appreciate 10m HR Layers – which is currently

being implemented with the HRLs 2018. A critical time lapse has been perceived between the Sentinel data acquisition and the timeliness of product update publication and availability of the pan-European Component (e.g. HRLs). In terms of future service specifications, a general requirement for shorter update frequencies and change products (e.g. through incremental updates) was mentioned throughout the user requirements collection process.

From the currently produced HRLs 2018, specifically the Grassland as well as Water and Wetness products require dense time series of the reference year, as well as time series going back to the past for six and seven years, respectively. Concerning new services, a particular need for a pan-European Agricultural Service as well as for a Phenology Layer were the most frequently recorded responses of the user requirements analysis. Such layers are subject to the availability of dense time series imagery from S-1, -2, and -3, possibly supported by other data, which are analysed in this deliverable. Particularly the procurement of a HR Phenology product is currently being prepared by the EEA, and is expected for publication still in the first quarter of 2019.

More frequent and incremental updates are already a key aspect of the developments addressed in ECoLaSS. Time series analyses from S-1 and S-2 data that build the backbone of future product developments in the ECoLaSS Task 3: Automated High Data Volume Processing Lines are further put to test for yearly updates in phase 2. In the absence of already usable Sentinel-3 time series, the complementary use of alternative MR optical satellite data is being explored by ECoLaSS.

2 State of Play and Assessment Approach

In this chapter, an overview of the current and past arrangements for the delivery of Copernicus Land Services is made considering that the thematic services became operational prior to the launch of the Sentinel constellation. In addition, the approach to assess EO and other data requirements toward future post 2020 Copernicus Land Services is presented focussing on available documentation and participation in relevant meetings.

2.1 Status of Copernicus EO and other data provision

The following sections provide an overview of the state of play for the provision of existing EO data (section 2.1.1) in the Very High Resolution (VHR), High-Resolution (HR) and Medium Resolution (MR) domain, and other data, e.g. in-situ data (section 2.1.2), and describe the approach for the assessment of EO and other data requirements as performed in the ECoLaSS project in preparation for future Copernicus Land Monitoring Services (section 2.2) as well.

2.1.1 EO data provision

The provision of Copernicus Land Services at pan-European level was initiated in 2012 with the so-called GMES Initial Operations (GIO) prior to the launch of the Sentinel constellation. As a result, the first full deployment of the HRL production (HRL IMD had already been produced for 2006 and 2009 as a fast track service) was based on the same data than that of the CORINE Land Cover production which was initiated in the 1990s and was based initially on Landsat 30m and then SPOT and IRS 20m resolution acquired over two coverages at least 6 weeks apart during the vegetation growing season. In 2012, IRS and SPOT data were replaced by 20m resampled RapidEye data for the second coverage. However, as opposed to previous periods, this dataset did not have a SWIR band which was a drawback for a number of applications. This was partially resolved by the acquisition of free Landsat-8 data launched in early 2013, but resulted in additional tasks for service providers. In addition, the initial coverage proved problematic and a gap filling exercise due to cloud cover had to be performed by service providers especially in northern latitudes also making use of Landsat-8 OLI data.

For 2015, S-2A was only launched in June and only became in full operations toward the end of the year. Therefore, a similar approach to that of the previous periods was implemented with the two coverages based on Copernicus contributing missions (primarily SPOT 5 and Resource Sat 2). However, Landsat-8 and S-2A data were also used to achieve a multi-temporal coverage over most of Europe. For the first time, S-1 was also used for some of the HRLs. However, the coverage achieved was patchy and the identification of cloud and cloud shadow has proven problematic to make full use of the multitemporal coverage. As illustrated in Figure 2, despite the multiple sensor approach, the multi-temporal coverage achieved is heterogeneous with northern latitudes and alpine regions less covered than Mediterranean regions.

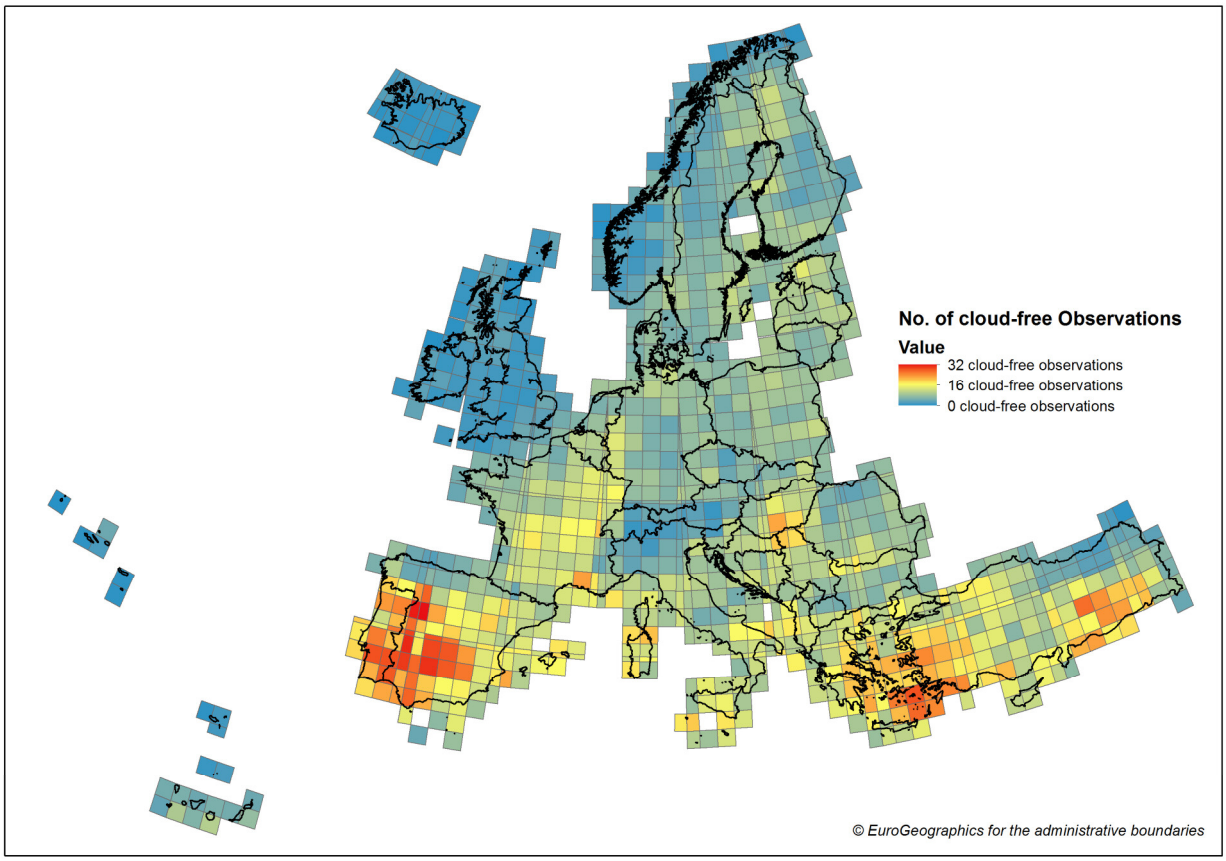


Figure 2: Number of cloud free observations for HRL2015 production per MGRS tile (incl. ResourceSat-2, SPOT-5, Landsat 8 and S-2) over the 2014-2017 period

Scrutiny of the S-2 coverage (see Figure 3) indicates that the use of S-2A was not sufficient at the time of the HRL production, which required further gap-filling datasets, such as Landsat-8. However, the full deployment of S-2B has proven to be sufficient over demonstration sites such as the West site Belgium, when coupled with S-1 data, in Phase 1, as described in section 2.2.2. However, the first analysis to identify what would be the minimum number of cloud free observations required to achieve optimal quality over all demonstration sites, in particular over the North site, tends to vary according to the HRL aimed to be produced. The Imperviousness layer (IMP) layer produced over the South-West site almost achieved the required accuracy using only automated processes, while the phenological layer related to the Maximal Phenological Activity (MAP) could not be produced over the West site using only optical S-2 data. Phase 2 will focus on demonstrating the operativeness of each layer over 3 different demonstration sites.

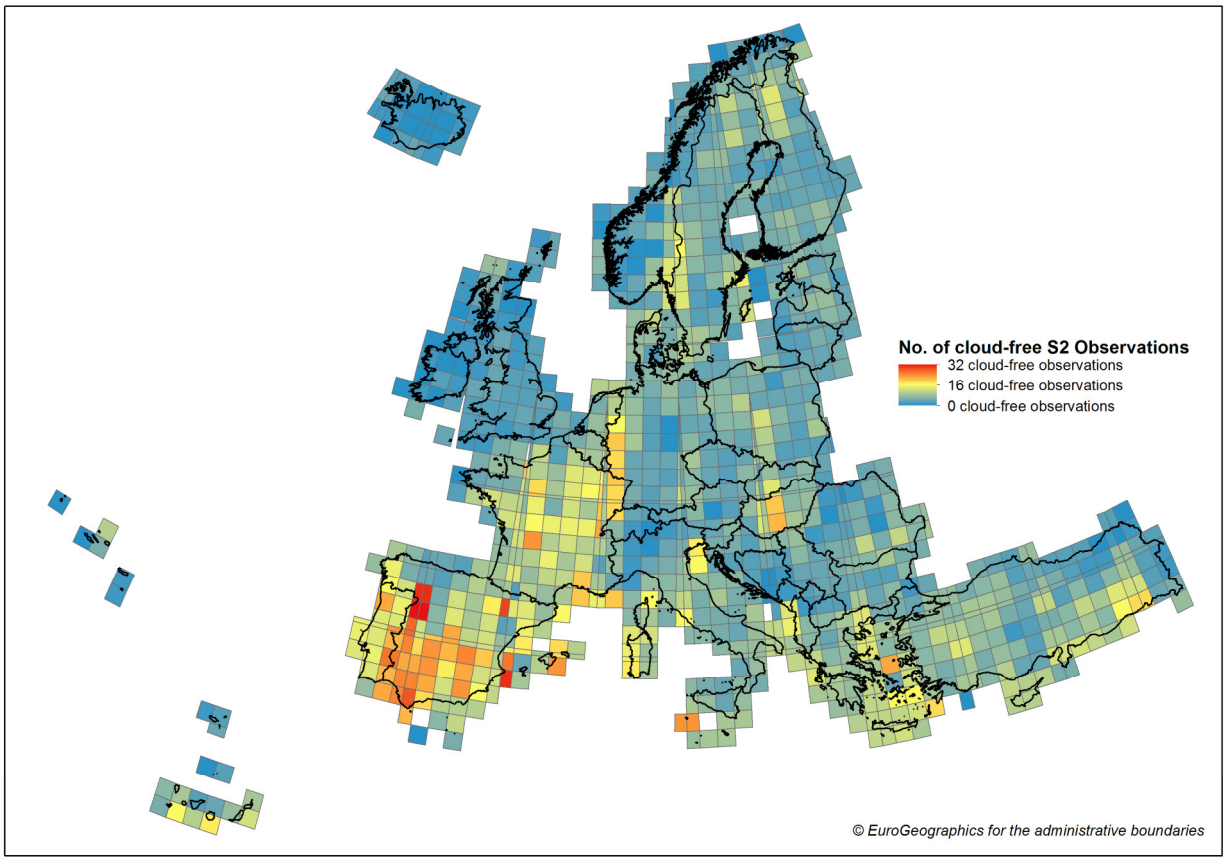


Figure 3: Number of cloud free S-2 observations for HRL2015 production per MGRS tile over the 2015-2017 period

For 2017-2018, for the first time, a separate strategy was adopted for CLC and HRL production that will be primarily based on S-2 imagery. Specifically and only for CLC, a specific dataset was constructed based on S-2 acquisitions and the two-coverage approach implemented in previous time stamps.

It should be highlighted that one of the major issues associated with the current use of S-2 data is the quality of the cloud masks (see Figure 4 and Figure 5) provided with the data as a standard, which still hampers the use of dense time series "as is", to realise the full potential of the S-2 constellation. Feedback on this issue has been provided by ECoLaSS already to the EEEs and the EC. Meanwhile a first improved implementation of the algorithm freely available in SNAP, called IDEPIX, has been released.

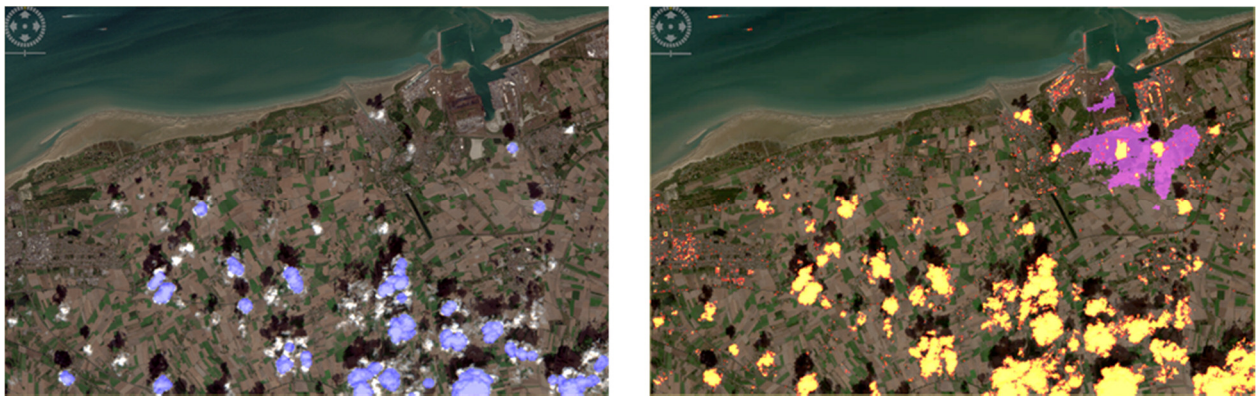


Figure 4: Example of S-2 images pre-processed in SNAP over the North of France. On the left, in blue, the partial cloud mask provided with the image. On the right, in yellow, the masking of opaque clouds obtained with the IDEPIX algorithm in SNAP. Red borders mark the fringe of the opaque cloud, while purple flags are supposed to spot cirrus. As can be seen, urban areas are falsely considered as clouds, while cloud shadows are not captured.

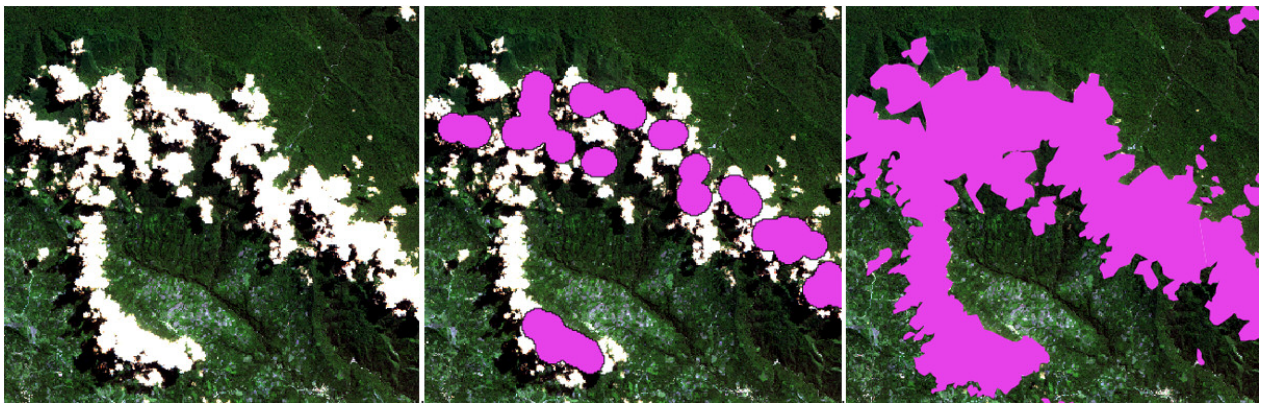


Figure 5: Example of S-2 image extract raw image (left) overlaid with S2 cloud mask and (middle) and custom produced cloud and shadow mask (right), using Copernicus Sentinel data dating from 2015.

However, confusions with urban areas and bright land surfaces (open soils, sand, gravel, rocks) are still common. The standard Sentinel-2 cloud mask as derived from Sen2Cor is still insufficient, in particular to flag cirrus and fringes of opaque clouds, see more details provided in the report related to WP32 (second Issue).

2.1.2 Other data provision

Copernicus defines in-situ data as "all non-space-borne data with a geographic dimension, including observational data from ground-, sea- or air-borne sensors as well as reference and ancillary data licensed or provided for use in Copernicus". Under the Copernicus Regulation, the cross-cutting in-situ coordination task has been delegated to the EEA. In-situ data provide a key information source contributing to achieving high quality, reliability and user acceptance of Copernicus products.

A number of reference products and in-situ data are directly provided via the Copernicus Land portal. The EU-DEM (see section 4.1.1) and the EU-Hydro (see section 4.1.2) are pan-European elevation and hydrographic reference datasets, primarily created to be used by the Copernicus services. Besides, the longstanding LUCAS (Land Use/Cover Area frame statistical Survey) database (see also section 4.1.3) provides a large number of in-situ observations throughout Europe on a three-yearly basis, starting at 2006. The main purpose of this database is the assessment of environmental factors and the verification and validation of the products and services of the Copernicus Land Monitoring Service portfolio.

With the Copernicus Reference Data Access (CORDA), EEA provides a single access point node to a multitude of in-situ information, e.g. in relation to administrative units, topographic maps, land cover & land use, transport networks, ortho-imagery or elevation information. The node provides access to an index of URLs with more than 2,100 geospatial datasets at regional, national and European level from the EEA39 countries (EEA 33 member countries and six cooperating countries). The access is restricted to Copernicus service providers only.

The Copernicus In-Situ component aims to identify data access gaps or bottlenecks related to the Copernicus Services and support the provision of cross-cutting data. In addition, it manages partnerships with data providers to improve access and use conditions of national geospatial datasets. Thus, the In-situ component is substantially supporting the implementation of the six Copernicus Services (Atmosphere Monitoring, Marine Monitoring, Land Monitoring, Climate Change, Emergency Management Service, Security Applications) (https://insitu.copernicus.eu/). Actual challenges, risks and opportunities linked to the access and use of in-situ data in Copernicus are presented for each Copernicus Service in so-called Fact Sheets available at https://insitu.copernicus.eu/library/fact-sheets/fact-sheets.

Besides the Copernicus driven provision of reference and in-situ data, a lot of other sources need to be mentioned. At European level, almost each member state provides access to in-situ data, mostly online and via different data portals hosted by national institutions or research organisations. The INSPIRE

Geoportal collects INSPIRE-compliant datasets and services from the EU-Member States and provides access to geographic information from governmental, commercial and non-commercial organisations (http://inspire-geoportal.ec.europa.eu/).

Outside of Europe, many international organisations (e.g. FAO, World Bank) and research institutions provide access to reference data, in-situ observations and derived products (e.g. maps and indicators). Such data has often a coarse resolution but is available at global scale and therefore of relevance for some Copernicus Services.

2.2 Approach to asses EO and other data requirements

This section outlines the approach to asses EO and other data requirements through the review of available documentation (section 2.2.1), conclusions drawn from Phase I (section 2.2.2) and the participation in relevant meetings (section 2.2.3) particularly focussing on future requirements.

2.2.1 Review of documentation

The collection of EO and other data requirements was compiled from different sources, such as (i) reports originating from previous studies and contracts e.g. related to the deployment of the Sentinel constellation, such as data product quality reports for S-2 and S-3; and (ii) presentations at relevant meetings and workshops on the topic of the CLMS. Both were either provided by the interview partners as part of WP21 or are available online or through the respective workshops. In particular, ESA official documentation, be it be through the official Sentinel website or the numerous downloadable documents, was consulted and summarized. Sources have been cross-checked when conflicted or approximated data were found and is appropriately referenced through the text of this document and listed in the Reference section at the end of the report.
A review of the use of past and current EO data was undertaken based on the consortium's collective knowledge of the CLMS implementation and identifying relevant documentation on specific services.
Partners in the consortium were asked to describe their use of EO data as part of CLMS, focusing on Sentinel and VHR images, and how to manage to incorporate others EO data when problems occur to fully use Sentinel images.
Analysis of users' needs as part of WP21, especially feedback from the EEA and the JRC, was also considered.

2.2.2 Preliminary conclusions drawn from Phase I

The use of EO, in-situ and ancillary datasets during the first phase of ECoLaSS is detailed in the Table 1. According to the reports related to WP52 and 53, the prototypes of Imperviousness (IMP), Forest (FOR) and Grassland (GRA) layers, as well as a new crop mask layer, were deemed altogether feasible, despite not yet having made full-use of the full potential of both S-1 and S-2 datasets.

Further work is planned in the ECoLaSS phase 2, in particular related to the integration of S-1 data in the processing chains and exploratory fusion between PROBA-V and S-2 images, but it should be noted that S-2 twin satellites are outperforming in terms of revisit time and spectral quality – even though geometrical inaccuracies remain, see for example the regularly updated Data Quality Report for S-2 (Team, 2018).

Table 1: EO, in-situ and ancillary datasets used during the prototyping of each product created during phase 1.

Prototypes		Sentinel datasets used	Ancillary datasets used
IMP	Status Layer 2017 Change Layer 2015-2017	- Sentinel-2 (2017), - Sentinel-1 (2017) – not conclusive enough	- Open Street Map - Google Maps - HRL 2015
FOR	Status Layer 2017 Change Layer 2015-2017	- Sentinel-2 (2017)	- VHR data
GRA	Status Layer 2017	- Sentinel-1 - Sentinel-2	- VHR data - LPIS, - LUCAS
INDICATORS	Generic LC Metrics	Landsat-8 Archive (2013-2017)	
	Multiannual trends	Sentinel-1 from (2015-2017)	
	Emergence date	Sentinel-2A data (2016-2017)	- In-situ observations Producer Independent Crop Estimate System - (PICES) for field boundary
	Crop growth Condition	Sentinel-2A data (2017)	
AGRI	Crop Mask Crop Type Map	- Sentinel-1 (2017) - Sentinel-2 (2016 & 2017)	- HRL 2015 - LPIS (2016 & 2017)
NLC	Status Layer	Sentinel-2 data (2017)	- Open Street Map - Google Maps - HRL 2015 - LPIS - CLC 2012 - EU-Hydro

2.2.3 Participation in relevant meetings

Participation in relevant meetings at national or European level, aiming at shaping the future of the Copernicus space segment, was useful to identify what will be the next generation of Sentinels as well as other EO space missions. This knowledge is crucial to identify future CLMS post 2020 requirements and highlight potential gaps in the future provision of EO data.

This process will continue throughout the project with interactions with other WPs, especially WP51 and WP61. Notably, this included the participation in the Multitemp 2017, WorldCover 2017, Big Data from Space 2017 and 2019 or the MARS 2017 and 2018 conferences by several members of the consortium, which was particularly useful to identify the role of the Sentinels and other EO data in potential future services. Another such occasion may be the Copernicus Supplier Industry Days on 27/28 March 2019, taking place in Noordwijk, the Netherlands, which focuses already on the next generation of the Sentinel missions. Information gathered at annual workshops on Sentinel calibration-validation have also been of use, in particular regarding S-3 quality assessment, detailed in the respective Technical Note (AD14).

3 Assessment of EO data provision in view of service needs

The chapter covers the analysis of EO data provision that is relevant to the future evolution of CLMS services at pan-European and global level.

3.1 Sentinel Constellation deployment and operational status

Both S-1 and 2 have deployed their two first satellites, 1A and 1B, on the one hand and 2A and 2B on the other hand. All four instruments have passed the testing phase and are now fully operational. S-3A and 3B have also been launched but are currently in the pre-operational phase. Selected few users are able to access all S-3 products. Some of those products, foreseen as complementary to S-2 time series, are not fully compliant with the quality expectations.

The Full Operational Capacity (FOC) will be reached once the constellation of S-1, -2, 3, A and B models, as well as Sentinel-5P, are in orbit and fully tested and validated (see https://earth.esa.int/documents/247904/685154/Sentinel_High_Level_Operations_Plan).

The whole Sentinel mission is separated in two parts, the core ground segment and the collaborative ground segment. The ground segment oversees the systematic acquisition, processing and distribution of the Sentinel data to the users in a single virtual access point. It also includes the monitoring, control of the satellites themselves. Mechanisms of quality control of the data, as well as archiving, have been incorporated in the treatment chain. Products are typically made available to the users within 3 to 24 hours of being sensed by the satellite. For the collaborative ground segment part, the Sentinel mission is allowing third parties to contribute to the distribution of the data, in the form of specialized solutions tailored for local coverage or specific applications and of mirror sites for the simple redistribution.

3.1.1 Sentinel-1

The S-1 mission consists in the provision of high-resolution radar imaging, even through cloudy atmosphere and during the night. SAR observations foreseen for land applications will include terrain motion surveillance or data for emergency response. Details can be found on the official webpage of the mission at https://sentinel.esa.int/web/sentinel/missions/sentinel-1.
S-1 ensures the continuity of the C-band SAR Earth Observation ESA missions of ERS-1, ERS-2 and ENVISAT.

Table 2: Detailed sensor characteristics of satellites from the S-1 constellation (http://copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Sentinel-1_fiche.pdf)

Platform(s)	
Name	Sentinel 1
Operational status	In fully operational mode: S-1A, S-1B To be produced: S-1C, S-1D
Launch date	S-1A: launched on 3rd April 2014 S-1B: launched on 25th April 2016 S-1C, S-1D: launch date to be determined
Life expectancy	Minimum of 7 years, with consumables for 12 years
Sensor	
Name	C-Band Synthetic Aperture Radar (C-SAR) instrument
Type	SAR MR1
SAR operation modes	- Interferometric Wide Swath [IW], with different schemes of polarisation: in Dual (HH+HV, VV+VH), or in Single (HH, VV) - Extra-Wide Swath Mode [EW], with different schemes of polarisation: in Dual (HH+HV, VV+VH), or in Single (HH, VV) - Wave-Mode [WV], which can only operate in single polarization (HH, VV)

	- Strip Map Mode [SM], with different schemes of polarisation: in Dual (HH+HV, VV+VH), or in Single (HH, VV) It should be noted that over land, IW is the baseline mode.
SAR frequency (GHz)	5.405 GHz
SAR Pixel Spacing (m)	- 5 x 20 m (IW mode) - 20 x 40 m (EW mode) - 5 x 20 m (WV mode) at 100km intervals - 5 x 5 m (SM mode)
Pan merge resolution (m)	N/A
Swath width (km)	- Interferometric Wide Swath: 250 km Swath - Extra-Wide Swath Mode: 400 km Swath - Wave-Mode: 20 km x 20 km - Strip Map Mode: 80 km Swath
Revisit time at the equator (days) with or without programming	6 days from the two-satellite constellation, 175 orbits in 12 days
Distribution	
Cost	Free
Licensing restrictions	ESA – User License
Accessibility	Through the Copernicus Hub (more generally the CSCDA) and other mirror sites
Current Role in CLMS	
Service(s)	- Monitoring the sea ice zones and the arctic environment - Monitoring land surface motion risks - Mapping of land surfaces and land use, such as forest, water, soil and agriculture - providing estimation of crop acreage, soil moisture information and forecast yields – making S-1 a valuable complement to the S-2 mission - Mapping support during humanitarian crises
Role	Additional/supporting data source
Current issues / gaps	S-1 radar imager can produce exploitable images during night time and through clouds (of water vapour, aerosol or ashes), meaning there is no gap in the time series. However, heavy rainfall can degrade the signal from the surface and military or marine radars can produce interference with the S1 resulting images exhibit artefacts over small areas.
Future Role in CLMS	
Service(s)	- Monitoring the sea ice zones and the arctic environment - Monitoring land surface motion risks - Mapping of land surfaces and land use, such as forest, water, soil and agriculture - providing estimation of crop acreage, soil moisture information and forecast yields – making S-1 a valuable complement to the S-2 mission - Mapping support during humanitarian crises
Role	Additional/Supporting data source, possible fusion with S-2 images will be explored
Potential issues / gaps	The military or marine radar produced artefacts can lead to the exclusion of some images, creating gap in the time series.

3.1.2 Sentinel-2

The S-2 constellation is set to produce high-resolution multispectral imaging, that are being used as the primary sources of data for Copernicus operational land services, in the continuity of Landsat, SPOT and IRS satellite missions. S-2 will be mainly focused on land cover and usage, change detection and geophysical variable maps, and will also be of use during emergency management. Details can be found on the official webpage of the mission at https://sentinel.esa.int/web/sentinel/missions/sentinel-2.

Table 3: Detailed sensor characteristics of satellites from the S-2 constellation (http://copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Sentinel-2_fiche.pdf)

Platform(s)		
Name	Sentinel 2	
Operational status	In fully operational mode: S-2A, S-2B To be produced: S-2C, S-2D	
Launch date	S-2A: launched on 3rd April 2014 S-2B: launched on 25th April 2016 S-2C, S-2D: launch date to be determined	
Life expectancy	Minimum of 7 years, with consumables for 12 years	
Sensor		
Name	Multi-Spectral Instrument	
Type	Optical HR2	
Number of bands	13 bands	
Spectral range (nm)	S-2A	S-2B
B1 (aerosol monitoring for atmospheric correction)	430.4-457.4 nm	419.8-464.8 nm
B2 (blue band)	447.7-544.4 nm	443.1-541.1 nm
B3 (green band)	537.5-582.5 nm	536-582 nm
B4 (red band)	645.5-683.5 nm	645.5-684.5 nm
B5 (vegetation detection with red-edge effect)	694.4-713.4 nm	713.8-723.4 nm
B6 (vegetation detection with red-edge effect)	731.2-749.2 nm	730.1-748.1 nm
B7 (vegetation detection with red-edge effect)	768.5-796.5 nm	756.7-793.5 nm
B8 (vegetation detection with red-edge effect)	762.6-907.5 nm	766.5-899.5 nm
B8a (vegetation detection with red-edge effect)	848-881 nm	848-880 nm
B9 (water vapour detection for atmospheric correction)	932-958 nm	929.7-956.7 nm
B10 (cirrus detection)	1336-1411 nm	1338.9-1414.9 nm
B11 (snow, ice and clouds discrimination)	1542.2-1685.2 nm	1539.9-1680.9 nm
B12 (snow, ice and clouds discrimination)	2081.4-2323.4 nm	2066.7-2304.7 nm
Spatial Resolution (m)	- 10 m resolution (B2, B3, B4, B8) - 20 m resolution (B5, B6, B7, B8a, B11, B12) - 60 m resolution (B1, B9, B10)	
Pan merge resolution (m)	N/A	
Swath width (km)	290 km	

Revisit time at the equator (days) with or without programming	5 days from the two-satellite constellation, 2-3 days in mid-latitudes
Distribution	
Cost	Free
Licensing restrictions	ESA – User License
Accessibility	Through the Copernicus Hub (more generally the CSCDA) and other mirror sites
Current Role in CLMS	
Service(s)	Main instrument for COPERNICUS land and security services: - Land cover and use, change detection - Geophysical variables production - Risk mapping - Primary images used for fast mapping during disaster
Role	Primary data source
Current issues / gaps	- Gaps due to cloud presence - Poor quality of the cloud mask (Sen2Cor, improvements through IDEPIX in SNAP, but still insufficient) - Insufficient numbers of GCPs and TPs - to improve the geometric correction - Change in the denomination made by the ESA since December 2016 Only daylight images can be acquired, where the target surface has a sun zenith angle below a certain threshold (82 degree)
Future Role in CLMS	
Service(s)	Main instrument for COPERNICUS land and security services: - Land cover and use, change detection - Geophysical variables production - Risk mapping - Primary images used for fast mapping during disaster
Role	Primary data source
Potential issues / gaps	- Gaps due to cloud presence - Debatable quality of the cloud mask (Sen2Cor, IDEPIX) - rooms for improvement - Insufficient numbers of GCPs and TPs – if not improved - Change in the denomination made by the ESA since December 2016 Only daylight images can be acquired, where the target surface has a sun zenith angle below a certain threshold (82 degree)

3.1.3 Sentinel-3

The S-3 mission is focalized on land and ocean colour, temperature, as well as sea and terrain topography, through the use of medium-resolution multispectral imaging and altimetry.
S-3, like S-1, is also ensuring the continuity of the C-band SAR Earth Observation ESA missions of ERS-1, ERS-2 and ENVISAT. Details can be found on the official webpage of the mission at https://sentinel.esa.int/web/sentinel/missions/sentinel-3.

Table 4: Detailed sensor characteristics of satellites from the S-3 constellation (http://copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Sentinel-3_fiche.pdf)

Platform(s)	
Name	Sentinel 3
Operational status	In pre-operational phase: S-3A In commissioning phase: S-3B To be produced: S-3C, S-3D
Launch date	S-3A: launched on 16th February 2016 S-3B: launched on 25th April 2017 S-3C, S-3D: launch date to be determined
Life expectancy	Minimum of 7 years, with consumables for 12 years
Sensor	
Name	OLCI (Ocean and Land Color Instrument)
Type	Optical MR2
Number of bands	21 bands (nominal Earth View), 45 bands (spectral campaigns)
Spectral range (nm)	From 400 to 1020 nm
Spatial Resolution (m)	(for each band) 300 m
Pan merge resolution (m)	N/A
Swath width (km)	1270 km
Revisit time at the equator (days) with or without programming	27-days repeat cycle (14+7/27 orbits per day)
Sensor	
Name	SRAL (S-3 Ku/C Radar Altimeter)
Type	SAR MR2
SAR operation modes	LMR (Low Resolution Mode) SARM (SAR Mode)
SAR frequency (GHz)	LRM mode: 1.9 KHz SAR mode: 17.8 KHz
Spatial Resolution (m)	Azimuth resolution for SARM/LRM: around 300 m
Pan merge resolution (m)	N/A
Swath width (km)	-
Sensor	
Name	SLSTR (Sea and Land Surface Temperature Radiometer)
Type	SAR MR-2
Number of bands	9 bands
Spectral range (nm)	from 550 nm to 12000 nm
Spatial Resolution (m)	500 m (VIS, SWIR bands) 1 km (MWIR, TIR bands)
Pan merge resolution (m)	N/A
Swath width (km)	For nadir view: 1420 km For dual view: 740 km
Distribution	

Cost	Free
Licensing restrictions	ESA – User License
Accessibility	Through the Copernicus Hub (more generally the CSCDA) and other mirror sites, as well as EumetCast
Current Role in CLMS	
Service(s)	- Land monitoring, through the determination of land surface temperature (e.g. fire location and classification)
Role	Additional/supporting data source
Current issues / gaps	- SLSTR acquired data out of eclipse only in the visible channel. The IR and SWIR channels operates permanently - OLCI products and their derivative, the SYN products, have not been validated regarding their quality
Future Role in CLMS	
Service(s)	- Land monitoring, through the determination of land surface temperature (e.g. fire location and classification) - Land surface colour - Topographic data - Generation of vegetation products (biophysical index)
Role	Additional/supporting data source, possible fusion with S-2 images will be explored once products will be validated
Potential issues / gaps	- OLCI operates during daylight, with a sun zenith angle of the sub-satellite point of less than 80 degree - SLSTR acquired data out of eclipse only in the visible channel. The IR and SWIR channels operates permanently

S-3 provides with OLCI an instrument with superior spectral and radiometric characteristics than the MERIS sensor but with additional spectral bands and improves the coverage to daily global revisit thanks to both satellites in orbit. The coverage of SLSTR nadir view also offers the capability to expand the spectral range to the SWIR. These were the major assets of the S-3 mission.

However, this observing capacity is at the cost of the combination of 4 different instruments on board on two different platforms to get the daily revisit cycle which is actually the main mission asset for land observation. As the specifications of the S-3 mission have been very predominantly driven by the ocean applications the OLCI instruments have tilted westwards and the equatorial crossing time is around 10:00 AM. The combination of both decisions reduces the observing capacity due to darkness in high latitude in winter time as the overpass is earlier than most land missions and the instrument tilted opposite to sunrise. These issues for the land community were reported in due time but did not impact the mission specifications.

The S-3 was foreseen as complementary mission to S-2 for land applications. The Copernicus Ground Segment, operated by ESA, is working towards generating a Synergy Level 2 product, which aims at combined surface reflectance spectrum from OLCI and SLSTR. This seems to be a much more challenging task than expected and results presented so far were not convincing. The Copernicus Global Land Services have decided to wait before starting using the S-3 data because of the current S-3 products quality. The most quantitative information on the current status of the S-3 products are reported in the S-3A OLCI Cyclic Performance Report Cycles No. 27, 30, 31 and 35 made available by the Mission Performance Center (MPC).
In order to clarify the current status of S-3 products, a dedicated Technical note related to S-3 has been produced (AD14), and parts of it have been reproduced below in this section for clarity.

AOT FAILING RETRIEVAL

The performance of the current algorithm for the aerosol content retrieval is not sufficient to deliver ready to use atmospherically corrected surface reflectance. OLCI measurements and the associated Aerosol Optical Thickness or Depth (AOT or AOD) retrieval are still impacted by the residual clouds in spite the standard cloud flags: *cloud, cloud margin and cloud ambiguous*. Further improvements are expected but the timeline for a validated solution towards an operational product cannot be set at this stage.

According to the Mission Status report published on 2 October 2018, the definition and implementation of the two new core data products, as requested by the European Commission, namely the AOD and Fire Radiative Power (FRP) is on-going with sample products expected to be available at the earliest in Q4 2018 with an official release planned shortly thereafter following a period of validation.

CLOUD SCREENING

The cloud screening for OLCI cannot take advantage of the SLSTR bands due to the angle and time differences. Consequently, the OLCI cloud screening faces the same challenge than the MERIS instrument missing both the SWIR and the thermal bands. According to the MPC report 27, the OLCI Level 2 cloud flag available during commissioning phase did not fulfil these requirements. Therefore, a big effort was taken by the S-3 MPC to improve the level 2 cloud flagging algorithms. The new cloud flagging is implemented in the current operational and reprocessed products. However, there is room for improvements, as the producer accuracy (PA) of clear pixels is only a little above 81%. This means, there is a commission error of clear pixels of above 19% and an omission error of cloud pixels of 8.1%.

Significant improvements are required to allow screening the clouds and the cloud shadows in an efficient way for land mapping and monitoring. It's worth mentioning that this cloud screening issues concern only land applications.

QUALITY FLAGS

The current version of the products does not provide consistent quality flags and apparently includes some coding errors. It is obviously difficult to figure if these are production or coding errors.

CURRENT REVISIT CYCLE

Early September 2018, the mission manager Susanne Mecklenburg announced the first S-3B SLSTR Level 1 sample data produced starting from the 03/09/2018 as a new step in the commissioning phase. On the 24/10/2018 the SLSTR-3B Level-2 Land Surface Temperature (LST) product notice indicates: "It is recommended that users do not utilise S-3B SLSTR Level-2 LST processing baseline v1.08 for any meaningful scientific analysis until the latest updates have been implemented in the IPF."

As S-3B is still in the commissioning phase, the current revisit cycle of the S-3 mission is not much better than the S-2 revisit cycle with two operational satellites in orbit. While a nominal 5-day revisit cycle was expected the location in high latitude of most ECoLaSS sites provides an effective revisit of the S-2 below 3 days for more than half of the area due to the overlap of converging orbits further polewards. Therefore the relevance to develop a Copernicus service based on S-3 in this context seems quite limited while S-2C is already expected to be launched in 2022.

CURRENT STATUS OF THE SYN PRODUCT FROM S-3A

On the 10/10/2018 ESA announced the first official release of the S-3A Synergy Level 2 data products and the availability of the product generated from the 10th of October 2018 onward. The Product Notice related to this first release (included in the appendix) gives a clear indication of the current processing baseline of Synergy products as well as their characteristics and current limitations. Here below are some examples of these limitations:

"Despite these evolutions and corrections, some choices and limitations need to be underlined:

• To avoid strong interfaces between the different aerosol models and waiting for an update of the corresponding Auxiliary Data Files, only the continental model is taken into account. This limitation can create erroneous patterns over deserts or mountains.

• Similarly to OLCI level 2 products, camera interfaces can also be visible on some SYN L2 products.

• As the aerosol retrieval is supposed to be more accurate on "dual-view" area, a transition between "nadir only" and "dual view" area can be observed in some SYN L2 products. In a majority of products, this transition is visible through sharp differences in the Aerosol Optical thickness Values.

• When the OLCI orbit file starts in ascending mode, an operational issue can prevent the SLSTR data to be well-handled by the SYN L2 module. There will be then no SLSTR data in the SYN product and the aerosol retrieval will be performed using only OLCI pixels. To avoid empty SYN L2 files, only the descending orbit parts will be considered in the Payload Data Ground Segment (PDGS) production. A full technical solution is currently investigated.

• The combination of {SYN_success; SYN_aerosol_filled; SYN_AOT_climato} flags can be misleading."

This review of the status of S-3 Land products highlighted the on-going technical challenges for both for OLCI and SLSTR instruments regarding the land products for S-3B, the very early days of the S-3A SYN product and its very limited availability (products from observation since the 10th October 2018).

Obviously, the gap filling role of both SYN products from S-3A and B needed to have a daily revisit cannot be investigated while the S-3B SYN product will be missing according to the current status of OLCI and SLSTR instruments on this platform. Furthermore, any investigation related to the potential contribution of S-3A SYN product will be fully dependent to the current quality and limitations of the current version of the product. No useful conclusion for a Copernicus service development can be expected from such an investigation which would mainly serve to review the current quality of the SYN product as implemented in the Instrument Processing Facility (IPF) while the MCP team is working on an already better version.

3.2 Assessment of third-party contributing missions as described in ESA DWH DAP

Based on the Data Warehouse (DWH) requirements specified by the European Commission (EC), ESA has built up a satellite Data Warehouse, providing all eligible users with free and open access to space-based Earth Observation data for the period covered by the GMES/Copernicus Regulation.

The Data Warehouse is based on two types of data:

i. a fixed part, called 'CORE datasets', which are typically well-defined large datasets covering the needs of FP7/H2020 project participants and other users and
ii. a flexible part called 'ADDITIONAL' datasets.

This approach has proven to be flexible enough to accommodate further additional requirements or specific requirements which were not covered by the CORE datasets and not known in advance.

The Data Access Portfolio (DAP) document defines all datasets (CORE and ADDITIONAL) that are made available to the Copernicus Users via ESA's Data Warehouse mechanism. It acts as baseline for implementation of the Copernicus Space Component Data Access (CSCDA) Services. The DAP document specifies the user's EO data requirements, time of data availability, mission type and the accessibility conditions (i.e. data licensing, product types, delivery timelines, data access mechanisms). The latest version of the DAP document is available for download at the CSCDA website under:

https://spacedata.copernicus.eu/documents/12833/14545/DAP+Document+-+current/

All Copernicus Contributing Missions (CCMs) of the Space Component are classified primarily by sensor type (SAR or Optical) and resolution. Six Mission Groups are guaranteeing the continuity and sustainability of operational applications by multi-source observations as shown in Figure 6.

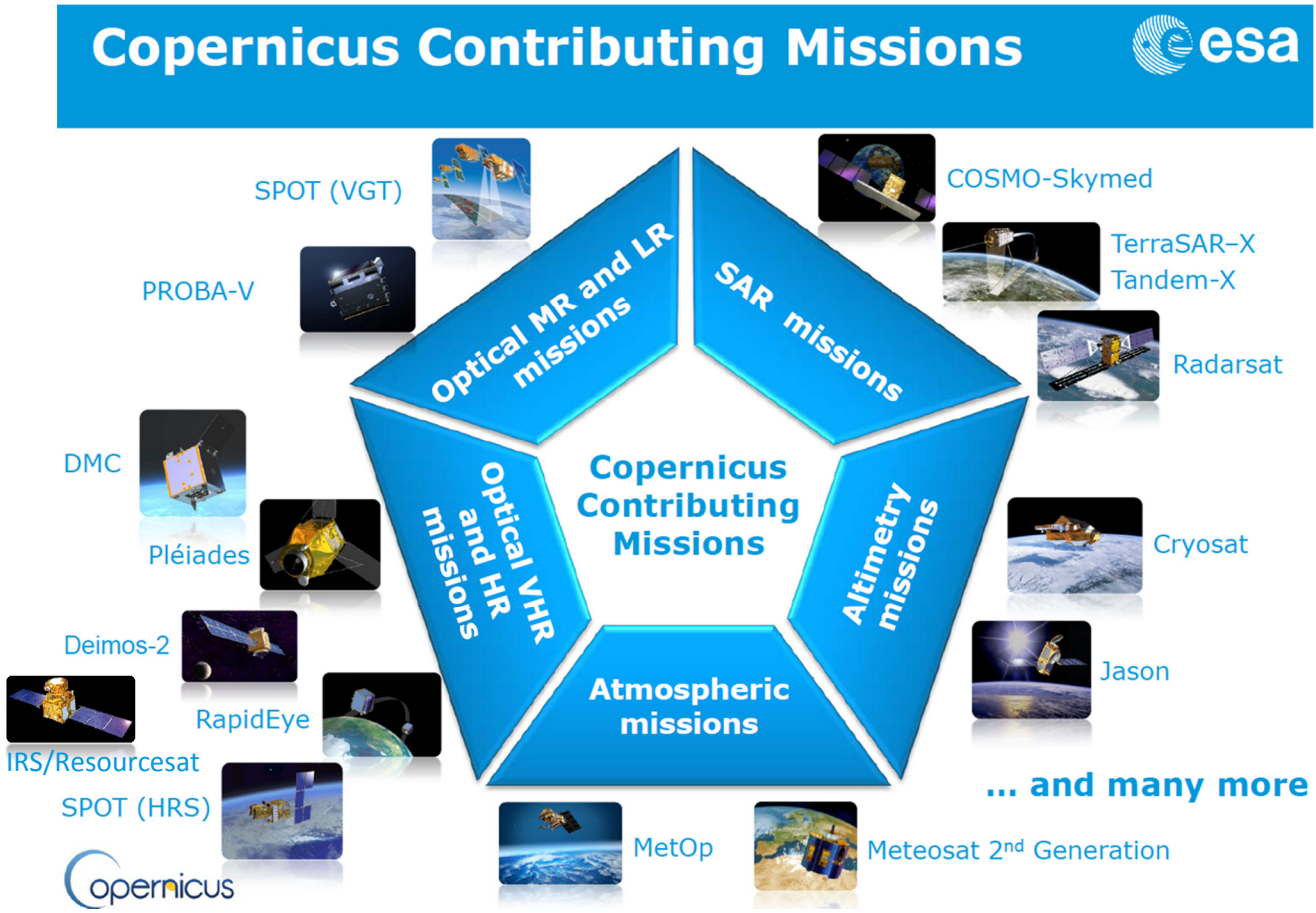


Figure 6: Copernicus Contributing Missions *© ESA, complemented by IRS/Resourcesat (© ISRO)*

Four out of these six missions are of relevance for the CLMS, as neither atmospheric nor altimetry missions are currently contributing to the Land Monitoring Service:

- Mission Group 1 - SAR VHR1-MR2
- Mission Group 2b - Optical VHR1/2
- Mission Group 2 - Optical HR1/2
- Mission Group 3 - Optical MR1/2

A further descriptor in the ESA DWH data supply chain is the resolution type, which is defined by seven spatial resolution categories. Data from all seven categories are of relevance for the past, current and future pan-European and global CLMS:

- VHR1 Very High Resolution 1 where resolution <= 1 m
- VHR2 Very High Resolution 2 where 1 m < resolution <= 4 m
- HR1 High Resolution 1 where 4 m < resolution <= 10 m
- HR2 High Resolution 1 where 10 m < resolution <= 30 m
- MR1 Medium Resolution where 30 m < resolution <= 100 m
- MR2 Medium Resolution where 100 m < resolution <= 300 m
- LR Low Resolution where resolution >= 300 m

Table 5 provides an overview of ESA + third party contributing missions which are listed in the DAP and which are of relevance to the CLMS:

Table 5: Missions made available in Data Warehouse Phase 2 (adapted after Table 2 Copernicus Space Component Data Access Portfolio: Data Warehouse 2014-2020); green meaning it is relevant for existing and potentially for upcoming CLMS, and *italic font* meaning the satellite has been newly integrated in the VHR 2018 offer.

Mission Group 1 - SAR VHR1-MR2	Mission Group 2b Optical VHR1/2	Mission Group 2 Optical HR1/2	Mission Group 3 Optical MR1/2
ALOS-PALSAR	Deimos-2	ALOS-AVNIR-2	PROBA-V
COSMO-SkyMed Constellation	Dubaisat-2	Deimos-1	Resourcesat-1, Resourcesat-2
Envisat ASAR	GeoEye-1	Landsat-5, Landsat-7, Landsat-8	Oceansat-2
ERS-1/2	IRS-P5 CartoSat	Proba	Sentinel-3
Kompsat-5	Ikonos-2	RapidEye Constellation	MODIS
PAZ	Kompsat-2, Kompsat-3/3A	ResourceSat-1, ResourceSat-2	
RADARSAT-2	QuickBird-2	Sentinel-2	
Sentinel-1	*PlanetScope*	SPOT-4, SPOT-5, SPOT-6-7	
TerraSAR-X, TanDEM-X	Pleiades-1A/1B	TH constellation	
	SPOT-5, SPOT-6-7	UK-DMC2	
	SuperView-1 Constellation		
	TH constellation		
	TripleSat Constellation		
	SkySat		
	WorldView-1, WorldView-2		
	WorldView-3		
	WorldView-4 (failure system at the moment)		

Data and services (including licensing) of the Copernicus Contributing Missions are based on agreements with the so-called Copernicus Contributing Mission Entities (CCMEs) – the EO data providers. In case of a Mission failure or temporary unavailability, ESA is forced to provide backup solutions or temporary replacements (if feasible).

3.2.1 VHR data

This section targets the optical VHR mission group relevant for existing and potential upcoming CLMS. In this second issue, subsection 3.2.1.1 is dedicated to describe VHR 2015 data and subsection 3.2.1.2 incorporates the VHR 2018. Subsection 3.2.1.3 describes other VHR data which are not part of the IMAGE datasets, but might become important in case of CLMS backdating activities. The reported VHR data are relevant for ECoLaSS, the current CLMS and as proxy for future such coverages. VHR datasets are used in training and validation sampling and for calibration purposes.

3.2.1.1 Selection of satellite missions in the VHR2015

Several tables are listed below arranged by the alphabetical order of the satellite missions that covers the VHR data as available as part of the VHR_IMAGE_2015 data set.**Deimos-2** is the imaging mission following Deimos-1, launched by Deimos Imaging S.L.U., a company from Boecillo, near Madrid, in Spain. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/d/deimos-2, as well as on the Earth Online: https://earth.esa.int/web/guest/missions/3rd-party-missions/current-missions/deimos-2, both maintained by the ESA.

Table 6: Detailed sensor characteristics of Deimos-2

Platform(s)	
Name	Deimos-2
Operational status	In operational use
Launch date	Launched on 19th June 2014
Life expectancy	7 years, up to 10 years
Sensor	
Name	HiRAIS (High Resolution Advanced Imaging System)
Type	Optical VHR1/2
Number of bands	4 bands and one panchromatic band
Spectral range (nm)	- B1 (Blue band): 466-525 nm - B2 (Green band): 532-599 nm - B3 (Red band): 640-697 nm - B4 (NIR band): 770-892 nm - PAN band: 560-900 nm
Spatial Resolution (m)	- All bands except PAN band: 4 m at an altitude of 590 km - PAN band: 1 m
Pan merge resolution (m)	0.75 m (PAN-sharpened)
Swath width (km)	12 km at nadir, 24 km in wide area mode
Revisit time at the equator (days) with or without programming	4 days
Distribution	
Cost	Priced
Licensing restrictions	Described in https://www.urthecast.com/company/terms/
Accessibility	Via Deimos Imaging website
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

GeoEye-1 is the next generation of high-resolution imaging mission launched by GeoEye, Dulles, Virginia, USA. GeoEye has been purchased in 2013 by DigitalGlobe, which is the world's largest commercial satellite imagery provider. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/g/geoeye-1, as well as on the Earth Online: https://earth.esa.int/web/guest/missions/3rd-party-missions/current-missions/geoeye-1, both maintained by the ESA.

Table 7: Detailed sensor characteristics of GeoEye-1

Platform(s)	
Name	GeoEye-1
Operational status	In operational use
Launch date	Launched on 6th September 2008
Life expectancy	7 years, up to 10 years
Sensor	
Name	GIS (GeoEye Imaging System)
Type	Optical VHR1/2
Number of bands	4 bands and one panchromatic band
Spectral range (nm)	- B1 (Blue band): 450-510 nm - B2 (Green band): 510-580 nm - B3 (Red band): 655-690 nm - B4 (NIR band): 780-920 nm - PAN band: 450-800 nm
Spatial Resolution (m)	- All bands except PAN band: 1.65 m at nadir - PAN band: 0.41 m at nadir
Pan merge resolution (m)	
Swath width (km)	15.2 km
Revisit time at the equator (days) with or without programming	< 3 days
Distribution	
Cost	Priced
Licensing restrictions	Described in http://www.digitalglobe.com/legal/information#licenses
Accessibility	Via https://apollomapping.com/imagery/high-resolution-imagery/geoeye-1
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

The **Pléiades** constellation is composed of two satellites; the mission designed by the CNES is expected to provide the same services offered by the SPOT program, to the civilian as well as the defence community. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/p/pleiades, maintained by the ESA, and on the CNES' website: https://pleiades.cnes.fr/fr/PLEIADES/Fr/index.htm.

Table 8: Detailed sensor characteristics of Pléiades 1A/1B

Platform(s)	
Name	Pléiades
Operational status	In operational use for both satellites
Launch date	Pléiades-1A: Launched on 17th December 2011 Pléiades-1B: Launched on 2nd December 2012
Life expectancy	5 years
Sensor	
Name	HiRI (High-Resolution Imager)
ah	Optical VHR1/2
Number of bands	4 bands and one PAN band
Spectral range (nm)	- Blue band: 450-530 nm - Green band: 510-590 nm - Red band: 620-700 nm - NIR band: 775-915 nm - PAN band: 480-820 nm
Spatial Resolution (m)	- All bands except PAN band: 2.8 m at nadir - PAN band: 0.7 m at nadir
Pan merge resolution (m)	
Swath width (km)	20 km at nadir, up to 800 km according to users' needs
Revisit time at the equator (days) with or without programming	Nominal repeat cycle of 26 days, down to 1 day using the capabilities of both satellites
Distribution	
Cost	Priced
Licensing restrictions	Described in http://www.intelligence-airbusds.com/files/pmedia/public/r13117_9_eula-pleiades-vuk-january_2015.pdf
Accessibility	Via http://www.intelligence-airbusds.com/fr/5114-parcourir-et-commander
Current Role in CLMS	
Service(s)	- High-quality observations to enable land mapping - Risk management support services
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired
Future Role in CLMS	
Service(s)	- High-quality observations to enable land mapping - Risk management support services
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

The **WorldView** satellite constellation is the next generation of commercial imaging system, launched by DigitalGlobe to replace QuickBird II. WorldView-2 and -3 are part of the VHR_IMAGE_2015 data set. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/worldview-1 for WV-1, at: https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/worldview-2 for WV-2 and at https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/worldview-3 for WV-3.

Table 9: Detailed sensor characteristics of WorldView-1, -2, -3

Platform(s)	
Name	WorldView-1, -2, -3
Operational status	All three satellites are in operational use
Launch date	WorldView-1: Launched on 18th September 2007 WorldView-2: Launched on 8th October 2009 WorldView-3: Launched on 13th August 2014
Life expectancy	7.25 years
Sensor	
Name	WV60 (WorldView-1 instrument)
Type	Optical VHR1/2
Number of bands	One PAN band
Spectral range (nm)	450 nm to 900 nm
Spatial Resolution (m)	- 0.46 m at nadir for the PAN band
Pan merge resolution (m)	N/A
Swath width (km)	17.6 km at nadir
Revisit time at the equator (days) with or without programming	1.7 days in average
Sensor	
Name	WV110 (WorldView-2 instrument)
Type	Optical VHR1/2
Number of bands	One PAN band and 8 other VIS bands
Spectral range (nm)	- MS7 [coastal aerosol detection]: 400 – 450 nm - MS4 [blue band]: 450-510 nm - MS3 [green band]: 510-580 nm - MS6 [yellow band]: 585-625 nm - MS2 [red band]: 630-690 nm - MS5 [red edge]: 705-745 nm - MS1 [NIR1]: 770-895 nm - MS8 [NIR2]: 860-1040 nm - PAN band: 447-808 nm
Spatial Resolution (m)	- 0.46 m at nadir for the PAN band - Other multispectral bands: 1.84 m
Pan merge resolution (m)	- 0.46 m resolution
Swath width (km)	16.4 km at nadir
Revisit time at the equator (days) with or without programming	1.1 days on average
Sensor	
Name	WV-3 Imager/WV110 (WorldView-3)
Type	Optical VHR1/2
Number of bands	One PAN band, 8 VIS bands, 8 SWIR bands and 12 CAVIS bands

Spectral range (nm)	- Band 1 [Coastal blue]: 400-450 nm - Band 2 [Blue]: 450-510 nm - Band 3 [Green]: 510-580 nm - Band 4 [Yellow]: 585-625 nm - Band 5 [Red]: 630-690 nm - Band 6 [Red Edge]: 705-745 nm - Band 7 [NIR-1]: 770-895 nm - Band 8 [NIR-2]: 860-1040 nm - SWIR band 1: 1195-1225 nm - SWIR band 2: 1550-1590 nm - SWIR band 3: 1640-1680 nm - SWIR band 4: 1710-1750 nm - SWIR band 5: 2145-2185 nm - SWIR band 6: 2185-2225 nm - SWIR band 7: 2235-2285 nm - SWIR band 8: 2295-2365 nm - CAVIS band 1 [Desert clouds]: 405-420 nm - CAVIS band 2 [Aerosols-1]: 459-509 nm - CAVIS band 3 [Green]: 525-585 nm - CAVIS band 4 [Aerosols-2]: 620-670 nm - CAVIS band 5 [Water-1]: 845-885 nm - CAVIS band 6 [Water-2]: 897-927 nm - CAVIS band 7 [Water-3]: 930-965 nm - CAVIS band 8 [NDVI-SWIR]: 1220-1252 nm - CAVIS band 9 [Cirrus]: 1350-1410 nm - CAVIS band 10 [Snow]: 1620-1680 nm - CAVIS band 11 [Aerosols-3]: 2105-2245 nm - CAVIS band 12 [Aerosols-3]: 2105-2245 nm - PAN band: 450-800 nm
Spatial Resolution (m)	- 0.31 m at nadir for the PAN band - 1.24 m for all multispectral bands - 3.7 m for all SWIR bands - 30 m for all CAVIS (clouds, aerosols, vapours, ice and snow) bands
Pan merge resolution (m)	
Swath width (km)	13.1 km
Revisit time at the equator (days) with or without programming	< 1 day on average
Distribution	
Cost	Priced
Licensing restrictions	Described in http://www.digitalglobe.com/legal/information#licenses
Accessibility	Via digitalglobe.com
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence

	- Only daylight images can be acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

3.2.1.2 Selection of satellite missions in the VHR2018

Several tables are listed below arranged by the alphabetical order of the satellite missions that covers the VHR data as available as part of the VHR2018 data set. Besides the Pléiades constellation, the following satellites are contributing to the VHR_IMAGE_2018:

Kompsat-3 (Korea Multi-Purpose Satellite-3) is an optical high-resolution Korean observation mission of the Korea Aerospace Research Institute (KARI). Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/k/kompsat-3, maintained by the ESA.

Table 10: Detailed sensor characteristics of Kompsat-3 and Kompsat-3A

Platform(s)	
Name	Kompsat-3/-3A
Operational status	In operational use
Launch date	Kompsat-3 launched on 17^{h} May 2012 Kompsat-3A launched on 25th March 2015
Life expectancy	4 years
Sensor	
Name	AEISS (Advanced Earth Imaging Sensor System)
Type	Optical VHR1/2
Number of bands	4 bands, one NIR band and one PAN band
Spectral range (nm)	- Blue band: 450-520 nm - Green band: 520-590 nm - Red band: 630-690 nm - NIR band: 770-890 nm - PAN band: 450-890 nm
Spatial Resolution (m)	- All bands except PAN band: 2 m at nadir - PAN band: 0.5 m at nadir
Pan merge resolution (m)	0.5 m
Swath width (km)	12 km at 530 km, 60 km by 70 km with all 4 satellites
Revisit time at the equator (days) with or without programming	Down to 1 day with four satellites
Distribution	
Cost	Priced
Licensing restrictions	
Accessibility	Via spaceview.com
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

PlanetScope is a satellite constellation, whose individual satellites are called DOVEs, totalling approximately 150 active satellites. Technical details can be found on their website: https://www.planet.com/products/satellite-imagery/files/1611.09_Spec_Sheet_Combined_Imagery_Product_Letter_DraftV3.pdf

Table 11: Detailed sensor characteristics of PlanetScope

Platform(s)	
Name	PlanetScope
Operational status	In operational use
Launch date	12 satellites (Flock 2p) launched on 22th June 2016 88 satellites (Flock 3p) launched on 15th February 2017 48 satellites (Flock 2k) launched on 14th July 2017
Life expectancy	4-5 years
Sensor	
Name	
Type	Optical VHR1/2
Number of bands	4 bands, one NIR band
Spectral range (nm)	- Blue band: 455-515 nm - Green band: 500-590 nm - Red band: 590-670 nm - NIR band: 780-860 nm
Spatial Resolution (m)	All bands: 3.7 m at nadir, depending on flock
Pan merge resolution (m)	
Swath width (km)	24.6 km by 16.4 km at 475 km
Revisit time at the equator (days) with or without programming	Daily at nadir
Distribution	
Cost	Priced
Licensing restrictions	
Accessibility	Via planet.com
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

SuperView-1 is a commercial constellation launched by Beijing Space View Technologies, a subsidiary of China Aerospace and Science Corporation (CASC). Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/gaojing, maintained by the ESA, and on the Space View webpage: http://www.spaceview.com/english/Satellite/SuperView_1/2016/0907/210.html.

Table 12: Detailed sensor characteristics of SuperView-1

Platform(s)	
Name	SuperView-1
Operational status	In operational use
Launch date	SuperView-1 01 launched on 28th December 2016 SuperView-1 02 launched on 28th December 2016 SuperView-1 03 launched on 9th January 2018 SuperView-1 04 launched on 9th January 2018
Life expectancy	8 years
Sensor	
Name	GaoJing-1
Type	Optical VHR1/2
Number of bands	4 bands, one NIR band and one PAN band
Spectral range (nm)	- Blue band: 450-520 nm - Green band: 520-590 nm - Red band: 630-690 nm - NIR band: 770-890 nm - PAN band: 450-890 nm
Spatial Resolution (m)	- All bands except PAN band: 2 m at nadir - PAN band: 0.5 m at nadir
Pan merge resolution (m)	0.5 m
Swath width (km)	12 km at 530 km, 60 km by 70 km with all 4 satellites
Revisit time at the equator (days) with or without programming	Down to 1 day with four satellites
Distribution	
Cost	Priced
Licensing restrictions	
Accessibility	Via spaceview.com
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

Latest status of data processing and delivery of the 2018 VHR Optical coverage of Europe (VHR_IMAGE_2018):

After a long phase of satellite data provider selection and contracting, data acquisition and data selection, the "Latest News" section of the ESA Copernicus Space Component Data Access portal (https://spacedata.copernicus.eu/web/cscda/news/archive/) informed on 11th February 2019, that finally the "data processing and delivery for VHR_IMAGE_2018 optical dataset acquired around the Reference Year 2018 has been initiated. The VHR_IMAGE_2018 dataset will provide one cloud-free Very High Resolution optical coverage of 39 European countries (EEA-39) including all islands of those countries plus the French Overseas Departments acquired within predefined windows corresponding to the vegetation season. The Ground sampling distance (GSD) of the VHR multispectral products range from 2 meters to 4 meters. Two processing levels are generated: L1 (system corrected) and L3 (Ortho). The spectral bands (for all selected missions) are Blue, Green, Red, NIR. The full dataset description is available at: https://spacedata.copernicus.eu/web/cscda/dataset-details?datasetId=vhr-image-2018

The processing of the imagery selected to be part of the coverage is on-going and the dataset will be made progressively available to users in the CDS archive. Data can be downloaded by eligible users either via FTP or, for smaller quantities of data, via PANDA (Planetary Data Access) using the CDS-SSO account in both cases. All data access information can be found on the CSCDA portal in the Data Discovery & Download section. The map below (Figure 7) shows the plan for data delivery based on four geographic zones, starting with Zone A (currently in production) and ending with Zone D (i.e. French Overseas Departments not included in the map extent)

The dataset status will be available in the DWH Phase 2 CORE dataset status report[1] from 1st March 2019 onwards."

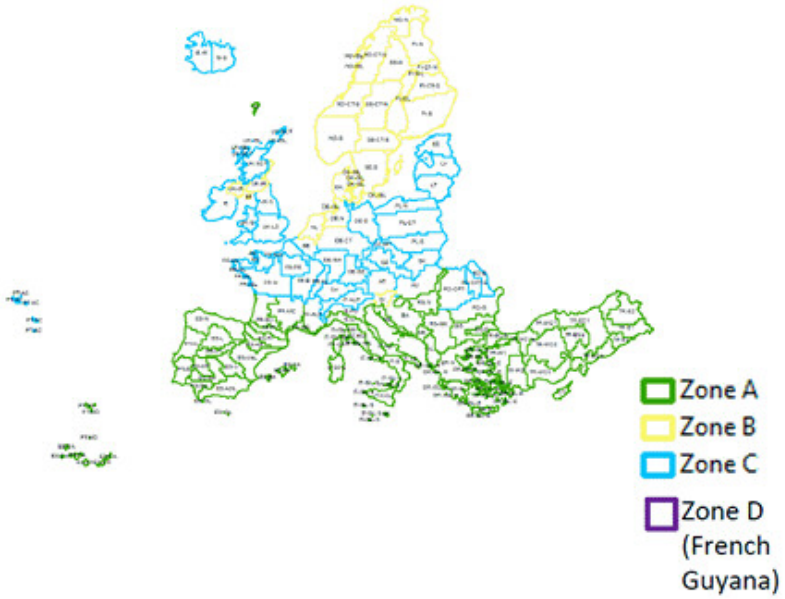


Figure 7: VHR_IMAGE_2018 Delivery Plan (ref. ESA CSCDA)

[1] Available from https://spacedata.copernicus.eu/web/cscda/data-provision-status/core-datasets

3.2.1.3 Other contributing missions

Dubaisat-2 is a remote sensing mission built by the Mohammed Bin Rashid Space Center (MBRSC), following the missions Dubaisat-1. The mission has been complemented by a third satellite, Khalifa Sat in October 2018. Its objectives are to provide data to the Dubai government, in fields such as urban planning or crises monitoring. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/d/dubaisat-2 maintained by the ESA.

Table 13: Detailed sensor characteristics of Dubaisat-2

Platform(s)	
Name	Dubaisat-2
Operational status	In operational use
Launch date	Launched on 21th November 2013
Life expectancy	5 years
Sensor	
Name	HiRAIS (High Resolution Advanced Imaging System)
Type	Optical VHR1/2
Number of bands	4 bands and one panchromatic band
Spectral range (nm)	- B1 (Blue band): 450-520 nm - B2 (Green band): 520-590 nm - B3 (Red band): 630-690 nm - B4 (NIR band): 770-890 nm - PAN band: 550-900 nm
Spatial Resolution (m)	- All bands except PAN band: 4 m at an altitude of 600 km - PAN band: 1 m
Pan merge resolution (m)	0.75 m (PAN-sharpened)
Swath width (km)	12 km at nadir
Revisit time at the equator (days) with or without programming	< 8 days
Distribution	
Cost	Priced
Licensing restrictions	
Accessibility	Via https://mbrsc.ae/en/page/satellite-imagery-services
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images can be acquired

Ikonos-2 mission was a commercial high-resolution imaging satellite owned by DigitalGlobe, Longmont, Colorado, USA, that has been decommissioned in March 2015. Its archive is still available and covers fifteen years. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/i/ikonos-2, as well as on the Earth Online: https://earth.esa.int/web/guest/-/ikonos-2-geo-ortho-kit-5692, both maintained by the ESA.

Table 14: Detailed sensor characteristics of Ikonos-2

Platform(s)	
Name	Ikonos-2
Operational status	Decommissioned, Archive available
Launch date	Launched on 24th September 1999 Deactivated on 31th March 2015
Life expectancy	5 years, extended to 15 years
Sensor	
Name	OSA (Optical Sensor Assembly)
Type	Optical VHR1/2
Number of bands	4 bands and one panchromatic band
Spectral range (nm)	- Blue band: 445-516 nm - Green band: 506-595 nm - Red band: 632-698 nm - NIR band: 757-853 nm - PAN band: 450-900 nm
Spatial Resolution (m)	- All bands except PAN band: 3.2 m at nadir - PAN band: 0.82 m at nadir
Pan merge resolution (m)	
Swath width (km)	12.2 km
Revisit time at the equator (days) with or without programming	14 days
Distribution	
Cost	Priced
Licensing restrictions	
Accessibility	Via CSCDA
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images have been acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping for images before March 2015
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images have been acquired - Archive available up to March 2015

QuickBird was a high-resolution commercial imaging mission, conceived by DigitalGlobe. The first satellite, QuickBird I, failed to reach the planned orbit, but the second satellite, QuickBird II, was a success, whose lifetime was extended up to fifteen years. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/q/quickbird-2, maintained by the ESA.

Table 15: Detailed sensor characteristics of QuickBird-2

Platform(s)	
Name	QuickBird-2
Operational status	Retired, archive available
Launch date	Launched on 18th October 2001 Deactivated on 27th January 2015
Life expectancy	5 years, up to 15 years
Sensor	
Name	BGIS 2000 (Ball Global Imaging System 2000)
Type	Optical VHR1/2
Number of bands	4 bands and one PAN band
Spectral range (nm)	- Blue band: 450-520 nm - Green band: 520-600 nm - Red band: 630-690 nm - NIR band: 760-900 nm - PAN band: 450-900 nm
Spatial Resolution (m)	- All bands except PAN band: 2.4-2.6 m at nadir - PAN band: 0.61-0.72 m at nadir
Pan merge resolution (m)	
Swath width (km)	16.5 km at 450 km
Revisit time at the equator (days) with or without programming	1.5 to 2.5 days with a two-satellite constellation
Distribution	
Cost	Priced
Licensing restrictions	
Accessibility	Via digitalglobe.com
Current Role in CLMS	
Service(s)	High-quality observations to enable land mapping
Role	Reference (VHR) data source
Current issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images have been acquired
Future Role in CLMS	
Service(s)	High-quality observations to enable land mapping for images before January 2015
Role	Reference (VHR) data source
Potential issues / gaps	- Gaps in the time series when images have not been ordered - Unusable images due to cloud presence - Only daylight images have been acquired - Archive available up to January 2015

3.2.2 HR data

The data portfolio in the ESA DWH comprises a number of HR EO datasets relevant for the CLMS. Each dataset has a unique Dataset ID, associated mission group, description and Area of Interest (AOI) to be covered.

The best-known datasets are the so-called IMAGE 20XX datasets, which aim at providing 2 optical multi-spectral pan-European coverages for the Land Monitoring Services and for a certain reference year in a regular 3-years cycle. Starting with the reference year 2006 (+/- 1 year), ESA provides now four IMAGE datasets (2006, 2009, 2012, 2015) in 20/25m spatial resolution. The next dataset, HR_IMAGE_2018 has been published after being processed by GAF AG. It is the first dataset of the series in 10m resolution and acquired by one mission (S-2A and B) only.

Even though the IMAGE datasets aim at providing 2 full pan-European coverages (in national and European projection), this is mostly not the case, as data availability and difficult cloud cover conditions have caused data gaps in almost each dataset. Besides, image acquisition extends to the time period of three years, with no or only little optimization in terms of phenology and/or seasons. Another weakness of these datasets is in the quality of the provided cloud masks, which are of minor quality only. Such circumstances need to be considered, if it should come to a backdating implementation of existing Copernicus layers or even new products/applications.

Besides the IMAGE_20XX datasets, the Data Warehouse is providing 2 Sub-Saharan optical coverages in 22m spatial resolution over the period 2009 – 2013. Both VNIR coverages have been mainly acquired within the dry season with low cloud cover and serve seasonal/annual land change monitoring services.

With the EUR_HR2_MULTITEMP dataset, ESA is providing the first multi-temporal pan-European dataset with monthly coverages of EEA-39 from April to October 2015 in HR2 category. These optical coverages with NIR band support pan-European mapping efforts as well as multi-temporal agricultural studies and crop classification.

Complementary to these DAP datasets, the S-2 satellites are permanently acquiring data between 56° South to 84° North in 10/20m spatial resolution as part of the HR1/HR2_Optical_Global dataset. This data is available via the Copernicus Open Access Hub. For the Copernicus Services, a dedicated access to Sentinels data is ensured via the Copernicus Services Data Hub (CopHub).

Amongst these optical EO datasets, ESA is also providing two SAR datasets in HR2-MR1 category: SAR_SEA_ICE and HR2-MR1_SAR_GLOBAL. The first one is focussing on the main sea ice zones Baltic, Eurarctic, Arctic Ocean, Greenland and Antarctic by systematic and daily coverages. The sea ice monitoring supports marine activities and data assimilation for ice and weather forecast models.

HR2-MR1_SAR_GLOBAL provides a global coverage for all land surfaces from 90° North to 90° South and from 180° West to 180° East by systematic and very frequent (daily) S-1 acquisitions in HR2 and MR1 resolution. The S-1 mission ensures observations for monitoring services related to oceans, seas and sea-ice in quasi real-time or near real-time (typically in less than 3 hours) and services/applications over land, which cover a wide range of different thematic domains.

Table 16: Overview of CCM datasets in High Resolution

Dataset ID	Selected missions	Area of Interest	Acquisition window
DAP_MG2_08 (IMAGE 2006)	ResourceSat-1, SPOT-4/-5	38 European states (EEA-38) plus French Overseas Departments	2005 - 2007
DAP_MG2-3_01 (IMAGE 2009)	ResourceSat-1, SPOT-4/-5	38 European states (EEA-38) plus French Overseas Departments	2008 - 2010
DAP-MG2_25	DMC Constellation, ALOS/AVNIR, ALOS/PRISM	Sub-Saharan Africa (48 states)	2009 - 2010
DWH_MG2_CORE_01 (IMAGE 2012)	ResourceSat-1/-2, SPOT-4/-5, RapidEye 1-5	38 European states (EEA-38) plus French Overseas Departments	2011 - 2013
DWH_MG2_CORE_09	Deimos-1	Sub-Saharan Africa (48 states)	2011 - 2013
EUR_HR2_MULTITEMP	Deimos-1, UK-DMC2	39 European states (EEA-39) plus French Overseas Departments	2015, monthly from April to October
HR_IMAGE_2015 (IMAGE 2015)	SPOT-5, ResourceSat-2, S-2A	39 European states (EEA-39) plus French Overseas Departments	2014 - 2016
HR_IMAGE_2018 (IMAGE 2018)	S-2A and B	39 European states (EEA-39) plus French Overseas Departments	2017 - 2019
HR1/HR2_Optical_Global	S-2A and B	Worldwide coverage: land masses between 56° South to 84° North	From summer 2015 onwards
SAR_SEA_ICE	S-1, Radarsat-2, TerraSAR-X, COSMO-SkyMed, TanDEM-X	Systematic daily SAR data over ice covered areas	From April 2015 to December 2020
HR2-MR1_SAR_GLOBAL	S-1	Worldwide coverage: all land surfaces from 90° North to 90° South and from 180° West to 180° East	From summer 2014 onwards

ALOS-AVNIR-2 - Advanced Land Observing Satellite (ALOS) is a platform combining optical and radar instruments was launched in 2006. The operation ended on May 12, 2011 due to loss of the satellite. The expected Lifetime of 3 – 5 years, however, was reached. The mission is presently continued by ALOS-2 (SAR satellite) (launched on May 24, 2014) and ALOS-3 (optical satellite), which was planned for 2016, but has been postponed to 2019 or beyond. Main applications for the ALOS mission are the mapping of land areas for cartographic applications as well as disaster monitoring on a global scale.

Table 17: Detailed HR sensor characteristics of ALOS-AVNIR-2

Platform(s)	
Name	ALOS
Operational status	End of operation May 2011 (mission continues by ALOS-2 (launch 2014) and ALOS-3(launch planned for 2019))
Launch date	January 24, 2006
Life expectancy	3-5 years
Sensor	
Name	AVNIR-2 (Advanced Visible and Near-Infrared Radiometer – 2)
Type	Optical HR1/2
Number of bands	4
Spectral range (nm)	B1 (blue): 420-500 nm B2 (green): 520-600 nm B3 (red): 610-690 nm B4 (NIR): 760-890 nm
Spatial Resolution (m)	B1 – B4: 10 m
Pan merge resolution (m)	2.5 m
Swath width (km)	70 km
Revisit time at the equator (days) with or without programming	46 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Land Monitoring Service, Urban Atlas, Emergency Mapping
Role	secondary/gap filling
Current issues / gaps	No SWIR band available, low revisit time
Future Role in CLMS	
Service(s)	Not yet defined
Role	additional/supporting data source
Potential issues / gaps	No SWIR band available, low revisit time

Deimos-1 is the first Spanish EO satellite and was launched on July 29, 2009, has a life expectancy of 10 years and is still in operation. It provides 22 m 3-band imagery with a swath wide of 650 km. With a high visit frequency, it is designed for monitoring applications in agriculture and forestry.

Table 18: Detailed HR sensor characteristics for Deimos-1

Platform(s)	
Name	Deimos-1
Operational status	Still operating
Launch date	July 29; 2009
Life expectancy	~ 10 years
Sensor	
Name	SLIM6-22 (Surrey Linear Imager Multispectral 6 channels)
Type	Optical HR1/2
Number of bands	3
Spectral range (nm)	B1 (green): 520-620 nm B2 (red): 630-690 nm B3 (NIR): 760-900 nm
Spatial Resolution (m)	B1 – B3: 22 m
Pan merge resolution (m)	NA
Swath width (km)	650 km
Revisit time at the equator (days) with or without programming	daily
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Land Monitoring Service
Role	additional/supporting data source
Current issues / gaps	No SWIR band available
Future Role in CLMS	
Service(s)	Not yet defined
Role	additional/supporting data source
Potential issues / gaps	No SWIR band available

RapidEye is an Earth Observation system with a constellation of five identical mini-satellites. They were launched on August 29, 2008 with a life expectancy superior to 7 years and are still operating. The constellation can collect around 5 million km² per day. RapidEye data have been used in the implementation of Copernicus Land High Resolution Layers (HRL) 2012.

Table 19: Detailed HR sensor characteristics for RapidEye

Platform(s)	
Name	RapidEye-1-5
Operational status	Still operating
Launch date	2008
Life expectancy	> 7 years
Sensor	
Name	REIS (RapidEye Earth Imaging System)
Type	Optical HR1/2
Number of bands	5
Spectral range (nm)	B1 (blue): 440-510 nm B2 (green): 520-590 nm B3 (red): 630-685 nm B4 (red-edge): 690-730 nm B5 (NIR): 760- 850 nm
Spatial Resolution (m)	B1 – B5: 6.5 m
Pan merge resolution (m)	-
Swath width (km)	77 km
Revisit time at the equator (days) with or without programming	1 day
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Land Monitoring Service
Role	Primary + secondary/gap filling
Current issues / gaps	No SWIR band available
Future Role in CLMS	
Service(s)	Land Monitoring Service
Role	additional/supporting data source
Potential issues / gaps	No SWIR band available

ResourceSat-1, formerly also known as IRS-P6 (Indian Remote-Sensing Satellite-P6) was launched on October 17, 2003. Life expectancy was 5 years. It is still operating with a reduced capacity of some instruments since 2012. The mission provides data for integrated land and water resource management.

ResourceSat-2 is a follow-on mission to ResourceSat-1 with improved spectral bands. It was launched on April 20, 2011. It has a life expectancy of 5 years and was followed by Resourcesat-2A on December 7, 2016. The ResourceSat data are used for applications in agricultural crop monitoring, precision farming, forest mapping, water resource and disaster management etc. ResourcceSat-2 data have played a substantial part in the Copernicus Land High Resolution Layer (HRL) 2015 production.

Table 20: Detailed HR sensor characteristics for ResourceSat-1, -2

Platform(s)	
Name	ResourceSat-1/2
Operational status	Still operating (ResourceSat-1 with reduced capacity)
Launch date	2003/2006
Life expectancy	5 years
Sensor	
Name	LISS-3 (Linear Imaging Self-Scanning Sensor-3)
Type	Optical HR1/2
Number of bands	4
Spectral range (nm)	B1 (green): 520-590 nm B2 (red): 620-680 nm B3 (NIR): 770-860 nm B4 (SWIR): 1550-1700 nm
Spatial Resolution (m)	B1 – B4: 23.5 m (20 m, system corrected)
Pan merge resolution (m)	NA
Swath width (km)	149 km
Revisit time at the equator (days) with or without programming	24 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Land Monitoring Service
Role	Primary
Current issues / gaps	Striping effects in some VIS bands
Future Role in CLMS	
Service(s)	Land Monitoring Service
Role	Secondary, gap-filling
Potential issues / gaps	Striping effects in some VIS bands

SPOT-4-7 (Satellite Pour l'Observation de la Terre) of the French SPOT programme were implemented to assure a continuity of service/data to the users. The first SPOT satellite in the SPOT series of CNES (Space Agency of France) was launched in 1986. SPOT-4 was then operating from 1998 until June 29, 2013, followed by the SPOT-5-8 missions. SPOT-5 was launched in 2002, SPOT-6 in 2012 and SPOT-7 in 2014. The VEGEATION program (SPOT-4/-5) for example allows the monitoring of terrestrial vegetation cover on a daily basis on a global level. SPOT-4 and SPOT-5 data is playing a substantial part in the ongoing Copernicus Land High Resolution Layer (HRL) 2015 production. SPOT-5 and SPOT-6 data is used for the current Copernicus Natura2000 and Riparian Zone LC/LU mapping.

Table 21: Detailed HR sensor characteristics of SPOT-4-7

Platform(s)			
Name	SPOT-4-7 (Satellite Pour l'Observation de la Terre)		
Operational status	Operation ended 2013 (was continued by SPOT-5-7 mission)		
Launch date	1998		
Life expectancy	5-7 years		
Sensor			
Name	HRVIR (High-Resolution Visible and Infrared sensor) (SPOT-4)	HRG (High-Resolution Geometrical) and HRS (High-Resolution Stereoscopic) (SPOT-5)	NAOMI (New AstroSat Optical Modular Instrument) (SPOT-6/7)
Type	Optical HR1/2	Optical VHR2/HR1/2	Optical VHR2/HR1
Number of bands	5	5	4
Spectral range (nm)	PAN: 610-680 nm B1 (green): 500-590 nm B2 (red): 610-680 nm B3 (NIR): 780-890 nm B4 (SWIR): 1580-1750 nm	PAN: 480-710 nm B1 (green): 500-590 nm B2 (red): 610-680 nm B3 (NIR): 780-890 nm B4 (SWIR): 1580-1750 nm	PAN: 450-745 nm B1 (blue): 450-520 nm B2 (green): 530-590 nm B3 (red): 625-695 nm B4 (NIR): 760-890 nm
Spatial Resolution (m)	B1: 10 m B2-B5: 20 m	PAN: 5 m B1-B3: 10 m B4: 20 m	PAN: 1.5 m B1-B4: 6.0 m
Pan merge resolution (m)	10 m	2.5-5 m	1.5 m
Swath width (km)	60 km	60 km	60 km
Revisit time at the equator (days) with or without programming	26 days	26 days	26 days
Distribution			
Cost	-		
Licensing restrictions	ESA – User License		
Accessibility	via CSCDA		
Current Role in CLMS			
Service(s)	Land Monitoring Service		
Role	Secondary, gap-filling		
Current issues / gaps	Small footprint, long revisit time		
Future Role in CLMS			
Service(s)	Land Monitoring Service		

Role	Secondary, gap-filling
Potential issues / gaps	Small footprint, long revisit time

Envisat (Environmental Satellite) is an EO mission of the ESA for monitoring the environment on different scales, regional to global. It was launched on March 1, 2002. The mission ended in 2012. Main application of the SAR instrument to the global mission are monitoring of Sea ice and ice sheets, ocean pollution and detection of vegetation changes. On a regional scale coastal pollution monitoring, agricultural and forest monitoring etc. Envisat-ASAR data is used for calibration of the S-1 soil moisture data in in the ongoing Copernicus Land High Resolution Layer (HRL) 2015 project.

Table 22: Detailed HR sensor characteristics of Envisat

Platform(s)	
Name	Envisat (Environmental Satellite)
Operational status	Mission ended in 2012
Launch date	2002
Life expectancy	5 years
Sensor	
Name	ASAR (Advanced SAR)
Type	SAR VHR1-MR2
SAR operation modes	VV, HH, VV/HH, HV/HH, or VH/VV
SAR : frequency (GHz)	C-Band (5.331 MHz)
SAR: Pixel spacing (m)	Pixel spacing: - 30 x 30 m (image mode) - 30 x 30 m (alternating polarization mode) - 150 x 150 m (wide swatch mode) - 1000 x 1000 m (global monitoring mode)
Pan merge resolution (m)	NA
Swath width (km)	56-100 x 100 km (image mode, 7 selectable swaths) 400 x 400 km (wide swatch mode) 400 x 400 km (global monitoring mode)
Revisit time at the equator (days) with or without programming	35 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Land Monitoring Service
Role	Secondary
Current issues / gaps	System offline
Future Role in CLMS	
Service(s)	Land Monitoring Service
Role	additional/supporting data source
Potential issues / gaps	System offline

ERS-1/2 (European Remote-Sensing Satellite) mission is the first ESA EO program to provide monitoring of the environment in the microwave spectrum. ERS-1 was operating from 1991 until March 10, 2000, far beond the expected lifetime. Its successorERS-2 was operating from 1995 until 2011. The spacecraft are identical, except that ERS-2 has an extra instrument to monitor the ozone levels. ERS-1/-2 provided datasets with an extend over two decades for applications in environmental and disaster monitoring, detection of land-use changes etc.

Table 23: Detailed HR sensor characteristics of ERS-1/2

Platform(s)	
Name	ERS-1/2 (European Remote-Sensing Satellite)
Operational status	Operation ended 2000 (mission was continued by ERS-2 (1995-2011))
Launch date	1991
Life expectancy	3 years
Sensor	
Name	AMI (Active Microwave Instrument)
Type	SAR VHR1-MR2
SAR operation modes	Image, wave and wind mode
SAR : frequency (GHz)	C-Band (5.3GHz)
SAR: Pixel spacing (m)	1000 m 10-30 m
Pan merge resolution (m)	-
Swath width (km)	500 km
Revisit time at the equator (days) with or without programming	35 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Not yet part of the Pan-European Component
Role	additional/gap-filling
Current issues / gaps	System offline
Future Role in CLMS	
Service(s)	Not yet defined
Role	additional/gap-filling
Potential issues / gaps	System offline

RADARSAT-2 is a follow-on satellite mission of RADARSAT-1. It provides data for Marine surveillance, monitoring of ice and environment as well for disaster and resource management. RADARSAT-2 was launched on December 14, 2007 and is still operating.

Table 24: Detailed HR sensor characteristics of RADARSAT-2

Platform(s)	
Name	RADARSAT-2
Operational status	Still operating
Launch date	December 14, 2007
Life expectancy	7 years
Sensor	
Name	SAR (Synthetic Aperture Radar)
Type	SAR VHR1-MR2
SAR operation modes	Full polarimetric quad-polarization (HH, HV, VV, VH)
SAR frequency (GHz):	C-Band (5.405 GHz)
Spatial Resolution (m) / SAR: Pixel spacing (m)	3-100 m
Pan merge resolution (m)	-
Swath width (km)	20-500 km
Revisit time at the equator (days) with or without programming	24 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Not yet part of the Pan-European Component
Role	additional/supporting data source
Current issues / gaps	N/A
Future Role in CLMS	
Service(s)	Not yet defined
Role	additional/supporting data source
Potential issues / gaps	N/A

RISAT-1 (Radar Imaging Satellite) provides data for applications in agriculture, forestry, geology, sea ice, flood monitoring etc. and is the first satellite mission with an active radar sensor system of the ISRO (Indian Space Research Organization). It was launched on April 26, 2012 and is still operating.

Table 25: Detailed HR sensor characteristics of RISAT-1

Platform(s)	
Name	RISAT-1 (Radar Imaging Satellite)
Operational status	Still operating
Launch date	April 26, 2012
Life expectancy	5 years
Sensor	
Name	RISAT-SAR (Synthetic Aperture Radar)
Type	SAR VHR1-MR2
SAR operation modes	Single, dual and Quad Pol
SARfrequency (GHz)	C-Band (5.350 GHz)
SAR Pixel spacing (m)	1-50 m
Pan merge resolution (m)	-
Swath width (km)	10-225 km
Revisit time at the equator (days) with or without programming	25 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Not yet part of the Pan-European Component
Role	additional/supporting data source
Current issues / gaps	N/A
Future Role in CLMS	
Service(s)	Not yet defined
Role	additional/supporting data source
Potential issues / gaps	N/A

3.2.3 MR data

Resourcesat-1 and **Resourcesat-2** are both remote sensing missions, whose satellites were built by the Indian Space Research Organization (ISRO) and have well outlived their life expectancies, while continuously acquiring HR and MR resolution optical EO data (cf. also section 3.2.2). One of the sensors aboard is the medium-resolution AWiFS (Advanced Wide Field sensor). Technical details can be found at the Earth Observation Portal:
https://directory.eoportal.org/web/eoportal/satellite-missions/r/resourcesat-2, as well as on the Earth Online:
https://earth.esa.int/web/guest/missions/3rd-party-missions/current-missions/resourcesat-1 and
https://earth.esa.int/web/guest/missions/3rd-party-missions/current-missions/resourcesat-2 for both satellites. Before the launch of Landsat-8, Resourcesat constellation was used as a gap-filling mission by the USGS (see: (Chander)).

Table 26: Detailed sensor characteristics of MR sensor AWiFS on Resourcesat-1/2 (National Remote Sensing Centre, Government of India)

Platform(s)	
Name	Resourcesat-1/2 AWiFS (Advanced Wide Field Sensor)
Operational status	Resourcesat-1: ended 30th September 2013, archive available Resourcesat-2: fully operational in February 2017
Launch date	Resourcesat-1: launched on 17th October 2003 Resourcesat-2: launched on 20th October 2011 Resourcesat-2A: launched on 7th December 2016
Life expectancy	5 years
Sensor	
Name	AWiFS-A and AWiFS-B
Type	Optical MR1/2
Number of bands	4 bands
Spectral range (nm)	- B1 band: 520-590 nm - B2 band: 620-680 nm - B3 band: 770-860 nm - B4 band: 1550-1700 nm
Spatial Resolution (m)	(for each band) 56-70 m
Pan merge resolution (m)	
Swath width (km)	Cumulated 370*2 = 740 km
Revisit time at the equator (days) with or without programming	5 days
Distribution	
Cost	-
Licensing restrictions	ESA – User License
Accessibility	via CSCDA
Current Role in CLMS	
Service(s)	Land Monitoring Service
Role	Secondary
Potential issues / gaps	System offline
Future Role in CLMS	
Service(s)	Not yet defined
Role	Additional/supporting data source
Potential issues / gaps	System offline

3.3 Assessment of freely and commercially available EO data sources

In the following, a short assessment of freely and commercially available EO data will be done. Especially the use of freely available data is of important use for the implementation of Copernicus Services, as these are often subject to strong budgetary restrictions. Freely available data exist in resolution categories HR2, MR1/MR2 and LR1 and are presented in section 3.3.1. In view of commercial data, a brief overview is given in section 3.3.2, focussing on EO data in the VHR and HR domain.

3.3.1 Freely available data

The Project for On-Board Autonomy – Vegetation (**PROBA-V**) was developed as a follow-up of the SPOT-VEGETATION mission, which is why PROBA-V's channels are similar to those of the SPOT-VGT instrument. Technical details can be found at the Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions/p/PROBA-V, maintained by the ESA.

Table 27: Detailed sensor characteristics of MR satellite PROBA-V (VITO, 2017)

Platform(s)	
Name	PROBA-V
Operational status	In operation
Launch date	PROBA-V launched on 6th May 2013
Life expectancy	2.5 years, extended for another 2.5 years – still in use
Sensor	
Name	VGT instruments (VGT 1 and VGT 2)
Type	Optical MR1/2
Number of bands	4 bands
Spectral range (nm)	- B1 (Blue band): 447-493 nm - B2 (Red band): 610-690 nm - B3 (NIR band): 777-893 nm - B4 (SWIR band): 1570-1650 nm
Spatial Resolution (m)	- 1/3 km and 1 km for Visible and NIR bands - 2/3 km and 1 km for SWIR band
Pan merge resolution (m)	Final composite products are disseminated at 100 m, 300 m and 1 km resolution
Swath width (km)	2295 km
Revisit time at the equator (days) with or without programming	100% two-daily imaging
Distribution	
Cost	All 1 km products are free, 300 m and Level 1C products are free, except when younger than one month. However, ESA-approved project and Copernicus users, as well as Belgian and Luxembourgian users can get all 300 m products freely.
Licensing restrictions	
Accessibility	Through the PROBA-V Mission Exploitation Platform (MEP)
Current Role in CLMS	
Service(s)	- Monitoring the extent and dynamics of land cover and land use such as deforestation, droughts, soil degradation or loss of wildlife - Assessing the climate change impact on water resource management and food security - Monitoring the status of crops and prediction of yields
Role	Gap filling data source between SPOT-VGT mission and S-3 satellites

Current issues / gaps	Solar zenithal angle value is limited to 90 degree, and viewing zenithal angle to 75 degree
Future Role in CLMS	
Service(s)	Not yet defined
Role	Additional/supporting data source
Potential issues / gaps	Solar zenithal angle value is limited to 90 degree, and viewing zenithal angle to 75 degree

The « Satellite Pour l'Observation de la Terre – Végétation » (**SPOT-VGT**) was a joint program by France, the European Commission, Belgium, Sweden and Italy. SPOT-5 was designed to ensure the continuity of the SPOT services while improving the quality of the data, and anticipating market expectations for relief mapping, for example.

Table 28: Detailed sensor characteristics of MR satellite SPOT-VGT (VITO, 2017, b), (Belspo, 2015)

Platform(s)	
Name	SPOT-VGT
Operational status	Retired in summer 2013 for SPOT-4 and in the year 2015
Launch date	SPOT-4: launched on 23rd March 1998 SPOT-5: launched on 3rd May 2002
Life expectancy	> 5 years
Sensor	
Name	VEGETATION-1 and VEGETATION-2, identical on SPOT-4 and SPOT-5
Type	Optical MR1/2
Number of bands	4 bands
Spectral range (nm)	- B0 (Blue band): 430-470 nm - B2 (Red band): 610-680 nm - B3 (NIR band): 790-890 nm - B4 (SWIR band): 1580-1750 nm
Spatial Resolution (m)	For each band: 1165 m x 1165 m
Pan merge resolution (m)	N/A
Swath width (km)	SPOT-4: 2250 km SPOT-5: 120 km
Revisit time at the equator (days) with or without programming	26 days
Current Role in CLMS	
Service(s)	Not yet defined
Role	Gap filling data source between SPOT-VGT mission and S-3 satellites
Current issues / gaps	N/A
Future Role in CLMS	
Service(s)	Not yet defined
Role	Global reference (e.g. VHR) data source
Potential issues / gaps	N/A

As mentioned in the Technical Note (AD14), PROBA-V datasets will be used to assess the interoperability of S-2 NDVI with the SPOT-Vegetation/PROBA-V NDVI time series in the second phase.

Landsat 5/7/8 from the US Landsat programme are EO satellites carrying high resolution optical sensors. The first Landsat satellite launched in (1972) was the first HR multispectral remote sensing mission with four spectral bands at that time. Landsat-4 was launched in 1982 and Landsat-5 on March 1st, 1984. The operation ended in 2013. The Landsat mission was continued until present, with Landsat 8 currently being operational. The mission is going to be continued with Landsat-9 (launch planned 2023). The data archive of more than 30 years of Landsat data is now used for multiple LC/LU applications including global applications (e.g. forest, water, settlements). Landsat data is playing a substantial part in the ongoing Copernicus Land High Resolution Layer (HRL) 2015 production.

Table 29: Detailed MR sensor characteristics of Landsat missions

Platform(s)			
Name	Landsat-5, -7, 8		
Operational status	Landsat-5 ended in 2013 (Mission was continued by Landsat-7 (launch 1999), Landsat-8 (launch 2013), both still operating)		
Launch date	1984 (LS-5), 1999 (LS-7), 2013 (LS-8)		
Life expectancy			
Sensor			
Name	OLI (Operational Land Imager) (LS-8)	ETM+ (Enhanced Thematic Mapper Plus) (LS-7)	TM (Thematic Mapper) (LS-4/5)
Type	Optical HR1/2	Optical HR1/2	Optical HR1/2
Number of bands	9	8	6
Spectral range (nm)	443-453 nm (deep blue), 450-515 nm (blue), 525-600 nm (green), 630-680 nm (red), 845-885 nm (NIR), 1560-1660 nm (SWIR 2), 2100-2300 nm (SWIR 3), 500-680 nm (Pan), 1360-1390 nm (SWIR)	0.52-0.90 µm (PAN), 0.45-0.52 µm (VIS), 0.53-0.61 µm (VIS), 0.63-0.69 µm (VNIR), 0.78-0.90 µm (VNIR), 1.55-1.75 µm (SWIR), 2.09-2.35 µm (SWIR), 10.4-12.5 µm (TIR)	0.45-0.52 µm (blue), 0.52-0.60 µm (green), 0.63-0.69 µm (red), 0.76-0.90 µm (NIR), 1.55-1.75 µm (SWIR), 2.08-2.35 µm (SWIR), 10.4-12.5 µm (TIR)
Spatial Resolution (m)	30 m	30-60 m	30-120 m
Pan merge resolution (m)	15 m	15 m	-
Swath width (km)	185 km	185 km	185 km
Revisit time at the equator (days) with or without programming	16 days	16 days	16 days
Distribution			
Cost	-		
Licensing restrictions	https://landsat.usgs.gov/documents/Landsat_Data_Policy.pdf		
Accessibility	via USGS EROS and certain data portals		
Current Role in CLMS			
Service(s)	Land Monitoring Service		
Role	Primary + secondary, gap-filling		
Current issues / gaps	Scan line corrector failure in Landsat 7		
Future Role in CLMS			
Service(s)	Not yet defined		
Role	gap-filling		
Potential issues / gaps	Scan line corrector failure in Landsat 7		

MODIS (Moderate Resolution Imaging Spectroradiometer) offers a wide range of spectral bands, that could clearly mimic the one offered by S-3. The products (MxD09Q1 and MxD09A1) are surface reflectance values for one day that could be considered as a replacement of S-3 SYN products.

Table 30: MODIS specifications

Platform(s)	
Name	MODIS (Moderate Resolution Imaging Spectroradiometer)
Operational status	
Launch date	December 18, 1999 (Terra), May 4, 2002 (Aqua)
Life expectancy	6 years, yet still operational after 18 years, stability checked with regular lunar observations
Sensor	
Name	MODIS Terra
Type	Optical MR1/2
Number of bands	36 bands
Spectral range (nm)	- B1 (Land/Cloud/Aerosols Boundaries): 620-670 nm - B2 (Land/Cloud/Aerosols Boundaries): 841-876 nm - B3 (Land/Cloud/Aerosols Properties): 459-479 nm - B4 (Land/Cloud/Aerosols Properties): 545-565 nm - B5 (Land/Cloud/Aerosols Properties): 1230-1250 nm - B6 (Land/Cloud/Aerosols Properties): 1628-1652 nm - B7 (Land/Cloud/Aerosols Properties): 2015-2155 nm - B8 (Ocean Color/Phytoplankton/Biogeochemistry): 405-420 nm - B9 (Ocean Color/Phytoplankton/Biogeochemistry): 438-448 nm - B10 (Ocean Color/Phytoplankton/Biogeochemistry): 483-493 nm - B11 (Ocean Color/Phytoplankton/Biogeochemistry): 526-536 nm - B12 (Ocean Color/Phytoplankton/Biogeochemistry): 546-556 nm - B13 (Ocean Color/Phytoplankton/Biogeochemistry): 662-672 nm - B14 (Ocean Color/Phytoplankton/Biogeochemistry): 673-683 nm - B15 (Ocean Color/Phytoplankton/Biogeochemistry): 743-753 nm - B16 (Ocean Color/Phytoplankton/Biogeochemistry): 862-877 nm - B17 (Atmospheric Water Vapor): 890-920 nm - B18 (Atmospheric Water Vapor): 931-941 nm - B19 (Atmospheric Water Vapor): 915-965 nm - B20 (Surface/Cloud Temperature): 3660-3840 nm - B21 (Surface/Cloud Temperature): 3929-3989 nm - B22 (Surface/Cloud Temperature): 3929-3989 nm - B23 (Surface/Cloud Temperature): 4020-4080 nm - B24 (Atmospheric Temperature): 4433-4498 nm - B25 (Atmospheric Temperature): 4482-4549 nm - B26 (Cirrus Clouds Water Vapor): 1360-1390 nm - B27 (Cirrus Clouds Water Vapor): 6535-9895 nm - B28 (Cirrus Clouds Water Vapor): 7175-7475 nm - B29 (Cloud Properties): 8400-8700 nm - B30 (Ozone): 9580-9880 nm - B31 (Surface/Cloud Temperature): 10780-11280 nm - B32 (Surface/Cloud Temperature): 11770-12270 nm - B33 (Cloud Top Altitude): 13185-13485 nm - B34 (Cloud Top Altitude): 13485-13785 nm - B35 (Cloud Top Altitude): 13785-14085 nm - B36 (Cloud Top Altitude): 14085-14385 nm

Spatial Resolution (m)	For each band: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36)
Pan merge resolution (m)	N/A
Swath width (km)	2330 km by 10 km
Revisit time at the equator (days) with or without programming	1-2 days
Current Role in CLMS	
Service(s)	Not yet defined
Role	Gap filling data source between SPOT-VGT mission and S-3 satellites
Current issues / gaps	N/A
Future Role in CLMS	
Service(s)	- Generation of vegetation products (biophysical index) - Land surface colour
Role	Additional/supporting data source
Potential issues / gaps	N/A

3.3.2 Commercial data

Besides the data portfolio of the ESA Data Warehouse, which is currently providing pan-European VHR and HR coverages in a 3 years interval, there are satellite data providers which offer a wide range of commercial VHR and HR products and services. Many data providers have a long track record in system operating, processing and distribution of satellite data and can access full data archives. The tremendous amount of data in the archives may contribute to a potential backdating of status layers by setting up an extended time series ranging 3-6 years into the past. This might be considered for the HRLs Grassland, Forest, Water and Wetness and Small Woody Features.

In the last years, the number of remote sensing systems has continuously increased. Especially the market for VHR data is in a state of upheaval. New players like Planet, TerraBella and Astro Digital have entered the floor and whole fleets of satellites such as the Flock-1-3 (88 earth-imaging Dove (cubesat nanosatellites), SkySat (24 cubesat microsatellites) and Landmapper-HD (20 cubesat microsatellites) have been launched. Even though most of these satellites provide data in VHR2 resolution only, existing and upcoming constellations will be permanently extended and drastically increase the VHR Earth Observation capacity in an unprecedented temporal resolution. Specific service providers have now gained the ability to acquire the whole Earth's landmass on a daily basis in very high resolution. Thanks to technological advances, substantial improvements in spatial and radiometric resolution are a matter of time only. In this context, and especially in view of potentially new CLMS products, such data may become relevant for Copernicus and R&D, as multi-temporal data and analyses become more and more important. The table below presents an overview of actual costs and constraints for recent VHR platforms.

Table 31: Information sheet on commercially available VHR1/2 and HR1 satellite data, distinguishing between archive data and new acquisition/tasking modes

Archive Data			
Satellite	**Resolution**	**Accessibility**	**Licensing restrictions**
WorldView-1/2/3/4	VHR1	https://discover.digitalglobe.com/	http://www.digitalglobe.com/legal/information#licenses
GeoEye-1	VHR1		
Pléiades-1A/1B	VHR1	http://www.intelligence-airbusds.com/geostore/	http://www.intelligence-airbusds.com/files/pmedia/public/r13117_9_eula-pleiades-vuk-january_2015.pdf
SkySat 1-7	VHR1	https://www.planet.com/products/hi-res-monitoring/	https://www.planet.com/terms-of-use/
Deimos-2	VHR1	n/a	https://www.urthecast.com/company/terms/
PlanetScope	VHR1	https://www.planet.com/scenes/	https://assets.planet.com/docs/upload-EULA-bv.pdf
SPOT-6+7	VHR2	http://www.intelligence-airbusds.com/geostore/	http://www.intelligence-airbusds.com/files/pmedia/public/r17523_9_eula-spot1-7-vuk-july_2015.pdf
Landmapper-HD	VHR2	https://astrodigital.com/satellites/	n/a
RapidEye-1/2/3/4/5	HR1	https://www.planet.com/contact-sales/	https://assets.planet.com/docs/upload-EULA-bv.pdf
Theia	HR1	n/a	https://www.urthecast.com/company/terms/
New Acquisition/Tasking Data			
Satellite	**Resolution**	**Accessibility**	**Licensing restrictions**
WorldView-1/2/3/4	VHR1	on demand	http://www.digitalglobe.com/legal/information#licenses
GeoEye-1	VHR1		
Pléiades-1A/1B	VHR1	http://www.intelligence-airbusds.com/geostore/	http://www.intelligence-airbusds.com/files/pmedia/public/r13117_9_eula-pleiades-vuk-january_2015.pdf
SkySat 1-7	VHR1	on demand	https://www.planet.com/terms-of-use/
Deimos-2	VHR1	n/a	https://www.urthecast.com/company/terms/
PlanetScope	VHR1	on demand	https://assets.planet.com/docs/upload-EULA-bv.pdf
SPOT-6+7	VHR2	http://www.intelligence-airbusds.com/geostore/	http://www.intelligence-airbusds.com/files/pmedia/public/r17523_9_eula-spot1-7-vuk-july_2015.pdf
Landmapper-HD	VHR2	https://astrodigital.com/satellites/	n/a
RapidEye-1/2/3/4/5	HR1	https://www.planet.com/contact-sales/	https://assets.planet.com/docs/upload-EULA-bv.pdf
Theia	HR1	n/a	https://www.urthecast.com/company/terms/

For the next years, a series of new satellite missions in the optical and SAR domain is planned. A selection of upcoming satellite launches is given below. These missions will further increase the Earth Observation capacity, and it is assumed, that some of them will become relevant for future Copernicus Services due to increased temporal and spatial resolution as well as cost efficiency.

Table 32: New satellites 2019 - 2022

VHR optical			
Satellite	**Launch**	**Resolution [m]**	**Special Features/Info**
CartoSat-3/3A/3B	2019-2020	0.25-12.0	Constellation of 3 satellites; 12 m hyperspectral mission
OptiSAR	2021-2022	0.5-5.0	Constellation of 16 satellites (8x optical, 8x SAR)
BlackSky	2018-2019	0.9-1.1	Constellation of 60 satellites
Pléiades Neo	2020-2021	0.3	Constellation of 4 satellites, EDRS data transfer
HR optical			
Satellite	**Launch**	**Resolution [m]**	**Special Features/Info**
OmniEarth	2019	2.0-5.0	Constellation of 18 satellites
UrtheDaily	2020	5.0	Constellation of 8 satellites
ResourceSat-3/3A/3B	2019-2022	10.0-20.0	Series of 3 satellites
SAR			
Satellite	**Launch**	**Resolution [m]**	**Special Features/Info**
RADARSAT Constellation	2019	1.0-100.0	3 X-band satellites
SIASGE Constellation	2018-2020	1.0-100.0	4x SAOCOM L-band, 6x COSMO X-band
KOMPSAT-6	2020	0.5-30.0	X-band
NISAR	2021	5.0	L- + S-band
TanDEM-L	2022	1.0-50.0	2 L-band satellites

With the launch of the Sentinels 1 to 3, HR and MR Earth Observation data has become available in an unprecedented temporal and spatial resolution on a fully free and open basis. Whilst other freely available data such as Landsat are already contributing to Copernicus Services, commercial data in HR1/HR2 category such as SPOT, IRS, Deimos and DMC may become relevant in case of backdating ambitions and for gap-filling purposes.

4 Review of provision of supporting geospatial data in view of service needs

Chapter 4 describes the provision and accessibility of Copernicus in-situ data on the one hand (section 4.1), and different in-situ data of other sources, i.e., aerial ortho-imagery, elevation data, topographic maps or various other thematic products and data on the other hand (section 4.2).

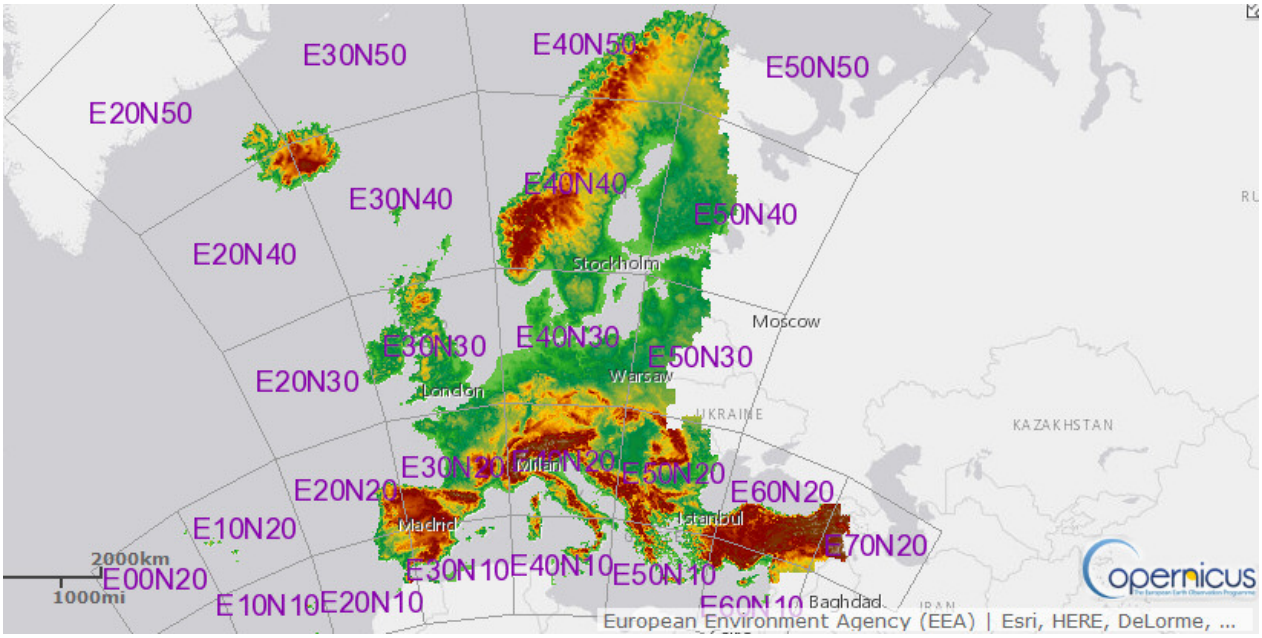
4.1 Provision of Copernicus reference data

This section highlights the importance of elevation data, which are crucial for a broad range of applications with different technical requirements and use cases in the various fields of earth observation, from image pre-processing to analysis.

The next sections describe the available Copernicus reference in-situ data sets on a pan-European scale, which are of use for current and potential future CLMS: The digital elevation model EU-DEM (section 4.1.1), the hydrographic network dataset EU-Hydro (section 4.1.2), the land use and land cover survey LUCAS (section 4.1.3), and other Copernicus products (section 4.1.4).

4.1.1 EU-DEM

The EU-DEM is a pan-European reference dataset, which is fully, freely and openly available for download via the Copernicus Land portal (http://land.copernicus.eu/). It provides spatially explicit digital information on the land surface elevation and fully covers the 39 EEA countries. The EU-DEM is a hybrid Digital Elevation Model (DEM) based on SRTM (Shuttle Radar Topography Mission) and ASTER-GDEM (Advanced Space-borne Thermal Emission and Reflection Radiometer - Global Digital Elevation Model) data, fused by a weighted averaging approach. Also publicly available Russian topographic maps were incorporated for areas north of 60° northern latitude. The EU-DEM provides pan-European elevation data at one arc second (approximately 30 m) posting. It is currently available as updated version 1.1 as a 32-bit GeoTIFF raster dataset with 25m pixel size and a vertical accuracy of 7 m RMSE. The dataset can be downloaded in tiles of 1000 x 1000 km size.



Ref.: http://land.copernicus.eu/pan-european/satellite-derived-products/eu-dem/eu-dem-v1.1

Figure 8: EU-DEM

DEMs provide information required for a broad range of applications with different technical requirements and use cases in the various fields of earth observation. From a Copernicus Services perspective, a consistent EU-DEM is considered important for various kinds of applications at pan-European level, such as consistent satellite image processing, data modelling, future higher-frequency HRL updates or other Copernicus and EU initiatives employing extensive time series analyses.

Many users as well as Copernicus service providers have voiced a clear and urgent requirement for an update/improvement of the EU-DEM, which appears necessary to fulfil the quality requirements (in terms of dataset/time series consistency, higher spatial resolution, better vertical accuracy) for further applications at pan-European level, particularly in consideration of the increased 10 m spatial resolution of S-2. A consistent European DEM of further improved quality would also be beneficial for various kinds of downstream Land applications on more regional scale, for example: water storage and volume assessment, assessment of precipitation run-off and flood risk, risk assessment of landslides and soil erosion. Moreover, the inclusion of high-resolution and high-quality DEMs is desired for various applications in urban areas (e.g. building height, damage assessment, or 3-dimensional modelling) and mountainous areas, which are subject to small-scale topography changes.

In summer 2018, ESA had published an open Call for Tender to procure a new Copernicus DEM. This is foreseeing the provision of a globally homogenous and more accurate 30 m and 90 m DSM and as an option an additional 10 m DSM for the EEA39 countries. By mid-February 2019, the outcome of this procedure has not yet been published. Anyway, this new DEM version is deemed to become the new elevation reference standard for the entire Copernicus programme.

It should be mentioned that the pan-European Copernicus DEM information may (have to) be complemented with national-level DEM datasets (section 4.2.2), which however are available not for all EEA39 countries, and with quite different specifications and quality levels.

4.1.2 EU-Hydro

EU-Hydro is a pan-European reference dataset. It is also fully, freely and openly available as Web Map Service (WMS) and for download via the Copernicus Land portal (http://land.copernicus.eu/). It provides hydrographic vector datasets of surface water bodies, i.e. lakes and the river network for the 39 EEA countries. This information is based on **(i)** originally photo-interpreted HR optical satellite imagery (reference year 2006), and **(ii)** a modelled drainage network with catchments, drainage lines and nodes, derived from the EU-DEM v1.0. The current EU-Hydro public beta version was significantly improved and enriched using **(iii)** photo interpretation of VHR Image Data (2011-2013) (http://land.copernicus.eu/pan-european/satellite-derived-products/eu-hydro, EU-Hydro Flyer).

The EU-Hydro dataset is composed of line, polygon and node types, which result in a connected network of water courses in hierarchical order, assigned Strahler level codes 1 to 9. Figure 9 below shows an example of the EU-Hydro dataset in a part of Western Europe. For reasons of discriminability, only Strahler level 1-3 rivers are displayed here. The very big EU-Hydro vector dataset is provided in ESRI File Geodatabase format with 12 feature classes with a minimum mapping unit of 1 ha, and in the coordinate reference system ETRS89-LAEA. The product is currently available as public beta version 0.9. A comprehensive validation of the dataset had been undertaken by the GMES Initial Operations / Copernicus Land monitoring services – Validation of products (Lot 1) activity in 2017 [AD15]. An improvement of the EU-Hydro dataset, including an extensive error-checking and bug-fixing of various sub-datasets, is currently being undertaken by the GMES Initial Operations / Copernicus Land monitoring services (Lot 2) activity on behalf of the EEA and is scheduled to finish by end-February 2019. The result is expected to be published by the EEA as EU-Hydro version 1.0.

Any further potential level of upgrade of the EU-Hydro dataset, providing potentially further spatial detail, will most likely depend on the envisaged EU-DEM update or the provision of a new pan-European or even globally available DEM with better spatial resolution and positional accuracy.

The hydrographic network is mainly used for applications in hydrology (such as assessment of water resources at European level, run-off modelling and flood forecasting) and ecological applications. It is also expected that the use of the EU-Hydro dataset for various hydrological and climate change related land surface modelling approaches, specifically in synergistic combination with VHR Land Cover/Land Use products, is going to increase.

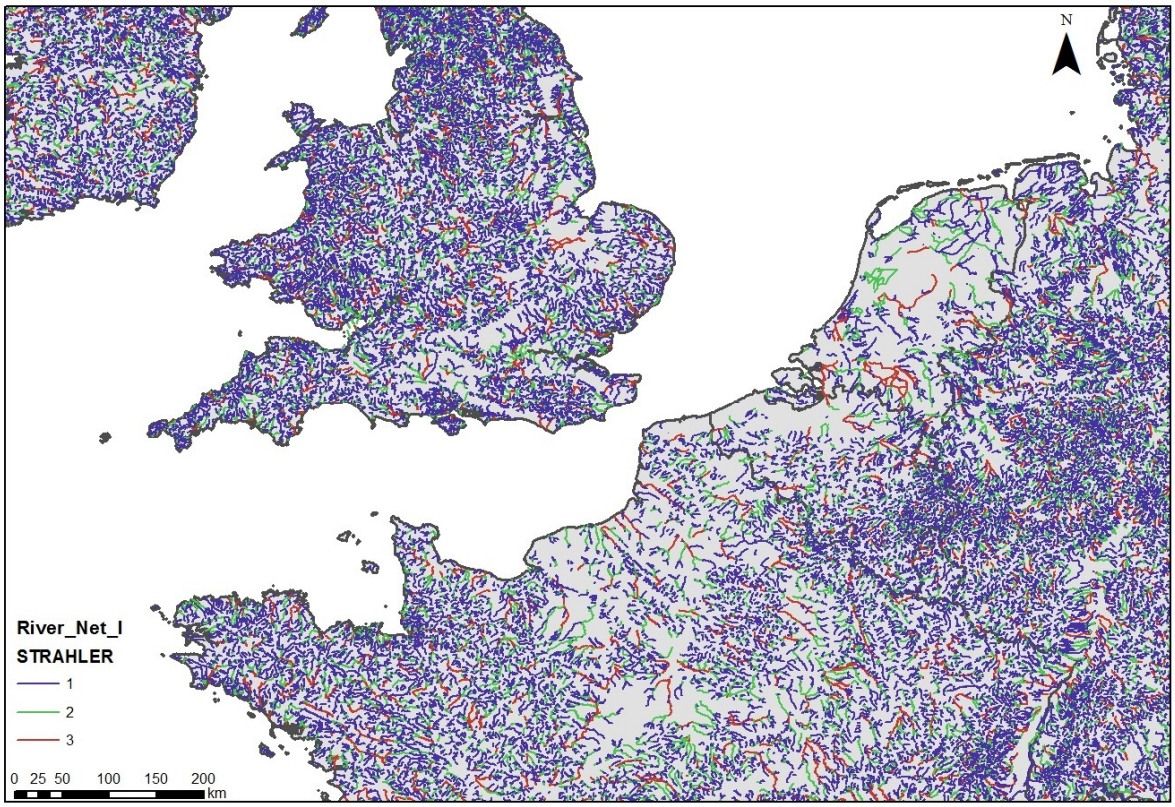


Figure 9: EU-Hydro of part of Western Europe (only Strahler levels 1 – 3 are shown) (source: EU-Hydro public beta version 0.9)

4.1.3 LUCAS

LUCAS (Land Use and land Cover Area frame statistical Survey) program provides statistical data derived from in-situ ground surveys, based on a well-designed sampling grid, all over Europe (Buck et al. 2015).

LUCAS runs operationally since 2009, and aims at collecting statistical observations on land cover/ land use, agro-environmental and soil data. Its main objective is to compile harmonized in-situ field observations, on referenced points, using a systematic and organized framework at European level, to monitor land resources.

Three kinds of information are provided:

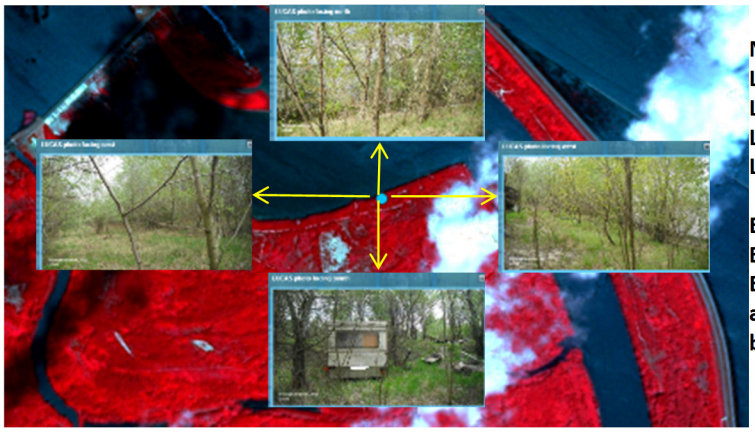
- Micro-data, such as land use or land cover parameters,
- Landscape photos,
- Statistical aggregates by land cover and land use at geographical level.

LUCAS data are derived in a two-phase systematic sampling, which involves in the first phase, the visual interpretation of ortho-photography based on a 2 x 2 km grid and broad land cover strata resulting in over 1 million points stratified over the EU territory. The sampling intensity for each stratum is calculated at NUTS2 level. For NUTS2 regions above 500km², a sampling scheme based on multivariate optimal

allocation (Bethel, 1989) was applied. For those smaller than 500km², an allocation to strata proportional to their size has been adopted. Sample points were grouped in 18 x 18 km blocks, resulting in 81 replicates (their location is selected such that replicate 2 is furthest from 1 and so on). Each replicate is drawn sequentially starting from 1 until the allocated number for each stratum is reached resulting in 270,000 points surveyed on the ground.

The last surveys took place in 2015 and 2012 and the next one has taken place for 2018, which corresponds well to the reference year of Copernicus Land products and is expected to be available in the first quarter of 2019. LUCAS data can potentially be used as a source of reference data for CLMS and an advantage for its use is that for every sample point, field photographs are systematically taken. A certain limitation is that LUCAS 2015 covers only the EU28 countries and the observations are taken over sample point over a small area potentially not compatible with the map product to be validated/reference. Moreover, LUCAS applies a different classification scheme than e.g. CORINE Land Cover and clearly distinguishes between land cover and land use.

This is the main reason why the LUCAS dataset may not be directly useable as training data or to assess the accuracy of map products. A study was commissioned by EEA to harmonise LUCAS nomenclature with that of the Copernicus CLMS products (Buck et al. 2015) and a report was also produced as part of the first extensive CLMS validation exercise to adapt the LUCAS sampling frame for the validation of CLMS products (http://land.copernicus.eu/user-corner/technical-library). However, a practical approach would be to re-interpret LUCAS points based on the acquired aerial and ground photography to match the map specifications in terms of MMU and nomenclature. Field photographs which were taken at every sample point would allow the reinterpretation and classification according to alternative schemes as illustrated in Figure 10.



NUTS region: SK 01
LUCAS Description: Area >10ha
LC1: C10- Broadleaved woodland
LC2: Grassland with sparse tree/shrub cover
Land use : U361- Recreation, leisure

Equivalent Nomenclature MAES level 3: Broadleaved forest (T.C.D. 50 - 80%) 3.1.2
Equivalent Nomenclature MAES level 4: Species associations based information (cf. EUNIS L3 based habitats)

Figure 10: Example of LUCAS point re-interpretation

4.1.4 Other Copernicus products

Further thematic reference data of relevance for the evolution of continental (and potentially global) component CLMS products, are provided directly by the CLMS, as shown in the table below.

Table 33: Overview of other available Copernicus products

Dataset Name	Description	Source	Link
Urban Atlas	The Urban Atlas is providing pan-European comparable land use and land cover data for Functional Urban Areas (FUA), derived from VHR satellite imagery	Copernicus	*http://land.copernicus.eu/local/urban-atlas/view*
Riparian Zones	Riparian Zones products provide detailed information on the state and characteristics of riparian zones across Europe.	Copernicus	*http://land.copernicus.eu/local/riparian-zones/view*
Natura2000	Natura 2000 is an EU-wide network of nature protection areas established under the 1992 Habitats Directive. The aim is to assure the long-term survival of Europe's most valuable and threatened species and habitats. A selection of N2K grassland-rich sites has been mapped for the 2006 and 2012 reference years.	Copernicus	*http://land.copernicus.eu/local/natura/view*
CORINE Land Cover	The CORINE Land Cover (CLC) inventory was initiated in 1985 (reference year 1990) and consists of an inventory of 44 land cover classes with a Minimum Mapping Unit (MMU) of 25 hectares (ha). Updates have been produced for the reference years 2000, 2006, and 2012. Next update is planned for 2018.	Copernicus	*http://land.copernicus.eu/pan-european/corine-land-cover/view*
High Resolution Layers	Pan-European High Resolution Layers (HRL) provide information on specific land cover characteristics on a three-yearly basis, produced from 20 m resolution satellite imagery.	Copernicus	*http://land.copernicus.eu/pan-european/high-resolution-layers/view*

4.2 Accessibility and provision of in-situ data of other sources

The following sections present an overview of the accessibility and provision of various in-situ and other reference data of other sources beyond Copernicus, which are potentially of use for CLMS production. These comprise an assessment of optical ortho-imagery as acquired by sensors mounted on airborne platforms (section 4.2.1), elevation data which are additional and complementary to the Copernicus reference in-situ data provision (section 4.2.2), topographic maps that can potentially be of use (section 4.2.3) and various other thematic products and data (section 4.2.4).

4.2.1 Ortho-imagery

Precise and accurate ortho-imagery (less than 10cm resolution and sub-metric absolute planimetric accuracy) are often available at EEA39 country level, as shown in Figure 11 for an area near Bergen in Norway. Such national ortho-imagery constitute reliable sources of VHR image information even in areas where frequent cloud cover can be a problem to acquire VHR satellite imagery systematically. Accessing

these data as a source of reference is in line with the Copernicus Regulation (Regulation (EU) No 377/2014) defining that in-situ data should be made available by Member States e.g. for Copernicus applications in support to public reporting obligations on environmental policies. Moreover, the INSPIRE Directive obliges European Member States to offer discovery and viewing services for national reference data. Ortho-photos are data specified in Annex II of the Directive.

Figure 11: Example of sub-decimetre ortho-imagery from area near Bergen, Norway (source: http://kart.finn.no)

As described by Rossi et al. (2015), EIONET National Reference Centres (NRCs), which manage the update of CLC, were asked to offer a number of datasets as part of the grant assignment process with EEA.
Orthophoto campaigns are usually conducted every 3-5 years. Moreover, only small countries typically manage to acquire the imagery for the whole country area within one calendar year. In larger countries, it is common to split the country area into several zones. Every year the imagery is acquired for another zone resulting in a 3-5-year update cycle of the whole country.
Many Member States already offer free access to ortho-photos, topographic maps and DEMs. In best case, they are provided through a Web Map Service (WMS) or Web Map Tile Service (WMTS) which are standard protocols for serving geo-referenced map images over the Internet or integrated in free datasets such as ESRI World Imagery. Other countries offer the data through web-viewers which sometimes allow to integrate own vector layers (e.g. sample points) but cannot be integrated in a user environment. Figure 12 provides an overview of EEA39 countries providing access to national reference data. Some of the ortho-imagery WMS are also restricted only to specific purposes, user categories, or provided only upon request

and individual use agreement. This highlights that access is unfortunately still far from being homogeneous across Europe, rendering the use of these valuable datasets not yet fully practical for pan-European consistent use.

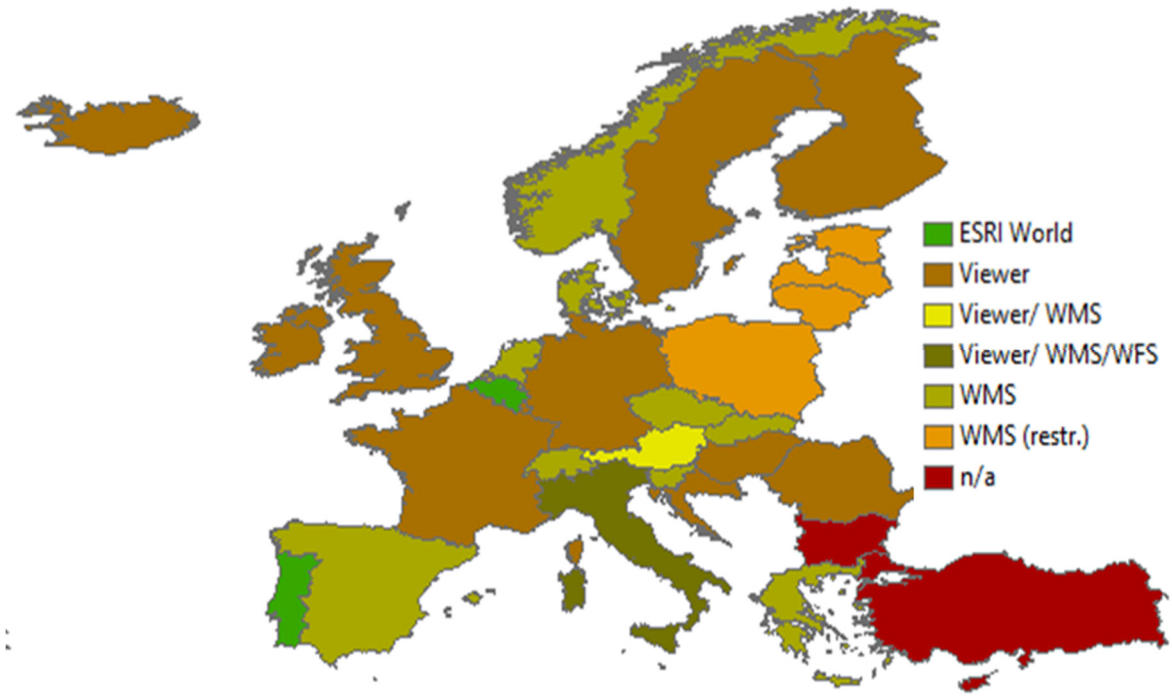


Figure 12: Best access to ortho-imagery for EEA39 countries (source: ECoLaSS)

4.2.2 Elevation data

As explained in sections 4.1 and 4.1.1, elevation data are crucial for a broad range of applications with different technical requirements and use cases in the various fields of earth observation. Therefore, for most of the Copernicus Services reliable elevation information is fundamental. All developments of future CLMS services will necessitate an excellent operational pre-processing of satellite imagery in terms of geometric, topographic and illumination effects, across different Copernicus satellites and contributing missions. This must be sustained by a consistent and freely available DEM with adequate quality.

Complementary to the EU-DEM (see section 4.1.1) additional national elevation datasets as well as data on global scale is necessary, as the EU-DEM fulfils the necessary quality requirements only partially. Besides commercial global DEMs, the following DEMs are freely available:

GLOBAL FREELY ACCESSIBLE DEMS:

Table 34 provides an overview of freely accessible DEMs with (near)-global coverage:

Table 34: Global freely accessible DEMs

Name	Type	Spat. Resol.	Acquisition date/interval	Coverage	Download URL
SRTM	DSM	30 m	Feb 2000	between 60°N and 56°S	https://earthexplorer.usgs.gov/
Aster GDEM v2	DSM	30 m	Oct 2011 – 2017	between 83°N and 83°S	https://asterweb.jpl.nasa.gov/gdem.asp
ALOS WORLD 3D	DSM	30 m	2006 – 2011	between 82°N and 82°S	http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm
GEDI	N/A	22 m	End 2018 – late 2020	between 51.6°N and 51.6°S	https://science.nasa.gov/missions/gedi/

The **SRTM DSM** is based on a radar system that was flown on board the Space Shuttle Endeavor in February 2000, named the NASA Shuttle Radar Topography Mission. With two radar antennas mounted on the Shuttle and on an attached boom, the generation of topographic elevation data by means of single-pass interferometry was applied. Previously available at 90m (3 arc sec) resolution, and as such input to the EU-DEM, a product version with a horizontal 30 m (1 arc sec) resolution was made freely available in late 2015. This void-filled DSM contains a vertical accuracy of 7.86 meters LE95. The SRTM dataset is available for land areas between 60°N and 56°S, can be downloaded via USGS Earth Explorer, and was widely applied for various purposes in the field of Earth observation (https://www2.jpl.nasa.gov/srtm/).

ASTER GDEM v2 (Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2)) is a global product that was provided by NASA and METI/Japan Space Systems on October 17, 2011. It had been generated using optical stereo-pair images from the multispectral ASTER sensor on board NASA's Terra satellite with a first version made available in 2009. The current version 2 – produced with 260,000 additional stereo-pairs – was significantly improved regarding the minimisation of voids, artefacts and flattening of water bodies, and is available with a 30 m posting (1 arc sec) and absolute vertical accuracy of 17 m LE95. An updated version 3 is planned. Compared to SRTM it includes also tiles with small islands. The data can be downloaded via USGS Earth Explorer, and served also as input to the EU-DEM (https://asterweb.jpl.nasa.gov/gdem.asp).

The **ALOS WORLD 3D** was provided by the Japan Aerospace Exploration Agency (JAXA). The DSM was generated from Advanced Land Observing Satellite (ALOS) PRISM Triple-Stereo satellite data from the years 2006-2011. The 5 m commercial product has been resampled to 30 m (1 arc sec). In March 2017 a completely void-filled version between 60°N and 56°S was published. The data can be downloaded on the ALOS World 30 website after registration (http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm).

GEDI (Global Ecosystem Dynamics Investigation) is a light detection and ranging (LiDAR) laser system mission which was installed on the International Space Station (ISS) in late 2018. After the successful launch GEDI has now moved ahead towards commissioning which should be completed in February 2019. The mission should last for 24 months where GEDI will acquire 15 billion cloud-free observations of 25 m spot footprints. GEDI aims at producing the first high resolution laser ranging observations of the 3D structure of the Earth, focussing on the Earth's forests and topography to address key challenges in carbon cycling and biodiversity. GEDI will greatly extend the land cover observations from NASA's Landsat and MODIS programs. It is assumed, that the data will be made freely available for scientific applications. (https://science.nasa.gov/missions/gedi/; https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/iss-gedi).

GLOBAL COMMERCIALLY AVAILABLE DEMS:

Table 35 provides an overview of commercially available DEMs with (near)-global coverage:

Table 35: Global commercially available DEMs

Name	Type	Resolution	Acquisition date/interval	Coverage	Reference URL
Elevation 30 (SPOT DEM)	DSM	30 m	*2002 – 2015*	between 60°N and 56°S	*http://www.intelligence-airbusds.com/en/6073-elevation30-products*
WorldDEM (TanDEM-X)	DSM	12 m	*2010 – 2014*	between 83°N and 83°S	*http://www.intelligence-airbusds.com/worlddem/*
ALOS WORLD 3D	DSM	5 m	*2006 – 2011*	between 82°N and 82°S	*http://aw3d.jp/en/*
Planet DEM 30	DSM	30 m	*2000 – 2017*	global	*http://www.planetobserver.com/products/planetdem/planetdem-30/*
NextMap World 30	DSM (DTM)	30 m 10 m	*1996 – 2017*	global	*http://www.intermap.com/data/nextmap-world-30*
Euro-Maps-3D	DSM (DTM)	5 m	*2005 – still acquiring*	between 70°N and 80°S (no complete coverage)	*http://www.euromap.de/products/prod_008.html*
Vricon DSM-10	DSM (DTM)	10 m	*N/A*	no up to date coverage information available	*http://www.vricon.com/products/*

The **Elevation 30 i**s a DSM based on SPOT 5 optical data, acquired between 2002 and 2015, and is under development by Airbus Defence and Space and the French Survey and Mapping Agency IGN. A suite of three DEMs at 30 m posting each will be offered: The SPOT DEM, the SPOT DEM Precision containing in addition quality layers, and the Reference 3D which includes quality layers and an ortho-image (http://www.intelligence-airbusds.com/en/6073-elevation30-products).

The **WorldDEM** is derived by interferometric SAR measurements from the TanDEM-X mission, which combines the two German X-band SAR satellites TerraSAR-X and TanDEM-X. It was produced at public-private partnership between Airbus Defense & Space and the Germany Aerospace Center (DLR). The World DEM is globally available in an edited version. The data has an absolute vertical accuracy of 4 m in a 12m x 12m raster and is delivered in geographic WGS84 projection (http://www.intelligence-airbusds.com/worlddem/).

The **ALOS WORLD 3D Standard** was provided by the Japan Aerospace Exploration Agency (JAXA), and – as the ALOS WORLD 3D – generated from PRISM Triple-Stereo data of the Advanced Land Observing Satellite (ALOS) from the years 2006-2011. This 5 m commercial product serves as basis for resampling to the freely available dataset. Some voids were filled with other DSM sources, such as the SRTM (http://www.aw3d.jp/en/).

The **Planet DEM 30** combines different data sources (SRTM, ASTER GDEM v, NSIDC, AGDC, CDED and topographic maps) into a 30 m DEM. Furthermore, the product is available in a 90 m resolution. The French company Planet Observer provides different coverage options from custom areas to global coverage (https://www.planetobserver.com/products/planetdem/planetdem-30/).

The **NextMap World 30** uses also multiple source data for a global coverage DSM in 30m resolution. Additionally to the SRTM, ASTER, GTOPO30 and other data global LiDAR is used in order to control the vertical spreading. Water bodies are flattened while oceans are generally set to a height of 0. The tiles in which the product is delivered by the US company Intermap each cover an area of 1°x1° (https://www.intermap.com/data/nextmap-world-30).

The **Euro-Maps 3D** DSM was developed in a co-operation between GAF AG and the German Aerospace Center (DLR). The spatial resolution of the product is 5 m. As input data IRS-P5 Cartosat-1 multi-stereo data acquired since 2005 are used. The absolute vertical and horizontal accuracy lies between 5 and 10 m. The tile size is 0.5°x0.5°. The product is accompanied by several quality and traceability layers to guarantee the transparency. Also other related products are available on request (http://euro-maps.gaf.de/products/prod_008.html).

The **Vricon DSM-10** is based on DigitalGlobe imagery which includes WorldView-1/-2/-3, Quickbird and GeoEye-1 data above others. The product is generated by a combination of stereo photogrammetry and big data processing. The resulting DSM has a spatial resolution of 10 m (another product with a spatial resolution of 0.5 m is also available). This medium-resolution product covers all terrain types on a global scale and can be used in different fields of defence and intelligence. (https://dg-cms-uploads-production.s3.amazonaws.com/uploads/document/file/211/Vricon_DSM-10.pdf).

REGIONALLY AVAILABLE AND NATIONAL DEMS:

The **ArcticDEM** is a DSM with a 2 m resolution available for the Arctic, which should represent all land areas north of 60°north latitude when finished completely. It is based on DigitalGlobe optical stereo imagery (WorldView-1/-2/-3 and GeoEye-1) and can be downloaded via http://pgc.umn.edu/arcticdem.

There is also a new and freely available elevation model available via https://www.pgc.umn.edu/data/rema/ (**The Reference Elevation Model of Antarctica (REMA)**). It provides the first, high resolution (8-meter) terrain map of nearly the entire continent and is also based on DigitalGlobe optical stereo imagery (WorldView-1/-2/-3 and GeoEye-1).

Table 36 describes available national DEMs in Europe:

Table 36: Available national DEMs

Country	Resolution	Type	Source	Data Info and Access
Austria	10 m	DTM	LiDAR	*https://www.data.gv.at/*
Cyprus	5 m	DTM	LiDAR	*http://eservices.dls.moi.gov.cy/inspire_downloads/EL/rasters/*
Denmark	0.4/1.6/ 10 m	DSM/ DTM	LiDAR	https://download.kortforsyningen.dk/content/geodataprodukter
Finland	2 m/10 m/ 25 m/200 m	DTM	LiDAR	*https://www.maanmittauslaitos.fi/en/research/interesting-topics/digital-elevation-model*
Iceland	20 m	DTM	Topographic maps	*http://www.lmi.is/en/stafraen-gogn/*
Italy	20 m	DTM	Interpolation of topographic data	*http://wms.pcn.minambiente.it*
Luxembourg	5 m	DTM	Aerotriangulation	*https://data.public.lu/en/datasets/bd-l-mnt5/*
Malta	1 m	DSM/ DTM	LiDAR	*https://msdi.data.gov.mt/download.html*
Netherlands	0.5 m/5 m	DSM/ DTM	LiDAR	*http://www.ahn.nl/index.html*
Norway	10 m	DTM	N/A	*https://kartkatalog.geonorge.no/search*
Slovenia	1 m	DTM	LiDAR	*https://gis.arso.gov.si/geoportal/catalog/main/home.page*

Spain	5 m, 25 m	DTM	LiDAR and photogrammetric flights	*http://centrodedescargas.cnig.es/CentroDescargas/*
Sweden	50 m	DTM	LiDAR and aerial images	*ftp://download-opendata.lantmateriet.se/*
UK (England)	0.5 m/1 m/ 2 m	DSM/ DTM	LiDAR	*https://environment.data.gov.uk/*

4.2.3 Topographic maps

Topographic maps can make a contribution to the reference sampling for initial LC classification and validation, as long as the timeliness of the maps show no larger reference time deviations compared to the used input satellite imagery. Besides **timeliness**, the **quality** (thematic detail, analogue or digital), **scale** and **accessibility** (license conditions, type of provision, performance) play an important role. Language barriers are typically only a minor issue. Even if topographic maps are not specified directly as individual dataset in the INSPIRE Regulation, layers which are typically forming a topographic map are specified in Annex I (transport network, geographical names, administrative units, hydrography, ...).

Topographic maps are provided by different institutions, regularly by national cadastral offices and governmental institutions, and are made available in a wide range of scales, starting at 1:5,000 and ending at 1:2,000,000. Experiences from service providers in previous pan-European mapping projects (such as the Copernicus High Resolution Layers) have shown, that maps beyond the scale 1:100,000 are of limited use due to the scaling issue and missing level of detail. However, the number of available topographic maps with a scale < 1:100,000 is quite huge, but coverage is often limited to local or regional scale and therefore less suitable for pan-European mapping activities.

CORDA provides access to more than 1,300 topographic maps for the time span 1942 to 2017 in various scales, ranging from 1:5,000 to 1:1,000,000. Maps are provided in digital format or rendered as WMS/WFS. However, only 137 maps show a scale under 1:100,000, mostly topographic maps of larger cities or certain administrative units (e.g. Federal States).

Very promising is OpenTopoMap, a community driven project, which aims to render topographic maps from free and open OSM and Shuttle Radar Topography Mission (SRTM) data with updates in every 5 minutes (https://opentopomap.org/). OpenTopoMap data is made available under the Creative Commons Public License (https://creativecommons.org/licenses/by-sa/3.0/legalcode) and can be easily integrated in the production process through a highly performant Web Map Service, rendering the map in dynamic scales.

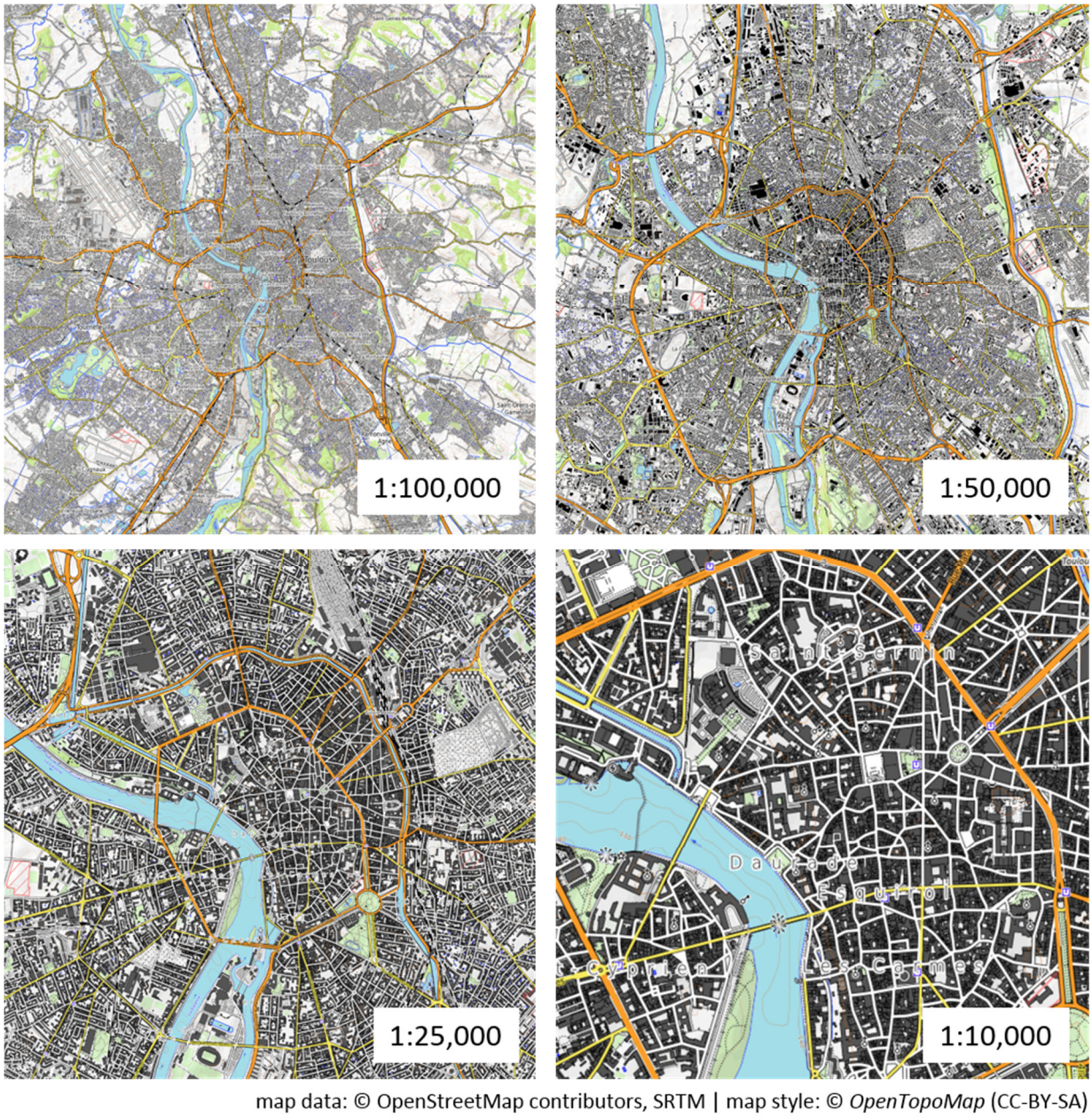


Figure 13: Section from OpenTopoMap within EcoLaSS Test Site in France

4.2.4 Other thematic products

Alongside the reference data and sources mentioned in the previous sections, a great variety of thematic datasets with specific content, detail, quality and coverage exist. Of great importance are datasets, which are freely available, ideally covering the largest possible area. Many of such datasets are provided by national, European and international organisations and the Open Community. The table below provides a selection of thematic products with relevance to the implementation and evolution of CLMS products.

Table 37: Overview of other thematic products relevant for the CLMS

Dataset Name	Description	Source	Link
National LC/LU data and maps	National LC/LU data with varying spatial and temporal extent, thematic detail and content.	EU Member States	*https://corda.eea.europa.eu/*
National LPIS data	National LPIS data with varying temporal extent and thematic content.	EU Member States	*https://corda.eea.europa.eu/*
Biogeographical regions 2016	Official delineations of biogeographical regions 2016 as used in the Habitats Directive and for the EMERALD network.	EEA	*https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3*
Digital map of European ecological regions	Delineation of ecological distinct areas in Europe, based on climatic, topographic and geobotanical European data.	EEA	*https://www.eea.europa.eu/data-and-maps/data/digital-map-of-european-ecological-regions*
European Soil Database	Harmonized European Soil Database (ESDB), extended to Eurasia.	JRC	*https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data*
Global Bare Ground circa 2010	Pixel estimates of circa 2010 percent minimum (peak of growing season) bare ground cover derived from cloud-free annual growing season composite Landsat 7 ETM+ data.	USGS	*https://landcover.usgs.gov/glc/BareGroundDescriptionAndDownloads.php*
Global Land Cover Validation Reference Dataset	Global raster reference dataset produced from very high resolution commercial remote sensing data, circa 2010, collected based on a stratified random sample of 500 sites.	USGS	*https://landcover.usgs.gov/glc/SitesDescriptionAndDownloads.php*
Global Food Security-Support Analysis Data at 30 m (GFSAD30)	GFSAD30 is a NASA funded project providing high resolution global cropland data and their water use that contributes towards global food security in the twenty-first century, derived through multi-sensor remote sensing data, secondary data, and field-plot data and aims at documenting cropland dynamics from 1990 to 2017.	USGS	*https://geography.wr.usgs.gov/science/croplands/*

Dataset Name	Description	Source	Link
Global Precipitation Analysis Products	Gauge-based gridded monthly precipitation data sets for the global land surface in 1 x 1 and 2.5 x 2.5 degree tiles for all products; 0.5 x 0.5 for non-real time products.	GPCC	*http://www.cgd.ucar.edu/cas/catalog/surface/precip/gpcc.html; ftp://ftp-anon.dwd.de/pub/data/gpcc/html/download_gate.html*
Global Historical Climatology Network	The Global Historical Climatology Network (GHCN) is an integrated database of climate summaries from land surface stations across the globe (more than 20 sources).	NOAA	*https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn*
Global Lake and Wetlands Database (GLWD)	Global Lakes and Wetlands Database (GLWD) on global scale (1:1 to 1:3 million resolution), focusing on three coordinated levels on (1) large lakes and reservoirs, (2) smaller water bodies, and (3) wetlands.	WWF	*https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database*
WorldClim - Global Climate Data	WorldClim is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 km2. This free data can be used for mapping and spatial modelling.	Worldclim	*http://www.worldclim.org/*
International Soil Moisture Network (ISMN)	The ISMN is an international cooperation to establish and maintain a global in-situ soil moisture database for validating and improving global satellite observations and land surface models.	ISMN	*https://ismn.geo.tuwien.ac.at/ismn/*
Ramsar Sites Information Service (RSIS)	The Ramsar Sites Information Service (RSIS) provides access to spatial information on wetlands designated as internationally important under the Convention on Wetlands (Ramsar, 1971).	RAMSAR	*http://archive.ramsar.org/cda/en/ramsar-activities-rsis/main/ramsar/1-63-97_4000_0__*
Global Ecological Zones (GEZ)	Global Ecological Zones (GEZ) classification and maps for FAO forest reporting, including information on biodiversity indicators and forest cover change.	FAO	*http://www.fao.org/forest-resources-assessment/remote-sensing/global-ecological-zones-gez/en/*
OpenStreet Map (OSM)	OpenStreetMap (OSM) is a community-driven international project, which provides free and open map data with the aim to create and maintain free geographic data for the world.	OSMF	*https://www.openstreetmap.org/*

5 Assessment of gaps and future improvement needs

Experiences from previous implementations of HRLs and other pan-European Copernicus Land products have highlighted a number of shortcomings in the provision of input EO and reference/in-situ data that will not be resolved short-term with the initiatives already ongoing or planned. This poses certain challenges for rolling out some of the products/services available at pan-European scale and globally. The sections below describe the main issues and how they could be solved.

In section 5.1, critical gaps and issues regarding the provision of input EO data are described, including suggested mitigation measures to address these gaps, and in section 5.2 such gaps, issues and mitigation measures are discussed regarding reference and in-situ data.

5.1 Identification of critical gaps/issues and potential mitigation measures in the provision of input EO data

5.1.1 Use of VHR EO data as Reference for calibration/validation of pan-European component

With respect to Copernicus VHR data as an open and common source for reference data and validation, significant efforts would need to be made to create a high-accuracy, harmonised planimetric reference dataset for Europe. For this purpose, a precise DTM in combination with clearly specified VHR image acquisition criteria (e.g. off-nadir angle < 10 degree, dependant on region and topography) would be necessary. Such reference dataset would enable the generation of high-quality pan-European VHR coverages, supporting the generation of accurate Copernicus Services. In particular, existing as well as new services of the CLMS Local Component and associated Downstream Services would benefit from such an initiative. Although such higher-precision DEM for Europe may actually be procured by ESA in the course of 2019 (cf. section 4.1.1), it will anyway come too late to support a better geometric consistency of the upcoming VHR_Image_2018 dataset (cf. section 3.2.1.3).

Since 2012, a first pan-European VHR2 coverage (mostly SPOT-5 based but also including FormoSat, SPOT-6 and other data sources for gap filling) was provided as part of the Copernicus DWH. This dataset proved particularly useful for a wide range of applications and as part of the production of the CLMS local component. It was also used as a source of geometric and thematic reference for the training and validation of the Pan-European component. However, as the data was mostly based on SPOT-5 2.5 m pan-sharpened data, the range of applications was limited due to its spatial resolution.

For 2015, the decision was taken to make use of the highest resolution satellite imagery available. The resulting VHR2015 was based on VHR1 imagery with mostly Pleiades, but also Digital Globe and Deimos-2 imagery. However, VHR2015 specifications were mostly still based on VHR2012 and therefore totally inappropriate in geometric terms to make use of the dataset as a proper reference dataset, with an RMSE around 5m for 1m and better imagery. In addition, some additional geometry issues (shifts of up to 15m between adjacent images of the same sensor) were found that made the imagery inappropriate for many applications, such as precise identification of training sites for the automatic classification of HR data or the validation of thematic layers.

It is understood that the lack of a pan-European sub metric accurate reference dataset is one of the reasons (alongside a missing precise DTM as stated above) why achieving geometric accuracies of 1-2m RMSE for VHR coverages currently cannot be reached. To overcome this, there would be a need to develop a pan-European sub-metric planimetric reference orthorectified imagery dataset to support accurate regular VHR coverages, of which the whole CLMS would benefit. This could be done e.g. based on the current VHR imagery that would need to be re-processed based on control points extracted from national orthophotos coverages.

In addition, the finalisation of the VHR2015 proved perhaps too ambitious, as demonstrated by the extension of the acquisition campaign well over the initially foreseen ± 1 year time window. Perhaps, a less ambitious task and still relevant for a large number of applications would have been to make use of

VHR2 sensors such as Pan-Sharpened SPOT-6/7 data which provide a 60km swath and higher revisit capabilities than the 20+km swath of VHR1 sensors.

In distinct contrast to the VHR2015 specifications, the upcoming VHR_IMAGE_2018 will be composed of various VHR2 sensors, with spatial resolutions varying between nominally 2 m and 4 m. Whereas the better end of the spatial resolution will be okay as reference data for most of the HRL (2018) implementation, the lower end with 4 m Planetscope data is expected to pose a real deterioration in geometric resolution, information content and discriminability of landscape features, as the Planetscope data are widely recognised to be somewhat blurry, and resembling rather 5.8 m RapidEye data. Another limitation will be introduced for the HR Forest Layer 2018, which is very much dependent on appropriate spatial resolution VHR imagery which allow identifying individual tree crowns vs. canopy gaps. This will largely not be possibly with the upcoming VHR_IMAGE_2018 data.

5.1.2 Input EO data for production

For future Copernicus Services based on optical Sentinel data, ideally, a consolidated and reviewed method to generate atmospherically and terrain corrected Level 2A products would be required. Currently, several L2A processors exist in parallel, providing different results, and the user community has not finally decided which method is to be favoured. In addition, aside from a precise atmospheric and terrain correction of the Sentinel data, the cloud masks currently generated are still inadequate, thus hampering the analysis of S-2 dense time series. Adequate L2A products will significantly reduce the efforts of the Copernicus service providers in view of the EO data pre-processing (atmospheric correction, scene-by-scene calibration, topographic normalisation) which are fundamental pre-processing steps for large-scale operational production. In this context, properly processed L2A products provide the basis for effective multi-temporal analysis and consecutive harmonised products, while simultaneously increasing cost efficiency. In case of gap-filling approaches within existing Sentinel coverages (e.g. due to high cloud cover within short observation intervals), contributing satellite data should be ideally also atmospherically corrected.

Dense S-1 time series in the testing and prototypic production of an improved GRA status layer and new agricultural layers in ECoLaSS have proven to be a reliable source of information, in particular for phenological purposes, to complement the optical time series. Further integration of radar acquisitions in the processing chains of the other prototypes will be tested in the second phase.

The operational production of S-3 SYN products is still delayed at the time of the writing of this report, therefore it has been proposed to use other MR data to simulate the potential added value that could be brought by S-3 satellites. However, it should be noted that this issue is not viewed as a critical gap in the Sentinel data availability, since S-2 satellites have been outperforming and their coupling with S-1 data has been leading to satisfying results in ECoLaSS phase 1.

The development of new services also requires access to historical EO data. Experience from the HRL2015 production has shown that missing or incorrect metadata entries in historic IMAGE_20XX datasets mean that metadata files had to be laboriously updated by service providers, but the resulting workaround-results have never been re-injected into the DWH.

Maintaining the quality of historic EO data collections and improving access thereto may become of increasing importance, as there appears to be a trend to consider retrospective monitoring approaches, to extend the time series of EO based LC/LU assessment and change analyses into the past. One recent example is an open Call for Tenders published by the EC's DG Environment just before Christmas 2018, aiming at establishing a system for a monitoring of grassland areas inside Natura2000 protected sites across Europe back to as late as 1992.

5.2 Identification of critical gaps/issues and potential mitigation measures in the provision of reference and in-situ supporting geospatial data

The Copernicus service providers require reference and in-situ data for creating, verifying and validating products and services derived from satellite images. Both, reference and in-situ data form a building block for the development and update of Copernicus Land Services. The various challenges of accessing and value-adding such data with heterogeneous specifications are known to the Copernicus service providers due to their extensive experience in previous projects and productions, and are repeatedly subject of political and technical discussions. One of the major criticisms is the availability or lack of homogeneous Europe-wide (or global) reference data of the same type and with similar specifications.

At this point, the ECoLaSS consortium refers to the ongoing Copernicus In-situ project as part of the Copernicus In-situ component led by EEA (https://insitu.copernicus.eu/). The project is analysing current in-situ data gaps and bottlenecks in accessing such data. The "State of Play Report – Geospatial Reference Data", available at: https://insitu.copernicus.eu/state-of-play/ summarizes the current recognition of the state of play concerning in-situ data gaps. This report is expected to be updated on approximately annual terms.

A detailed assessment of service-specific needs, challenges, risks and opportunities is given for each Copernicus service in dedicated Fact Sheets. With regards to the Pan-European component of the CLMS, reference is made to the Fact Sheet available at https://insitu.copernicus.eu/FactSheets/CLMS_Pan-EU/. The listed required key in-situ/reference data are: (i) ortho-imagery, (ii) additional thematic information depending on the respective product (e.g. forest inventories, ecosystem maps, wetland maps), as well as (iii) topographic maps, Land Parcel Information System (LPIS) data, elevation data, administrative boundaries and additional data from open sources such as Open Street Map, BingMaps and Google, whereby the reference time stamps of all in-situ data should be generally as close to the reference year of the relevant CLMS product as possible.

The main challenges regarding in-situ data are related to the access, consistency and timeliness. This fact shall be demonstrated using LPIS as an example. LPIS data proved to be very useful in the thematic classification process of satellite imagery and the resulting products' subsequent validation, as it provides reliable information on land cover and land use. Even though LPIS data is produced by all EU countries, access to it is still very heterogeneous and the data are currently not made available at full European level (see Figure 14 below). The reason for this is fairly simple: the creation of nation-wide LPIS data is a cost-intensive process and member states and some national institutions have built up business models to distribute such types of data commercially. However, a number of Member States is providing LPIS data on a free and open basis. It is important to note, that this data is made available in different ways (WFS, WMS, shapefile, geodatabase) with varying thematic content (different level of thematic detail) and aggregation, as well as with different temporal extents. Therefore, improvements in the access, consistency and timeliness would be much appreciated by the Copernicus service providers. The current LPIS availability situation is depicted in the figure below.

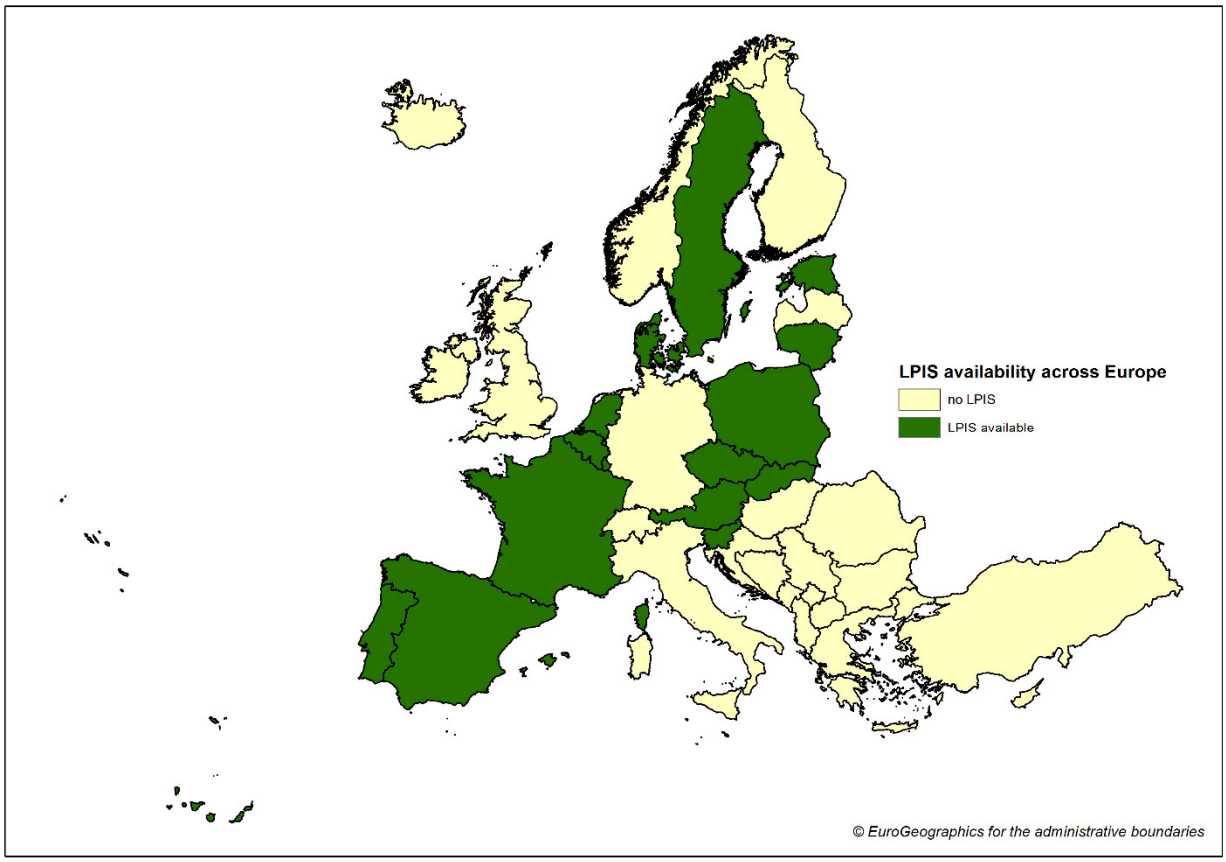


Figure 14: Availability of accessible LPIS data across Europe

The lack of existing pan-European consistent datasets with reliable accuracy and content is currently forcing Copernicus service providers to utilize existing products and data from the Pan-European and Local components, as well as a range of heterogeneous country-specific in-situ/reference databases, collecting the best available datasets, modified and prepared to fulfil the thematic needs of e.g. each individual HR layer in the best possible manner.

With respect to the Global Component, until now the development of services has focused on the provision of biophysical variables from MR sensors. For these, detailed in-situ data requirements, challenges as well as data gaps and risks have been documented in the Global Component Fact Sheet available at https://insitu.copernicus.eu/FactSheets/CLMS_Global/. Considering that similar thematic products to those of the Pan-European component are now envisaged, the Global Component will also need to rely on in-situ data at global level: elevation data, land cover/use maps/masks, calibration and validation measurements as well as hydrographical and meteorological data, or settlement layers. Main challenges are related to the global coverage of the in-situ requirements in general and to a homogeneous data quality and consistency of available datasets. To overcome these restrictions, satellite-derived products and indices are used as a proxy for in-situ measurements. Validation is also supported by comparing the derived products with products generated by other organisations (e.g. project-specific and international databases). However, it can be expected that the quality level of completion of data at global level will be lower than at European level, but it remains to be tested which impact this will have on the quality of the resulting CLMS global thematic services.

6 Conclusions and outlook

This report represents the second issue of the WP22 deliverable, incorporating the experiences made in the first implementations of the improved/new next-generation CLMS candidate services in the demonstration sites (Task 4) of ECoLaSS project phase 1 and the outcome of WP21 for phase 2 in terms of user requirements. A detailed review of the status of Copernicus-related EO and other reference/in-situ data requirements and offering was made, outlining both the status and the shortcomings of the current data situation, and the consequences this might have for future services.

This review comprised, amongst others, a detailed assessment of the current and future offering in terms of EO data including the Sentinel constellations and VHR data for calibration and validation. The EO data availability was confronted with the needs identified as part of WP21, to assess any critical gaps and potential mitigation measures as briefly summarised below:

- There is still a lack of a reliable VHR geometric reference dataset, which is somewhat restricting the full use potential of the Copernicus VHR datasets for calibration and validation of the investigated thematic products of HRLs and alike products at pan-European level. This could be resolved e.g. by improving the quality of the pan-European DTM and/or by developing a reliable VHR geometric reference based on one of the VHR coverages and making use of available orthophoto coverages from EEA39 member states.
- The specifications of the upcoming VHR_IMAGE_2018 data with 2-4 m spatial resolution will pose a limitation in terms of information content and discriminability of landscape features. Specifically, the largely contained Planetscope data will not allow identifying the “quasi-ground truth” calibration information needed for all HR Layers, e.g. it will not be possible to reliably identify individual tree crowns vs. canopy gaps for the HRL Forest’s Tree Cover Density and Dominant Leaf Type products.
- The available standard level of pre-processing for S-2 imagery as provided by ESA/Sen2Cor is currently still not adequate, thus somewhat restricting the quality of the results from automated processing chains based on dense time series. Cloud, haze and shadow masks need to be improved further for large-scale operational application.
- Alternatives to the cloud mask provided by Sen2Cor, such as MAJA pre-processing or a customised cloud mask, have proven to be viable, as outlined in (AD07). The prototypes developed in Task 4, namely the improved HR IMP, FOR and GRA Layers, which substantially rely on optical S-2 datasets, have demonstrated their operability at a 10 m resolution, for shorter updates, with a 2-year window – and this will be further tested on a yearly incremental update basis in the second ECoLaSS project phase.
- Newer candidate products such as phenological layers and crop type layers could benefit more from the deeper integration of S-1 images into the processing chain, in particular to mitigate the occurrence of cloud cover, which will be further tested in the second project phase of ECoLaSS.
- At the time of this report’s writing, the products of S-3 were still under review in order to improve their quality and robustness. As a substitute, the densification of the time series of optical data from S-2 will be investigated in the framework of ECoLaSS by using PROBA-V data in the meantime.
- Maintaining the quality of historic HR/VHR EO data collections and improving access thereto may become of increasing importance. Recent examples at European level suggest there may be a trend to consider retrospective monitoring approaches, to extend the time series of EO based LC/LU assessment and change analyses also into the past, allowing comprehensive and informed policy decisions.

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

- Although a higher-precision DEM for Europe may be procured by ESA in the course of 2019, it will come too late to support a better geometric consistency of the upcoming VHR_Image_2018 dataset. However, future generations of Copernicus services may greatly profit from it.

- Supporting in situ data for training and validation of thematic data are not homogeneous across the EEA-39 countries.
- One of the more obvious examples is LPIS which could provide reliable training and validation data for the production of HRL grassland and a future crop layer, but its availability at pan-European level is far from complete despite the INSPIRE Directive. This would require further support and strengthening of the Copernicus In-situ Component to improve the access to such high quality reference and in-situ data for the Copernicus Services.
- The use of LUCAS dataset will be further explored in the second ECoLaSS phase as a basis for a crop mask layer.

The analysis of critical gaps and the provision of mitigation measures will be picked up and re-evaluated again towards the end of the project through the reports of WP52 and 53, which will assess the overall feasibility of each prototype for future operational implementation.

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