Horizon 2020

LC-SPACE-02-EO-2018: Copernicus Evolution – Mission Exploitation Concepts

Capacity for Copernicus REDD+ and Forest Monitoring Services

REDDCopernicus

This project has received funding from the European Union's Horizon 2020 Work Programme 2018-2020 Leadership in Enabling and Industrial Technologies – Space, Coordinated Support Action under Grant Agreement No 821880.

Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 2

Grant Agreement No.:	821880
Doc. No.:	D12.2
Issue/Rev.:	1.0
Date:	07.06.2021

Supported by:

Partners:

GAFAG an e-GEOS (ASI / Telespazio) Company

European Commission

CLS

WAGENINGEN UNIVERSITY & RESEARCH

VTT

Consortium Partners

No.	Name	Short Name	Country
1	GAF AG (Coordinator)	GAF AG	Germany
2	JOINT RESEARCH CENTER	JRC	Belgium
3	COLLECTE LOCALISATION SATELLITES (CLS) (formerly SYSTEMES D'INFORMATION A REFERENCE SPATIALE - (SIRS) SAS)	CLS (formerly SIRS)	France
4	WAGENINGEN UNIVERSITY	WU	Netherlands
5	TEKNOLOGIAN TUTKIMUSKESKUS VTT Oy	VTT	Finland

Disclaimer:

The contents of this document are the copyright of GAF AG and Partners. It is released by GAF AG on the condition that it will not be copied in whole, in section or otherwise reproduced (whether by photographic, reprographic or any other method) and that the contents thereof shall not be divulged to any other person other than of the addressed (save to the other authorised officers of their organisation having a need to know such contents, for the purpose of which disclosure is made by GAF AG) without prior consent of GAF AG.

Summary

This document (deliverable D12.2 of project REDDCopernicus) contains information that is based on the second year of work package 12 'Infrastructure developments for the space and ground component'. Based on earlier work packages on user requirements and forest monitoring capacities, gaps of the Copernicus space component (including contributing missions) and Copernicus ICT infrastructure are analysed from the point of view of REDD+ and monitoring of sustainable forestry. The final version of this deliverable (D12.3) will include a more elaborated and updated version of these analyses.

	Affiliation/Function	Name	Date
Prepared	VTT WU GAF AG	Yrjö Rauste, Jukka Miettinen Sarah Carter, Martin Herold Peter Navratil	01/03/2021
Reviewed	GAF AG	T. Haeusler	09/03/2021
Approved	GAF AG, Project Coordinator	T. Haeusler	10/03/2021

The document is accepted under the assumption that all verification activities were carried out correctly and any discrepancies are documented properly.

Classification of the Document

Classification status
Public

Distribution

Affiliation	Name	Copies
REA	M. Kacik	electronic copy
Partners	Consortium Members	electronic copy

Document Status Sheet

Issue	Date	Details
0.9	01/03/2021	2nd Draft Document Issue
1.0	07/06/2021	Final Version

Document Change Record

#	Date	Request	Location	Details

Executive Summary

Introduction

This document - deliverable D12.2 of project REDDCopernicus 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component' presents results of work package 12 'Infrastructure developments for the space and ground component'. The deliverable will be developed into its final form in three versions (12.1, 12.2 and 12.3). Two separate parts of the space and ground infrastructure system are investigated for the purposes of this deliverable:

1. The space segment including satellites, their sensors, and the satellite-specific ground segment.
2. The ICT (Information and Communication Technology) facilities used to process the EO data including computers, telecommunication facilities, and cloud-based ICT platforms.

The first version of the deliverable provided the frames for the work to be conducted and presented results of the initial analyses performed over the first year of the project. The first version also included a survey of the Copernicus space segment and gaps in its capacity. The main focus in this second version is related to the analysis of the Copernicus DIAS systems. Updated information on the status of the DIAS platforms, their usability and user experiences were gathered during the second project year. Value added ecosystems around DIAS and TEP platforms were also elaborated in the current version. In addition, all other sections of the deliverable were updated.

Space segment updates

As discussed in the first version of this deliverable D12.1, main gaps of the Copernicus space segment are lack of L-band radar data and lack of imaging spectrometer data. These gaps are going to be filled with the Copernicus expansion missions ROSE-L and CHIME, which are under construction. Satellite data offering outside the Copernicus programme has increased, especially in experimental and commercial X-band SAR satellites. On the optical domain, the Norwegian initiative to offer monthly 4.7-m image mosaics over Tropics free of charge is going to change the landscape for tropical forest projects.

DIAS systems

The analysis of the DIAS platforms revealed significant differences in the approach how Copernicus Sentinel data is accessed in the five platforms. Some DIAS systems have a large archive of Sentinel data on discs connected directly to the processing computers of the DIAS system, while some systems have a fairly short local archive of latest Sentinel data. Images outside the local cache of latest Sentinel imagery must be copied over network connections from some cloud archives, which causes some delays in processing. Considering for example a hypothetical EO case of compiling monthly composites of Sentinel-2 Level 1C images in Africa for five years 2016-2020, the DIAS systems are very different. In CREODIAS, all needed input data are available on the disc system of the DIAS. In Mundi, the data of 2020 is mostly available in the archive of the DIAS, but data for years 2016-2019 must be fetched from some external archives. In Sobloo, about half of the 2020 data are available (in March 2021), and the data for the remaining 4.5 years must be fetched from some external archives. In ONDA, no data are available on-line for this example case (if conducted in March 2021), but all data must be fetched from the cloud archive of ONDA DIAS. Likewise in WEkEO, all data must be fetched from the archive maintained by Cloud Ferro (Poland). In EO applications aiming at a single, limited time period like e.g. chosen summer months, the differences in data transfer volumes between DIAS systems are naturally smaller.

The relatively small amount of paying customers of the DIAS systems does not generate high enough revenue to fund large on-line archives of Sentinel data for this type of public-benefit services. The free and open access to all Copernicus Sentinel data - which is the data policy of the Copernicus Sentinel satellite system - must be organized from other archives than those on the DIAS systems - unless public funding is available to DIAS operators for this purpose.

For many users, the workflow of EO data processing is still based on downloading satellite imagery to the local computer system of the user. The recognition of the opportunity and benefits of processing

EO data in cloud facilities like DIAS systems has been slower than expected, and many users still prefer to stick to their old ways of working. This has been one of the major challenges in marketing services of the DIAS systems. Now the situation seems to be finally changing and more and more users of EO data are moving to cloud processing on DIAS systems.

Regarding the usability of the DIAS platforms in tropical countries, there is considerable variation in internet access speed across the countries. During the Learning Exercises workshops, 93% of the participants found cloud-based approaches very user-friendly, and over 80% of the participants believed that they could be integrated into their current practices. However, only 55% of the participants chose web portal as the most preferred access to the future Copernicus REDD+ service, fearing potential problems in accessing and working with the data due to unreliable internet access.

Value added ecosystem

The European EO service industry has shown strong growth over the past years, more than tripling its revenue over the past ten years. At the same time, the number of companies have doubled. There is a strong potential for further growth with ever increasing monitoring requirements that EO based applications can respond to. According to the yearly survey of the European Association of Remote Sensing Companies (EARSC), the biggest barriers of growth are market/user acceptance of EO based approaches and customer's lack of budget. The Copernicus Programme has had a very positive influence on the European EO Service Industry, with over 80% of the companies perceiving Copernicus as positive or very positive influence for their business in the latest survey. The perceived impression have improved strongly over the past three years, potentially due to the successes of the Sentinel satellites and the new DIAS platforms.

The European EO industry has a large potential pool of new users in European and non-European customers and it has access to the latest technologies and methods. The Copernicus space and ICT components support this positive development. The network of DIAS systems forms a favourable environment for the European EO industry. However, there are also aspects in the European EO industry scene that causes challenges and may limit the growth. Potential hindrances for competitiveness include at least: 1) Delayed launch of European online data and processing platforms, compared to non-European competitors, 2) Unclear roles of the numerous platforms in Europe, 3) Limited direct data access in most platforms and 4) Lack of anchor clients, compared to all major non-European EO industry platforms who have large secured funding from the other activities of the companies. To promote an active and successful platform ecosystem, European users should be strongly encouraged to use European EO platforms for service development and provision. Overseas commercial operators like Amazon AWS, Google, and Microsoft Azure are nowadays the main competitors of European (partially publicly funded) platforms.

Conclusions

The final conclusions and recommendations of the Compendium of R&D Needs for the Evolution of the Copernicus Space Component deliverable will be defined over the last project year using all the information collected throughout the project and reported in the final version of the deliverable (Version 3). However, some preliminary findings can be outlined already at this point.

Overall, the Copernicus space segment lead by the Sentinel fleet has proven highly usable for forest monitoring purposes. The space segment will become even more comprehensive with the planned ROSE-L and CHIME satellites. The main gap in the space component is the lack of a sensor that can be used to map forest biomass reliably and without serious limitations from signal saturation with higher biomass levels. The BIOMASS mission (ESA Explorer planned for launch 2022) may mitigate this gap essentially in those areas where P-band SAR can be operated (under the use restrictions of the frequency allocation organisation International Telecommunication Union). The recent and future planned L-band SAR systems may also contribute to better biomass mapping but less than the use of P-band data. Use of space-borne profiling Lidar sensors like GEDI may alleviate the saturation-related bias of L-band estimated biomass in high-biomass forests.

The Copernicus ground infrastructure for storage, distribution and utilization of the data is built around the DIAS platforms. The transfer to cloud processing has been slow to start and the potential of the

DIAS platforms is still not fully used in the European EO industry. The DIAS platform operators are in a key role to support users to make this leap. But the DIAS system needs clarification, especially regarding business model and delineation between public and commercial functions and funding.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

API	Application Programming Interface
CCM	Copernicus Contributing Mission
CSCDA	Copernicus Space Component Data Access system
CESBIO	Centre d'Etudes Spatiales de la BIOsphère, France
CHIME	Copernicus Hyperspectral Imaging Mission
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIAS	Data and Information Access Service
EC	European Commission
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FM	Forest Monitoring
FMS	Forest Monitoring Service
GAF	GAF AG, Consultant for Geoinformation services
GEOSS	Global Earth Observation System of Systems
GFOI	Global Forest Observations Initiative
GIS	Geographic Information System
GUI	Graphical User Interface
HR	High Resolution (resolution 4-30 m)
ICT	Information and Communication Technology
LAN	Local Area Network
MEP	Mission Exploitation Platform
MMU	Minimum Mapping Unit
MR	Medium Resolution (resolution 30-300)
MRV	Monitoring, reporting and verifying
REA	Research Executive Agency
REDD	Reducing Emissions from Deforestation and Degradation
REDD+	Reducing Emissions from Deforestation and Degradation "plus" conservation, the sustainable management of forests and enhancement of forest carbon stocks
REP	Regional Exploitation Platform
REST	REpresentational State Transfer
ROSE-L	Radar Observation System for Europe in L-band
SAR	Synthetic Aperture Radar
SIRS	Systèmes d'Information à Référence Spatiale, France
SP	Service Provider
TEP	Thematic Exploitation Platform
VHR	Very High Resolution (resolution better than 4 m)

This page is intentionally left blank!

1 Introduction

1.1 Infrastructure Framework for EO Data Utilization in Forest Mapping Services

The 'Infrastructure Developments for the Space and Ground Component' work package (WP 12) of the REDDCopernicus project is part of Task 4: 'Research and infrastructure gaps'. The objective of WP 12 is to use the outcomes of Tasks 1 and 2, recent research results and other relevant information to identify and then prioritise the main infrastructure and space component gaps for the provision of operational Forest Monitoring Services (FMS).

Results of WP 12 are reported in the 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component' deliverable, which will be developed into its final form in three versions (12.1, 12.2 and 12.3). For the purposes of this deliverable, two separate parts of the space and ground infrastructure system are treated:

1. The space segment including satellites, their sensors, and the satellite-specific ground segment.
2. The ICT facilities used to process the EO data including computers, telecommunication facilities, and cloud-based ICT (Information and Communication Technology)platforms.

The name of this deliverable was specified in the REDDCopernicus description of activity to be 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 2'. Even though this form of the name does not include the ICT infrastructure part of the work package, the name was not changed to better reflect the content of this deliverable.

The space segment needs to be able to provide data with specifications that enable processing of data products required by the stakeholders, in a consistent and reliable manner. With the increasing amount of data, the ICT facilities are gaining importance in efficient utilization of satellite based information. The ICT facilities need to provide efficient and user friendly environment for value added processing and utilization of the products derived from the satellite data.

The potential gaps in these two components for the provision of operational Forest Monitoring Services (FMS) will be evaluated based on current understanding on the user needs and infrastructure development plans, assessed through literature review, desk studies and stakeholder interaction.

1.2 Copernicus Space Segment - Current Status

The main component of the Copernicus space segment is the Sentinel family of missions. These satellites are complemented by missions from other space agencies, called Contributing Missions. The ESA's Sentinel constellation is a family of satellite missions developed specifically for the Copernicus programme. The family includes six missions (Table 1), each of which is based on a constellation of two satellites. Copernicus programme ensures a free, full and open data policy[1] for all Sentinel data. This means that all the data produced by the satellites is freely available for use globally.

[1] Legal notice on the use of Copernicus Sentinel Data and service Information (2014), https://sentinel.esa.int/documents/247904/690755/Sentinel_Data_Legal_Notice

Table 1: Main characteristics of Sentinel missions

Mission	Type	Purpose	Spatial resolution	Operational status
Sentinel-1	Polar orbiting C-band radar	Land and ocean monitoring	10 m	Both satellites in orbit: S1A launched on 3 Apr 2014 and S1B on 25 Apr 2016
Sentinel-2	Polar orbiting Multispectral optical	Land and coastal area monitoring	10-60 m	Both satellites in orbit: S2A launched on 23 Jun 2015 and S2B on 7 Mar 2017
Sentinel-3	Polar orbiting Multi-instrument mission	Sea-surface topography, ocean and land temperature and colour monitoring	500 -1000 m	Both satellites in orbit: S3A launched on 16 Feb 2016 and S3B on 25 April 2018
Sentinel-4	Geostationary Multi-instrument mission	Atmospheric monitoring	4-8 km	Under construction (in Feb 2021)
Sentinel-5 (Precursor)	Polar orbiting Multispectral UV – SWIR	Atmospheric composition, air pollution and ozone layer monitoring	7 km	Precursor launched 13 Oct 2017. The Precursor satellite aims to fill the gap between Envisat and future Sentinel-5 satellites
Sentinel-6	Polar orbiting Radar altimeter	Global sea surface height for oceanography and climate studies		Under construction (in Feb 2021)

The three satellite missions most relevant for REDD+ and forestry monitoring services are the Sentinel 1, 2 and 3 satellites. The Sentinel 1 and 2 satellites enable high frequency, high-resolution C-band and optical multispectral forest monitoring capabilities globally. These two satellites are supported by the coarse resolution Sentinel 3 satellite, capable of providing e.g. daily active fire detections.

In addition to Sentinel family of missions, ESA (European Space Agency) organizes the procurement of EO data from a number of Copernicus Contributing Missions (CCMs) that complement the Copernicus data offer. Data from the Copernicus Contributing Missions are available from the Copernicus Space Component Data Access system (CSCDA) to Copenicus and other EU projects according to quota allocated to the projects. The Copernicus Contributing Missions are divided into six mission groups, based on the mission type (SAR [Synthetic Aperture Radar]/optical/atmospheric) and, for the SAR and optical missions, spatial resolution. Table 2 (Ottavianelli 2021)[2] lists missions within the three groups considered potentially the most useful for REDD+ and forest monitoring services. More detailed description of the Sentinel fleet and the CCMs can be found in Deliverable 2.2 ’Review Assessment for Forest Monitoring Capacity’.

[2] https://spacedata.copernicus.eu/documents/20126/0/DAP+Release+phase2+V2_8.pdf/82297817-2b96-d3de-c397-776292336434?t=1609864430015

Table 2: Copernicus contributing missions in the very high and high spatial resolution range (optical datasets) as well as SAR data

SAR VHR1-MR1*	Optical VHR1/2*	Optical HR1/2*
ALOS/PALSAR +	DEIMOS-2 +	ALOS/AVNIR-2 +
COSMO-SkyMed +	SuperView-1 +	DEIMOS-1 +
Envisat +	GeoEye-1 +	Landsat 5, 7 & 8 +
ERS ½ +	IRS-P5/CartoSat +	RapidEye Constellation +
Kompsat-5 +	Ikonos-2 +	ResourceSat 1 & 2 +
RADARSAT-2 +	SkySat +	SPOT 6 & 7 +
TerraSAR-X, TanDEM-X +	Kompsat-2 &3 +	
	Pleiades-1A/1B +	
	QuickBird-2 +	
	SPOT-6/7 +	
	PlanetScope +	
	WorldView 1, 2 & 3 +	

***) VHR1 < =1m spatial resolution; VHR2 1-4 m; HR1 4-10 m; HR2 10-30 m, MR1 30-100 m;**

1.3 Copernicus Ground Infrastructure - Current Status

Data reception and initial processing

Each Copernicus mission and the contributing missions have their own ground segments that are operated independently. All the ground segments are linked to form the Copernicus Ground Segment. This large space capacity is coordinated through the Space Component Data Access System. The Copernicus Ground Segment is complemented by the Sentinel Collaborative Ground Segment, which was introduced with the aim of exploiting the Sentinel missions even further. This entails additional elements for specialised solutions in different technological areas such as data acquisition, complementary production and dissemination, innovative tools and applications, and complementary support to calibration and validation activities. The Sentinel Core Ground Segment and the Data Access Coordinated System are managed directly by ESA, while other parts are managed by third parties such as National Space Agencies. The Collaborative Ground Segment systems interface to the core ESA elements via specific agreements with the Agency.

Data distribution

Data received by Copernicus satellite missions are available through several portals including the two main channels: Copernicus Open Access Hub (previously known as Sentinels scientific data hub) and the Data and Information Access Services (DIAS). Amazon AWS distributes Copernicus Sentinel products, but the download is not necessarily free of charge. Google Earth Engine also includes Copernicus Sentinel data for the registered users of the system. Sentinel-1 images are available as ortho-rectified data but without radiometric normalisation (a.k.a. terrain flattening).

The Copernicus Open Access Hub provides complete, free and open access to all Sentinel data. The access hub can be used via the ‘Open Hub’ through an interactive graphical user interface or through the ‘API Hub’ (API = Application Programming Interface). While the ‘Open Hub’ allows user to search, browse and download images using interactive map search, the ‘API Hub’ is designed for users who download data regularly through API connections. In Copernicus Open Access Hub, Sentinel-1 data are kept on-line 12 months, after which the data are moved to the long-term-archive on tapes. Sentinel-2 level-1C and level-2A data are also kept on-line 12 months[3] (for the time being 24.2.2021). Users can request re-loading off-line data from the Copernicus Open Access Hub, but only two products at a time.

The Data and Information Access Services (DIAS) platforms allow users to discover, manipulate, process and download Copernicus data and information (including both satellite data and Copernicus core products). Currently, there are five DIAS platforms: CREODIAS[4], ONDA[5], Mundi[6], Sobloo[7] and WEkEO[8]. Each DIAS runs its own storage and computing infrastructure, providing the back-end support for user interface and third party applications. By providing the wide range of data and services in a single storage and processing infrastructure, the DIAS platforms enable users to develop and host new applications in the cloud, while removing the need to download large quantities of data from several access points and process them locally. The DIAS systems are described in detail in REDDCopernicus deliverable D2.2 'Review Assessment for Forest Monitoring Capacity' and their current status is analysed in sections 2.2 and 3.2.1 … 3.2.3 of this document (D12.2 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 2').

The Copernicus Contributing Missions (CCMs) data are made available through the Copernicus Space Component data and services portal[9]. The datasets include standard 'Core' datasets, as well as on-demand 'Additional' datasets. Please see more detailed description on the availability of the contributing missions data in REDDCopernicus deliverable D2.2 'Review Assessment for Forest Monitoring Capacity'.

Value added processing

Finally, there is a third level of access to Copernicus data, the ESA's exploitation platforms. There are three different types of exploitation platforms: 1) Thematic Exploitation platforms (TEP), 2) Mission Exploitation Platforms (MEP) and 3) Regional Exploitation Platform (REP). The EPs aim to be collaborative, virtual work environments providing access to EO data and the tools, processors, and ICT resources required to work with them, through one coherent interface. The EPs provide both readily available tools (created by EP operators or third parties) and possibility to develop own tools for data processing. The TEPs now sit on top of the DIAS platforms, providing direct access to Copernicus satellite images and data from Copernicus core services, in addition to all other datasets available in the DIAS platforms. When analysing the roles of TEP and DIAS systems, it is useful to remember that the development of TEP systems was started before DIAS systems existed.

The TEPs focus on six different thematic areas: 1) Coastal, 2) Food Security, 3) Forestry, 4) Geohazards, 5) Hydrology, 6) Polar and 7) Urban. The idea of the TEPs is to serve networks of Copernicus data users under specific thematic areas, by providing them access to the data and tools specifically designed to meet their needs, and create communities with similar interests. The MEPs focus on specific missions, providing interface, tools and processing capabilities for data from a specific mission. Currently, there is only one MEP functioning, for the Proba-V satellite data. And finally, the REPs aim to bring together communities interested in some specific geographic area. There are currently no REPs as platforms functioning. The current status and functioning of the exploitation platforms is analysed in sections 2.2.3 and 3.2.4.

---

[3] https://scihub.copernicus.eu/userguide/LongTermArchive
[4] CREODIAS website (2019), https://creodias.eu/
[5] ONDA website (2019), https://www.onda-dias.eu/
[6] Mundi website (2019), https://mundiwebservices.com/
[7] Sobloo website (2019), https://sobloo.eu/
[8] WekEO website (2019), https://www.wekeo.eu/
[9] Copernicus Space Component portal (2019), https://spacedata.copernicus.eu/web/cscda/home

1.4 Objectives

The deliverable D12.2 is the second version of the 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component', which will be developed into its final form in three versions (12.1, 12.2 and 12.3). The overall objectives of these deliverables are:

- to identify and analyse development needs in the space segment of Copernicus programme from the point of view of EO-based forest monitoring, and
- to identify and analyse development needs in the ICT infrastructure offered by the Copernicus programme, again from the point of view of EO-based forest monitoring.

The first version of the analyses provided the frames for the work to be conducted and presented results of the initial analyses performed over the first year of the project. The main focus in this second version D12.2 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 2' is related to the analysis of the Copernicus DIAS systems. Updated information on the status of the DIAS platforms, their usability and user experiences were gathered during the second project year. In addition, all other sections of the deliverable were updated to current status. Value added ecosystems around DIAS and TEP platforms are also elaborated in the current version.

2 Approach for Assessing Infrastructure Gaps

2.1 Space Segment

2.1.1 Research Literature Review

User requirements as described in deliverables D1.1 'Stakeholder and Requirements Assessment Report' and D2.1 'Workshop Report: Inventory of State-of-the-Art Technical Capacities in Europe for FM Capacities and Infrastructure' were used as the starting point when analysing gaps in the Copernicus space segment from the point of view of forest monitoring for REDD+ in tropical countries and for forest monitoring for sustainable forest management in Europe. In addition, experience from past forest monitoring projects of the authors formed a background of the gap analysis.

For mapping the current status and plans, literature review was used as a tool. The extensive literature review conducted in WP11 provided valuable information on the use of different types of sensors in operational and research activities. This information was passed to WP12 to draw conclusions of the requirements of the space segment.

2.1.2 Candidate Mission Documentation Analysis

All the original six candidate missions of the Copernicus expansion programme[10] are still under consideration, and the B2 phase is ongoing. The decisions (by EU and ESA member countries) are expected in the second half of 2021[1].

The candidate missions include:

1. ROSE-L: L-band Synthetic Aperture Radar
2. CHIME: Copernicus Hyperspectral Imaging Mission
3. LSTM: Copernicus Land Surface Temperature Monitoring
4. CO2M: Copernicus Anthropogenic Carbon Dioxide Monitoring

10 https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Contracts_awarded_for_development_of_six_new_Copernicus_missions

5. CIMR: Copernicus Imaging Microwave Radiometer
6. CRISTAL: Copernicus Polar Ice and Snow Topography Altimeter

The documentation of these missions was used in analysing their role in filling potential observation gaps for forest monitoring that have come up in the literature review and stakeholder interaction.

2.1.3 Copernicus and GEOSS Development Plans

Published documentation on the Sentinel next generation plans as well as plans by GEOSS (Global Earth Observation System of Systems of GEO, Group on Earth Observations) were studied to analyse the long term development plans of the space component from the point of view of gaps for forest monitoring.

2.2 ICT Infrastructure

2.2.1 Survey/Interviews to Gather Views of DIAS Providers

A survey to platform owners was carried out in WP 2 to a chosen set of platforms (5 DIAS platforms and Forestry TEP). The answers in the WP2-deliverable D2.2 'Review Assessment for Forest Monitoring Capacity' gave a fairly comprehensive picture of the offered capacities of the DIAS systems.

The DIAS operators were again interviewed during the second year to update developments on services provided for the users. These DIAS interviews were conducted in January…February 2021 (Table 3). From VTT, Yrjö Rauste and Jukka Miettinen participated in all DIAS interviews. Renne Tergujeff/VTT also participated the CREODIAS interview on 20.1.2021.

Table 3: Interviews of DIAS providers.

DIAS	Date	Participants
CREODIAS	20.1.2021	Monika Krzyżanowska, Maciej Krzyżanowski, Przemysław Mujta
Mundi	22.1.2021	Jean-Baptiste Lavedrine
Sobloo	28.1.2021	Ludovic Auge, Wendy Carrara, Patryk Jaskula
WEkEO	4.1.2021	Peter Albert, Alain Arnaud
ONDA	5.1.2021	Franck Ranera

In addition, user experiences were collected during REDDCopernicus workshops and through discussions with users. Further, DIAS user interviews will be conducted during the last project year.

2.2.2 Analysis of Development Plans

DIAS systems and TEPs are supposed to be self-sustained, operating like commercial entities. Therefore, part of the plans may be commercial secrets not communicated publicly. Nevertheless, the development plans of each of the platforms were discussed in the DIAS interviews conducted in early 2021. All of the platforms were willing to provide at least some key points of their future development plans.

2.2.3 Desk Study on TEP and DIAS Capabilities and Status

The capabilities and status of the DIAS and TEP infrastructure were analysed through a desk study on the specifications and capabilities of the platforms. An extensive analysis of the offering and status of the DIAS systems was conducted in WP2 via a questionnaire survey to the platform operators. These information were updated and complemented by interviews of all the five DIAS operators (section 2.2.1).

In addition, a simple test of the functionality of the DIAS systems was made during the first project year and described in D12.1 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 1'. The test case of the first project year was downloading a Sentinel-1 image using the graphical user interface of the DIAS systems. In the second project year, a test was made to download a Sentinel-1 image from DIAS systems using their API (Application Programming Interface) to get an idea of the programming environment of the DIAS systems. The tests were made in July 2020 and reported in section 3.2.2.

A test of Internet speed between Europe and Africa was made during the first project year to illustrate the possible challenges in using European ICT platforms from developing countries.

3 Results of the Gap Analyses

3.1 Gaps Related to the Development of Copernicus Space Segment

3.1.1 General Considerations on Copernicus Space Segment Development

The Copernicus space component is planned to be expanded by new missions in the coming five years. After that, the Sentinel next-generation satellites are planned (around 2029). The Copernicus space component is augmented by the ESA Explorer satellites and a wide range of Copernicus contributing missions and other satellites.

The Sentinel next generation systems are in a very early state of planning, depending on the Sentinel system. For Sentinel-1, the following developments have been proposed (Zonno et al, 2019):

- full polarimetric capability,
- extended swath width,
- improved spatial resolution, and
- slightly improved temporal resolution.

For Sentinel-2, the following developments have been proposed:

- spatial resolution to 5 m, and
- a possible third satellite.

In the domain of optical high-resolution sensors, the Sentinel-2 system (10 m resolution, two satellites, 280 km swath) has introduced a major step forward compared to the situation before it (Landsat-8, 30 m resolution, one satellite, 200 km swath). Moving from 30 m pixels to 10 m pixels reduces the amount of mixed pixels, improves the location accuracy of boundaries of mapped features and enables a smaller minimum mapping unit. In forest areas, a 10 m pixel does not introduce significant single-tree texture except in forests with very large trees. A pixel spacing of 5 m introduces more variation in most types of old forest with large trees, even though mapping single trees is not feasible. If texture measures are used in image analysis algorithms, 5 m data may improve the separation of old forests from regeneration areas and younger forests, where the canopy top tends to be more uniform due to more trees per hectare.

Sentinel-2 type of optical imagery is the main data source in wall-to-wall mapping in most forest monitoring applications in REDD+ and sustainable forestry contexts. Clouds create gaps in coverage in optical satellite imagery especially in tropical areas and also in other cloud-plagued areas like the polar front zone. The probability to obtain cloud free (and cloud-shadow free) images at a certain time can be improved by increasing the number of satellites in the space segment, but not without limits. If an area is cloud covered every day in *e.g.* one month, no cloud free images are possible during that month regardless of the number of satellites.

VHR imagery is used as a substitute or as an augmenting element for ground reference data in many forest and land cover mapping tasks connected with REDD+ or sustainable forest management. The Copernicus Sentinel system does not currently produce VHR imagery, but VHR imagery is included in the Copernicus Contributing Missions offer (see Table 2). VHR imagery can also be purchased directly from commercial satellite operators. Recently, a new initiative funded by the Norwegian government was launched, providing free monthly mosaics of 4.7 m resolution data over the tropical belt (see Section 3.1.5).

In addition to cost issues, the acquisition policy of VHR imagery may cause gaps in the availability of VHR imagery. In the early days of VHR satellites like Ikonos, the operating policy was to acquire imagery only if there was an imaging order in place (and a paying customer) for some area. This led to a patchy image archive. Nowadays VHR imagery is acquired systematically at least by Pleiades and Planet Labs. A dedicated Copernicus VHR imager would allow Copernicus to decide on the acquisition policy.

3.1.2 L-Band and Longer Wavelength SAR Systems

There is a consensus within GFOI (Global Forest Observatory Initiative) that many forest monitoring products are mature using L-band SAR data but not mature using C-band SAR data (Baltzter *et al* 2013). The GFOI document 'Review of priority research & development topics' (Baltzter *et al* 2013) lists two forest map products (Forest/Non-Forest and Forest/Non-Forest change) as operational using L-band SAR (and optical) data and in research and development phase using C-band SAR data. The same GFOI document lists four forest map products (Forest stratification, All land use categories, Land use change between forests and other land uses) as pre-operational using L-band SAR data and in research and development phase using C-band SAR data. One forest map product (Near-real time forest change indicators) is listed in research and development phase for both L and C-band data (Baltzter *et al* 2013). Even though operational supply of suitable C-band SAR data was a limiting factor in 2013, many of the reasons for the superiority of L-band over C-band in forest and land cover applications stem from observation physics. Due to its longer wavelength, L-band is more sensitive to forest plant components and other land cover constituents and also less sensitive to disturbing effects like meteorological phenomena. L-band SAR is a needed data source to obtain data for many land cover and forest related EO products to augment optical products, especially in areas with persistent cloud cover like the equatorial belt and the polar front zone.

L-band SAR data are available from ALOS-2/PALSAR-2, but the basic operation scenario limits the dual-polarized acquisitions to one or two per year (in summer) and the number of fully polarimetric acquisitions to one per year (in spring). This limits the use of ALOS-2/PALSAR-2 data in forest change monitoring. L-band data are available also from the new Argentinian SAOCOM L-band SAR satellite, which has been in operation since 2018. SAOCOM 1-A was launched on 8.10.2018 and SAOCOM 1-B on 30.8.2020. Access to data catalogue is provided to registered users, but download is not included in the free registration. The data coverage varies from year to year. The best geolocation option is accurate to 70 m (Figure 1). The future acquisition plan and image acquisition frequency of SAOCOM is also unknown.

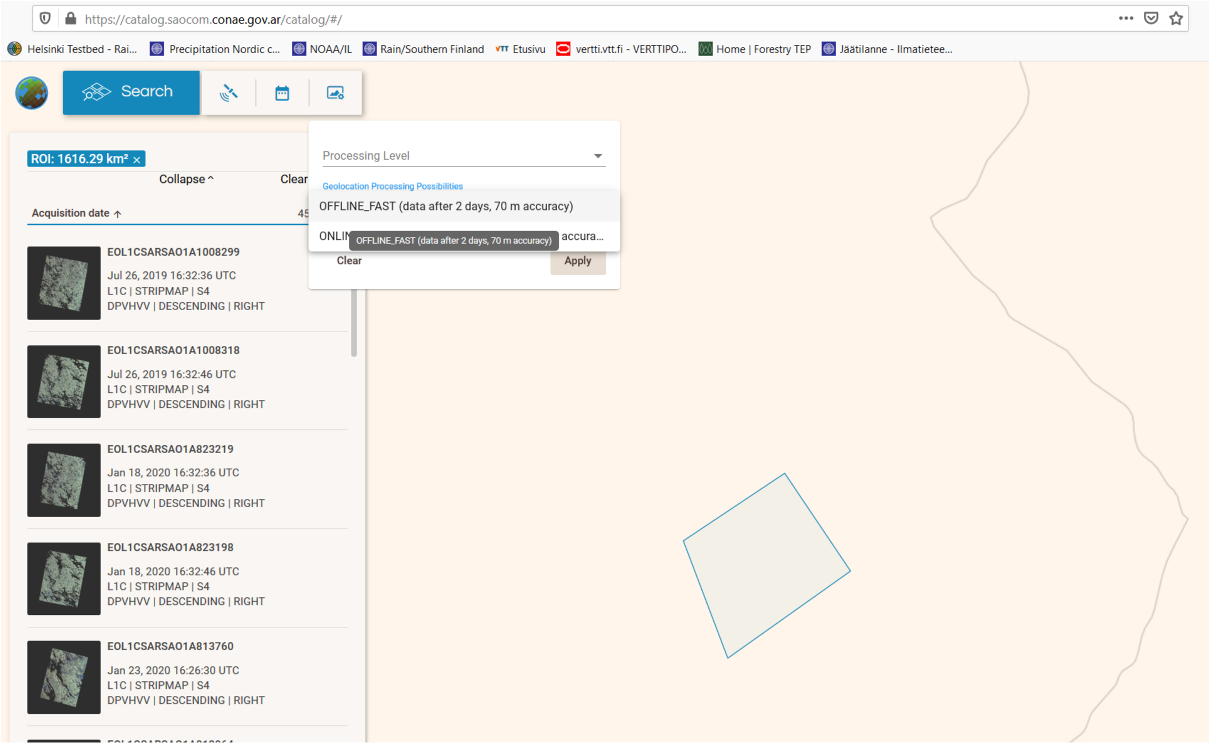

Figure 1: An example of SAOCOM catalogue.

The NISAR is an Indian-American satellite with dual-band SAR in L and S bands. The orbit repeat cycle is 12 days, and with both ascending and descending orbits NISAR is supposed to image a point on earth every 6 days. The data policy is open and free. The NISAR launch is planned in 2022 (https://nisar.jpl.nasa.gov/mission/quick-facts/). The swath of NISAR L-band SAR is 240 km in the sweepSAR mode. The resolution in dual-polarized mode is 8m by 12 m[11].

Other future planned L-band SAR systems include e.g. the German TanDEM-L.

Regarding Sentinel-1, Davidson *et al* 2018 state that "*the current Sentinel-1 SAR system should be incrementally switched to a combination of two or more C-band and two L-band SAR satellites*". Taking into account the performance of L-band in forest monitoring tasks as described by the GFOI document (Baltzter *et al* 2013) and research papers like Sirro *et al* (2018), the L-band component of the envisioned future Copernicus SAR system may even be more important than the current Sentinel-1 SAR system or its next-generation version.

ROSE-L (Radar Observation System for Europe in L-band) has been chosen as a candidate mission in Copernicus expansion (Davidson *et al* 2018). The mission requirements of ROSE-L include, among other things:

- The mission shall support quick successive collocated L-band SAR image acquisitions with Sentinel-1. The time interval between L-band and C-band acquisitions shall be 1 minute or less;
- The instantaneous coverage (as defined by ground swath) shall be sufficient to cover collocated Sentinel-1 acquisitions;
- Repeat coverage shall be less than 1 day (Arctic), 3 days (Europe) and 6 days (Global); and
- The mission and payload shall support resolutions equal to or higher than 50 m^2 (*e.g.* 5 x 10 m or similar).

[11] https://nisar.jpl.nasa.gov/files/nisar/NISAR_Science_Users_Handbook.pdf

These requirements mean that the ROSE-L system will likely be very similar to Sentinel-1 but operating in L-band. Unlike NISAR, which relies on a reflector type SAR anatenna, ROSE-L has a large (11 m by 3.6 m) phased-array antenna. The launch of ROSE-L is planned in 2028[12].

In addition to L band, the S band offers benefits over shorter wavelength X and C bands. This band (9.6 cm, Rosenqvist 1996) has not been available from civilian Earth Observation satellites since the soviet/Russian Almaz satellite in 1990'ies. NovaSAR-S is a technology demonstration mission designed to complement much larger, complex radar satellites with a smaller, lighter and more cost effective platform that delivers Earth observation Synthetic Aperture Radar imagery[13]. The satellite was constructed by Surrey Satellite Technology Ltd (SSTL, UK) and launched to space on 16.9.2018. CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Australia has launched an announcement-of-oportunity campaign for the data from this experimental satellite[14].

3.1.3 Hyperspectral, Thermal, and other Copernicus Candidate Missions

CHIME (Copernicus Hyperspectral Imaging Mission, Rast et al 2019) is a candidate hyperspectral imager mission in Copernicus expansion. Even though hyperspectral data were not explicitly mentioned in the REDDCopernicus stakeholder survey as a need for forest monitoring (D1.1 'Stakeholder and Requirements Assessment Report' and D2.1 'Workshop Report: Inventory of State-of-the-Art Technical Capacities in Europe for FM Capacities and Infrastructure'), species identification, monitoring forest health and ecosystem functions, and biodiversity could benefit from a sensor with high spectral resolution in the visible-IR spectrum.

CHIME will have a resolution requirement similar to Sentinel-2 (10–20 m) with a limit of 30 m. It will provide information on essential biodiversity variables, some of which are important for REDD+, *e.g.* taxonomic diversity, biomass, LAI, crown cover, vegetation height, productivity. However, forestry is not among the key application areas for CHIME. Most of the current results on hyperspectral mapping of forests come from airborne instruments with spatial resolution allowing for mapping single trees, indicating that spectral data can yield information on species composition, diversity, forest functioning and stress detection. Up to date, only two experimental civilian hyperspectral instrument with similar properties has been placed in orbit, EO-1/Hyperion and PRISMA with very limited spatial coverage. The number of studies on hyperspectral applications for forestry with CHIME-like data is hence low and no robust algorithms which could be implemented operationally exist: the size of the gap in forest mapping caused by no operational hyperspectral mission is not known exactly. The situation is likely to improve shortly because the Italian PRISMA hyperspectral imager was launched on 22.3.2019, and the German EnMAP is awaiting launch. PRISMA data are available for announcement-of-opportunity studies from the web site of ASI[15].

LSTM (Koetz *et al* 2019) is a candidate thermal imager mission in Copernicus expansion. Even though thermal image data did not come up as a need for forest monitoring (D1.1 'Stakeholder and Requirements Assessment Report' and D2.1 'Workshop Report: Inventory of State-of-the-Art Technical Capacities in Europe for FM Capacities and Infrastructure'), modelling of carbon and water circle connected with forest vegetation could benefit from a thermal imager.

CO2M is a candidate mission in Copernicus expansion. The objective of the CO2M mission is direct measurement of CO_2 concentration in the air. Its relation to REDD+ process or EO-based forest monitoring for sustainable forestry is unclear, at best.

---

[12] https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Contract_signed_for_new_Copernicus_ROSE-L_mission
[13] https://www.sstl.co.uk/media-hub/latest-news/2017/sstl-announces-novasar-s-data-deal-with-australia-
[14] https://research.csiro.au/cceo/novasar/
[15] http://prisma-i.it/index.php/en/

In addition to the three missions described above and the ROSE-L mission described in section 3.1.2, there are two other candidate missions in Copernicus expansion:

1. CIMR (Copernicus Imaging Microwave Radiometer) with a spatial resolution of 5 km, and
2. CRISTAL (a radar altimeter mission to determine the thickness of sea ice).

Need for these types of data did not come up in the stakeholder requirement analysis (D1.1 'Stakeholder and Requirements Assessment Report' and D2.1 'Workshop Report: Inventory of State-of-the-Art Technical Capacities in Europe for FM Capacities and Infrastructure').

3.1.4 Earth Explorers and New-Space Missions

The **Earth Explorer missions** of ESA[16] are research missions designed to address key scientific challenges identified by the Earth science community while demonstrating breakthrough technology in observing techniques. The explorer series has so far included in orbit:

1. GOCE, a gravity mission;
2. SMOS, Soil Moisture and Ocean Salinity mission (an L-band passive microwave radiometer with a spatial resolution of 35-50 km);
3. CryoSat, a sea ice thickness mission;
4. Swarm, a mission to measure Earth's magnetic field;
5. Aeolus, a wind measurement mission;

The planned Explorer missions include:

1. EarthCare, a cloud and aerosol mission;
2. BIOMASS, a forest biomass mission with P-band SAR;
3. FLEX, a mission to measure vegetation photosynthesis using chlorophyll fluorescence and imaging spectroscopy in the visible-to-near-infrared spectrum; and
4. FORUM, a mission to measure the radiation balance of Earth in far-infrared radiation.

The three candidates for the 10th explorer mission are:

1. Harmony (formerly Steroid, a companion satellite for Sentinel-1 for interferometry),
2. Daedalus (a mission concentrating on the upper atmosphere), and
3. G-Class (a geosynchronous SAR mission).

Of all the Explorer missions, the most important from the point of view of REDD+ and sustainable forestry monitoring is the BIOMASS[17] mission, which is planned to be launched around 2022. Biomass and biomass change maps were considered as useful or very useful by 85 percent of the consulted stakeholders (D1.1 'Stakeholder and Requirements Assessment Report') for the potential REDD+ service component. Only analysis-ready image mosaics as well as forest and land cover and change maps were more popular (87 and 87 percent, respectively).

Forest biomass is needed for assessing the carbon loss when forest is logged. Even though there are even global maps of biomass such as the ESA Climate Change initiative biomass map or the ESA GlobBiomass map (both described in D2.2 'Review Assessment for Forest Monitoring Capacity' and assigned the CALM level of 4 or 3, respectively) these products are far from perfect in terms of accuracy. The satellite sensors used for the wall-to-wall mapping in these products tend to saturate at a fairly low level of biomass (*e.g.* Rodriguez-Veiga *et al* 2019). The BIOMASS mission with its P-band SAR (Le

[16] http://www.esa.int/Applications/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/About_Earth_Explorers2

[17] https://www.esa.int/Applications/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Biomass

Toan *et al* 2011) is expected to bring a major improvement to biomass mapping capacity, despite its poor spatial resolution (50 m resolution for a 4-look image) and despite its limited deployment opportunities due to radio frequency allocation issues (Carreiras *et al* 2017).

The main mission objective of the BIOMASS mission - mapping forest biomass over extended areas - is supported by LiDAR instruments like the current ICESat-2, GEDI[18] and the planned (by JAXA, launch planned 2022) MOLI[19]. These space-borne instruments (unlike airborne LiDAR systems) measure the tree height in cloud free areas, but only for a small number of profiles (one for ICESat-2, two for MOLI, and 12 for GEDI) under the spacecraft - not imaging a swath like optical or radar imagers. The role of LiDAR instruments is to serve as auxiliary data in wall-to-wall biomass mapping with imaging instruments like the SAR sensor of the BIOMASS mission.

In addition to photosynthesis, the FLEX mission (expected to be launched in 2024) will map vegetation structure and, as a higher-level product, vegetation stress. It will provide very high spectral resolution (1 nm) data at relatively low spatial resolution (300 m). The mission can hence measure vegetation pigment content, but as the spatial resolution is much coarser than the useful limit for many practical applications (e.g., approx. 10 times coarser than the requirement for CHIME), it will not be able to fill the gap of a hyperspectral imager for diversity and forest function. Also, the studies carried out in preparation of FLEX have focused on unforested biomes and, likely, FLEX products will not contribute significantly to REDD+.

The two other planned Earth Observer missions - whose connection with forest monitoring is looser than that of BIOMASS and FLEX - are EarthCARE, which is planned to be launched in 2022 (https://www.esa.int/Applications/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/About_Earth_Explorers2) and FORUM, which is planned to be launched in 2026 (http://www.esa.int/Applications/Observing_the_Earth/A_new_satellite_to_understand_how_Earth_is_losing_its_cool).

The term **new space missions** is here used to refer to satellites developed and operated by new aerospace companies working independently of governments and traditional major aerospace companies. This group of satellite projects is very heterogeneous. Typical characteristics of satellites include small size (down to a few cubesat units - about 10 cm cube), relatively low cost, and sometimes relaxed practices in radiation harnessing. Some of the satellites can be considered as technology demonstrators while others aim at producing significant amounts of useful data. Some examples of new space missions include: the Finnish-Polish IcEye and the American Planet Labs.

IcEye[20], which was already mentioned in the first version of this deliverable (D12.1) has developed its functions and the satellite constellation. The company aims at a constellation of 18 satellites with a VHR SAR instrument. After the latest launch of 21.1.2021, there are up to eight working satellites in orbit. An IcEye satellite weighs less than 100 kg. IcEye sells SAR imagery commercially, and IcEye data have been available from the ESA Earthnet Third Party mission programme. IcEye has also sold or is planning to sell a satellite to the Brazilian government[21].

The American Capella launched their second X-band SAR satellite on 30.8.2020. They claim to have the highest resolution commercial SAR satellite with 50-cm resolution.[22]

The latest X-band SAR satellite is the StriX-α of the Japanese company Synspective. The satellite was launched on 15.12.2020, and the first image captured on 8.2.2021[23]. Synspective aims to build a constellation of six satellites by 2023 and 30 satellites by the late 2020s. The ground resolution is 1-3m, single polarized (VV). The swath width is more than 10-30km.

[18] https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/iss-gedi
[19] https://www.eorc.jaxa.jp/ALOS/kyoto/feb2019_kc25/pdf/2-12_KC25_MOLI_Mitsuhashi.pdf
[20] https://www.iceye.com/resources/satellite-missions
[21] https://nord.news/2021/01/12/the-sale-of-a-finnish-microsatellite-to-brazil-is-being-criticized/
[22] https://www.capellaspace.com/capella-unveils-worlds-highest-resolution-commercial-sar-imagery/
[23] https://synspective.com/news-press/first-image/

A further example of the new space segment is Planet Labs, which has developed into an established supplier of VHR optical imagery from a fleet of some 150 micro satellites and also into a Copernicus contributing mission (see Table 2 and D2.2 'Review Assessment for Forest Monitoring Capacity').

Most of the new space missions are in experimental phase and obtaining data for operational applications like REDD+ or sustainable monitoring is difficult. The technologies tried and demonstrated in these experimental missions may give indications about the direction of the development of satellite industry. Some of the new space missions may also develop into operational data suppliers like the Planet Labs case shows. Therefore, the development of new space missions is followed in the last version (D12.3) of this deliverable.

3.1.5 Tropical-Belt Very-High-Resolution Satellite Data – Monthly Mosaics

On 22 September 2020, it was announced that the first-ever global contract of very high-resolution satellite data was awarded by Norway's Ministry of Climate and Environment, and the data would be provided with universal access to support efforts to stop deforestation and save the world's tropical forest. Even though the resolution of these data are 4.7 m, we refer to these data as VHR data in this section because the Norway's Ministry of Climate and Environment uses the term "very high resolution". The Copernicus terminology sets the limit between "very high resolution" and "high resolution" at 4 m. Three initiatives were awarded; Kongsberg Satellite Services (KSAT), Planet and Airbus. This contract, valued at 405M NOK (approx. 37M EUR) should revolutionize the use of these data, which until now are only available often on request from the satellite data providers at high costs.

Currently high-resolution satellite data are, already available free-of-charge to view (but not to download) from platforms including Google Earth Engine and SEPAL. In some cases, downloaded data is required for detection of small forest changes using machine learning algorithms for example. Very-high-resolution imagery is essential for the calibration and validation of a number of satellite data products, including deforestation maps, and for this purpose, data from specific time-periods are required, particularly for the validation of near-real time products. Google Earth data is often used for validation of products, but the infrequent temporal resolution means it is not always fit for purpose. In addition, also issues with ortho-rectification which leads to shifts in the location of the data mean that for validation of high resolution products (i.e 10 m products based on Sentinel data), it cannot be easily used.

The contract will provide free monthly (September 2020 onwards) optical cloud free mosaics of the full tropical land mass, and historical data will be provided through a Bi-Annual archive (December 2015-August 2020).

The licensing terms are also beneficial as they allow everyone to access to the very-high-resolution satellite data, without restrictions on use and distribution. The open source nature of this product will facilitate uptake from wider audiences.

The contract has a duration of two years (until end of 2021) with an option for extension for a further two years (until end of 2023).

Monthly mosaics from August 2018-August 2020 are already available on Global Forest Watch, meaning users can already familiarize themselves with the data.

Table 4: Specifications of the High Resolution Satellite data

Characteristic	Specification
Resolution	4,7m x 4,7m
Bands	Visual 3-band (RGB)
Coverage	30 degrees North to 30 degrees South
Availability	Every month, plus every 6 months between December 2015 and December 2019
Duration	Until December 2021 with option for extension to December 2023
License	None

This dataset provides many opportunities in that it is open, available across the pan-tropics, is cloud free and has frequent time steps. However, some challenges regarding its use remain, including that it should be often used in conjunction with sampling strategies and uncertainty analysis which are complex. Although guidance is available on appropriate sampling strategies (GFOI 2020), methods are not always correctly used. Although the time-steps are frequent (monthly), this may not be sufficient for validation of NRT (forest change alerting) data. In order for interventions to address illegal logging activities – one of the uses of NRT alerting data – information needs to be available at high confidence, and quickly. Where costly field visits are planned, visual interpretation of alerting data to confirm alerts could be helpful, and for this, more frequent information than monthly mosaics would be required. Another challenge, there are large volumes of data which can potentially be used, and this can lead to processing challenges for large area analyses. In many developing countries, downloading data is hampered by the quality of the internet connection. Opportunities to use these datasets in cloud computing could aid uptake. Data are also only provided for tropical land masses, and other areas currently lack free and open very-high-resolution data. Data continuity is another challenge, in that data provision has only been assured until 2021/2023 at present.

This has reached a CALM level of 5: Specific Planning in Relevant Environment. CALM is a system for describing technical readiness levels for tropical EO application, which is described in an annex of deliverable D10.2 'Compendium of Research and Development Needs for Implementation of Copernicus REDD+ Capacity Version 2'. Although there are no use cases identified, large-area, monthly mosaics are already available. Guidance documentation on their use is also missing, however, experiences of use of similar products is widespread. More information can be found in the annex of D10.2 'Compendium of Research and Development Needs for Implementation of Copernicus REDD+ Capacity Version 2'.

3.1.6 Technical Requirements for Future Optical Missions to Sufficient Data Quality for Operational Forest Monitoring

For wall-to-wall mapping, a system like Sentinel-2 is adequate. Possible improvements include slightly better resolution (for a smaller minimum mapping unit or for more pixels in a minimum mapping unit for better reliability). The clouds are always a problem for optical remote sensing. Better utilization of image acquisition opportunities in cloudy regions asks for more satellites. The current orbit configuration of Sentinel-2 repeats the exact same orbit every 12 days. A fleet of 12 satellites would generate an image acquisition attempt every day, but this many satellites is most likely beyond financial limits of the Copernicus space segment.

VHR imagery is needed for visual interpretation of reference data. Whether the VHR satellite system is part of Copernicus space segment or not, the following properties are desirable:

- 0-cost (free and open data like Copernicus Sentinels),
- systematic acquisition so that the user is not required to pre-order image acquisition,
- bands should include at least red, green, blue, and NIR; 1.6 µm IR and the red edge bands are desirable,
- spatial resolution better than 1 m, preferably better than 0.5 m, and
- as the use is mainly visual interpretation, no need for accurate atmospheric corrections so no 2.2 µm band is required.

The provision of the free 4.7 m spatial resolution data discussed in the previous section only partially satisfies the need for VHR imagery for the tropical belt. Although the 4.7 m resolution may be sufficient for some types of reference data (e.g. for deforestation), it may be insufficient for other types of analysis (e.g. forest degradation).

An imaging spectrometer with a spatial resolution comparable to current Sentinel-2 is also desirable, especially for forest photosynthetic productivity, biodiversity and forest health mapping (detecting abiotic and biotic stress). Much research and development is needed before these applications reach a concrete, operational level for wide acceptance of stakeholders in the sustainable forestry and REDD+ communities.

3.2 Gaps Related to the Development of Copernicus ICT Infrastructure

3.2.1 Interview Survey of DIAS Providers

3.2.1.1 General Findings from DIAS Interviews

All five DIAS systems are in operation.

The approach in accessing Copernicus Sentinel data varies a lot between DIAS systems (Table 5). Some DIAS systems have a large archive of Sentinel data on discs connected directly to the processing computers of the DIAS system. These data are immediately available for processing without downloading from cloud archives somewhere else on the Internet. Some DIAS systems have a fairly short local archive of latest Sentinel data. Images outside this local cache of latest Sentinel imagery must be copied over network connections from some cloud archives, which causes some delays in processing. The largest on-line archive of Sentinel-1 and Sentinel-2 data is in CREODIAS (full global archive since the beginning of Sentinel-1 and Sentinel-2 missions). WEkEO does not have DIAS-local on-line archive of Sentinel-1 and Sentinel-2 data at all, but the Sentinel images are always fetched from a cloud archive.

Table 5. Sentinel-1 and Sentinel-2 coverage in DIAS-local archives.

DIAS	Sentinel-2 (at least level L1C) and Sentinel-1 GRD archive coverage
CREODIAS	Full global archive
MUNDI	3 years in Europe, 1 year elsewhere
Sobloo	9 months global archive
ONDA	1 month global archive
WEkEO	None (always copied from Cloud Ferro archive)

Considering a hypothetical EO case of compiling monthly composites of Sentinel-2 Level 1C images in Africa for five years 2016-2020, the DIAS systems are very different. In CREODIAS, all needed input data are available on the disc system of the DIAS. In Mundi, the data of 2020 is mostly available in the archive of the DIAS, but data for years 2016-2019 must be fetched from some external archives. In Sobloo, about half of the 2020 data are available (in March 2021), and the data for the remaining 4.5 years must be fetched form some external archives. In ONDA, no data are available on-line, but all data must be fetched from the cloud archive of ONDA DIAS. Likewise in WEkEO, all data must be fetched from the archive maintained by Cloud Ferro (Poland). In EO applications aiming at a single, limited time like e.g. a chosen summer period, the differences in data transfer volumes between DIAS systems are naturally smaller.

Downloading Copernicus Sentinel imagery has been implemented in all DIAS systems, and this download service is free of charge. The relatively small amount of paying customers of the DIAS systems does not generate high enough revenue to fund large on-line archives of Sentinel data for this type of public-benefit services. The free and open access to all Copernicus Sentinel data - which is the data policy of the Copernicus Sentinel satellite system - must be organized from other archives than those on the DIAS systems - unless public funding is available to DIAS operators for this purpose. Currently the free and open access to Sentinel imagery is via the open-access hub (https://scihub.copernicus.eu/), which is under heavy load of download traffic. Recent Sentinel images can be downloaded from the open-access hub with patience. Older Sentinel images have been moved to the long-term archive. A user can request imagery from the long-term archive, but only one image at a time. As fetching an image from the long-term archive takes about half a day, this mechanism is not suited for projects where long time-series (and therefore older data) are needed.

For many users, the workflow of EO data processing is still based on downloading satellite imagery to the local computer system of the user. The recognition of the opportunity and benefits of processing EO data in cloud facilities like DIAS systems has been slower than expected, and many users still prefer to stick to their old ways of working. This has been one of the major challenges in marketing services of the DIAS systems. Now the situation seems to be finally changing and more and more users of EO data are moving to cloud processing on DIAS systems. The DIAS operators are supporting this development by offering services that facilitate users' easy onboarding to cloud processing. These services include e.g. high-performance computing and Jupyter notebook environments, in addition to additional datasets like VHR imagery. Overall, the aim is to provide the users with services that meet their requirements technically, thematically and geographically, and support moving their operations to cloud environment.

The following six sections address the six topics discussed in the interviews.

3.2.1.2 Users of DIAS Systems

The interviews were started with a general question about user statistics of the DIAS system. The question asked to the DIAS providers (to solicit views and comments on user statistics and related aspects) was "Could you provide some kind of generalized (or even better, detailed) user/usage statistics. Or is this information considered as commercial secrets ? How many registered users? Active users? Download volumes? etc.". All DIAS operators provided some kind of overview of the user statistics, in varying forms. However, the user number statistics are not reported here because (as Sobloo rightly put it) "*The user numbers are not comparable between DIAS systems because the criteria to count users differ from DIAS to DIAS*". Instead, general findings regarding the user base of the DIAS platforms are highlighted.

All DIAS platforms have over 1000 registered users, including users from public, private and educational sectors. All DIAS providers were of the opinion that the users of their DIAS system were mostly satisfied with the services they obtained from the DIAS. As ONDA put it: "*There have been almost no stops in contracts, but the users renew their contracts when the previous ends. This indicates that the users are happy with ONDA DIAS. The market is getting confident in DIAS and cloud processing*". Most DIAS providers also considered that the users had become more and more efficient and comfortable in using the DIAS systems. Mundi highlighted that: "*During the lifetime of Mundi, users have learned how to use cloud effectively - they have moved from the download-and-local processing mentality towards effective processing on Mundi*".

There were some differences in how the DIAS providers aim to enlarge their user bases. All DIAS providers emphasized the necessity to provide services that meet the needs of the users. For example, Sobloo raised their potential of providing "*cloud coaching in the context of EO, for customers needs*". In addition, CREODIAS, who has a competitive advantage of having a large on-line archive of Sentinel and other data (Table 5), mentioned ways such as "*a public price list, which is designed to be competitive against the prices of other IaaS provider including AWS or other DIASes*" and "t*he CREODIAS team works hard to be able to follow a maximum data scenario (at least current EO data availability with possible extension to all Copercnius data online)*".

Overall, the DIAS operators agreed that there is a large potential user base that is slowly engaging into cloud based EO processing and analysis. This provides a solid based for continued increase in the number of DIAS users. At the same time, the competition over users is strong, not only between the DIAS systems, but also between DIAS and other alternatives (e.g. non-European commercial providers, and the various application platforms designed to provide cloud based EP services, like the ESA TEPs).

3.2.1.3 Sentinel Archives

The question to provoke comments and views was: "The current status of Copernicus Sentinel archives regarding the on-line/off-line status and mechanisms to obtain off-line products now that obtaining off-line products via EU/open-access hub is prohibitively clumsy (or practically impossible for larger projects)".

As shown in Table 5, the approach on the extent of Copernicus Sentinel data that is kept on-line within the DIAS varies a lot between DIAS systems. CREODIAS has the largest archive. In addition to the complete global archive of Sentinel-1 GRD products, CREODIAS has a complete archive of Sentinel-1 SLC products over Europe, and elsewhere a running archive of last six months. All on-line data are unzipped (uncompressed) and accessible immediately: "*As this is an online storage access times are of* *ms orders. Single session data delivery bandwidth is at the level of 150 MBytes/s*". For comparison, in the VTT office LAN (Local Area Network) data transfer rates between a laptop computer and the disk servers of the LAN are of the order of 70 Mbytes/s, so the internal network solutions of CREODIAS seem to be fast.

With this level of DIAS-internal on-line Sentinel archive, storing of the data is a resource-demanding task: "*Currently there is nearly 21 PB of online EO data. The repository grows by more than 20 TB daily.*" CREODIAS estimated the cost of keeping up with the growing data volumes based on their price list, which is just one cost estimation basis among several approaches to cost estimation: "*The cost of repository build-up can be approximated with the use of a public CREODIAS price list – yearly cost for 10 PB increase can be approximated at around 1,4 mln Euro*". This is 140 €/Terabyte. Disc drives can be purchased today at 31… 35 €/Terabyte. Adding disc space to a large storage system requires other components in addition to the disc drives, though.

MUNDI holds the second-largest on-line archive of Sentinel data: "*Regarding Sentinel 1 and 2, Mundi has on-line data over the latest 3 years in Europe and over 1 year elsewhere. There are about 8500 000 products on-line. A user can request off-line products, and the data will appear in a matter of hours (or tens of minutes, depending on the data type)*". Like all other DIAS platforms, also Mundi raised the uncertainty of the financial support from ESA for Sentinel data storage beyond 2021, and the effects of potential termination of the support. All DIAS operators would need to re-evaluate their Sentinel storage strategy. Long term online storage currently forms the largest cost of the platforms.

Sobloo has the third-largest online archive of Sentinel data. They have made an observation that: "*Sentinel data over the past 9 month represent more than 90% of the data requested by users*". This has encouraged them to adapt the size of the rolling archive accordingly: "*Sobloo DIAS keeps the latest nine months of every sensor on-line (S1, S2, S3, S5P …). For older (non warm) data, users' download requests are forwarded to ESA hub. The Sobloo quota on ESA hub is divided between downloading recent Sentinel data to the on-line storage of Sobloo DIAS and forwarded download requests of users*".

ONDA has also monitored image request, and resulted in using a one month cut-off date between data storage methods: "*Sentinel and other satellite data are split between on-line and off-line storage in ONDA DIAS. On-line products are directly available. Off-line (in a cloud archive) is a cheaper to store than on-site storage. Off-line products are available in around 10 min from the request. ONDA DIAS has noticed that satellite image products are requested mostly during one month from the acquisition. Some requests come also after one month, but much less than during the first month*".

WEkEO counts on high-speed network connections: "*A strength of WEkEO DIAS is the continuity of data from production to users. Data connections within the system (between archives or storages) are mainly with high speed optical fibre connections. The individual Data Processing Infrastructures (DPI) are interconnected with 10Gbps connection links*". The archive of Sentinel-1 and Sentinel-2 data is outsourced: "*The data archive of Sentinel-1 and Sentinel-2 data is the currently the same as in CREODIAS. The access to Sentinel-1 and Sentinel-2 is arranged by an agreement with Cloud Ferro (via Thales Alenia)*".

3.2.1.4 Major Improvements since 2019, Extra Features

The question to provoke comments and views was: "Improvements in the DIAS functionality since the EARSC or WP 2 survey in 2019 - new features and functionality, features not covered in the EARSC or WP 2 survey".

Three themes rose up in the new developments among DIAS systems:

1. High-performance computing (HPC and the use of Graphical processing Units (GPU)
2. Commercial VHR imagery, and
3. Jupyter notebooks.

CREODIAS mentions as a component in IaaS (Infrastructure as a Service): "*New VM flavours (e.g., of virtual machines with multi-GPUs)*". Mundi lists as a future development goal: "*Making Processing-as-a-Service a key service including HPC (High Performance Computing) functionality and services based on the HPC experience of Atos accessible to users of MUNDI*". Sobloo emphasizes machine learning: "*Sobloo offers some machine learning services through the cloud offer. This point to be put more in the forefront in 2021*". ONDA lists as a development target: "*Also, integration of HPC (High Performance Computing) and GPU (Graphical processing Unit) facilities to ONDA DIAS is important*". WEkEO lists HPC as one of its advantages: "*WEkEO DIAS offers access to HPC (High Performance Computing) resources provided by EODC (the Austrian Earth Observation Data Centre for Water Resources Monitoring)*". This development is natural (and welcomed) due to the high computational cost of many large data processing tasks, like time series analyses.

Another key development feature is the VHR imagery. "*CREODIAS offers the opportunity to buy commercial VHR data from 3 satellite systems (KazEOSat, Jilin-1, KOMPSAT)*". Mundi mentions as planned new data type: "*VHR satellite images from commercial partners*". Sobloo highlights the Airbus analytics platform One Atlas as a source of VHR data: "*Sobloo DIAS is about to offer a unified delivery point where you can also find the data purchased from OneAtlas (ie Very High Resolution)*", obviously including at least Pleiades data. ONDA has a long list of VHR satellite imagery in their offering: "*Additional data offer by ONDA includes commercial VHR data (Deimos, Kompsat, Maxar [GeoEye, WorldView and many other VHR satellites])*".

The third major direction of development is the provision of Jupyter notebooks for user friendly implementation and running of processing scripts in the DIAS platforms. Free Jupyter notebooks play an important role in the WEkEO GUI (Graphical user Interface): "*A speciality of WEkEO are free Jypyter notebooks. A notebook has one CPU and 2 GB of RAM (these are planned to be larger in future). The Jupyter notebooks operate on the WEkEO infrastructure and can be accessed by the users in the WEkEO GUI*". Jupyter notebooks are also offered by ONDA: "*ONDA has also developed the CLEOPE (CLoud Earth Observation Processing Environment) service. Python-3 based Jupyter notebooks are used for processing, analysing, and visualisation of EO data. … A version of Jupyter notebook (with very limited computing resources) is available to registered user for free upon request. Jupyter notebooks with better computing resources can be rented for a monthly fee*". Jupyter notebooks were integrated also to Mundi DIAS: "*The improvements in 2020 included, among other things, ESA RACE data integration and NoR (Network of Resources) integration, elasticity of Jupyter notebooks…*". Jupyter is also included in CREODIAS who highlights that: "*For the scientific users there is growing library of the tools and scripts in CREODIAS Jupyter Hub*".

In addition to the common themes described above, the new development included some more characteristic elements of DIAS systems. Mundi emphasized the significance of the used cloud infrastructure: "*Not only MUNDI platform evolves, but also the underlying cloud infrastructure evolves, which improves the user experience and functionality of MUNDI*". Sobloo emphasized the role of complementing platforms: "*On the intelligence side, there is another platform called One Atlas, an analytics platform. Sobloo DIAS and the One Atlas together form a unified delivery platform for all Airbus services*". ONDA highlighted their education programme and explained that: "*ONDA for education programme was set up in 2020. It is dedicated to the educational users. ONDA for education helps to democratize the use of Sentinel data. A set of virtual machines and tailored trainings are provided in the ONDA for education programme. Training sessions are organized as webinars or face-to-face*". WEkEO emphasized the development of network connection speed: "*Recent focus on improvements has been on improving the connection speed between the Data Processing Infrastructures (DPI)*".

3.2.1.5 Opinions on the Development of DIAS Network

The question to provoke comments and views was: "Opinions how the DIAS system/network should be developed to ensure sustainability for providers and optimize user experience - uniform DIAS interface ? - should all Sentinel products be available on-line ? (what level products ?) - …". The objective of this question was to give the interviewees the opportunity express their - partly subjective - opinions on the role of DIAS systems.

CREODIAS elaborated on the roles of users and funding: "*For the operation and development of a DIAS system, an "anchor tenant" is important. According to Wikipedia, an anchor tenant in a shopping mall is a store that is given large discounts on rent in exchange for signing long-term leases in order to provide steady cash flows for the mall owners. For instance, in case of Amazon, Google, Microsoft,* *they all have a kind of anchor tenant within their own company. The anchor tenant could be linked to the delivery of data. In case of DIAS systems, mixture of public, long-term funding (anchor tenancy) and private users would be optimal. Public funding would support e.g., provision of full online Sentinel archives.*".

Mundi took up the uniform DIAS interface theme: "*Uniform DIAS interface in terms of API is not needed. Basically all DIAS systems conform to same standards via the open-source software components used. The way things are implemented in Mundi DIAS is a competitive advantage for Mundi DIAS.*".

Sobloo discussed the role of the DIAS a bit wider: "*Some streamlining of the DIAS system would be a good thing. Five DIAS systems is confusing to users. Different approaches are needed, but five DIAS systems is confusing. Sobloo is focusing on providing valuable advices and human support to the users to help them understand and efficiently assess what they really need to do to move to cloud and DIAS. It's not just data and cloud. Also, simplifying for end users access and use of EO data (for example with Sobloo desktop) is a key driver*.".

ONDA emphasized the continuity of services from the point of view of customers: "*The mission of DIAS systems should be defined clearly. There should be continuity of the work done so far. There is confidence on the market on ONDA DIAS and on DIAS systems in general. This should not be endangered. Users' investments are important. Some users invest more than 10 000 € and still moving to higher levels. Most of the customers were initially signing contracts of less than 6 months, now 12 months is common. There is also an increase of contracts that are longer than 1 year*.".

WEkEO emphasized the division between public and commercial services: "*WEkEO does not see themselves as a purely commercial DIAS, but as providers of open and free access to Copernicus data, giving room for further commercial exploitation. WEkEO wants to promote the uptake of the data by the users. The key is to offer the packet of Copernicus data and processing services together, as a public service.*".

3.2.1.6 Advantages of DIAS-X

The question to provoke comments and views was: "What are the advantages of DIAS-X (are you happy with it, is it user-friendly, is it developer-friendly, is it cost-effective) ?". The following excerpts from the responses were selected so that they represent typical advantages and so that they are understandable without lengthy technical explanations.

A major advantage of CREODIAS is the large on-line archive of Sentinel data: "*In CREODIAS, all data and products are on-line in disc storage (no tape robots used for less-often needed data) and uncompressed (no need to unzip data). There is no need to copy data to local (user) storage for processing, but data can be accessed from a virtual machine via network-mounted filesystems or object (s3 compatible) interface. The online available data is extremely extensive with some 21 PB of data available today and quickly growing*".

Scalability and customizability of virtual machines is also seen as an advantage of CREODIAS: "*User applications can be easily on-boarded and are easily scalable in CREODIAS. They can also be chained into more complicated processing systems. The user has root access to virtual machines, the user can install all needed application programs on the virtual machine*".

Documentation and user support are also listed as advantages of CREODIAS: "*The documentation of finder and other CREODIAS features is clear and descriptive. The CREODIAS user support is highly appreciated by users.*".

Mundi has several features and technical aspects of implementation that Mundi considers as advantages of the Mundi DIAS: "*Mundi is based on micro services architecture and is relatively simple to upgrade. Many products are also available as cloud optimized geotiff (CoG). The Mundi platform benefits from the development of the underlying cloud platform (Open Telekom)*".

Sobloo considers the Airbus ecosystem and good user support as advantages of the Sobloo DIAS: "*A key advantage of Sobloo DIAS is the whole Airbus ecosystem, which is connected with Sobloo DIAS. This ecosystem includes OneAtlas (commercial VHR data) and UP42 (analytics, off the shelf compute* *services, developer community centered). Customer services combined with easy access to cloud and data is another advantage. Customers are satisfied and willing to continue their experience with Sobloo. A DIAS system has to provide a lot of support to customers. In Sobloo DIAS, one central theme in this support is 'cloud coaching in the context of EO, for customers needs'*".

Flexibility of the system and good user support are central advantages of the ONDA DIAS: "*Flexibility of the ONDA platform is an advantage. The ticketing system in technical support is another advantage. Each customer is followed by a customer account manager (to build confidence and to guarantee that problems of the customer are solved)*".

WEkEO emphasizes the benefits of its distributed-archive approach and its public-private nature: "*WEkEO has broad base and direct integration of consortium partners. Data ownership is clear. Users have access to data experts through the WEkEO help desk. WEkEO does not duplicate data in cloud systems (less waste of resources). Instead, e.g. real-time Copernicus monitoring products are accessed from the servers of the producers of those products. WEkEO offers free Jupyter notebooks, which are used in training. This helps a lot user uptake. WEkEO DIAS introduces no latency in near real-time Copernicus products. The moment the products are ready, they are available in WEkEO. WEkEO is a public-private DIAS. It ensures public data access and enables commercial services*".

3.2.1.7 Disadvantages of DIAS-X

The question to provoke comments and views was: "What are the disadvantages of DIAS-X ? How it should be improved? - in terms of data offer ? - in terms of usability of GUI services ? - in terms of the developer services or API ?". In the disadvantage theme, many DIAS providers took up the conservative attitudes of earth observation data users to prefer downloading and local processing as the first priority and the cloud approach only as a backup approach, which was seen as a disadvantage of DIAS systems. The implementation-related disadvantages that were discussed seemed minor to interviewers, especially because they were planned to be corrected in future. Therefore, these implementation-related disadvantages are not emphasized in the following citations.

CREODIAS: "*CREODIAS is affected by the attitudes of users. Many users consider downloading Copernicus Sentinel data and local processing as the preferred way to proceed. Communication to users about the benefits of cloud processing on the CREODIAS platform is a challenge*".

Mundi took up the competition issues between a truly commercial European DIAS and publicly funded platforms or platforms connected to other business branches of big American companies: "*The competition situation of Mundi includes overseas competitors like Amazon AWS, Google, and Microsoft Azure as well as publicly funded platforms like Code-DE (Copernicus Data and Exploitation Platform Germany), PEPS (the French Sentinel Products Exploitation Platform), EODC (the Austrian Earth Observation Data Centre for Water Resources Monitoring) …*".

Sobloo also took up the users' conservative attitudes to cloud processing: "*The appetite for cloud services was over-estimated in 2017 when DIAS tenders were submitted. Sobloo DIAS has helped customers to understand EO cloud processing. Move to cloud processing has been bigger threshold than expected (this is not typical to only Sobloo, but a general lesson learnt)*".

ONDA also talks about the customers' way of working: "*DIAS system should be deeply rooted in the way customers work. The reliability and capabilities of the ONDA DIAS, and communicating this with customers is a continuous effort. For this, ONDA created a role of account manager to establish a relationship with customers, trying to meet their requirements and aiming at excellence in this*".

WEkEO pointed out the need of fast communication in their distributed-archive approach: "*In the distributed-archive architecture of WEkEO, fast telecommunication lines are needed. This is a prerequisite for user friendly harmonized data access. The cost is probably still lower than having duplicated data sources*". WEkEO also mentioned that "*Currently WEkEO cannot rely on ESA hubs for Sentinel data*".

3.2.1.8 Ideal DIAS systems

The question to provoke comments and views was: “What is your view on the development of DIAS systems on the European level ? How should the DIAS systems be organized and funded in an ideal world ?”

CREODIAS emphasizes the European aspect of DIAS: “*Europe should have European ICT infrastructure and knowhow. European institutions should avoid buying ICT services from non-European providers. Mixture of public funding and paying customers would be an optimal solution. More than one DIAS would be optimal to allow healthy competition*”.

Mundi is concerned with the competition between commercial and publicly funded operators in the same market: “*There should be less competition with publicly funded platforms. The situation is difficult for commercial entities if there are publicly funded competitors in the same market. Four (commercial) DIAS systems is too many. It is too difficult for users to understand and see the differences between DIAS systems and the characteristics of each of them. The DIAS systems should be hosted, operated and managed for the European market*”.

Sobloo would like to see an efficient and fast-connected archive system of Sentinel data operated and publicly funded outside the DIAS systems: “*Storage is a key issue. Data will need to be stored with efficient access. For Copernicus Sentinel data there should be an efficient central archive operated by ESA, which would back up the smaller on-line archives of DIAS systems. The access to this central archive should be fast enough not to cause unnecessary delay or negative effects on the user experience of the DIAS systems. Separating storage issues and cost from services and market-place: this would allow DIAS to concentrate on mission to foster the use of Copernicus data by start-ups, big companies, labs and institution, business uptake*”.

ONDA also sees the need for public funding in the DIAS world: “*Even though most of the customers are from the industrial world, most of funding is from projects funded with public money. Industry has typically small contracts. Public ITTs are needed to maintain the service. DIAS should be part of the Copernicus data storage and access system. The Copernicus Sentinel ground segment should also utilize cloud services of the DIAS systems. There is still a lot of unused potential for expanding cloud processing approaches on the user side. Thus, DIAS should also target the downstream market*”.

ONDA also sees the satellite image offering to grow and wants to play a part in its marketing to the users: “*The prices of satellite imagery are expected to go down and the offering of free satellite imagery is expected to grow and even extend to VHR imagery. This will enable new applications and EO services. ONDA (and other DIAS systems) should be part of that process, offering downstream services to customers. Overall, the DIAS network should boost the usage of data and downstream applications*”.

WEkEO considers the data archival and distribution to belong to the publicly funded part of the EO ecosystem: “*ESA approach of merging free and open data access with commercial service can create some confusion. It is very important to have a public part securing free data access and to give support to European providers to create business on that. The commercial part of DIAS systems cannot generate enough revenue from the cloud services to fund the resources needed to provide free access to all Copernicus Sentinel data and to all Copernicus services products for all free of a DIAS system. Public money should be focused on the public data part (archive of all Copernicus data with free access)*”.

WEkEO also discussed the roles of DIAS or the definition of a DIAS in relation to the cloud industry: “*No DIAS based on the merging of free and paying services is actually needed. But the cloud access to data is needed and cloud paying resources for processing too. It is essential to secure long term continuity and free access to data and services from Copernicus core products with public money. Other functionalities may be built on top of this, typically as commercial services provided by the European cloud industry*”.

3.2.2 Test on Accessing Copernicus DIAS Systems

In the first version of this deliverable (D12.1 - Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 1), a short test was made downloading a selected Sentinel-1 image from all five DIAS systems using their tools in a graphical user interface (GUI). It was stated in D12.1 that to properly assess the capacities and gaps of the DIAS systems for REDD+ and other forest monitoring services, test with downloading Copernicus Sentinel images via GUI tools is not sufficient. A more comprehensive test would include:

1. renting one or more virtual servers from the DIAS systems
2. specification of a typical but small application case or a smaller specific part of an application
3. implementing the chosen sample application case on each DIAS using a suitable programming/scripting language (or a suite of programming/scripting languages) and the application programming interface of the DIAS.

It was also stated in D12.1 that testing the DIAS systems on the level described above goes beyond the scope of the REDDCopernicus project. No resources were planned for the renting cost of DIAS resources when planning the REDDCopernicus project. Even though a proper testing of DIAS systems via renting virtual machines is excluded, a small test was made in July 2020 to familiarize with the programming interfaces of DIAS systems. This was made by developing small program fragments for downloading a chosen Sentinel-2 image (S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025) using the Application Programming Interface (API) of the DIAS systems. The tests were made between 9.7.2020 and 31.7.2020.

The downloading of images from DIAS systems is a two-phase process. In the first phase, a catalogue search is made using geographic, temporal, and other search criteria. This search gives as a result an excerpt of the image catalogue of the DIAS system in question, which also includes a download code that specifies the exact location of the image product within the disk (or tape) storage structure of the DIAS in question. Image catalogue search can be made without authentication to the DIAS except in WEkEO DIAS. Image downloading always requires an authentication. The authentication method is in four DIAS systems some kind of authentication token (a computer-generated character string) that can only be obtained using the user name and password of the DIAS in question. ONDA DIAS relies on direct use of username and password in image download. The implementation details of the catalogue search and image downloading vary widely between DIAS systems.

The Image catalogue and download API in all five DIAS systems is based on the REST (Representational State Transfer) protocol. There are wide differences in the REST API between DIAS systems. No two DIAS systems share the same API. Four of the DIAS systems have implemented the REST API in such a way that both catalogue search and image download can be made in a synchronous way with GET requests *i.e.* the requested item is returned as a response message to the GET request. The API of the WEkEO DIAS on the other hand employs both POST and GET requests. Image catalogue search and image download preparation are initiated by a POST request. The catalogue/download program of the user must then poll the DIAS system to see that the request has been successfully completed. Only then can it send a GET request to obtain the catalogue excerpt or the image dataset.

The program fragments to test image download from DIAS systems were programmed in C language on a Linux platform (The WSL [Windows System for Linux] system on a Windows-10 computer). The Linux environment was chosen to alleviate problems escaping[24] special character in commands of auxiliary programs. The API requests were made using wget and curl auxiliary programs. Other helper programs included xmllint (adding new-line characters to XML files) and 7z (for zipping a Sentinel-2 product structure including several directories).

[24] Escaping is a computer term which means prefixing certain characters in a text string so that a command line interpreter does not interpret these characters as their control characters possibly removing them from the string before feeding the string into a client program.

3.2.2.1 CREODIAS

The image catalogue and download API of CREODIAS is not the easiest to find and follow. On the other hand, the catalogue GUI of CREODIAS shows the query commands which can be then tailored for use in API-based searches.

An image catalogue excerpt can be made with a command like (as documented at `https://creodias.eu/eo-data-finder-api-manual`):

```
wget -O -
"https://finder.creodias.eu/resto/api/collections/Sentinel2/search.atom?_pretty=tru
e&maxRecords=10&startDate=2020-06-15T00:00:00Z&completionDate=2020-06-
15T23:59:59Z&cloudCover=[0,20]&processingLevel=LEVEL1C&sortParam=startDate&sortOrde
r=descending&status=all&geometry=POLYGON((29.89687075995382+62.82315213420844,30.11
219748355609+62.82769092263334,30.10888476473144+62.68666243356961,29.8935580411291
7+62.68970240185408,29.89687075995382+62.82315213420844))&dataset=ESA-DATASET" >
S2catalogueTest.xml
```

A small program displays the catalogue excerpt as pair of image name and download code:

```
yrcatlist_creodias S2catalogueTest.xml
```

The above command displays:

```
Filename: S2catalogueTest.xml
2 images:
1: S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025 78000914-511a-5fce-
bd9c-0068fd7d8e87
2: S2A_MSIL1C_20200615T093041_N0209_R136_T36VUQ_20200615T110025 e431cc4e-7eb8-51cc-
b440-828eac174816
```

A small program can then be used to download an image:

```
yrgetimg_creodias S2A_MSIL1C_20200615T093041_N0209_R136_T36VUQ_20200615T110025 \
e431cc4e-7eb8-51cc-b440-828eac17 user pw
```

The program yrgetimg_creodias does the following:

1. obtains an authentication token using program curl, the username, and password as documented in section “Authentication” at `https://finder.creodias.eu/api/doc/`
2. downloads an image as a .zip file using program wget as documented at: `https://creodias.eu/-/how-to-download-eodata-products-using-eofinder-api-?redirect=https%3A%2F%2Fcreodias.eu%2Fknowledgebase%3Fp_p_id%3D3%26p_p_lifecycle%3D0%26p_p_state%3Dmaximized%26p_p_mode%3Dview%26_3_redirect%3D%252Fknowledgebase%253Fp_p_id%253D3%2526p_p_lifecycle%253D0%2526p_p_state%253Dnormal%2526p_p_mode%253Dview%2526_3_groupId%253D0%26_3_keywords%3Ddownload%2BAPI%26_3_groupId%3D0%26_3_struts_action%3D%252Fsearch%252Fsearch&inheritRedirect=true`

The first step above uses auxiliary programs python, grep, and awk.

3.2.2.2 MUNDI

As noted in the first version of this deliverable (D12.1 - Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 1), MUNDI DIAS (unlike any other DIAS) exposes each elementary file of an image product for downloading separately. The combination of these files is then left as a homework to the user, unless the user wants to make a program downloading and reconstructing an image product in its documented .zip form. It is hard to find use cases where this type of separate file downloading has advantages over a zip packet. The user probably wants to download the largest files of 10-m bands of Sentinel-2 images anyway. One scenario benefitting from separate file downloads is if a user wants to screen the images using the landcover/cloud mask of level-2A products (the cloudiness information in most image download sources is based on the level-1C cloud mask, which is unreliable - a downloaded level-2A cloud mask also enables a detailed analysis regarding the cloud coverage in user-interesting targets within an image, not only an overall figure) and then possibly download the selected images from some more convenient download source.

The documentation of the MUNDI catalogue/download API is fragmented but most features can be found at `https://mundiwebservices.com/help/documentation`.

An image catalogue search can be made with a command like:

```
wget -O -
"https://mundiwebservices.com/acdc/catalog/proxy/search/Sentinel2/opensearch?q=sensingStartDate:[2020-06-15T09:30:00Z TO 2020-06-15T09:33:00Z]&bbox=29.9,62.6,30.1,62.8&onlineStatus=ONLINE&processingLevel=L1C&maxRecords=50&platform=Sentinel2" > S2catalogueMundi.xml
```

After cleaning with xmllint, the resulting file can be used in a small image listing program:

```
yrcatlist_mundi S2catalogueMundi.xml
```

This displays:

```
Filename: S2catalogueMundi.xml
2 images:
1: S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025
  https://obs.eu-de.otc.t-systems.com/s2-l1c-2020-q2/35/V/PK/2020/06/15/S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025
2: S2A_MSIL1C_20200615T093041_N0209_R136_T36VUQ_20200615T110025
  https://obs.eu-de.otc.t-systems.com/s2-l1c-2020-q2/36/V/UQ/2020/06/15/S2A_MSIL1C_20200615T093041_N0209_R136_T36VUQ_20200615T110025
```

An access token is needed for downloading a Sentinel-2 image from MUNDI DIAS. The access token cannot be generated by API tools but it must be copied from the GUI (in the user profile tab). The image download program yrgetimg_mundi_whole assumes the access token to be written into a simple text file containing nothing else except the token. An image can then be downloaded:

```
yrgetimg_mundi_whole \
https://obs.eu-de.otc.t-systems.com/s2-l1c-2020-q2/35/V/PK/2020/06/15/S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025
munditoken4.txt
```

The download program yrgetimg_mundi_whole does the following:

- makes a .SAFE directory for the image to be downloaded,
- downloads the manifest.safe file with wget,
- reads the manifest.safe file and for each line containing string <fileLocation href=":
    - creates the directory of the file if it does not exist,
    - downloads the file with wget;
- creates a .zip file of the contents of the .SAFE directory using 7z.

3.2.2.3 ONDA

The documentation of the ONDA DIAS API, which is scattered to several pages and a bit difficult to follow, can be found at https://www.onda-dias.eu/cms/knowledge-base/dataaccess-via-catalogue-odata-api/

Unlike all other DIAS systems, ONDA does not use access tokens, but download requests are authenticated with a username and password.

An image catalogue search can be made with a command like:

```
wget -O - 'https://catalogue.onda-dias.eu/dias-catalogue/Products?$search="beginPosition:[2019-08-30T09:30:00Z%20TO%202019-08-30T09:31:00Z] AND instrumentShortName:MSI AND productType:S2MSI1C AND footprint:"Intersects(POLYGON((29.89687075995382%2062.82315213420844,30.11219748355609%2062.82769092263334,30.10888476473144%2062.68666243356961,29.89355804112917%2062.68970240185408,29.89687075995382%2062.82315213420844)))""&$format=atom' > S2OndaCatalogueTest.xml
```

After searching the resulting .xml file for image name and download code, an image can be downloaded with a command like:

```
wget --user=yrjo.rauste@vtt.fi --password=yyyyyyyyy -O \
```

```
S2A_MSIL1C_20190830T093041_N0208_R136_T35VPK_20190830T105637.zip \
'https://catalogue.onda-dias.eu/dias-catalogue/Products(6ffa5923-36f9-4476-9db8-
dce62ade1bdf)/$value'
```

In the download command above, the chosen image is different from the sample download commands of other DIAS systems. The reason for this is that the image used in other examples was not found on the ONDA DIAS in July 2020. The graphical user interface of the image catalogue on ONDA DIAS also suffered from anomalies in July 2020 (see Figure 2). In addition to the spurious latitude-oriented lines, the display scale also returned to global view in all search operations.

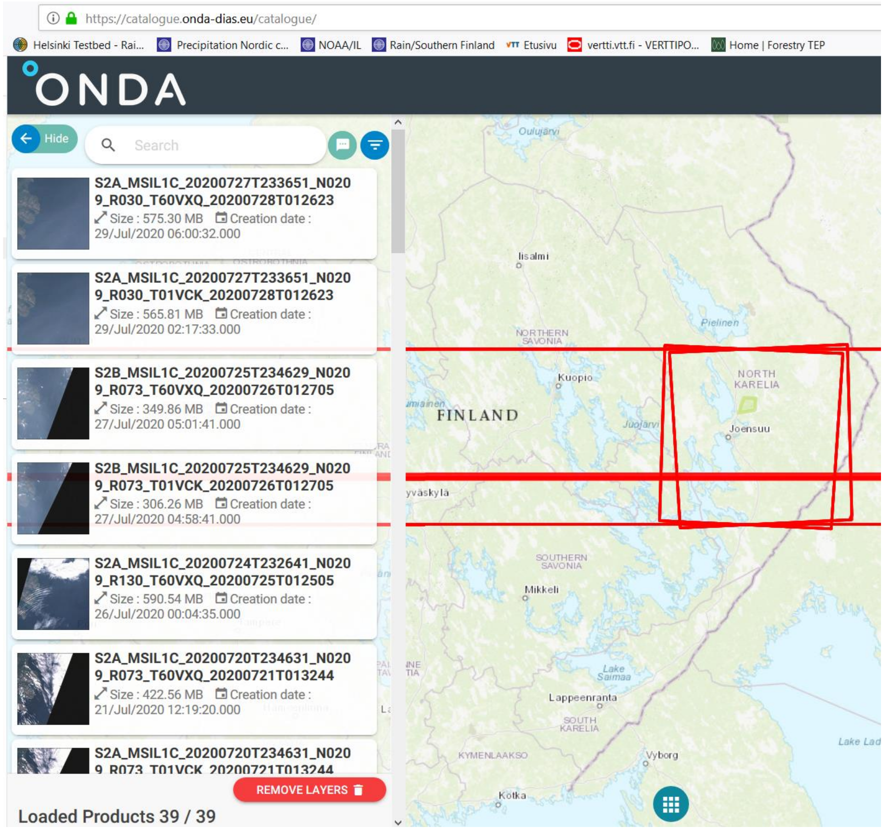

Figure 2. Anomaly in the catalogue GUI of ONDA DIAS on 31.7.2020.

3.2.2.4 SOBLOO

The API documentation of SOBLOO DIAS is written entirely in python (https://gitlab.com/pub-sobloo/support/-/wikis/Tutorials/Basic%20API%20usage). The relevant URL formats can be extracted for many functions, though. The geographic search is not documented or is well hidden. No systematic documentation of all variables that are usable in queries is provided, neither a specification/schema file.

If knowing a Sentinel-2 image name (e.g. S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025), its download code can be found with a command like:

```
wget -O soblooID.json \
'https://sobloo.eu/api/v1/services/search?f=identification.externalId:eq:S2A_MSIL1C
_20200615T093041_N0209_R136_T35VPK_20200615T110025&include=previews,identification&
pretty=true'
```

An API key (like SOBLOO calls the access token) can be generated in the GUI, not via the API. Once the API key is generated and image download code fetched from the .json file, an image can be downloaded with a command like:

```
wget -O S2A_MSIL1C_20200615T093041_N0209_R136_T35VPK_20200615T110025.zip --header \
'Authorization:Apikey
v2kLpT1VHxDpEP0BcI5ZA1hB9t8cc3W0MfPrXtxj21077bCpHVRcU7zxKg5sflYh-
VlEGBEYiGtVfVhkbd5g==' \
'https://sobloo.eu/api/v1/services/download/223d73c4-e556-4200-a286-528601d7b9f2'
```

3.2.2.5 WEkEO

The API documentation (https://www.wekeo.eu/web/guest/hda-api) of WEkEO is fairly clear and comprehensive. The API documentation fits one WWW page. All details are not documented, however. The examples in the documentation are for Sentinel-1 data. A document for variables for Sentinel-2 can be downloaded if the user knows the data type code for Sentinel-2. Fortunately this can be obtained from GUI because the GUI shows the generated queries in json. However, optional variables cannot be used in queries (at least not documented). Neither can cloud cover.

The API download process in WEkEO is more complex than in any other DIAS. All other DIAS systems can be accessed just using GET requests and e.g. the wget program. The WEkEO DIAS requires the use of POST requests and following the running/completion status in the catalogue access and image download operations.

First, an access_token is generated with a small program:

```
yrgetwekeotoken zzzzzzzzzzzzzzzzzzzzzzzzzzz
```

where zzzzzzzzzzzzzzzzzzzzzzzzzzzz = base64-encoded user:passwd. The WEkEO documentation advices to use a web service (https://www.base64encode.org/) to encode the user:password string but this can be considered a bit questionable (submitting credentials of a web service to another internet service). The access_token is valid only for an hour.

Program yrgetwekeotoken asks WEkEO DIAS to convert the username-password string into a short term access token (usin wget).

When an access token is generated, a catalogue extract can be queried with another small program:

```
yrwekeocatalog ce7925a2-262a-3d1d-90f3-2c466be197e4 62.82x29.89x62.68x30.11 \
2020-06-15T00:00:00.000Z 2020-06-16T00:00:00.000Z wekeo_catalog.json
```

The arguments of program yrwekeoctalog are: 1) access token, 2) a bounding-box argument LATMAXxEASTMINxLATMINxEASTMAX, 3) start time of the search, 4) end time of the search, and 5) output file name. Program yrwekeocatalog does the following:

- turns the bounding-box and time arguments into a WEkEO query,
- submits the query (with curl, POST) and reads the response for a jobId,
- queries WEkEO every 10 seconds until the search job is completed,
- fetches the result of the catalogue query with wget.

A download URL can be extracted from the output of `yrwekeocatalog`:

```
grep url wekeo_catalog.json
```

An image can then be downloaded:

```
yrgetimg_wekeo ce7925a2-262a-3d1d-90f3-2c466be197e4 \

988b11ca-1f7f-5d99-
84f385add3e7cb3/S2A_MSIL2A_20200615T093041_N0214_R136_T35VPK_20200615T120311.SAFE \

-bjl_BXIaJ4e7JxeMwSpZ7oP5mI
```

Here the first argument is the access-token, the second the extracted URL, and the third one the jobID from the yrwekeocatalog run. Program yrgetimg_wekeo does the following:

- submits a query (order) for the image (with curl, POST) and reads the response for an orderId,
- queries WEkEO every 10 seconds until the image order job is completed,
- fetches the result of the image request query with wget.

The image data of WEkEO DIAS are downloaded from https://zipper.creodias.eu/download, which is the same address as the download server of CREODIAS.

3.2.2.6 Lessons Learned on the API Use of DIAS Systems

The test in using API facilities to download Copernicus Sentinel-2 data from DIAS systems is not completely representative of the EO work on DIAS when virtual machines are rented for the work. However, accessing Copernicus Sentinel data on a virtual machine also requires some catalogue/download interaction. In many cases, the catalogue/download functionalities are the same on a virtual machine within the DIAS and on a user-local machine outside the DIAS. The documentation of the API functions on DIAS systems is written for both of these cases. In some cases there may be less cumbersome facilities to access the Copernicus Sentinel data on a virtual machine inside a DIAS system. For instance, the MUNDI DIAS documents an alternative catalogue/download interface (accessing Amazon-type disc storage) that can only be used inside the DIAS system. In most cases, the Sentinel data are copied from the image archive of the DIAS to the user-rented virtual machine using the same or similar facilities as tested here in sections 3.2.2.1 through 3.2.2.5. The main difference is that the image download path goes via Internet in the case where a local computer is used. File copying inside a DIAS system can be expected to be much faster if the image archive is inside the DIAS. If the image archive system is located physically far from the main DIAS infrastructure, like using an external image archive for some, possibly older Sentinel data the data transfer delay in processing may be as long as in the case of local processing. Fast telecommunication links between the DIAS and the external image archive can shorten the transfer delay, but transfer rates of LAN (Local Area Network) of a DIAS are hard to obtain over longer distances, especially if the transfer capacity is divided between many simultaneous users working on the DIAS. Apart from the image access tasks (and interactive tools - where the user experience most likely suffers from latency and data transfer rate issues over the Internet), the rest of the EO work on a DIAS system is presumably very similar to working with a Linux system in general, with the complexities (like firewalls) in connecting to the system over the Internet.

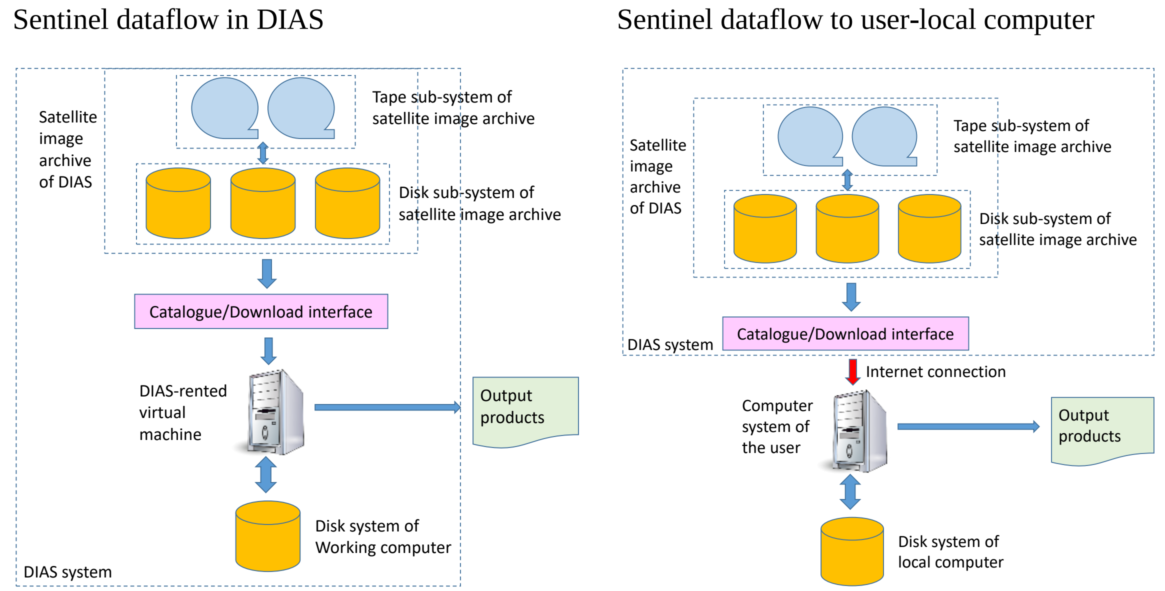

Figure 3: Sentinel data flow when working on a DIAS system compared to working on local computer of a user.

The documentation of the API functions was on such a level that essential tasks for image catalogue access and image download were successfully tested via the API in all DIAS systems. The clarity and coverage of documentation varied a lot between DIAS systems. There were several features that needed to be discovered by trial and error. One complicating factor when using wget and curl programs was the command line interpreter and feeding special characters in the URL text strings.

There were no major differences in the developer-friendliness between the DIAS systems. Some tasks were straightforward in one DIAS while some other tasks in the next DIAS. It took several days but less than a week to test the image catalogue access via API per DIAS. The developer's previous experience in needed tools affects the time consumption. The estimate above (several days but less than week) was for a developer who is fluent in C programming and has a fair amount of experience with wget and curl programs.

There are several aspects of usability that are not visible in an image download experiment. One is the type of user access to the DIAS or other platform. If the user is only allowed to make customized docker images and run these on the platform via some pre-determined mechanism without direct access to command line interpreter, the development or customization process may be slower. If the user is allowed access to the command line interpreter on a virtual machine of the platform, the development or customization can be faster. If the user is not allowed root (or administrator) access (e.g. for installing additional programs using the standard installation interface of the operating system) and additional software components must be installed via requests to the platform provider, the development or customization process may again be slower than with a platform with full root access to the virtual machines.

3.2.3 Functionality of Copernicus DIAS Systems in Developing Countries

The speed and reliability of Internet access is a key factor affecting the functionality and user experience of DIAS systems when accessing these systems from far-away developing countries. Slow internet connection makes use of interactive tools on DIAS systems very inconvenient if not irritating to the user. In the worst case with slow and unreliable internet connection, the use of interactive tools may become practically impossible due to long delays in getting any feedback from the system to the user actions. On the other hand, the use of DIAS systems enables processing of Earth Observation data very close to an archive of those data. Only output maps and other output data need to be downloaded over the slow internet connection instead of very large volumes of Earth Observation raw data.

Internet access was identified as a challenge for forest monitoring activities in developing countries in the deliverable D1.1 ‘Stakeholder and Requirements Assessment Report’. Especially World Bank, Tanzania, and Malawi mentioned this in their responses to the stakeholder requirements survey. Therefore, usability and reliability of online based applications was included as one of the main aspects evaluated through the user feedback gathered in conjunction with the WP4 Learning Exercises. The learning exercise workshops themselves - which were realized as webinars due to the COVID-19 problems - were an encouraging indication of mature internet connections as no major connectivity related obstacles were identified in the course of these webinars. The on-line platform that was used in the hands-on demonstrations in the webinars was the REDDCopernicus Geoportal at the address https://redd4view.mundi.gaf.de. Overall, the great majority of the workshop participants were happy with the online platform usability during the Learning Exercises (Figure 4). However, significant variation can be seen between different regions. While 88% of the participants considered the performance good in Brazil, only 47% and 50% percent were happy with the usability in Central Africa and Southeast Asia (respectively). This indicates that although the majority of the users in tropical countries would likely be able to use online platform based applications with satisfactory experience, limitations and bad experiences can be expected in some countries.

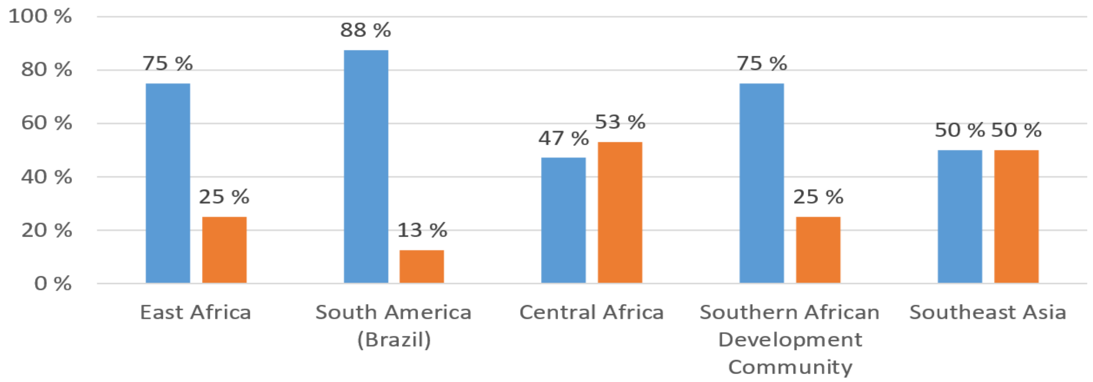

Figure 4: Answers of the WP4 workshop participants to the question: Do you think that the performance of the presented platform application is sufficient - taking into account your internet connection? Blue indicates ‘Yes, performance is good’ and red indicates ‘No, internet connection is limiting the performance’.

To further investigate the issue, a small experiment on internet access speed was made during the first project year and described already in D12.1 'Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 1'. One of the most popular internet services in many countries is weather forecast and weather report service. In vast majority of countries, the national meteorological organization maintains a national weather portal distributing the latest weather reports and forecast. A sample of African countries were chosen in the member list of World Meteorological Organization (WMO[25]) among those countries where the listing included a WWW address. The Finnish site (www.fmi.fi) was chosen to represent a site as close as possible and the UK site (www.metoffice.gov.uk) to represent a European site that can be considered as a typical access speed between the DIAS systems and European users. The ping utility was chosen for the Internet access speed test. It sends a packet of 32 bytes and measures the time difference between sending the packet and the reception of the response from the remote site. The ping response time is more representative for the speed of packet traffic in interactive applications than for the speed of large file transfers.

Table 6 shows the results of the internet access speed tests, carried out between 14 and 15 UTC on 2.12.2019 between Espoo/Finland and the chosen weather service sites on the Internet. The experiment wa repeated on 1.3.2021 at 10 UTC. Two of the selected four countries timed out in 2019 and one in 2021, (indicating long transfer time, or that the sites do not accept ping requests). The 221 ms round-trip time of the Zimbabwe weather service is 37 times the time of the UK weather service. This highlights the different situation where users in Zimbabwe might be while using European DIAS systems in interactive applications, potentially causing considerable slowness. However, the Angolan weather service is only five times further (in terms of Internet access speed) from the test position (Finland) than the UK weather service. It has to be also remembered that the test was run with weather services, which have typically the most advanced internet connection. Government offices related to forestry activities are not necessarily equipped as well.

Table 6: Two-way packet transfer times in the ping utility between VTT/Finland/Espoo and selected national weather sites.

Country	Site	Ping time (ms) 2019	Ping time (ms) 2021
Zimbabwe	msd.org.zw	221	273
Tanzania	www.meteo.go.tz	Time out	Time out
Kenia	www.meteo.go.ke	Time out	212
Angola	WWW.INAMET.GOV.AO	29	29
UK	www.metoffice.gov.uk	6	6
Finland	www.fmi.fi	1	1

Overall, it can be concluded that there is considerable variation in internet access speed across tropical countries, which is bound to affect the usability of any online based applications in some countries. This is particularly the case, since the majority of tropical users of the service expected (according to the WP4 Learning Exercises) functionalities that typically require high internet access speed, like data upload and download as well as interactive GIS analysis functions (Figure 5). Nevertheless, internet speeds are expected to improve over the coming years, alleviating the hindrance throughout tropical areas little by little.

[25] https://public.wmo.int/en/about-us/members

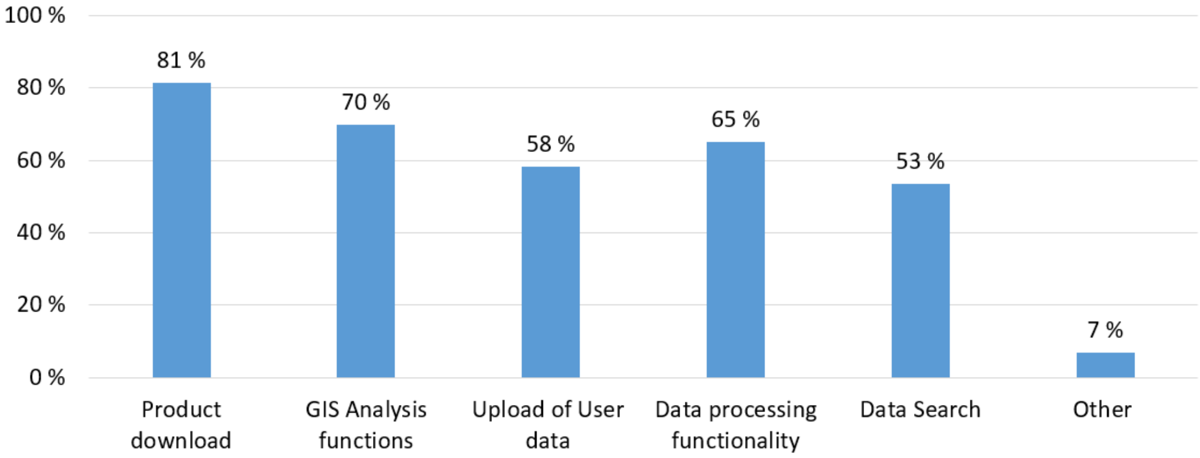

Figure 5: Functionalities expected from the Copernicus REDD+ service.

3.2.4 Status and Gaps of TEP Platforms

The WWW page of ESA (https://tep.eo.esa.int/) lists the following Thematic Exploitation Platforms (TEPs):

- TEP Coastal (https://www.coastal-tep.eu/)
- TEP Food Security (https://foodsecurity-tep.net/)
- TEP Forestry (https://f-tep.com/)
- TEP Geohazards (https://geohazards-tep.eu/#!)
- TEP Hydrology (https://hydrology-tep.eu/#!)
- TEP Polar (https://portal.polartep.io/ssoportal/pages/login.jsf)
- TEP Urban (https://urban-tep.eu/#!)

The idea of all the TEP platforms is to provide an online environment where EO data, in-situ data and other auxiliary datasets may be accessed, processed, analysed and shared within the thematic community. The TEPs are primarily application platforms, located on top of the DIAS systems, providing users with means to effectively utilize the datasets and processing power offered by the DIAS systems. Of the seven TEP systems, the most central for REDD+ and sustainable forest monitoring services is the Forestry TEP, which was covered in detail in D2.2 'Review Assessment for Forest Monitoring Capacity'.

The Coastal TEP aims to support maritime management, research and R & D sectors. The Food Security TEP concentrates on agricultural services. The Geohazards TEP concentrates on earthquakes, volcanic activity and other phenomena causing changes to the earth surface elevation. The Hydrology TEP aims to create a community of scientific users, river basin organisations and service providers. The Polar TEP concentrates in its applications on sea ice and icebergs. The Urban TEP concentrates on the spatial extent and temporal development of human settlements.

All of the TEP's have been funded by ESA until recently, and are now starting commercial operations. Service prices were already visible the Food Security, Hydrology and Polar TEPs (as of 17.2.2021), with other TEPs expected to release their prices shortly. However, ESA will continue to support uptake of the TEPs through the Network of Resources (NoR) initiative, which provides funding for the platform usage for research and development purposes.

In addition to TEPs (Thematic Exploitation Platform) two other types of exploitation platforms have been defined: MEP (Mission Exploitation Platform) and REP (Regional Exploitation Platform).

The Proba-V MEP is operated by VITO[26], and it provides the full archive of Proba-V data. As the resolution of the data is 100 m at best, its role in REDD+ and forest monitoring for sustainable forestry is limited. The SMOS Pi-MEP[27] provides data from the SMOS (Soil Moisture and Ocean Salinity) mission, an L-band microwave radiometer. Also this data is of limited value for REDD+ and forest monitoring for sustainable forestry.

So far (17.2.2021) there are no REPs (Regional Exploitation Platform) openly advertised and available to users. A similar concept is the national ground segment like *e.g.* the CODE-DE system described in D2.2 'Review Assessment for Forest Monitoring Capacity'. The availability of national ground segments and their services varies a lot from country to country, and their suitability may be limited for large, international projects for Earth observation for REDD+ and forest monitoring for sustainable forestry.

The analysis of European EO capacities (D2.2 'Review Assessment for Forest Monitoring Capacity') included the DIAS systems and the Forestry TEP. Based on the analysis of the TEP, MEP, and REP systems above, this was justified. The various forms of exploitation platforms can serve some augmenting data for the Copernicus service components for REDD+ or sustainable forestry monitoring, but the most important cloud service candidates for these services are included in the DIAS plus Forestry TEP subset of the systems.

3.2.5 Value-Added Ecosystem around EO Resources

Currently the earth observation market within the forest domain is in a phase of development where all opportunities are not addressed to the full potential. However, when the technology, accuracy and services are developing further, it is possible that service providers using satellite technology are starting to take over the current market of actors using other, more labor intensive methods and technologies to chart large forest areas. The EO market in forestry domain can be divided into three groups with respect to the end users:

1. (Inter-) National public organizations, research organizations and NGOs
2. Forest owners and their associations
3. Wood buyers

Examples of international public organizations, research organizations and NGOs include e.g. UN FCCC, UN REDD+, UN FAO, World Bank, WWF and Greenpeace. Examples of national public organizations, research organizations and NGOs include e.g. Ministry of Agriculture and Forestry of Finland, LUKE (Natural Resources Institute Finland), Metsäkeskus (The Finnish Forest Centre) and corresponding institutions in other countries. Typical questions of international public organizations, research organizations and NGOs that drive earth observation applications can be summarized in:

- Setting regulations to drive sustainable development of forest areas on global and local levels:
    - What should be the commonly agreed guiding principles regulating the forestry activities on global and local levels?
    - How should we follow up the annual development around the world? How should different actors report on their forest assets and their development?
- Following the actualization of the planned activities and the overall global and local development:
    - What are the indicators telling us about the global and local development trends? What kind of further actions should we take?
- Supporting the different actors to meet the objectives
    - How could we support the different actors to better meet their objectives?

[26] http://proba-v.vgt.vito.be/en
[27] https://www.smos-pimep.org/

- What kind of tools, guidance and data can we provide to the different actor groups to support them to meet their objectives?
- How could we steer the research to provide useful insight?
- How could we enhance the general knowledge on forest related issues?

Examples of forest owners, and their associations include among others: individual private forest owners (e.g. citizens), commercial private forest owners (e.g. companies), public forest owner (e.g. state and municipalities). Typical questions of forest owners and their associations that drive earth observation applications can be summarized in:

- Having holistic understanding of my forest assets and their parameters:
  - What is my current forest asset like?
  - What is the current monetary value?
  - What kind of other values does it have?
  - How might the asset develop in the future?
  - What kind of regulations are related to it?
  - What are the potential threats related to it?
- Having a clear strategic and operational plan for forest management
  - What are the strategic options and scenarios related to the forest asset?
  - How should I manage and treat the forest in order to reach my objectives in the optimal manner?
- Executing the planned actions related to the forest asset:
  - When is the right time to do specific strategic or operative activities relating to the forest asset?
  - Who could help me executing the planned activities?
- Monitoring the changes related to the forest asset:
  - How my forest is developing in comparison to my strategic objectives?
  - How do I derive the information that I need to report for regulatory agencies and voluntary certification schemes?

Examples of wood buyers include forest companies like e.g. Stora Enso, UPM. Typical questions of wood buyers that drive earth observation applications can be summarized in:

- Having a secure and continuous access to wood resources with affordable price:
  - Where should I acquire the needed wood resources now and in the future?
  - What is the material value of a particular forest area now and in the future?
  - What are the benefits and possible risks related to buying wood from specific areas?
  - How do we price the buy in of the raw material?
  - What are the logistics and productions costs?
  - What is the level of the local forestry infrastructure?
  - Should we invest in building forestry infrastructure?
  - How much profit can we make?
- Maintaining a healthy relationship with forest owners:
  - How can we activate and support forest owners to nurture their forests in an optimal manner?
  - How can we activate forest owners to provide raw material for our needs?
  - How do we negotiate raw material price that satisfies both parties objectives?
- Meeting the sustainability targets and maintaining responsible brand image:
  - What are the sustainability targets related to our business and operations?
  - How do we prove to the society and authorities that we are working in a sustainable manner?
  - How do we help the forest owners to maintain their forests in a sustainable manner and still producing us the needed raw material?
  - What is our decision criteria from sustainability point of view, when choosing suppliers and buying raw material from them?
  - How do we ensure that the raw materials we are buying are produced in a sustainable manner?
  - How do we measure the effects of our operations in the specific forest areas?

- How do we measure the sustainability of our business and operations in the larger scale?

The wide range of questions and topics listed above illustrates the challenges involved in forest EO applications. This necessitates a versatile set of actors needed from the acquisition of EO data, value adding and processing the data, interpreting and analyzing the data, and presenting and storing the data in a suitable format for the end users' needs. Applications differ in many aspects. For instance, clear-cut monitoring for a national forest authority requires open and transparent operation, while forest resource mapping for forest industries' investment decisions require high levels of confidentiality with strict non-disclosure agreements. As the characteristics of applications vary widely, one actor or group of similar actors cannot satisfy the needs and requirements of all end users. An ecosystem of inter-connected EO companies and other actors has developed in Europe during the last decades.

To understand the current status of the European EO ecosystem, it is essential to understand the development that has led to the current ecosystem. Several development versions can be identified in this development:

1. Early Landsat era/v 1.0: Research is done by many universities and research institutes. International scientific symposia serve as the focus of exchange of information and experiences.
2. European industrial policy drivers start to influence the EO scene/v 2.0: ESA and EU put a strong emphasis on the development of EO business in Europe. Incentives by ESA, EU, and national governments move the centre of gravity in EO business towards private sector companies. Major European EO projects gain importance in exchange of information and experiences
3. GMES and Copernicus era/v 3.0: The developments made in the GMES (Global Monitoring of Environment and Security) and Copernicus programme forms a major step up in EU funding to EO activities. The avalanche of cost-effective satellite data stimulates the proliferation of EO activities in many previously uninvolved sectors of geo-informatics and in the ICT sector in general.

The new EU Space budget proposed by EC has an overall budget of 16 billion euros, with 5.8 billion euros reserved for Copernicus. Furthermore, ESA Earth Observation budget has been agreed to 2.5 billion for the next five years. The five DIAS platforms have been set up by Copernicus. These strong strategic actions taken by EC and ESA have aimed to boost the EO industry in Europe.

According to the European Association of Remote Sensing Companies (EARSC) EO services industry survey 2020[28], there are 572 EO services companies in Europe, with a total revenue of 1.4 billion euros. These companies employ over 9800 people. Note that these figures are based on 2019 data, before the Covid-19 pandemic. Any potential effects of the pandemic will only be visible in the following survey, to be conducted early 2021. It is also important to understand that the EO service companies are not limited to forestry domain, although terrestrial area monitoring is a key application area of European EO service companies.

The EO service industry sector has shown strong growth over the past years, more than tripling its revenue over the past ten years (Figure 6). At the same time, the number of companies have doubled. There is a strong potential for further growth with ever increasing monitoring requirements that EO based applications can respond to. The biggest barriers of growth were considered to be market/user acceptance of EO based approaches and customer's lack of budget, for over 40% of the companies (EARSC 2020). Over 20% of the companies also reported lack of competent staff.

[28] https://earsc.org/wp-content/uploads/2020/07/Industry-survey-2020-Final-version-1.pdf

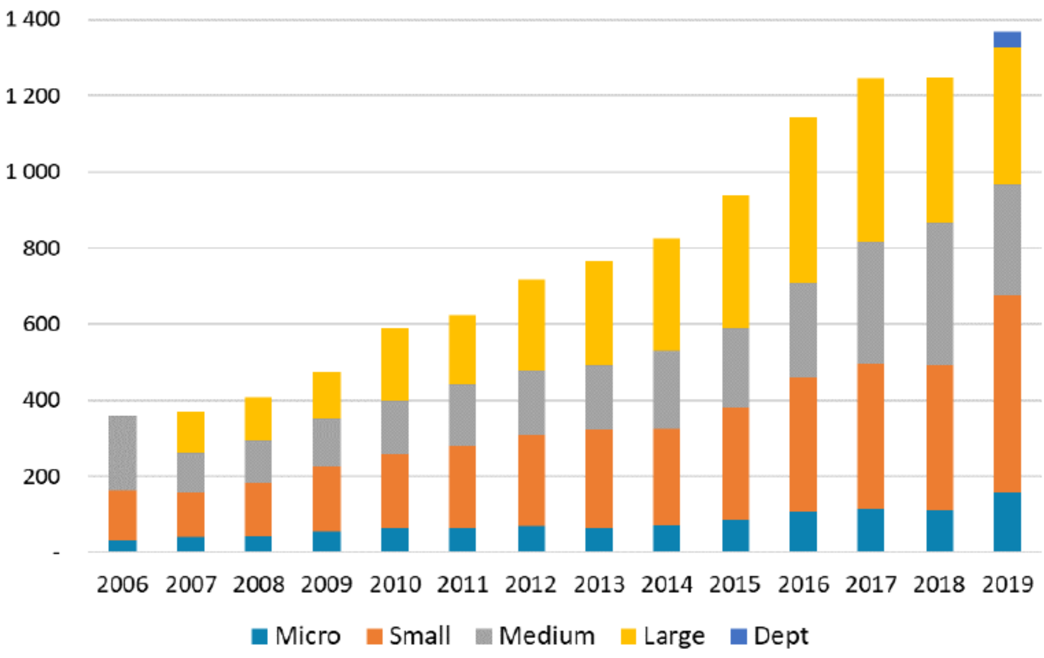

Figure 6: Evolution of EO service industry revenues by company size (EARSC 2020)

The Copernicus Programme can be seen as a very positive influence on the European EO Service Industry. In the latest survey, over 80% of the companies perceived Copernicus as positive or very positive influence for their business. The perceived impression have improved strongly over the past three years, potentially due to the successes of the Sentinel satellites and the new DIAS platforms. The most popular Copernicus service is the Copernicus Land Monitoring Service (CLMS), with around 50% of the EO service companies either contributing to or using (or both) the products. None of the other Copernicus services attract the interest of over 20% of the companies. In 2019, only 12% of the companies were using DIAS platforms to access Copernicus data and services, although nearly all companies had tried one or more of the five DIAS platforms. The division between DIAS systems is shown in Figure 9. It must be remembered, however, that the platforms had been set up only in 2018 or later. It is interesting to see how the situation will develop in the coming years.

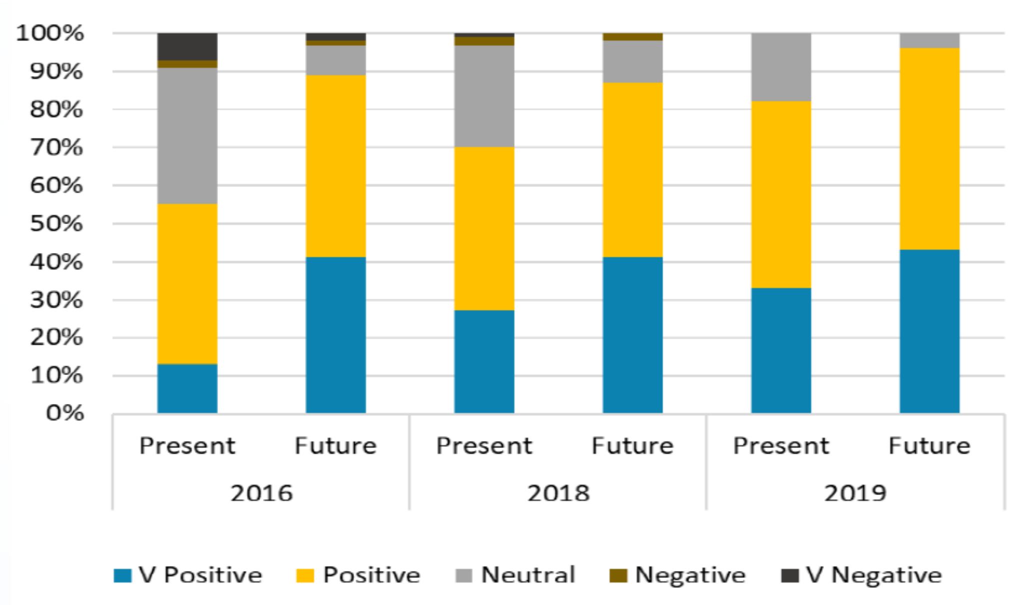

Figure 7: Perception of EO service industry companies on the impact of Copernicus Programme for their business (EARSC 2020)

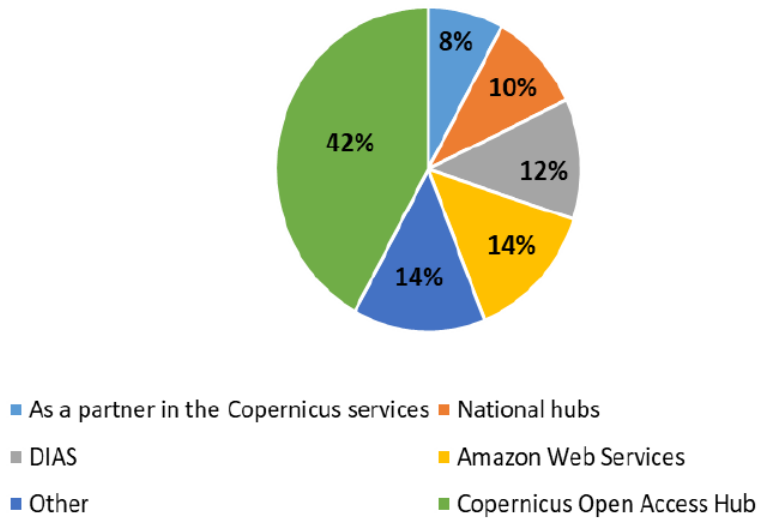

Figure 8: Route most frequently used to access Copernicus data (EARSC 2020)

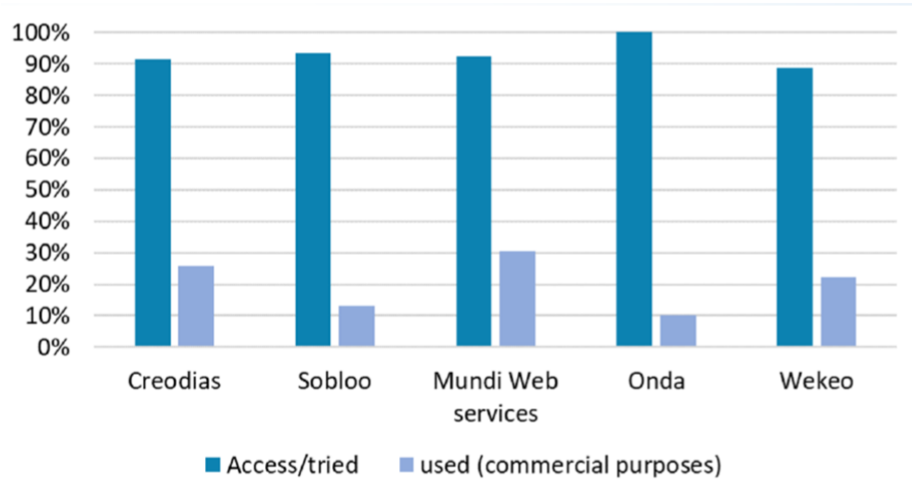

Figure 9: Use and trials of DIAS systems by European EO companies (from EARSC 2020).

The future of the value-adding European EO industry looks bright (Figure 6) as long as the growth of the market can grow without major disturbances.

3.2.6 Local vs. Cloud Processing

One competitor for cloud platforms is always local processing. Every EO project, even the largest possible areas and highest-resolution data, can be implemented using computer and storage infrastructure of the EO analyst company responsible for the project - at least in theory. In practice, buying lots of storage space and processing power for a single, time-limited project may involve prohibitive cost. The downloading time of extensive EO datasets may also form a practical obstacle for local processing. On the other hand, local processing means usually operating systems and tools that are already familiar to the personnel implementing a project. Applications on cloud platforms run today most often on Linux operating systems. It is possible to rent a virtual machine with Windows operating system, but the renting is more expensive than for Linux-based virtual machines because the cloud operator must include the operating system license cost in the rent of the virtual machine.

The adoption of cloud platforms in EO applications can involve a steep learning curve. For instance, all DIAS systems expose an API (Application Programming Interface) for accessing EO data and services of the platform. The API of one system is not always the same or even similar on other platforms. The API may also require the use of a programming or scripting language that is not in use on the local system.

To attract use and paying customers, platforms must keep prices for processing and data storage services on a competitive level. This may in the long run lead to a situation where EO companies reduce their spending on computer infrastructure and rely on cloud platforms in all larger projects.

Local processing and cloud platforms do not exclude each other. Very few companies, if any, rely exclusively on local processing or cloud platforms. A flexible approach may use either cloud platforms or local processing depending *e.g.* on:

- the amount of EO data involved,
- availability of local computing resources,
- cost of cloud platform resources, and
- familiarity of project personnel with the cloud platform or local EO tools.

When implementing or automating applications or processing steps on cloud platforms it is usually very useful to have a local test environment for the initial development of processing algorithms and workflows. This can reduce the project development time significantly. Setting up a similar-enough test environment may be a non-trivial task, depending on the cloud platform and their disc storage organization.

From the end-user point of view, there are at least three major aspects that affect the preference between local or cloud processing: 1) the user-friendliness of the interfaces, 2) suitability of the applications for user's own established practices and 3) internet speed and reliability. The internet speed and reliability issue has already been discussed in Section 3.2.3. The other two aspects were also investigated during the WP4 Learning Exercises workshops, through participant questionnaires.

During the workshops, the participants were shown demonstrations and performed hands-on exercises with both a cloud-based platform (the REDDCopernicus Geoportal at the address https://redd4view.mundi.gaf.de) and a desktop application. Nearly all participants (93%) found the cloud-based platform user-friendly. There was no difference in the user friendliness between the cloud-based platform and the desktop application, which was also found user friendly by 93% of the participants. This highlights that it is not significant for the user-friendliness, whether the application is cloud-based platform or run on the desktop. Both approaches enable high level of user-friendliness.

When asked whether such platform application could be integrated in your agency work practices and/ or decision making cycles, 81% answered yes. Although, this is a relatively high number, it is somewhat less than the corresponding answer for desktop applications (86%). Conversely, it means that nearly a fifth of the workshop participants could not see it possible to integrate such cloud based applications with their current practices.

Overall, when asked of their general preference for online based or desktop applications for accessing the future Copernicus REED+ services, only 55% chose web-based portal, while 32% would prefer desktop clients. Most of the people who chose 'Other', elaborated their answer by requesting both types of access opportunities. Many of them further highlighted that this would allow accessing and working with the data also in time of bad internet access. Thus, it seems that at the end of the day, the reliability of the internet access becomes key limiting issue. 93% of the participants found cloud-based approaches very user-friendly, over 80% of the participants believed that they could be integrated into their current practices, but only 55% chose web portal as the most preferred access to the service, fearing potential problems in accessing and working with the data due to unreliable internet access. Although certain level of cautiousness is understandable and expected, this rather weak preference for web-based access portal needs to be taken into account when implementing the service, particularly since most of the users of the Copernicus REDD+ service component can be expected to be located in tropical countries.

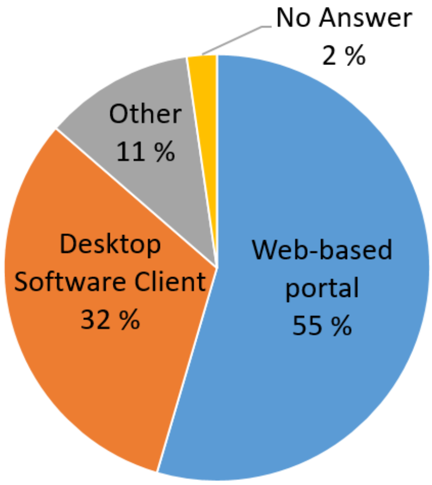

Figure 10. Preference for Copernicus REDD+ service access.

3.2.7 Competitiveness of European EO Industry

In general, the competitiveness of the European EO industry is fairly good as discussed in 3.2.5. However, the competitiveness can be improved.

In the long run, the Copernicus ICT infrastructure including the DIAS systems and Thematic Exploitation Platforms (TEPs) can make a significant boost to the competitiveness of the European EO industry. As already highlighted in Section 3.2.5, the Copernicus Sentinel fleet and Copernicus services have already proven a very valuable competitive advantage for European EO industry. If properly managed, the Copernicus ICT and platform infrastructure can do the same. Fast, reliable and free access to EO data forms a solid base for building competitiveness for the EO industry. Another important aspect for the EO industry is continuity. It would be essential that EO service providers who build their services on top of a given storage and access system, can rely on the quality and continuity of the service. During the DIAS interviews it was e.g. highlighted that companies should be given guarantee that support of transfer to another platforms will be provided if the chosen platform terminates its operations. This kind of transfer is not straightforward due to the differences in the philosophy and architecture of DIAS systems. Support guarantee for DIAS transfers would encourage companies to commit to service development on online platforms.

Overall, the European EO industry has a very positive trend of growth (see Section 3.2.5), it has large potential pool of new users in European and non-European customers and it has access to the latest technologies and methods. The support from Copernicus space and ICT components support this positive development. The network of DIAS systems, regardless of their deficiencies, forms a favourable environment for the European EO industry.

However, there are also aspects in the European EO industry scene that causes problems and may limit the growth. Potential hindrances for competitiveness include at least:

1. Delayed start on cloud processing: The European EO industry was slow to start on cloud processing. Non-European competitors have gained strong advantage by consolidating their reputation and user base.
2. Unclear roles of the numerous platforms: Europe has a broad range of platforms, but their roles are unclear. This leads to unnecessary competition between European platforms and potentially inefficient modes of operation.
3. Availability of data: Related to the previous point, in some cases EO industry cannot access the raw data for their analyses in a convenient manner in European platforms, forcing them to rely on non-European platforms for fast and reliable data access.
4. Lack of anchor clients: All major non-European EO industry platforms have large secured funding (see the following).

Regarding the base funding, European DIAS providers are in a very different situation compared to their main competitors. For example the Google Earth Engine has a very strong commercial backing and operates with a very different ideology than the European based online platforms. It was highlighted during the DIAS interviews that in the European approach EO is separated from other business areas, which is a problem from funding perspective. The DIAS approach is more limited compared to commercial competitors (like Google or Amazon), whose main revenues come from other areas of business, EO industry being only in a supporting role.

It is important that Europe maintains and further develops online platform competence. To promote an active and successful platform ecosystem, European users should be strongly encouraged to use European EO platforms for service development and provision. Overseas competitors like Amazon AWS, Google, and Microsoft Azure are nowadays the main competitors of European (partially publicly funded) platforms.

Universities and the educational sector in general can have a role in guiding young professionals towards the European EO platforms so that the European EO industry can leverage the power of Copernicus data and DIAS systems to win in international competition. Today the cloud services of Amazon AWS and Microsoft Azurre are widely used in educational institutes in the ICT field and to some extent also in the EO field. Google Earth Engine is widely used in universities in the EO field because it is free for scientific use. If a professional who has experience on using these American cloud services (either in a university or in past professional life) starts planning a new project the professional most likely is inclined to use a known (to the professional) system where the professional feels at home - the professional does not start surveying new European options even though these European options might be more fit for the planned project. Similarly, if a Google-Amazon-Microsoft-trained professional encounters problems when using a DIAS system, the professional can be inclined to resort to the familiar American platform instead of studying options in other DIAS systems.

European Union, ESA, and the member states should have funding mechanisms to support DIAS operators so that they can offer DIAS datasets and processing services to universities for free for research and education. This steers young students and post-graduate students in the EO and ICT fields away from Google Earth Engine (GEE) and Amazon AWS. The offering of DIAS systems should be further developed so that it is more comprehensive, powerful, and competitive than that of GEE or AWS (it can be argued that the offering of DIAS systems already is more powerful for large EO projects). When the professionals then move to industry they are trained to use the European DIAS systems instead of the American systems. If the DIAS system offering is more powerful and comprehensive than that of the foreign competition this creates a competitive advantage to the employers of the DIAS-accustomed EO professionals. The DIAS and TEP systems should also be more strongly marketed towards universities and other educational institutes if there were this kind of European-funded free (to the universities) services available on the European platforms.

A funding mechanism to DIAS scientific use should be augmented with a funding mechanism to support European EO companies to experiment with DIAS and TEP systems so that the companies are ready to utilize the scale benefits of DIAS and TEP systems in those projects and tasks where large disk space and powerful computers are essential. The Network of Resources (NoR) by ESA is a step towards funding scientific use and experimentation of DIAS systems by companies. However, the extent of NoR is limited compared even to the educational needs for a one-year equivalent of ICT and EO students over Europe.

When the user base of DIAS and TEP systems grows and the growth of large EO projects continues, the European value added EO ecosystem can be expected to reach a new phase after the historic phases listed in section 3.2.5: The European ecosystems in space 4.0. Version 4.0 - the platform economy EO ecosystem - is characterized by efficient EO platforms, competitive EO companies winning international project competitions, and a balance between research and development organizations and commercial companies taking advantage of world-leading satellite data and ICT infrastructure for the processing of that data.

4 Conclusions and Recommendations

The final conclusions and recommendations of the Compendium of R&D Needs for the Evolution of the Copernicus Space Component deliverable will be defined over the last project year using all the information collected throughout the project and reported in the final version of the deliverable (Version 3). However, some preliminary findings can be outlined already at this point.

Overall, the Copernicus space segment lead by the Sentinel fleet has proven to be very good and highly usable for forest monitoring purposes. The space segment will become even more comprehensive with the planned ROSE-L and CHIME satellites. Cloud cover forms a gap in all optical EO and will form a gap also in the future. An increased number of satellites in future can reduce the gap. Fusion of radar and optical data can mitigate this gap as identified as research gap in D10.1 'Research and Development Needs for Implementation of Copernicus REDD+ Capacity'. The L-band ROSE-L (Copernicus expansion mission) may significantly improve the reliability of land cover mapping in cloud gaps of optical data as well as the reliability and timeliness of forest logging mapping.

Another gap in the space segment is the lack of a sensor that can be used to map forest biomass reliably and without serious limitations from signal saturation with higher biomass levels. The BIOMASS mission (ESA Explorer planned for launch 2022) may mitigate this gap essentially in those areas where P-band SAR can be operated (under the use restrictions of the frequency allocation organisation International Telecommunication Union). The recent and future planned L-band SAR systems may also contribute to better biomass mapping but less than the use of P-band data. Use of space-borne profiling Lidar sensors like GEDI may alleviate the saturation-related bias of L-band estimated biomass in high-biomass forests.

Another aspects that can be seen as a gap in the current Copernicus space segment is the VHR imagery. Recent VHR optical imagery is not currently available free of charge like Copernicus Sentinel data. VHR optical data are available from commercial providers at a cost. Even then, availability may be limited, especially if historical VHR data are required for instance for reference data in forest or land cover change mapping. The 4.7-m mosaics of optical data funded by the Norway's Ministry of Climate and Environment (as described in section 3.1.5) may alleviate this need for VHR optical imagery.

The Copernicus ground infrastructure for storage, distribution and utilization of the data is built around the DIAS platforms. This system offers an opportunity to utilize powerful computers with large disk space even for such EO actors that cannot invest in expensive hardware. The transfer to cloud processing has been slow to start and the potential of the DIAS platforms is still not fully used in the European EO industry. This is partially caused by the fact that the EO actors need to learn how to effectively combine their human and computing resource in an optimal way in this new environment. The DIAS platform operators are in a key role to support users to make this leap.

But the DIAS system also needs clarification, especially regarding business model and delineation between public and commercial functions and funding. The relatively small amount of paying customers of the DIAS systems does not generate high enough revenue to fund large on-line archives of Sentinel data for this type of public-benefit services. The free and open access to all Copernicus Sentinel data - which is the data policy of the Copernicus Sentinel satellite system - must be organized from other archives than those on the DIAS systems - unless public funding is available to DIAS operators for this purpose. For operations handling massive amounts of EO data, like the production of Copernicus core products, direct access to the data is essential for smooth operations. This is true also for time series analysis and multi-temporal image compositing in general, which are both key functionalities expected from cloud processing platforms for EO data.

5 References

Balzter, H., Foody, G., Gautam, B., Haarpaintner, J., Heath, L., Hoekman, D., Kastdalen, L., Kuntz, S., Lowell, K., Lynch, J., Mora, B., McRoberts, R., Olsson, H., Pandey, D., Penman, J., Sannier, C. 2013. Review of Priority Research & Development Topics - R&D related to the use of Remote Sensing in National Forest Monitoring, Version 1.0, December 2013, GFOI, Geneva, Switzerland, 159 p.

Carreiras, J., Quegan , S. Le Toan, T., Minh, D., Saatchi , S., Carvalhais , N., Reichsteine, M., Scipal, K. (2017) Coverage of high biomass forests by the ESA BIOMASS mission under defense restrictions, Remote Sensing of Environment 196 (2017) 154–162.

D1.1 ‘Stakeholder and Requirements Assessment Report’, Carter, S., Herold, M., Navratil, P., Gomez, S., Achard, F., Miettinen, J., Rauste, Y., Häme, T., Sannier, C., Langner, A., Ballhorn, U., and Huge, J. (2019) REDDCopernicus - Stakeholder and Requirements Assessment Report (D 1.1), project report, 169 p.

D2.1 ‘Workshop Report: Inventory of State-of-the-Art Technical Capacities in Europe for FM Capacities and Infrastructure’, Carter, S., Navratil, P., Achard, F., Langner, A., Sannier, C., Hugé, J., and Miettinen, J. (2019) REDDCopernicus - Workshop Report: Inventory of State-of-the-Art Technical Capacities in Europe for FM Capacities and Infrastructure (D2.1), project report, 42 p.

D2.2 ‘Review Assessment for Forest Monitoring Capacity’, Carter, S., Herold, M., Navratil, P., Gomez, S., Enssle, F., Ballhorn, U., Hugé, J., Sannier, C., Langner, A., Achard, F., Desclee, B., Stibig, H., Eva, H., Miettinen, J., and Rauste, Y. (2019) REDDCopernicus - Review Assessment for Forest Monitoring Capacity, project report, 251 p.

Davidson, M., Chini, M., Dierking, W., Djavidnia, S., Haarpaintner, J., Hajduch, G., Laurin, G., Lavalle, M., Lopez Martinez, C., Nagler, T., Piericca, N., Su, B. 2018. Copernicus L-band SAR Mission Requirements Document, ESA/ESTEC, ESA-EOPSM-CLIS-MRD-3371, 13/07/2018, 72 p.

GFOI, 2020. Integrating remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests: Methods and Guidance from the Global Forest Observations Initiative. Edition 3.0. https://www.reddcompass.org/download-the-mgd

Koetz, B., Berger, M., Blommaert, J., Del Bello, U., Drusch, M., Duca, R., Gascon, F., Ghent, D., Hoogeveen, J., Hook, S., Kerr, Y., Lagouarde, J-P., Manolis, I., Marini, A., Menenti, M., Martimort, P., Masek, J., Massart, M., Notarcicola, C., Sallusti, M., Saudholt, I., Schuettenmeyer, D., Sobrino, J., Strobl, P., Volden, E., and Udelhofen, T., 2019. Copernicus High Spatio-Temporal Resolution Land SurfaCE Temperature Mission: Mission Requirements Document, ESA, ESTEC, ESA-EOPSM-HSTR-MRD-3276, Issue 2, 08/03/2019, 89 p.

Ottavianelli, G. Copernicus Space Component Data Access Portfolio: Data Warehouse 2014 - 2022, European Scape Agency, Issue 2.8, 4.1.2021, ref: COPE-PMAN-EOPG-TN-15-0004, 91 p.

Parmes, E., Rauste, Y., Molinier, M., Andersson, K., and Seitsonen, L. 2017. Automatic Cloud and Shadow Detection in Optical Satellite Imagery Without Using Thermal Bands — Application to Suomi NPP VIIRS Images over Fennoscandia, Remote Sensing, 2017, 9, doi: 10.3390/rs9080806, 17 p.

Rast, M., Ananasso, C., Bach, H., Dor, E., Chabrillat, S., Colombo, R., Del Bello, U., Feret, J-B.. Giardino, C., O Green, R., Guanter, L., Marsh, S., Nieke, J., Ong, C., Rum, G., Schaepman, M., Schlerf, M., Skidmore, A., and Strobl, P. 2019. Copernicus Hyperspectral Imaging Mission for the Environment - Mission Requirements Document, ESA, ESTEC, 23/07/2019, ESA-EOPSM-CHIM-MRD-3216, 95 p.

Rodríguez-Veiga, P., Quegan, S., Carreiras, J., Persson, H., Fransson, J., Hoscilo, A., Ziółkowski, D., Stereńczak, K., Lohberger, S., Stängel, M., Berninger, A., Siegert, F., Avitabile, V., Herold, M., Mermoz, S., Bouvet, A., Le Toan, T., Carvalhais, N., Santoro, M., Cartus, O., Rauste, Y., Mathieu, R., Asner, G., Thiel, C., Pathe, C., Schmullius, C., Seifert, F., Tansey, K., and Balzter, H. 2019. "Forest biomass retrieval approaches from earth observation in different biomes." International Journal of Applied Earth Observation and Geoinformation 77, p. 53-68.

Rosenqvist, Å., 1996. Evaluation of JERS-1, ERS-1 and Almaz SAR backscatter for rubber and oil palm stands in West Malaysia, International Journal of Remote Sensing, Vol. 17, No. 16, p. 3219-3231.

Sirro, L., Häme, T., Rauste, Y., Kilpi, J., Hämäläinen, J., Gunia, K., de Jong, B., and Paz Pellat, F. 2018. Potential of Different Optical and SAR Data in Forest and Land Cover Classification to Support REDD+ MRV, Remote Sensing, 10, No. 6, 26 p.

Le Toan, T., Quegan, S., Davidson, M., Balzter, H., Paillou, P., Papathanassiou, K., Plummer, S., Rocca, F., Saatchi, S., Shugart, H., Ulander, L. 2011, The BIOMASS mission: Mapping global forest biomass to better understand the terrestrial carbon cycle, Remote Sensing of Environment 115 (2011) 2850–2860

Zonno, M., Bordoni, F., Matar, J., de Almeida, F. 2019. Sentinel-1 Next Generation: Trade-offs and Assessment of Mission Performance, ESA Living Planet 2019, 2 p.

End of Document!