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Report for existing services

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Abbreviations

API	-	Application Programming Interface
CRS	-	Coordinate Reference System
CSW	-	Web Catalogue Service
DIAS	-	Data and Information Access Services
DPS	-	Data Provider Solution
EO	-	Earth Observation
G-Pod	-	GRID Processing on Demand
HMA	-	Heterogeneous Missions Accessibility
RSS	-	RESEARCH & SERVICE SUPPORT
SDC	-	Swiss Data Cube
ODC	-	Open Data Cube
OGC	-	Open Geospatial Consortium
OWS	-	Open Web Services
VM	-	Virtual Machine
WFS	-	Web Feature Service
WGISS	-	Working Group on Information Systems and Services

Introduction

Changes in the environment are ongoing and need to be monitored continuously in order to achieve environmental and sustainable development goals (Reid et al. 2010). Earth observation (EO) data can support monitoring activities to analyse these environmental changes. The importance of EO data has been recognized by various research communities, funding agencies and governments, and new satellites are still being launched (Berger et al. 2012). Archives of EO data allow the derivation of information about the changing planet. Many of these data archives have been made available to the public in recent years in the spirit of a free and open data policy (Woodcock et al. 2008; Aschbacher & Milagro-Pérez 2012). This meets the increasing demands of users who analyse environmental changes and leads to research and the possibility of setting up monitoring services for environmental purposes using EO data (Wulder et al. 2012; Roy et al. 2014; Turner et al. 2015).

A wide range of activities is based on the analysis of EO time series data, as these can be continuously used to identify trends and changes in the environment (Gutman & Masek 2012; Lasaponara & Lanorte 2012; Künzer et al. 2015). The use of EO time series data enables the investigation of environmental changes around the world. EO data are accessible as near real-time data, although they also include archive material from more than 40 years. This allows the derivation of ready-to-use information for various topics (e.g. biodiversity, ecology and agriculture) to support science and policy-making (Atzberger 2013; Künzer et al. 2014; Pettorelli et al. 2014; Turner et al. 2015). Research on the analysis of vegetation season series data has been carried out on a large scale, resulting in analysis tools that can be used in operational land monitoring systems and linked to EO data archives (Verbesselt et al. 2010a; Forkel et al. 2013; De Jong et al. 2013).

With the regular launch of new satellites and the increasing amount of EO data based on open data licenses, large data technologies have been introduced into the geospatial domain (Birkin 2013). As the use of EO data in research and industry has increased enormously (Ma et al. 2015; Nativi et al. 2015), new technologies for handling EO time series data need to be considered. With the increasing size and number of EO data archives, the processing of these data must be adapted to lead to automated workflows, distributed processing, parallelization and scalable, cloud-based infrastructure (Yang et al. 2017a). Data cubes and web-based processing systems have recently been combined with large EO data archives so that users can perform processing in close proximity to the data archives (Pagani & Trani 2018; Yang et al. 2017b).

The geospatial web has evolved rapidly in recent years, enabling the development of interactive web-based tools, applications for mobile devices and web services (Veenendaal et al. 2017). Mediation systems and data cubes have been introduced to reduce the limiting factors in terms of discovery, access and processing of data. Web-based tools can be developed using common scripting languages without the need for web development (Swain et al. 2016; Yin et al. 2017).

However, there are many challenges in terms of discovery, access and analysis of EO time series data that need to be improved: The discovery of and access to EO time series data still involves complex data processing tasks. For further analysis, EO data must be prepared for use in geographic information systems and analysis tools. Although geospatial standards are available for the discovery of and access to EO time series data (Nativi & Bigagli 2009), users have to learn many specifications in order to handle data provided by distributed environments. To answer a question like "Has my area of interest been affected by flooding in recent years?", the user has to find EO data for the area in question and perform download and processing steps for each date. Many of these technical challenges can be solved and automated. Access to EO data and analysis tools must be simplified to make them more user-friendly. This provides an overview for user-oriented and standardized web services that allow for simplified exploration of EO time series data. It is partially based and structured on Eberle (2019).

Basic Requirements

Web platforms

As regards to future users of web platforms, various aspects, such as the availability of data, functionality, services, and user management, need to be considered, investigated, and defined when designing a web-based EO platform. These are described in the following paragraphs.

Data availability

The availability of geodata is the fundamental basis of any platform. Therefore, different EO time series and additional geodata must be available in easy-to-use data formats. The platform provider should be able to integrate additional data, such as time series data from climate stations, which can be analyzed together with EO time series data.

Functions

In terms of functionality, various tools are required for geodata, such as data visualization, data download and pixel extraction. Visualization tools allow users to easily work with data and analysis tools. Tools for downloading data are important so that users can work with the data on their own computers. Users must be able to define an area of interest or a single pixel for further exploration of the available spatial data. Time series data analysis tools are useful for exploring the data available on the platform. In addition to providing specific analysis tools, external applications and interactive development environments for different programming languages (e.g. Python and R) can be connected to the platform and made available to users.

Web services

All functions of a platform can be represented as web services for use by external applications (e.g. web and mobile applications and desktop software). Standardized web services can be provided for data collection, visualization, download and analysis. These can be used by external applications and geodata to enable interactive exploration of data, the provision of metadata catalogs and for geoprocessing and analysis tools. In order to provide standardized and geospatial web services, some requirements have to be considered when comparing software solutions:

1) Geospatial data needs to be published automatically as visualization and download services with a pre-defined style for visualization,

2) Metadata needs to be published automatically for new datasets as output from data integration and data analysis, and

3) Users working on their own areas of interest need their own metadata catalogue and geospatial data-service instance separated from services for other users.

User management

The platform stores and manages various information about connected data providers, available data sets and users of the system. All this data must be made available via Web services, since various applications require access to this data. In addition, user-specific data such as areas of interest, data integration performed and analysis tasks can be stored and managed, such as desktop GIS tools or other web-based applications, without the need for customization (Eberle 2019). Geographic Web Services thus are a tool to reduce access and integration issues of heterogeneous geographic datasets. This can ultimately benefit any sector of ecology, economy or society and ensure the development

and expansion of the geospatial data applications, infrastructure and the users community (Alves & Davis 2008).

Web technologies

In the provision of Web services, various aspects of technologies can be considered and evaluated, such as their architecture, long-running processes, service chaining, standards-compliant services and uniform Web service specifications. These are described in the following sections.

Web service architecture
Web services are available with different architectural styles and protocols for distributed service architectures. Therefore, the evaluation of Web service architectures is an important part of building Web-based platforms.

Long-running processes
Both synchronous and asynchronous execution of Web services can be considered for user-oriented Web services. The difference in both cases - whether or not to wait for the result - depends on the application using the Web service. If Web services are executed asynchronously, the client must regularly check the status of the process. In most cases, both types of execution are relevant for the application and depend on each individual process that is provided. Therefore, client and server applications must support both types of execution. Asynchronous execution is particularly important for long ongoing processes, such as data analysis and large data integration tasks It allows users to close the application and check the status later. In addition, the loss of an Internet connection does not stop the Web service that the user is running. Another problem with the execution of the service is that the Web service provides immediate access to the outputs when it is ready, without waiting for all outputs to be generated. This allows the client application to view the results as soon as they are available. For example, the user can see a time series graph of the input data even though another analysis task is still running as part of the same process request.

Service chaining
The concatenation of services often only includes the direct use of a web service as input of another web service. Thus the output of the first web service is directly an input for the second. Since this is useful for many purposes, when using a large time series data output, it is more complex to send it to the next web service. Therefore, a concept is needed that allows subsequent Web Services to know where the data of a previously executed Web Service can be found for further processing on the same server. For example, a data access request is followed by a time series analysis request that is performed with the data of the previously executed access Web service. In most cases, users are not only interested in gaining access to the data, but also in performing analyses. If both Web Services are available on the same infrastructure, search, access and analysis services can be linked together. Thus the output data of the first process must be available for the second process. In addition, algorithms that are provided as Web services (for example, the breakpoint analysis service) must know where the data is stored and how it is managed. If the location and structure of the data within these processes is taken into account, the execution of processing workflows - from data discovery to data access to data analysis - can be realized.

Standard-compliant services
Standard-compliant specifications of Open Web Services (OWS) are defined by and available from the Open Geospatial Consortium (OGC). These can be used by most GIS software and geodata web applications. Compared to a self-developed web service specification, standardized specifications

allow the use of web services from standardized programming libraries and a wide range of geodata tools. Standards are available for various geospatial tasks, such as data visualization, discovery, download and processing.

Uniform web service specification

The specifications of Web services can vary, as different tasks (e.g. data collection, access and analysis) are provided and different data providers offer their services with different performance specifications (e.g. self-developed vs. standard-compliant interfaces). Although standardization organizations like the OGC provide different service specifications for data discovery, access and analysis, they share common methods and data formats that are optimized for machine-to-machine communication with individual output results. A uniform Web service specification is envisaged with the aim of providing several output formats simultaneously for all Web service tasks (detection, access and analysis) (Eberle 2019).

Data formats

In contrast to current web service specifications for data discovery and data access, multiple output formats are required to fulfill the needs of different user personas. This allows the optimizing of the outputs individually for each service in respect of the user personas and their requirements. Examples of output formats for data discovery, access, and analysis are provided in the following paragraphs and summarized in Table 1.

Data discovery

Increasing amounts of EO data and the different requirements of users are challenges when providing EO data archives. A complex task is to find suitable EO data for specific areas of interest, time, and specific parameters (e.g., cloud coverage and sensor type). Considering the user personas described in the previous section, different aspects need to be evaluated. A thematic expert may be more interested in how many satellite scenes are available in the area of interest (e.g., as provided in a figure or a summarized table), while a researcher is interested in an output file, which can be processed by any other software (e.g., by providing CSV or Shapefile formats). A developer is interested in a web service feed, which can directly act as input to further processing workflows. It is not only standardized web formats that are suitable for data discovery. In particular, additional commonly used data formats, such as those of spreadsheets or geospatial data formats increase the ability to use discovery results. Enabling discovery services to comply with the different needs of users leads to the need for multiple data formats for the resulting outputs. Table 1a shows the individual requirements of output formats for fostering their re-use by different user personas.

Data access and extraction

Although the principle of "algorithm to data" is advanced today, many users still download and process data on their own infrastructure. Therefore, EO data access is still an important issue for discussion and evaluation. To comply with the needs of different user personas, besides the requested EO data, it is necessary to provide different outputs (Table 2.3b), such as statistical summaries (e.g., the mean minimum and maximum standard deviation) for each date or chart of time-series data of individual pixels. In addition, the data access service needs to provide processing capabilities to ensure the delivery of pre-processed data that is ready for analysis, including the consideration of quality masks and scaling factors applied to data. Furthermore, the resulting data can be directly converted into formats that can be read by other software, such as the Rasdaman database, Open Data Cube or xcube software. In addition, specific data formats for data extraction services requested directly by applications are necessary (Table 1c).

Data analysis

The ability to provide analysis services enables users to convert data into information. However, in many cases, the algorithms for analyzing time-series data need to have input data in a specific data format and structure. In addition, in most cases, there are several dependencies when setting up the algorithm on local computers. Thus, web processing services, which allow the conducting of analyses in addition to accessing data, are an important step forward in traditional EO data analysis. Furthermore, as the resulting output formats of the algorithms are not always considered to be user-friendly, additional post-processing steps are necessary to provide specific data formats, services, and tools (Table 1d). This allows users direct visualization and interpretation of the results of analysis without the use of additional software.

Table 1: Potential output and response requirements for data discovery (a), data access (b), data extraction (c), and data analysis (d) service outputs (Eberle 2019).

	a) Data discovery	b) Data access	c) Data extraction	d) Data analysis
Data formats				
Vector (e.g., Shapefile)	☑			☑
Raster (e.g., GeoTIFF)		☑		☑
Figures (e.g., PNG, JPEG)	☑	☑	☑	☑
CSV	☑		☑	☑
JSON	☑		☑	
Services				
Web service feed	☑		☑	
OGC download service		☑	☑	☑
OGC visualization service	☑	☑		☑
Tools				
Application-Ready-Data*		☑		
Downloads	☑	☑		☑
Summaries	☑	☑		☑

Summary and conclusions

Several functional and technical requirements for the user-oriented exploration of EO time series data were investigated and categorized into web platforms, web technology and data formats. These have to be considered when developing user-oriented services for the exploration of EO data. The fundamental basis of user-oriented exploration of EO data is the availability of different, individual EO data sources as well as individual analysis tools that are linked to the data. From a technical point of view, web services based on current web technologies, user-specific output formats and uniform and standardised specifications are important requirements (Eberle 2019).

Review of EO Web Services, Tools, and Platforms

DATA Provider Solutions (DPS)

DPS1. ESA/Copernicus Open Access Hub (Sentinel)—OpenSearch

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://scihub.copernicus.eu	ESA	Sentinel	Global	REST	yes	XML, JSON	no

ESA provides the REST-based OpenSearch specification for the discovery of EO data from Sentinel satellites. A single polygon can be used to intersect spatially with the scene of the EO data. The data format for the response can be either XML or JSON with the additional parameter "format". The response contains all available properties for each satellite scene, including identifier, sensor mode, footprint, product type, size, data, and mission specific properties (e.g. polarization mode for radar data and cloud coverage for optical data). However, the quality and format of Quick Look images can be improved for some satellite missions (e.g. Sentinel-1). In addition, a user account is required and only two parallel service requests are allowed (Eberle 2019).

DPS2. USGS Earth Explorer (Landsat, MODIS, Sentinel–2)—self-developed REST API

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://earthexplorer.usgs.gov/inventory	USGS	Landsat, MODIS, Sentinel–2	Global	unknown	yes	JSON	no

The inventory service of the USGS Earth Explorer allows searching for data record collections and satellite scenes. Spatial and temporal filters can be used for both search queries. Cloud cover and individual months can be set for the search for satellite scenes. In addition, additional criteria can be used to filter the satellite scene search with dataset-related parameters. Since USGS Earth Explorer consists of a variety of EO data (e.g. Landsat, MODIS and Sentinel-2), EO data from multiple sources can be searched. The search parameters are encoded as JSON and sent to an individual Web service endpoint for login, collection search, or satellite scene search. The response is encoded as JSON. Each resulting scene contains the following information: Start time, end time, polygon footprint, a bounding box, a quick look image link, a data order link, a link to the data download page, a scene identifier, and a metadata URL. However, only a non-standard Web service interface is available, and an interface key is required to make requests to the service. This key can be obtained via the Login Web Service with a username and password. Full metadata information is only available when an additional external metadata URL is requested (Eberle 2019).

DPS3. NASA CMR (Landsat, MODIS)—self-developed REST API

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://cmr.earthdata.nasa.gov	NASA	Landsat, MODIS, Sentinel–2	Global	unknown	yes	CSV, KML, XML, JSON	no

NASA's Common Metadata Repository (CMR) contains metadata records for EO data. Among others, Landsat and MODIS data are included. A list of record collections can be searched using several filter parameters. Based on a collection identifier, the individual satellite scenes (granular) can be searched using additional parameters. Different types of output formats can be requested for the responses (e.g. CSV, JSON, Keyhole Markup Language and XML). With two Web service endpoints, dataset collections and satellite scenes can be searched. Each of the resulting scenes contains the following information: Start time, end time, polygon footprint, scene identifier as title, quick look image link and data download link. Although filtering can be done by cloud coverage within the request, this information is only available after the full metadata set has been requested. The services can be used without user registration. However, only a fixed set of standardized filter parameters is available, and collection-specific parameters cannot be used to query the catalogue. The responses contain only a limited set of parameters; a further request must be made to query the full metadata set (Eberle 2019).

DPS4. Sinergise Sentinel-Hub (Sentinel, Landsat)—OGC WFS

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://www.sentinel-hub.com/	Sinergise	Landsat, MODIS, Sentinel 2	Global	unknown	yes	XML, JSON	OGC WFS

Sinergise's Sentinel Hub infrastructure provides Web services that are compliant with the OGC for data discovery. Although the common standard for providing data discovery is the OGC CSW, Sinergise publishes the OGC Web Feature Service (WFS) that is used for vector data access to enable satellite scene discovery. The WFS contains a list of dataset collections, which is available with a "GetCapabilities" request. To retrieve the scenes available for a particular data collection, parameters can be used to filter them with a spatial bounding box within the GetFeature request. The response is available in XML or GeoJSON formats, both of which are standard formats of the OGC WFS specification. Each of the resulting scenes contains only a few metadata: date, time, coordinate reference system (crs), a bounding box, the percentage of cloud coverage, the scene identifier (format depending on the satellite mission), the polygon footprint and the path to the local data. However, only a limited set of parameters can be used to detect scenes and only a limited set of metadata is provided in the results. Additional metadata must be requested from external services. A commercial interface key is required to use the services (Eberle 2019).
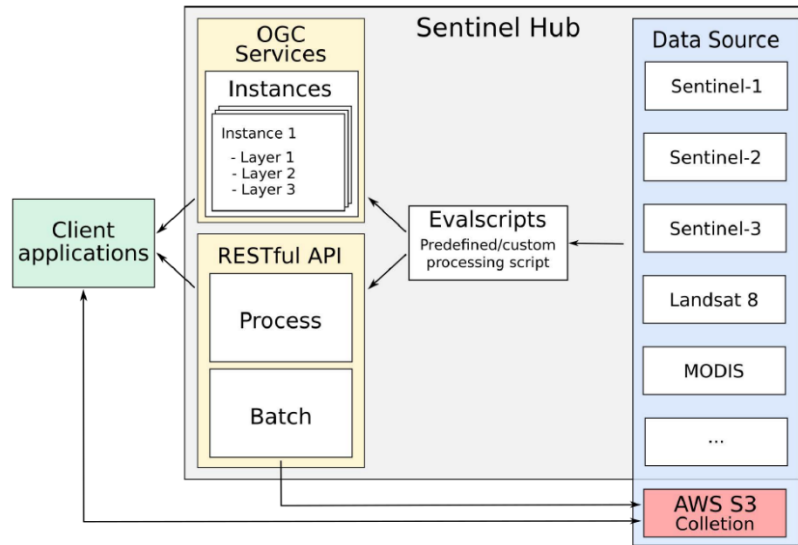
Figure 1: Sentinel Hub service and data abstraction diagram (Gomes et al. 2020)

DPS5. **Airbus Defence & Space**

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
http://www.geoapi-airbusds.com/	Airbus DS	Pléiades Spot	North America, Europe, Asia, Australia and Middle East	unknown	yes	GeoTIFF / JPEG2000	yes

With Airbus OneAtlas API, the access of Airbus satellite images of Pléiades and Spot is possible. The API automatically handles access to Airbus servers, data downloading and map display. API calls can be used to manage subscription to Airbus streaming plans and change detection services.

DPS6. **Planet**

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://developers.planet.com/docs/data/	Planet	Planetscope Skysat RapidEye Landsat-8 Sentinel-2	Global	unknown	Rest	NITF GeoTIFFs	yes

Planet Explorer is an online tool used to search and analyze geospatial imagery, enabling users to see change across the planet over time. Planet Explorer can be used to search through an imagery catalog and either download full-resolution images or stream images and analyze them in the browser.

Planet Explorer can also be used to search and view imagery from Planet's catalogue (PlanetScope, SkySat and RapidEye) as well as public imagery from Sentinel-2 and Landsat 8. Planet's imagery is available at multiple cadences, ranging from daily scenes to weekly, monthly and quarterly basemaps.

Brokered web service solutions BWS

BWS1. CEOS WGISS Integrated Catalog (CWIC)—OGC CSW, OpenSearch

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
http://ceos.org/ourwork/workinggroups/wgiss/access/cwic/	CEOS	Landsat, MODIS	Global	International Directory Network (IDN)	CSW API	catalogue dependent	no

With CWIC19, the CEOS Working Group on Information Systems and Services (WGISS) provides an integrated data catalogue for providers of EO data based on a brokering approach (Shao et al. 2013). The brokering includes metadata catalogues of various organisations such as NASA (USA), USGS (USA), the High Resolution Sea Surface Temperature Group, the European Organisation for the Exploitation of Meteorological Satellites and other international space agencies from India, Brazil, China and Canada. This includes data from Terra, Aqua (both with a MODIS sensor) and Landsat-8 satellites. Standardized interfaces, such as OGC CSW and OpenSearch, are provided by CWIC. The OpenSearch interface has been tested for Landsat-8 data. Filters, such as a bounding box, geometry, start time and end time, can be applied to the search query. Each of the resulting Landsat-8 scenes is described with the following information: Title (this refers to the unique identifier of each Landsat scene), CWIC identifier, date, collection identifier, data center and polygon footprint. Additional external links are provided to access the data download page, Quick Look image, and full metadata set. Although there are a large number of mediated resources from international space agencies, there is currently no support for Sentinel satellites. In addition, it is not obvious that historical Landsat missions are available through the CWIC, as they do not appear in the list of data collections. However, Landsat data are registered in NASA's CMR, which is mediated by the CWIC. The search functionalities are limited (e.g. no filtering for cloud cover). The use of this broker depends on which satellites the users are interested in and whether they have been integrated into the CWIC (Eberle 2019).

BWS2. GEODAB (Sentinel, Landsat, MODIS)—OGC CSW, OpenSearch

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
http://production.geodab.eu/gi-cat-StP/	GEO	Landsat, Sentinel-2 MODIS	Global	several search interfaces, see website	GEO API (DAB)	catalogue dependent	OGC WFS, WMS, WCS

The GEO Discovery and Access Broker (GEODAB; Nativi et al., 2014) acts as a mediation service to mediate between metadata and catalogue standards and to harmonise them. Currently more than 150 data catalogues are registered with the Broker. In addition to the geodata catalogues, GEOSS has also been used to make available data catalogues from EO data providers, such as ESA's Copernicus Open Access Hub, CEOS' FedEO, USGS Landsat-8 and CWIC. Several REST-based resource interfaces are available, such as OGC CSW and OpenSearch. Several search filters can be applied to the search query, such as relative orbit, product type, product level, sensor operation mode, sensor width, processing level, cloud coverage and polarization mode. Additional parameters can be set, but the description will only show abbreviations such as "illazan", "illzean", "sarPolCh", without any further description. The resulting metadata for a Sentinel 2 scene includes the following data: a bounding box, start/end date, platform name, instrument, instrument operating mode, product type, percentage of cloud coverage, relative orbit, polygon footprint, processing baseline and level, orbit direction, start orbit number, download link and several OGC WMS layers added by GEOSS and linked to the Sinergise Sentinel Hub services. Additional metadata for other satellites (e.g. Sentinel-1) can be included in the request to the service. The scene identifier of the original data provider is not a provider, so a subsequent retrieval of metadata from the original data provider is not possible. Although GEODAB can be used to search for satellite data in different data catalogs, the resulting metadata per scene is limited. In most cases, additional metadata must be requested via other services (Eberle 2019).

BWS3. ESA FedEO (Landsat, Sentinel, MODIS)—OGC CSW, OpenSearch

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
http://fedeo.esa.int/opensearch/readme.html	ESA	Landsat, Sentinel-2 MODIS	Global	unknown	no	Atom, RDF/XML, JSON-LD, GeoJSON	Heterogeneous Missions Accessibility (HMA)

The FedEO, established by ESA, provides a unique entry point for multi-source satellite missions. FedEO was originally developed as a prototype for GEOSS and has been provided by CEOS since 2012. It includes EO data archives from ESA (e.g. Copernicus satellites, Landsat data at ESA and historical ESA-SAR missions) as well as EO missions from Canada, an associated ESA member state. In addition, the NASA CMR has been integrated into FedEO, which provides access to other EO data, such as Landsat and MODIS data. OpenSearch and OGC CSW interfaces are provided via FedEO's web service infrastructure. Several response formats are available, including Atom, RDF, JSON-LD (JSON for Linked Data), and GeoJSON, all of which are suitable for developers. A "description document" lists some available data collections as "parentIdentifier", which must be used when searching for satellite scenes. Although the NASA CMR and ESA/Copernicus Open Access Hub data collections are searchable, the collections are not displayed in this list. Therefore, users must know in advance how to search for collections from NASA CMR. Filters such as cloud cover, orbit direction, swath identifier, orbit number, start and end date, and geometry can be applied when requesting the service. Each resulting Sentinel 2 scene is described with the following information: start time, end time, instrument, sensor type, operating mode, orbital number,

orbital direction, polygonal footprint, quick look image link, data download link, cloud coverage percentage, scene identifier, product type, relative orbital number, and tile identifier. The resulting metadata contains a reasonable amount of information, although this depends on the service provider that is being switched. Generally, no user login is required to use this service. However, this may be necessary for some mediated services (e.g. Copernicus Open Access Hub).

BWS4. Planetary Data Access (PANDA)

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://panda.copernicus.eu	ESA	several	depends	unknown	yes	depending	OpenSearch HMA

PANDA (Planetary Data Access) is the CSCDA Catalogue of EO products provided by ESA. It allows browsing of EO products stored in the Copernicus Space Component Data Access (CSCDA) infrastructure or in the Copernicus Contributing Missions (CCMs) archives.
Search results can be exported, opened in Excel or used to create scripts for automatic downloads and also shared with other users. PANDA also supports machine-to-machine access to catalogue products via the OpenSearch and HMA protocols (ESA).

BWS5. EOC Geoservice

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://geoservice.dlr.de/web	DLR	Landsat, Sentinel 2 MODIS	Global	unknown	yes	depending	WMS, WCM, WFS, WCS, CSW,

The EOC Geoservice of the Earth Observation Center (EOC) of the German Aerospace Center (DLR) provides discovery, visualization, and direct download services for a selection of the geospatial data hosted by the German Satellite Data Archive (D-SDA). Based on web technologies and running on high-performance hardware large geospatial datasets can be accessed through the EOC Geoservice. The geospatial data of the EOC Geoservice are accessible through standardized OGC-services which can directly be used by customers to discover and extract data. Additionally, Geoservice data can be discovered and accessed by OGC-based clients and portals, such as the Earth Observation on the WEB (EOWEB©) Portal, the Geoportal.DE, or the GEOSS Data Portal.

BWS6. EUMETSAT

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://www.eumetsat.int/	EUMETSAT	Sentinel 3 and several others	Global	unknown	yes	depending	WCM

EUMETSAT offers a portfolio of data access options that allow users to view imagery and download data, as well providing data push services. Depending upon the choice of data access, users can receive data in either near real-time and/or historical mode.

Our product catalogue, the Product Navigator, allows users to discover which data collections are available through our different data access service. The **Pilot Data Services** offers customized data access. The implemented **Data Tailor** makes it possible for users to subset and aggregate our data products in space and time, filter layers, generate quicklooks, project onto new coordinate reference systems, and reformat into common GIS formats (netCDF, GeoTIFF, etc.). It offers a uniform way to transform both historical and near real-time satellite data provided by EUMETSAT. The **EUMETSAT Data Centre** provides a long-term archive of data and generated products from EUMETSAT, which can be ordered online. **EUMETCast** is EUMETSAT's primary dissemination mechanism for the near real-time delivery of satellite data and products. The Sentinel-3 Marine Products are available through the **Copernicus Online Data Access** (CODA) service.

Cloud-based EO Time-series Data Platforms CTP

Several CTPs have implemented a processing and service platform inside the general cloud based infrastructure. In case, there is an option for that, it will be further addressed.

CTP1. Amazon Web Services

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://registry.opendata.aws/	Amazon Web Services S1+S2 managed by Synergise	Landsat-8, Sentinel-1 Sentinel-2 and others	Global	VMs	Amazon API	Provider dependent	no

Amazon Web Services (AWS) is the world's most comprehensive and widely used cloud platform, with more than 175 feature-rich services deployed in globally distributed data centers.
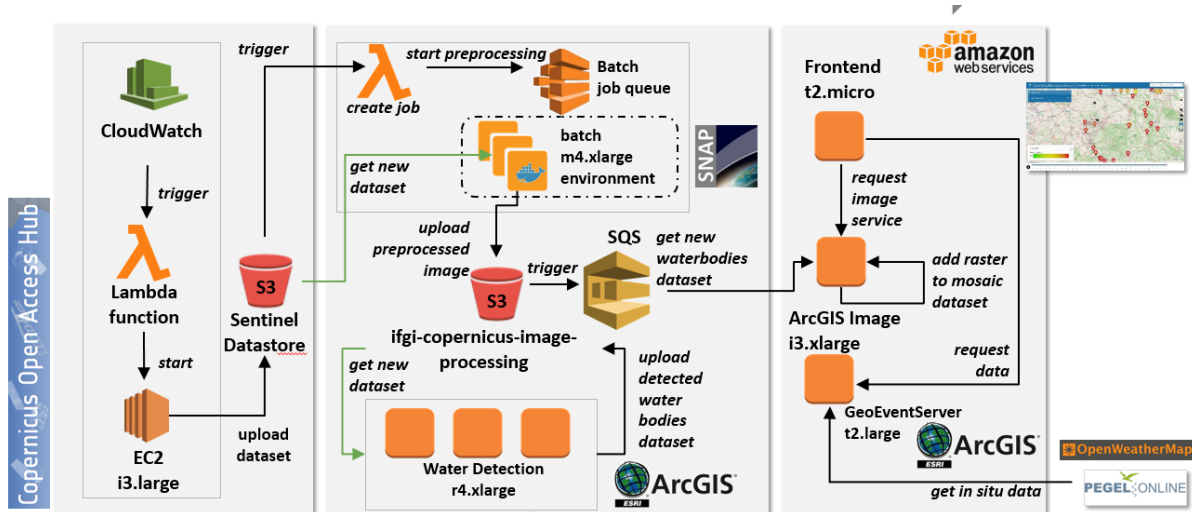
*Figure 2: Example of a Diagram of AWS processing Implementation
(https://aws.amazon.com/de/blogs/publicsector/eogis-training-lab-with-on-demand-services-from-aws/)*

CTP2. Google Cloud / Earth Engine - Python API

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://cloud.google.com/ storage/docs/public-datasets/ https://earthengine. google.com/	Google Cloud Earth Engine	Landsat 1-8, Sentinel-2, MODIS, USGS Archive	Global	Google Compute engine, Google ML	yes	provider dependent	yes

Google provides discovery, access and analysis tools for a wide range of spatial data sets, including EO data archives from USGS Landsat, ESA Sentinel and several MODIS products (Gorelick et al. 2017). All tools are available via the web-based JavaScript editor (Playground) and the web services based Python library 'earthengine-api'. A whitelist service account is required to run the Python Earth Engine API in automated workflows (e.g. within a web processing service). Within the Google Earth Engine, satellite scenes can be filtered from data collections using various metadata properties (e.g. cloud cover, temporal and spatial boundaries, or any metadata element). In addition, individual properties can be calculated and used to filter the collection. The metadata does not include links to external Quick Look images or links to download data, as both can be calculated and provided directly within the Google Earth Engine. Listing shows the request for a Sentinel 1 collection filtered by point geometry and additional properties of the data set (VV polarization and descending orbit direction). The response within the Python API is a list of objects that can be processed directly in Python. So far, however, only the Python library is available for use in self-developed applications. Therefore, these applications must be developed in Python or a Python script must be available that is executed from the command line (Eberle 2019).
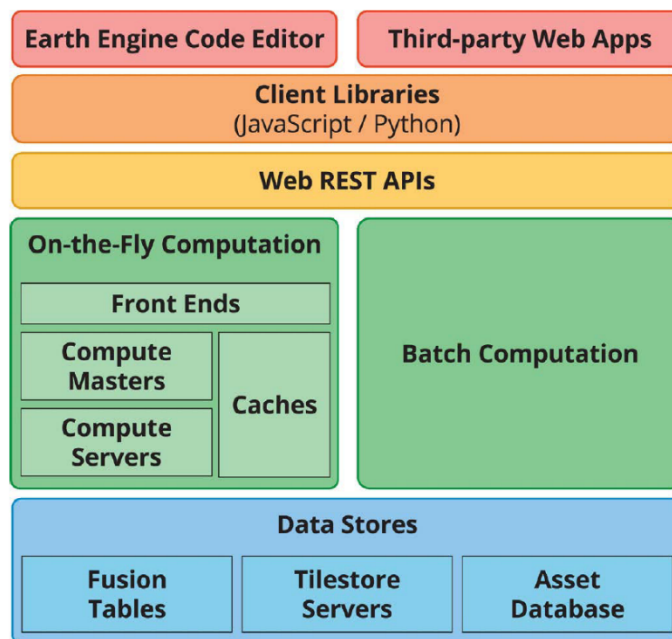
Figure 3: Simplified Google Earth Engine (GEE) system architecture diagram. (Gorelick et al. 2017)

CTP3. Copernicus DIAS

Since Copernicus became the largest space data provider, producing several terabytes per day, there is a need to facilitate and standardise access to this data. The following five Data and Information Access Services (DIAS) representing cloud-based platforms for users to discover, manipulate and process of EO data from Copernicus (and earlier GMES).

CTP3.1. CREODIAS

URL	Data	Extent	Architecture	API	Data format	Web Service
https://creodias.eu/	Sentinel-1 Sentinel-2 Sentinel-3 Sentinel-5P Landsat5 Landsat7 Landsat8 Envisat SMOS S2GLC	Europe + Global + S1 Global (6 month rolling archive)	cloudferro based VMs	EO Browse EO Finder (JSON)	GDAL	OGC WMS WCS WFS WMTS

The design of CREODIAS, like other DIAS, allows third party users to build and manage their own processing chains trough access to array of Platform as a Service appliance.

CTP3.2. MUNDI

URL	Data	Extent	Architecture	API	Data format	Web Service
https://mundiwebservices.com/	Sentinel-1 Sentinel-2 Sentinel-3 Sentinel-5P Landsat8	Europe + Global	Telekom Cloud based on OpenStack	HTTP REST API	GDAL	OGC WMS WCS WFS WMTS

Beside several commercial applications to be processed cloud-based, Mundi is providing directly available open source components like the Orfeo Tool Box and ESA SNAP.

CTP3.3. ONDA

URL	Data	Extent	Architecture	API	Data format	Web Service
https://www.onda-dias.eu/cms/	Sentinel-1 Sentinel-2 Sentinel-3 Sentinel-5P Landsat8 KOMPAS Deimos-2 Envisat VHRD	Europe + Global	VMs OpenStack	ENS (Elastic Node Server)	GDAL	OGC WMS WCS WFS WMTS

One of the individual components of ONDA is to provide a database of in situ datasets which could be expanded by user demand and be available at the ONDA Web portal.

CTP3.4. WEkEO

URL	Data	Extent	Architecture	API	Data format	Web Service
https://www.wekeo.eu/	Sentinel-1 Sentinel-2 Sentinel-3 Sentinel-5P	Europe + Global	VMs Jupyter Notebooks	Harmonised Data Access (HDA) API	GDAL	OGC WMS WCS WFS WMTS

The option to discover what other users have built with the data and processing tools provided by WEkEO will be implemented.

CTP3.5. SOBLOO

URL	Data	Extent	Architecture	API	Data format	Web Service
https://sobloo.eu/	Sentinel-1 Sentinel-2 Sentinel-3 Sentinel-5P SPOT 6/7 Pleiades	Europe + Global	Orange Business Services based on OpenStack	OpenSearch CSW REST	GDAL	OGC WMS WCS WFS WMTS

Besides providing open source components like other DIAS, one highlight of sobloo is so CAP, a detailed satellite-derived crop analytics tool in collaboration with Airbus.

CTP4. SEPAL

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://sepal.io/	Open Foris team	Landsat Sentinel-1 Sentinel-2	global	AWS	yes	unknown	yes

SEPAL is an opensource project by the Open Foris team in Forestry Department of the United Nations Food and Agriculture Organization (FAO), funded by the Government of Norway. The SEPAL platform can be accessed through a web portal (https://sepal.io), running on the AWS infrastructure, or it can be installed on the user own infrastructure using Vagrant for the management of processing instances.
The web portal provides following functionalities that are divided into 4 areas—Process, Files, Terminal, and Apps (Gomes et al. 2020).

- Process: the user can search and retrieve images for further processing or viewing, by selecting the area, the sensor (Landsat or Sentinel-1 and 2) and the period of interest on the web interface.
- Files: this platform does not provide any web service to access the data or send processing requests to the server. Its features are more focused on the management of computational resources (virtual
- Terminal: The area called Terminal allows users to start a machine in the AWS cloud. Before executing it, users must choose one of the 22 hardware configurations available. Each machine is associated with a cost per hour of use.
- Apps: SEPAL also supports applications like RStudio, Jupyter Notebook, Jupyter Lab, and interactive documents that run on an R Shiny Server.
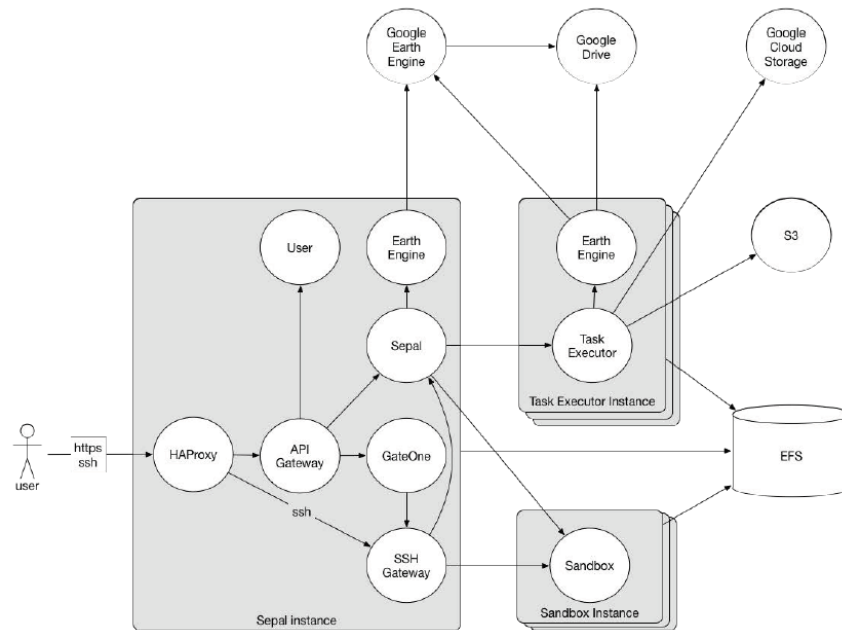
Figure 4. Architecture diagram of the System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) platform (FAO 2020)

CTP5. JEODPP

The Joint Research Center (JRC) Earth Observation Data and Processing Platform (JEODPP) is a closed solution developed since 2016 by the JRC for the storage and processing of large volumes of Earth observation data. This platform has features for interactive data processing and visualization, virtual desktop and batch data processing.

Figure 5: System architecture for interactive visualization and processing ofEarth observation (EO) data on Joint Research Center (JRC) Earth Observation Data and Processing Platform (JEODPP) platform. (Soille et al. 2018)

Toolboxes for Desktop or VMs

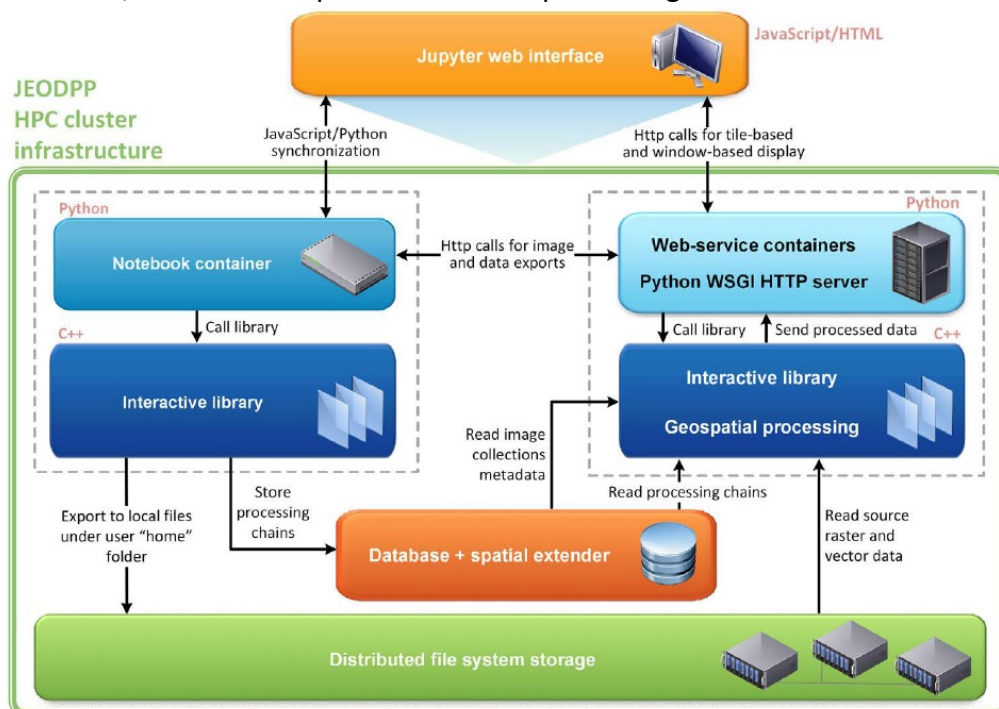The use of Toolboxes, to process EO data with predefined possible selection options and the possibility to use batch processing, promoted this service during the last years. In the range of Copernicus data, in the following we do not consider all available toolboxes.

TB1. ESA G-Pod (RSS Cloudtoolbox)

URL	Data	Extent	Architecture	API	Data format	Web Service
http://eogrid.esrin.esa.int/cloudtoolbox/	ESA EO Data	Global	VMs	yes	depending	OGC WMS, WCS, WFS, WMTS

ESA provides an on-line platform, called GRID Processing on Demand (G-Pod), to support the development, test and hosting of Processing Services provided by Institutions and Researchers for the access and processing of EO data.
The RSS CloudToolbox service provides registered ESA EO-SSO users with customised virtual machines made available on a cloud infrastructure. To support the specific needs of the Earth Observation community, RSS provides CloudToolboxes that are equipped with the latest ESA and third-party tools for EO data processing (e.g. SNAP, BEAM and PolSARPro).

TB2. SNAP

URL	Data	Extent	Architecture	API	Data format	Web Service
http://step.esa.int/main/toolboxes/snap/	ESA EO Data	Global	Desktop / VM	yes	GDAL DIMAP	no

SNAP is common architecture for all Sentinel Toolboxes is being jointly developed by Brockmann Consult, SkyWatch and C-S called the Sentinel Application Platform (SNAP).
The SNAP architecture is ideal for Earth Observation processing and analysis due to the following technological innovations: Extensibility, Portability, Modular Rich Client Platform, Generic EO Data Abstraction, Tiled Memory Management, and a Graph Processing Framework.

TB3. Sen2Agri

URL	Data	Extent	Architecture	API	Data format	Web Service
http://www.esa-sen2agri.org/	Sentinel 2 Landsat8	Global	Desktop / VM	RESTful API	GDAL DIMAP	no

The Sen2-Agri system is an operational standalone processing system generating agricultural products from Sentinel-2 (A&B) and Landsat 8 time series along the growing season. These different products consist of:

- monthly cloud-free composites of surface reflectance at 10 – 20 m resolution;
- monthly dynamic cropland masks, delivered from the agricultural mid-season onwards;
- cultivated crop type maps at 10 m resolution for main crop groups, delivered twice along agricultural seasons;
- periodic vegetation status maps, NDVI and LAI, describing the vegetative development of crops each time a cloud-free observation is recorded.

The Sen2-Agri system is free and open source, allowing any user generating near real time products tailored to his needs at its own premises or on cloud computing infrastructure (www.esa-sen2agri.org). Mainly the processing is based on Orfeo Toolbox.

TB4. Orfeo Tool Box

URL	Data	Extent	Architecture	API	Data format	Web Service
https://www.orfeo-toolbox.org/	various	Global	Desktop / VM	python	depending	no

Orfeo ToolBox (OTB) is an open-source project for state-of-the-art remote sensing. Built on the shoulders of the open-source geospatial community, it can process high resolution optical, multispectral and radar images at the terabyte scale. A wide variety of applications are available: from ortho-rectification or pan sharpening, all the way to classification, SAR processing, and much more!

All of OTB's algorithms are accessible from Monteverdi, QGIS, Python, the command line or C++. Monteverdi is an easy to use visualization tool with an emphasis on hardware accelerated rendering for high resolution imagery (optical and SAR). With it, end-users can visualize huge raw imagery products and access all of the applications in the toolbox. From resource limited laptops to high performance MPI clusters, OTB is available on Linux, macOS and Windows. It is community driven, extensible and heavily documented.

National Services

National Services, as we considered them here are (beside CODE-DE) implemented as an Open Data Cube (ODC). ODC is an Open Source Geospatial Data Management and Analysis Software project that helps harness the power of EO data. At its core, the ODC is a set of Python libraries and PostgreSQL database that helps you work with geospatial raster data. The ODC seeks to increase the value and impact of global Earth observation satellite data by providing an open and freely accessible exploitation architecture. The ODC project seeks to foster a community to develop, sustain, and grow the technology and the breadth and depth of its applications for societal benefit. Due to the open data policy of the Copernicus Satellite missions, the gathered data can be easily implemented in the ODCs of the individual participating nations. Until 2022, the ODC initiative is willing to achieve at least 20 ODCs. For more information visit https://www.opendatacube.org/.
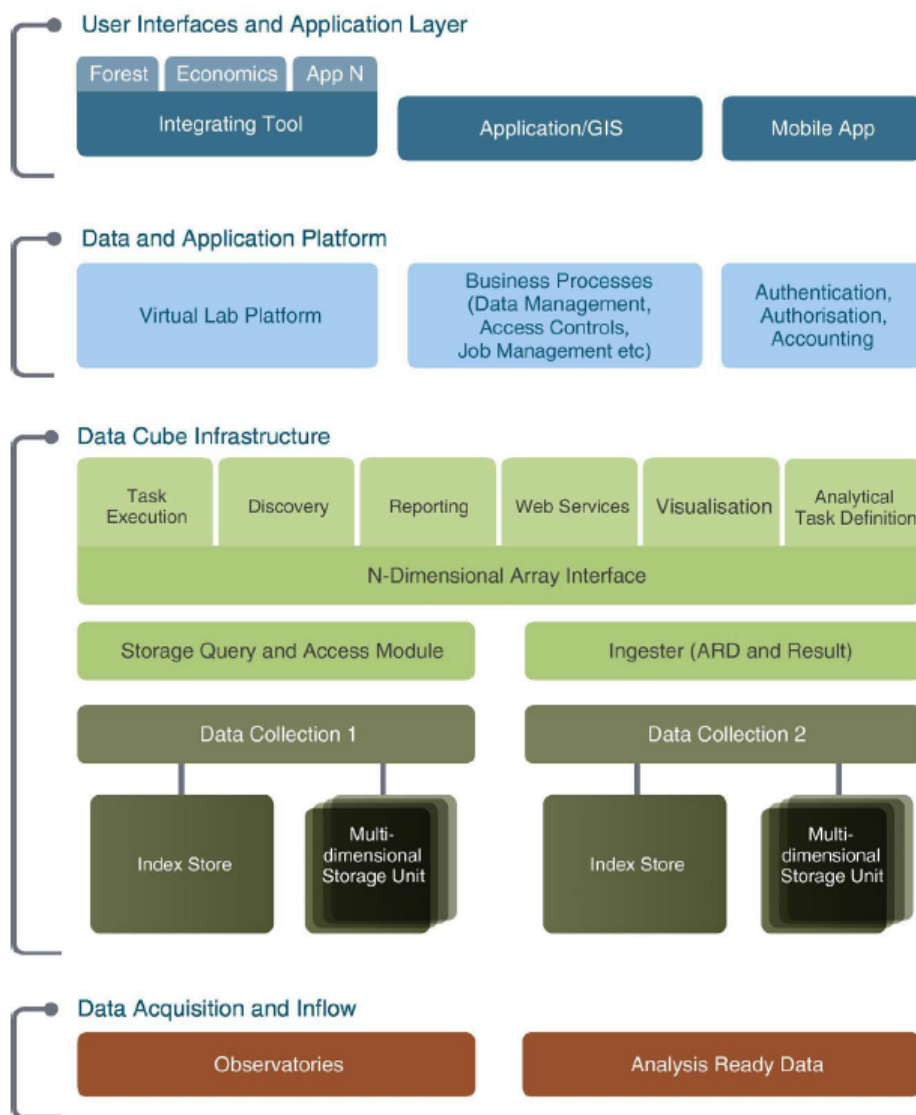

Figure 6: Architecture diagram of the Open Data Cube (ODC) platform (Lewis et al.)

NaS1. Swiss Data Cube Switzerland

URL	Data	Extent	Architecture	API	Data format	Web Service
http://www.swissdatacube.org	Landsat 5-7-8 Sentinel 1 Sentinel 2	Global	ODC	yes	depending	OGC & API

To fully benefit from freely and openly available Landsat and Copernicus data archives for national environmental monitoring purposes, the Swiss Federal Office for the Environment (FOEN) is supporting the development of the Swiss Data Cube (SDC—http://www.swissdatacube.ch). The SDC is currently being developed, implemented and operated by the United Nations Environment Program (UNEP)/GRID-Geneva in partnership with the University of Geneva (UNIGE), the University of Zurich (UZH) and the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). The objectives of the SDC are twofold. First, to support the Swiss government for environmental monitoring and reporting; and second, to enable Swiss scientific institutions to take advantage of satellite EO data for research and innovation.

The SDC is built on the Open Data Cube software suite, and currently holds 36 years of Landsat 5, 7, and 8 (1984–2020), 6 years of Sentinel-1 (2014–2020), and 5 years of Sentinel-2 (2015–2020) of ARD over Switzerland. This archive is updated on a daily basis with the most recent data and contains approximately 10,000 scenes, accounting for a total volume of 6 TB, and more than 200 billion observations nationwide.

Initial interoperability arrangements are currently under development. In the SDC, we decided to distinguish between upstream and downstream services. The upstream tier relates to services to interact with the infrastructure (e.g., processing, view, download) while the downstream tier allows users interacting with decision-ready/value-added products. Both tiers are implementing widely adopted open standards for modeling and implementing geospatial information interoperability advanced by the OGC and ISO/TC211.

Upstream tier:

- *SDC Web Interface*. This allows users to explore the potential of the Data Cube technology and run different algorithms using a web-based graphical user interface. http://sdc.unepgrid.ch
- *SDC Jupyter Notebook*. This Notebook allows to use the Data Cube Python API to develop tailored algorithms and applications. Compared to the web interface, this is for more advanced users and requires having an account to get access to it. http://sdc.unepgrid.ch:8080/
- *Discovery:* SDC description is being done using the ISO19115-2 and ISO19139-2 standards to support gridded and imagery information. The XML schema has been deployed and exposed using the GeoNetwork metadata catalog to store all relevant information to adequately describe the SDC content (e.g., sensors, spatial resolution, temporal resolution, spectral bands). The schema plugin has been downloaded from the GeoNetwork GitHub repository: https://github.com/ geonetwork/schema-plugins. Moreover, the GeoNetwork catalog allows exposing an OGC CSW interface for publishing metadata records and allowing users to query the catalog content.

- *View and Download:* To leverage the content of the SDC for visualization and download, respectively OGC WMS and WCS are under implementation. The datacube-ows component (available at: https://github.com/opendatacube/datacube-ows) implements the WMS and WCS standards allowing an interoperable access to Landsat and Sentinels data.
- *Process:* To expose analytical functionalities (e.g., algorithms) developed in the SDC using the ODC Python Application Programming Interface (API), it has been decided as using a PyWPS implementation (https://pywps.org). The main advantage is that it is also written in Python, and allows easy to expose, dedicated Python scripts as interoperable WPS services. That approach is currently under implementation and testing.

Concerning the *downstream tier*, it has been separated from the SDC for the reason that only final products (e.g., validated analysis results) are concerned. That facilitates the publication and sharing of good quality results through value-added/decision-ready products, while at the same time separating the usage of the Swiss Data Cube between scientific/data analysts end-users and more general end-users.

To that, a specific GeoServer (http://geoserver.swissdatacube.org) instance with dedicated EO extensions and time support has been implemented. It allows users to efficiently interact with multi-dimensional (e.g., space and time), gridded, and image products generated with the SDC. It currently supports:

Discovery services
- CSW 2.0.2.
- OpeanSearch EO 1.0.

View services
- Web Map Service (WMS) with EO extension 1.1.1/1.3.0.
- Web Map Tile Service (WMTS) 1.0.0.
- Tile Map Service (TMS) 1.0.0.
- Web Map Tile Cached (WMS-C) 1.1.1.

Download services
- Web Coverage Service (WCS) with EO extension 1.0.0/1.1.0/1.1/1.1.1/2.0.1.
- Web Feature Service (WFS) 1.0.0/1.1.0/2.0.0.

NaS2. CODE-DE Germany

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://code-de.org	DLR / CloudFerro	Sentinel-1 Sentinel-2 Sentinel-3 Sentinel-5P and other	depending on sensor	see Figure 4	yes	depending on process	see Figure 4

The German Copernicus Data and Exploitation Platform (CODE-DE) provides tools for discovery and access to worldwide Sentinel data as well as TerraSAR-X, SRTM-X-SAR and other data for visualization purposes. User registration is required to download and process the data. Since CODE-DE provides a rolling archive, not all scenes are available (Reck et al. 2019).

The length of the rolling archive depends on the geographical region and the EO mission. The files are stored in the same format as on the ESA/Copernicus Open Access Hub, so that a zipped archive file is available. Scenes can be accessed using the URLs below, which include variables for the year, month and day the scene was shot, as well as the scene label (Reck et al. 2019) (Eberle 2019). The Copernicus data is free available for government, science and commercial use.

In 04/2020 CODE.DE was relaunched based on CloudFerro Copernicus DIAS.

CODE.DE Web Interface. This allows users to explore the data of Sentinel-1, Sentinel-2 and Sentinel at different processing level using a web-based graphical user interface.

- CODE.DE contains all available S1, S2, and S3 data for Germany and data for Europe for the last 12 months.

The data can be accessed also via API using the Copernicus Data-access and Exploitation platform for Germany (CODE-DE) - user tools (https://github.com/dlr-eoc/code-de-tools). For downloading data via the web platform or API an account is necessary.

Information and data products are accessible through a web map viewer where several layers are shown. Furthermore tools can be applied on the data.

NaS3. THEIA Land Data Centre - France

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
http://theia-land.fr	IRSTEA, IRD, CNRS, INRA, IGN, MeteoFrance, CIRAD, ONERA	e.g. Pleiades, Landsat, Sentinel-2, Spot, Venµs	France + global	unknown	yes	depending	OGC-ODC

Theia Data and Services centre for continental surfaces was created at the end of 2012 by 9 French public institutions involved in Earth observation and environmental sciences. The purpose of this scientific and technical structure is to facilitate the use of images resulting from the spatial observation of continental surfaces.

Theia provides the national and international scientific community and public policies aiming to monitor and manage environmental resources with a wide range of images at different scales, products, methods and training related to the observation of continental surfaces, particularly from space.

Theia provides several satellite data and satellite-based products as well as in-situ data and provides also software products.

NaS4. NOA Hellenic National Sentinel Data Mirror Site – Greece

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
sentinels.space.noa.gr	NOA, IAASARS	S1, S2, S3	Aroud Mediterranean Sea	ODC	yes	depending	OGC-ODC

The HNSDMS is a web based system designed to provide EO data users with search, catalogue, sorting and dissemination capabilities for Sentinel products. The retention time of the provided products is only limited to 30 days.

NaS5. NationalMap Australia

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://nationalmap.gov.au/	Australian Government	wide range of data	mostly national	ODC	yes	depending	OGC-ODC

NationalMap is an online map-based tool to allow easy access to spatial data from Australian government agencies. It was an initiative of the Department of Communications and the Arts (DCA) now currently managed by the Digital Transformation Agency (DTA) and the software has been developed by Data61 working closely with the DCA, Geoscience Australia and other government agencies.

NaS6. Taiwan Data Cube Taiwan

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
https://twdc.colife.org.tw/	National Space Organization, NAR Labs	wide range of data	national	ODC	yes	depending	OGC-ODC

The Taiwan Data Cube (TWDC) based on the power of the Open Data Cube to help address the needs of satellite data users, giving them a better picture of their land resources and land change. The system provides:

- Ease of use and access to satellite-based data
- Multiple dataset interoperability and spatial consistency
- Use of "Analysis Ready" Data Products
- A Shift in Paradigm from Scenes to Pixels

URL	Provider	Data	Extent	Architecture	API	Data format	Web Service
http://52.54.26.108/	Global Partnership for Sustainable Development Data (GPSDD)	focus on forest, illegal mining, urbanization, flooding	Intranational: Kenya, Tanzania, Sierra Leone, Ghana, Senegal	ODC	yes	depending	OGC-ODC

The Taiwan Data Cube (TWDC) based on the power of the Open Data Cube to help address the needs of satellite data users, giving them a better picture of their land resources and land change

Conclusions

As shown in this article, there is a wide variety in access opportunities and services, provided in the context of EO data. Through standardized web services, data formats and web based discoverable data, the user can focus more on the gain of information, rather than the (pre)processing and storage necessities. EO data, which is accessible directly from the data provider also processable by middleware broker and cloud-based systems, to be implemented directly in several programming language environments or costumer ready software. Commercial services might come with the downside of long-term costs, but high initial costs as for own server architectures can be omitted. That said, the open source and non-commercial data providing- and processing services listed in this article, serving already a vast amount of opportunities for researchers, governmental employees. The application reaches from agriculture, forest, marine and urban monitoring to risk management, SDG and so on. Figure 7 & 8 show comparison of user requirements between different web services providers for discovery, access and processing of EO data.

Since the open access policy of the Copernicus data it is very likely, that we couldn't consider every service, which is connected to those data. A still growing users community and the general potential growth in the utilization of data, also undoubtedly effect the geospatial data services emerging in the next time.

a) Data discovery services

	ESA/Copernicus Open Access Hub	USGS Earth Explorer	NASA CMR	Google Earth Engine	Sentinel-Hub	GEOSS Broker	CEOS WGISS	ESA FedEO
Service architecture	REST	REST	REST	N/A	REST	REST	REST	REST
Asynchronous	❌	❌	❌	N/A	❌	✅	❌	❌
Standardized services	OpenSearch	❌	❌	❌	OGC WFS	OGC CSW, OpenSearch	OGC CSW, OpenSearch	OGC CSW, OpenSearch
OGC specification	❌	❌	❌	❌	✅	✅	✅	✅
Output formats	XML, JSON	JSON	XML, JSON, CSV	N/A	XML, GeoJSON	XML, JSON	XML	XML, GeoJSON
Authentication needed	Yes	Yes	No	Yes	Yes	No	No	*

b) Data access services

	ESA/Copernicus Open Access Hub	USGS Earth Explorer	NASA CMR	Google Earth Engine	Sentinel-Hub	USGS ESPA	Amazon Web Services	Google Cloud
Service architecture	REST	REST	REST	N/A	REST	REST	REST	REST
Asynchronous	❌	❌	❌	✅	❌	✅	❌	❌
Standardized services	Open Data Protocol	❌	❌	❌	OGC WCS	❌	HTTP URL	HTTP URL
OGC specification	❌	❌	❌	❌	✅	❌	❌	❌
Output formats	XML, JSON	JSON	XML, Atom, JSON	N/A	XML	JSON	N/A	N/A
Data formats	ZIP	GeoTIFF, ZIP	*	Python object, GeoTIFF	GeoTIFF, PNG, JPEG	GeoTIFF, HDF-EOS, ENVI	GeoTIFF	GeoTIFF
Authentication needed	Yes	Yes	*	Yes	Yes	Yes	No	No
Summarized results	❌	❌	❌	❌	❌	❌	❌	❌

* dependent on data provider

Figure 6. Comparison of user requirements between different web services providers for discovery and access of EO data (Eberle 2019).

	Google Earth Engine	Sentinel-Hub	NASA Giovanni	ORNL DAAC	Open Data Cube	Rasdaman
Multi-source EO and geospatial data*	Landsat, MODIS, Sentinel	Landsat, MODIS, Sentinel	MODIS	MODIS	Landsat, MODIS, Sentinel**	Landsat, MODIS, Sentinel**
EO data visualization	✓	✓	✗	✓	✗	✓
Time-series data download	Export to Google Drive or download links	Individual requests to web service	Individual data requests	Zipped archive file after order submission	✗	Summarized statistics, individual requests
Analysis tools	Various programming functions	Various programming functions	Fixed set of tools	Phenology, Land cover	Fixed set of tools**	Through WCPS query
Analysis output formats	Interactive maps and charts, GeoTIFF	Through OGC WMS, WCS web service	Interactive charts, netCDF, CSV	GeoTIFF, Graphics, R, CSV, Interactive charts	Default**: PNG, GeoTIFF, netCDF	GeoTIFF, CSV, PNG
Data analysis with various programming languages	✗	✗	✗	✗	Python through connected Jupyter Notebook	
EO data discovery	✓	✓	✗	✗	✗	✗
Own user management	✓	✗	✗	✗	✓	✗
Self-hosting	✗	✗	✗	✗	✓	✓
Interfaces	Python API, UI	REST, UI	UI	REST, SOAP, UI	Python, REST, UI	REST
OGC web services	TMS	WMS, WCS, WFS	✗	✗	WMS, WCS**	WCPS
Lineage information	✗	✗	✓	✗	✗	✗

* Only Landsat, Sentinel, and MODIS are considered here

** Dependent on each instance

UI = User interface

Figure 7: Comparison of user requirements between different processing and service platforms for access and analysis of EO data (Eberle 2019).

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