European Commission

JRC TECHNICAL REPORTS

Sentinel-2 web platform for REDD+ monitoring

Online web platform for browsing and processing Sentinel-2 data for forest cover monitoring over the Tropics

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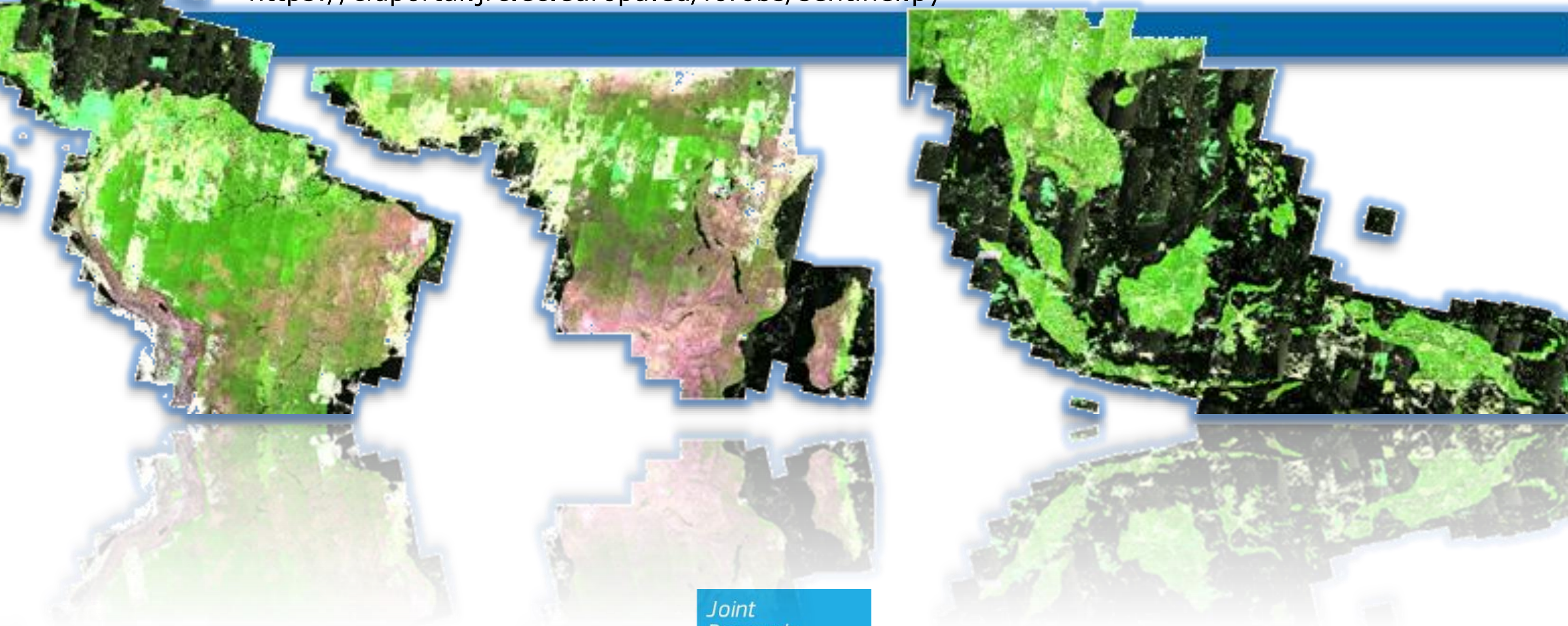
Strobl P., Burger A., Soille P., Achard F., Eva H., Stibig H.J., Beuchle R.

2017

https://cidportal.jrc.ec.europa.eu/forobs/sentinel.py



Joint Research Centre

EUR 28658 EN

This publication is a Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication.

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JRC Science Hub
https://ec.europa.eu/jrc

JRC105805

EUR 28658 EN

PDF ISBN 978-92-79-69733-3 ISSN 1831-9424 doi:10.2760/790249

Ispra: European Commission, 2017

How to cite this report: Simonetti D., Marelli A., Rodriguez D., Veselin V., Strobl P., Burger A., Soille P., Achard F., Eva H., Stibig H.J., Beuchle R., Sentinel-2 web platform for REDD+ monitoring, online web platform for browsing and processing Sentinel-2 data for forest cover monitoring over the Tropics. EUR 28658; doi:10.2760/790249

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Acknowledgements

This work would not have been possible without the free access to satellite data sets provided through the COPERNICUS programme (http://www.copernicus.eu/)

The feedback received from partners from the ReCaREDD project (http://forobs.jrc.ec.europa.eu/recaredd/partners.php) has largely contributed to defining and improving the tool functionalities.

Authors

The Sentinel-2 web platform has been developed by staff from the Bio-Economy Unit of Directorate D - Sustainable Resources - and from the Text and Data Mining Unit of Directorate I – Competences - in the framework of the ReCaREDD project (Reinforcement of Capacities for REDD+) and the Big Data pilot project on Earth Observation and Social Sensing (EO&SS@BD)

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Abstract

The recent availability of time series of Sentinel-2 imagery represents a significant technological step in the use of Earth Observation (EO) data for forest cover monitoring. The 5 days revisiting time (S-2 A and S-2B satellites) and the 10m spatial resolution imply the need for much larger storage and processing resources than ever. To facilitate the use of Sentinel-2 imagery by national forestry services in the tropics (in particular in relation to REDD+ activities), the JRC has developed the *Sentinel-2 web platform*, an online Web system which is aimed at browsing, exploring and processing the full dataset of Sentinel-2 imagery available over theTropical belt.

1 Introduction

In the context of the European Union's fight against global warming, the Joint Research Centre (JRC), is developing services and methods to support the monitoring of forest degradation and carbon emissions in tropical countries through the ReCaREDD project (Reinforcement of Capacities for REDD+) initiated in 2013. The JRC is also supporting the development of future services of the Copernicus programme.

ReCaREDD project

The ReCaREDD project (Reinforcement of Capacities for REDD+) is aimed at enhancing the capacity of existing institutions and networks to report on their mitigation actions in the forest sector (REDD+). This project uses the best available science and knowledge to develop, jointly with partner countries, techniques for forest monitoring and to strengthen national capacities to report on REDD+ challenging activities, such as forest degradation.

The project is relying on fine resolution optical satellite imagery. A large amount of imagery is needed to test and develop pertinent methodologies together with the partner institutions. Appropriate satellite imagery is freely available since 2015 through the Copernicus programme of the European Commission, in particular from the Sentinel-2a satellite launched in 2015 by the European Space Agency (ESA).

The access to reliable and free software is often a bottle-neck in the use of satellite imagery in developing countries. Therefore, the project aimed at developing free open-source software for accessing, processing and analysis of satellite imagery at the various steps of the processing chain, from image selection to the production of maps.

Sentinel-2 satellite imagery for forest monitoring

The recent availability of time series of Sentinel-2 imagery at fine spatial resolution (10 m) and high temporal frequency (every 5 days with S-2A and S-2B) represents a significant "scale-step" in the use of Earth Observation (EO) data for the monitoring of forest resources.

This expectation is based on 3 major aspects of the Copernicus programme, each of which contrasts markedly with previous EO scenarios:

1. the unprecedented technical quality of the sensors, in each of the radiometric (relevant channels), spatial (resolution and swath-width) and temporal (revisit frequency) sense;
2. the "Full, Free and Open" data policy /licensing scheme;
3. the global coverage of land with a guaranteed continuity (> 10 years) of observations.

Tropical forest mapping and monitoring is a key application domain for EO due to the need for recurrent and frequent data to produce annual information on forest cover in humid and seasonal domains and regular information on forest disturbance processes. It benefits from long term consistent archives of Landsat imagery for forest area change, for instance in support to various mature and operational applications such as the Global Forest Watch (GFW) platform ([1]) of the World Resources Institute and the PRODES project ([2]) of the Brazilian National Space Agency. Previous attempts to integrate high resolution EO imagery into operational forest degradation mapping and monitoring have largely failed due to inadequate technical parameters, high costs and uncertain long term perspective. The EO use in this community is currently mostly limited to Landsat sensors (30 m), with global or

([1]) http://www.globalforestwatch.org/
([2]) http://www.obt.inpe.br/prodes/index.php

regional coverage products of tree cover percentages or forest / non-forest binary maps, released at yearly intervals.

Key limitations in the use of Landsat sensors are the mixed nature of the measured signal, and the difficulty in identifying forest cover disturbances. The latter aspect is especially important in areas where small scale processes are significant. The introduction of Sentinel-2 is essential for the generation of the estimation of areas under specific disturbance factors and the separation of forest specific biophysical parameters. The use of forest-specific map layers derived from Sentinel-2 will become essential time series in inter-annual trend analysis in forest area change, even if it requires a number of years of consistent observations.

The Sentinel 2 sensors – together with Landsat 8 - will provide a core capacity on which a viable set of globally consistent services in the forestry domain could be based, setting the stage for a number of innovative and challenging applications, and to the redesign of monitoring systems for more accurate monitoring of forest degradation.

The introduction of Sentinel-2 will potentially lead to a spread of forest monitoring capacities to national and regional government levels in the next 5 to 10 years, for instance, as an extension or component of National Forest Inventory (NFI) systems.

Issues related to access and processing of Sentinel-2 imagery

Since June 2015 Sentinel-2 MSI products are available to users via the ESA DataHub (scihub and cophub) in compressed .SAFE format [1], designed to wrap a folder containing image data and product metadata as follows:

- a manifest.safe file which holds the general product information in XML;
- a preview image in JPEG2000 format;
- subfolders for measurement datasets including image data (granules/tiles) in GML-JPEG2000 format at native spatial resolutions (10,20,60 mt) and coordinate system (UTM);
- subfolders for datastrip level information;
- a subfolder with auxiliary data (e.g. International Earth Rotation & Reference Systems (IERS) bulletin);
- HTML previews.

Before October 2016 one Sentinel-2 image (.SAFE) was about 6Gb, a volume of data often difficult to handle, especially in areas with week internet connections. Additionally the individual granules (13) following the Military Grid Reference System (see Annex 1) could have different coordinate system (UTM zone). After that date, to overcome the 256 characters limitation on pathnames imposed by Windows platforms and to reduce the size, all products were delivered in the form of one granule per .SAFE, about 600Mb.

Despite those improvements, the volume of data to be transferred over internet remains significantly high and the .SAFE file format handling could be an obstacle for non-technical users due to the heterogeneity of data formats and spatial resolutions contained.

Rationale for a Sentinel-2 platform for REDD+ monitoring

In this technical report, we describe the platform that has been developed for contributing to the MRV (Monitoring, Reporting and verification) purposes of the REDD+ activities by:

- improving image screening offering full resolution browsing to better identify cloud-free areas before downloading;
- reducing data volume and file format conversion with server-side pre-processing facilities.

ReCaREDD partners will have the possibility to visualize, select and download a tailored product to better cope with the frequent problem of internet capacities and stability at their institutions.

Due to the daily data volume received and hardware demanding processing workflows, implementation has only been possible tanks to the collaboration with the Earth Observation and Social Sensing Big Data pilot project (EO&SS@BD) teams.

EO&SS@BD project

The JRC Earth Observation and Social Sensing Big Data (EO&SS@BD) pilot project was launched on the 1st January 2015 as a response to the need for JRC to pursue a dedicated approach to 'Big Data' and address the volume, variety, and velocity of the data flows originating from the EU Copernicus programme. As a result, the setting up of a JRC Earth Observation Data and Processing Platform (JEODPP) for big data storage, management, processing, and analysis was initiated in 2016 with first hardware received in June 2016.

Its specifications are primarily based on the requirements of JRC Knowledge Production Units. During the period 2017–2018, the JEODPP will be further developed and scaled-up while increasing its user basis.

The EO&SS@BD project contribute to the establishment of a European Big Data Centre at JRC mentioned in the Communication from the Commission on the European Cloud Initiative ([3]). Furthermore, by improving information retrieval and delivery while enabling and promoting collaborative working and knowledge sharing, the EO&SS@BD project meets several of the actions referred to in the Communication of the European Commission on Data, Information and Knowledge Management at the European Commission ([4]).

Finally, the EO&SS@BD multi-year pilot project contributes to JRC collaborations with international institutions, in particular with CERN, ESA, and SatCen.

([3]) Obser1COM(2016) 178, SWD COM(2016) 106 and 107, see http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=15266

([4]) COM(2016) 6626, SWD(2016) 333 final, see http://ec.europa.eu/transparency/regdoc/rep/10102/2016/EN/SWD-2016-333-F1-EN-MAIN-PART-1.PDF.

2 Sentinel-2 data browser and processing tool

Sentinel-2 data browser (https://cidportal.jrc.ec.europa.eu/forobs/sentinel.py) provides a user-friendly interface to query and browse the entire archive of Sentinel-2 images hosted in the JEODPP storage (see Chapter 3). It is built on free and open source solutions for both client-side user interface (OpenLayers [2] and ExtJS [3]) and server-side applications such as Apache [4], Python [5], Mapserver [6] and GDAL [7].

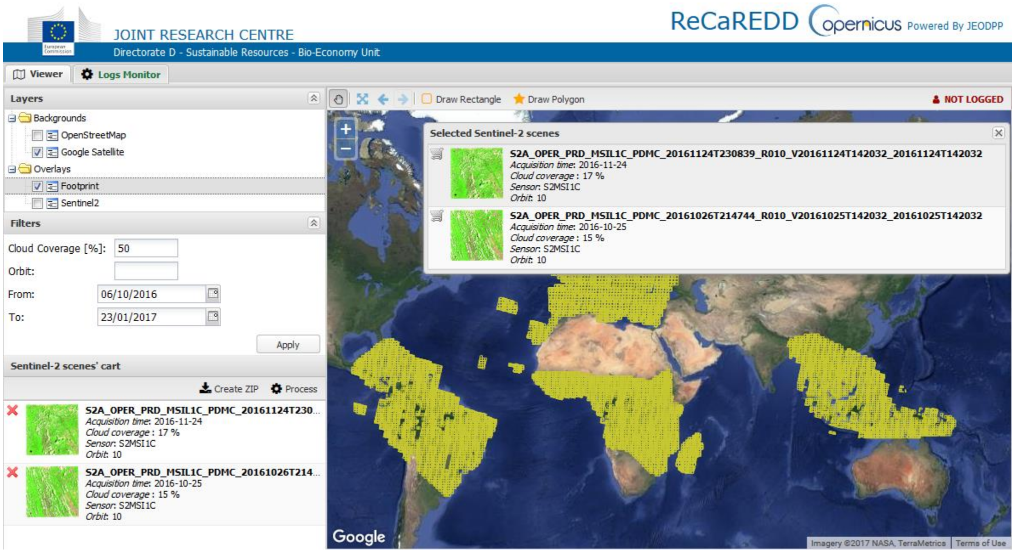


Figure 1 Sentinel-2 data browser

Compared to existing Sentinel-2 data browser solutions, the JRC Sentinel-2 data browser offers improved image screening capabilities exposing to partners the full resolution imagery acquired over tropics from late 2015 allowing better identification of cloud-free areas before downloading. Secondly, but not less important, the tool gives the possibility to download raw ESA .SAFE archive or tailored made product such as single GeoTiff file with limited spatial extent (subsetting) and/or selected bands, custom resolution and geographical projections.

2.1 Image screening

Sentinel-2 data browser implements different strategies to guide users in searching the most suitable images by offering:

- Customizable filter such as maximum cloud coverage, orbit and time range;
- Automatic level of details according to map scale (zoom): from simple image footprints at country level, through pre-generated quick-looks to better identify the area of interest and its characteristics till the full 10Mt resolution below 1000Km^2;
- Possibility to set different band combinations and specific stretch once reaching the full resolution mode;
- Auto selection of the best image to be rendered on top, based on internal ranking build upon percentage of cloud cover and no-data;
- Query mode to interact with the archive showing useful information such as quick-looks, acquisition time, orbit, cloud coverage of all images intersecting the point on the map (click) and fulfilling the selected filters.

2.2 Image Processing & Download

Once desired images have been inserted in the user’s cart is possible to choice two processing options:

- *Create ZIP*: create a compressed archive containing the original .SAFE format. For each image in the cart, server-side processing takes approximately 10 seconds while downloading time depends on user’s internet bandwidth since each file is about 600Mb.
- *Processed GeoTIFF*: this option allows processing steps including band selection, projection, output resolution and subsetting by using area of interest (AOI) previously drawn or uploaded. For each image in the cart, server-side processing takes from 2 minutes to few seconds according to the number of bands and conversion steps. However, the size to be transferred over internet might be drastically reduced.

Is worth noting that pre-processing and conversion to GeoTIFF does automatic bands layer-staking at desired resolution and projection using nearest-neighbour resampling method; is also possible to reduce the data type format from Unsigned Integer 16Bit to Byte 8Bit (Reflectance $_{byte}$ = Reflectance $_{Uint}$ * 0.0255).

Once ready, images can be downloaded using the link provided in the Log Monitor panel; logs and processed data will be kept on the server for 7 days.

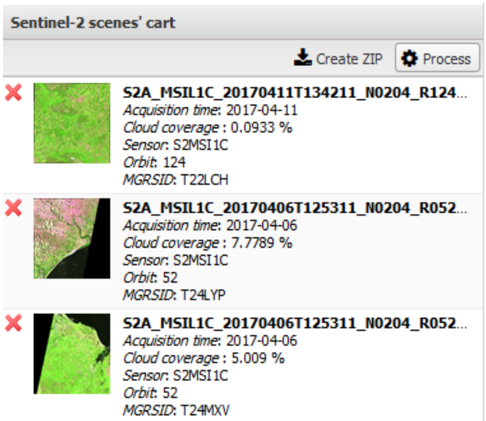


Figure 2 User’s cart

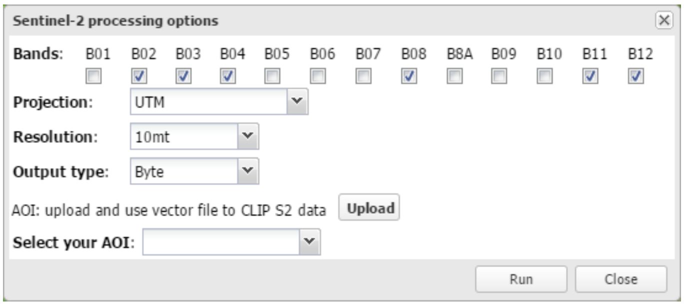


Figure 3 Sentinel-2 processing options

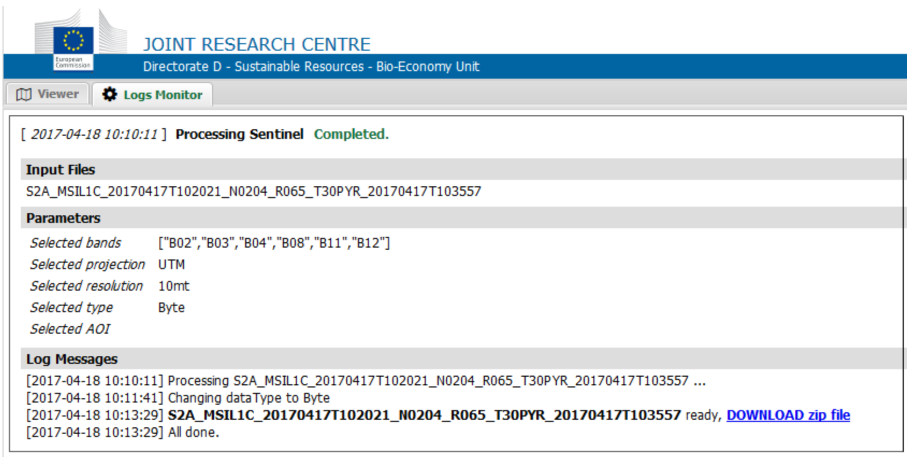
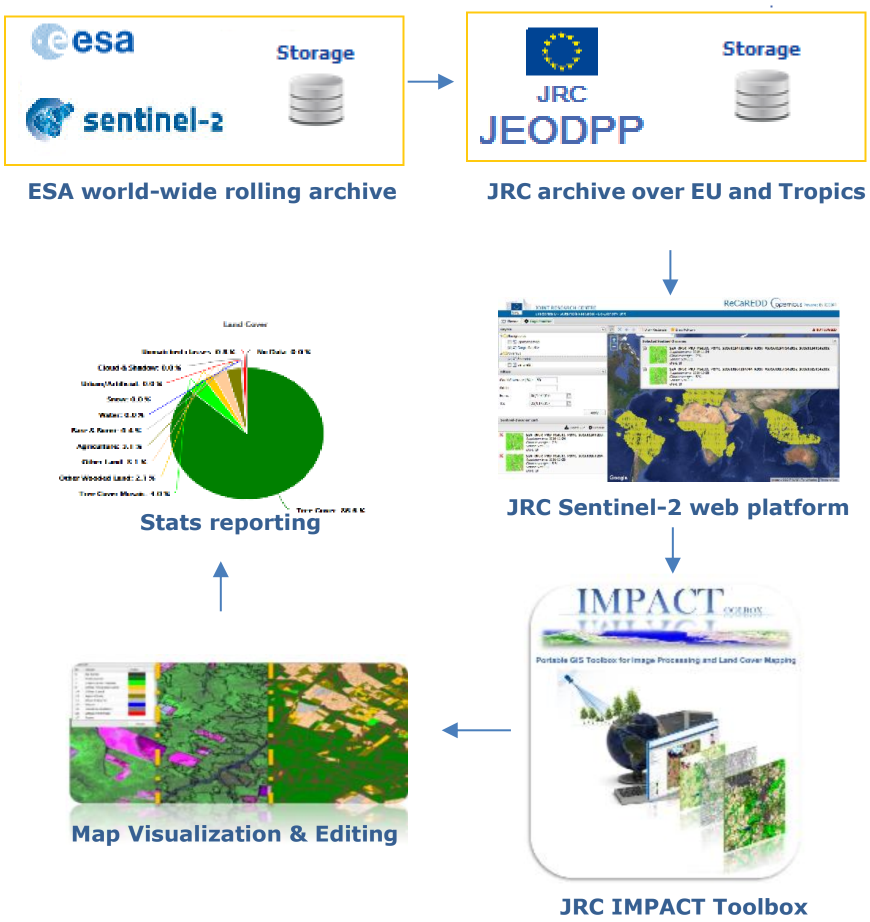


Figure 4 Log Monitor panel showing active processing and download links

3 Sentinel-2 web platform: integration with other REDD+ monitoring tools

The access to reliable and free software is often a bottleneck in the use of satellite imagery in developing countries. Therefore, the project aimed at developing a suite of free open-source software for accessing, screening, downloading, processing and analysis of satellite imagery.

Sentinel-2 web platform represents the bridge between "the cloud" (either storage or processing) and user "local" data that can be further processed, analysed, transformed to generate maps and statistics using the JRC IMPACT Toolbox [8], a free and open-source software tailored to the mapping and monitoring of disturbed/degraded tropical forest using Sentinel-2, Landsat and RapidEye data.



Both applications are sharing the same processing modules to ensure quality standards and preserve data interoperability; therefore a TOA reflectance Sentinel-2 multi spectral image downloaded from ESA and processed with IMPACT will coincide with the same image processed and downloaded from the Sentinel-2 web portal. However, is worth noting that the "cloud" processing option might drastically reduce processing and downloading time, enabling ReCaREDD partners to better cope with the frequent problem of internet capacities and stability at their institutions.

4 The JRC Earth Observation Data and Processing Platform

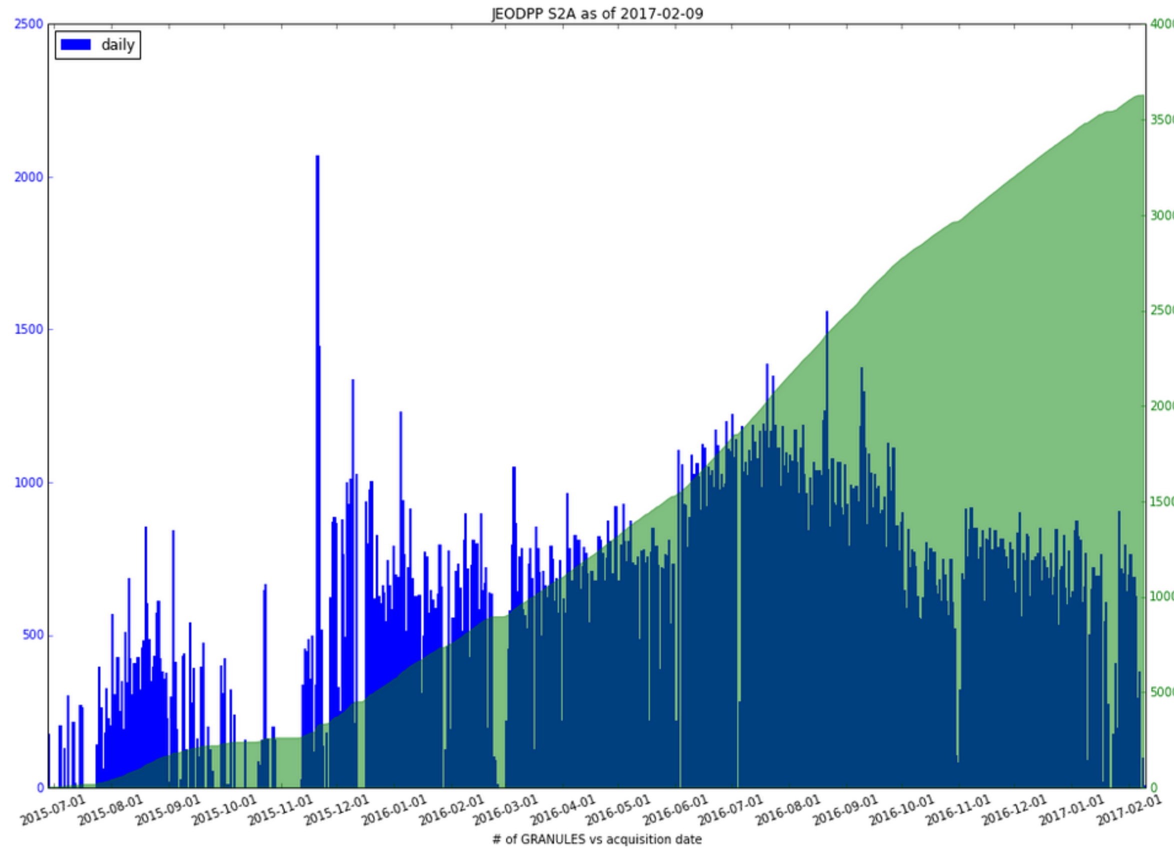
The IFORCE web interface application is deployed on the JRC Earth Observation Data and Processing Platform (JEODPP) developed in the context of the JRC Earth Observation and Social Sensing Big Data EO&SS@BD pilot project. This section describes briefly the JEODPP platform, the Sentinel-2A data collection, and the containerisation technology enabling the IFORCE web interface to run on the JEODPP

Hardware components and distributed file system

The JEODPP relies on combined distributed storage and processing servers based on commodity hardware [8] [9]. The servers are interconnected thanks to 10 gigabit per second (Gbps) ethernet connections relayed by a dedicated network switch. As of April 2017, the JEODPP is equipped with 1.9 petabyte of raw storage made available from 14 storage servers. The storage servers are associated with 37 processing servers for a total of 992 CPUs and 15 terabytes of RAM. Files are automatically distributed to disks associated with the storage servers thanks to the EOS distributed file system developed by CERN [10]. The deployment of the JEODPP EOS instance benefits from the CERN-JRC collaboration agreement. From a user perspective, the whole storage space is accessible from a single location. All data is stored with a replica level set to 2 to secure data integrity and increase the data throughput so that the net storage space amounts to 0.95 petabyte.

Data population

The automatic download of Sentinel-2 data is achieved by using a time-based job scheduler launching OpenSearch and OpenData (ODat) scripts every night. The data is selected taking account user areas of interest (AOIs) as well as maximum cloud coverage percentage. It is then downloaded from the ESA Sentinel data hubs (scihub and cophub). For Europe, all products with a cloud coverage less than or equal to 70% are downloaded while a value of 90% is considered for the tropical belt. As soon as a new Sentinel-2 product is downloaded from the ESA data hubs (scihub and cophub), it is uncompressed and stored on EOS keeping its original data structure (.SAFE) and file format (JPEG-2000). Note that after the 24th of October 2016, all products are delivered in the form of one granule/tile per product. Each granule corresponds to a tile of the Military Grid Reference System (see Annex 1). Figure 5 shows the amount and geographic distribution of the Sentinel-2 data available on the JEODPP storage. The creation of an additional GDAL [7] virtual file provides a unique access point to all bands and resolutions to ease cataloguing and data browsing while avoiding any kind of data redundancy or transformation. Although the JPEG-2000 file format guarantees the best compression factor limiting the amount of data to be transferred over the network, RGB false colour composite rendering at full resolution is resource demanding and requires optimisation on both hardware and software sides.



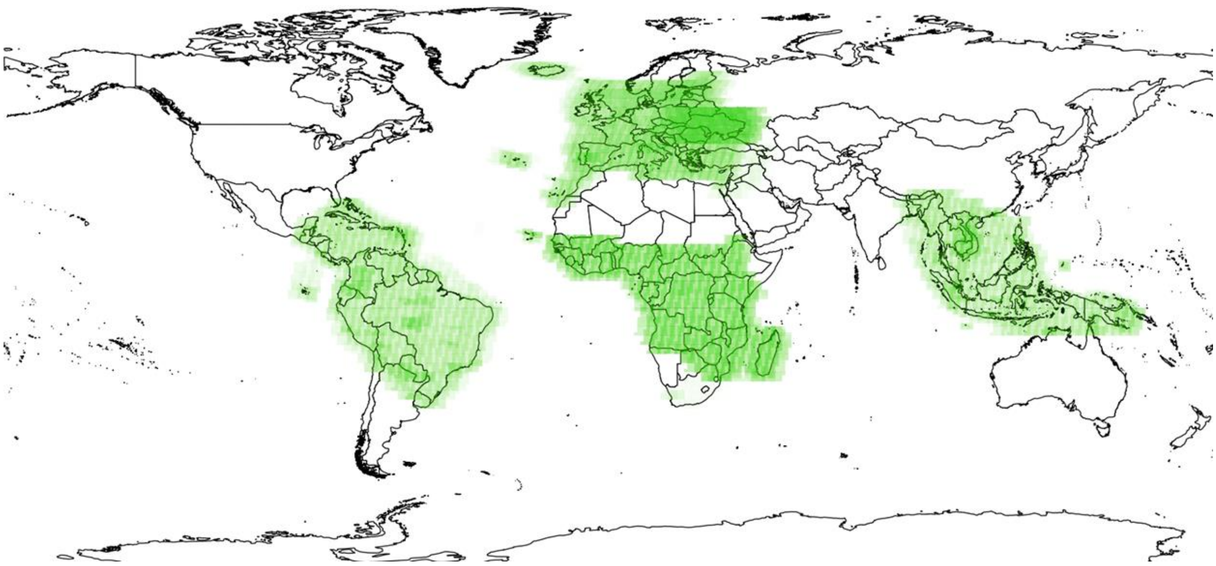


Figure 5 Sentinel 2A data available on JRC Earth Observation Data and Processing Platform (JEODPP). Top: daily and cumulative number of granules downloaded on JEODPP versus their date of acquisition (from launch on the 23rd of June 2015 to February 2017). Bottom: accumulation map indicating the number of S2A available observations on the JEODPP as of February 2017.

Containerisation

Virtualisation technologies enable the creation of a series of virtual machines on the same server that all act if they were real machines with their own operating system. Containerisation is a lightweight type of virtualisation also called operating-system-level virtualisation in which the kernel of an operating system allows the existence of multiple isolated user space instances, instead of just one([5]). Thanks to the user-space isolation, containers with different software libraries can run in parallel without interfering with each other. Also, there is almost no overhead in running an application in a container for it relies on the kernel of the underlying operating system. The JEODPP implements lightweight virtualisation based on Docker containers [11] ([6]). Each Docker container executing a given task is triggered from a Docker image file that contains all the required software and associated libraries. The Docker images themselves are built from Docker files, i.e., scripts containing all the instructions to build step-by-step, layer-by-layer, automatically from a source (base) image a target image satisfying all the desired software requirements.

([5]) https://en.wikipedia.org/wiki/Operating-system-level_virtualization

([6]) https://www.docker.com

5 Web-service container approach

The concept of web-service containerisation for Sentinel-2 data consists of a layer of abstraction that holds the services for web browsing and processing. Containers are also providing a solution for the separation between development and production environments. To fulfil the IFORCE requirements, Docker containers are deployed with GDAL 2.1.0 [7], Impassive 7 [12], Web Server Apache2 [4], Jupyter console 5.1 [13](7), and Python 2.7 [5]. The Sentinel-2 web-service provides a set of processing functions that is in continuous evolution. For this reason, the JEODPP offers to developers and users high service availability implemented following the architecture depicted in Figure 6.

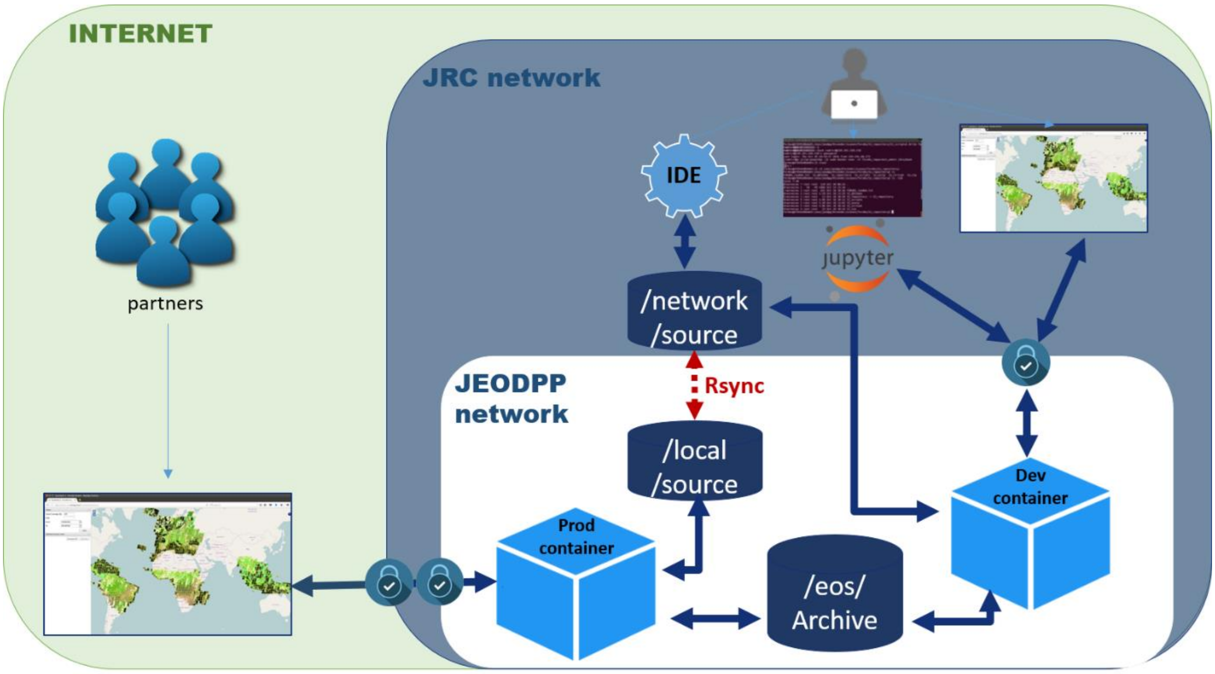


Figure 6 JEODPP web-service container based architecture for IFORCE

The service architecture consists of two layers based on two distinct Docker containers: (i) a dev-container focused on the development and testing and (ii) a prod-container for production accessible to internal and external users. The dev-container consists of three main components providing a flexible environment to the developers:

1. Shared drive: this network drive is mounted from the development container. It provides access to the source code of the application edited outside the JEODPP with a dedicated Integrated Development Environment (IDE);
2. Web bash terminal: based on interactive shell architecture of Jupyter [13] where the developers can execute bash commands and launch scripts on the development container each time the source code is updated. The access is granted solely to developer accounts (8) through a secure network gateway;
3. Development site: internal web site to assess the results of the new developments before deploying a new release on the production site.

(7) http://jupyter.org

(8) https://cidportal.jrc.ec.europa.eu/jhub/

The prod-container is handled exclusively by the administrators of the JEODPP in close collaboration with the IFORCE developers. It is based on a Docker image matching a stable instance of the dev-container. Each stable instance corresponds to a given release of the application. The prod-container hosts the production web-service open to external users through a secure network gateway. The functions offered by IFORCE client-server application on the JEODPP are also useful for other projects within the JRC using Sentinel-2 data. This illustrates that the JEODPP is enabling and promoting collaborative working and knowledge sharing, as opposed to a fragmented approach, where functions are restricted to the project level and cannot be scaled to massive data sets.

6 Outlook

Originally developed to provide users having limited technical abilities with an easy and lightweight access to the full wealth of Sentinel-2 data, the chosen architecture and the implementation of the Sentinel-2 web platform yield a large potential well beyond that. Since the launch of the Google Earth Engine (GEE) in 2010, image processing through a browser based application instead of locally installed software has already received quite some attention.

The massive amounts of Earth Observation data that become available with the launch of several Sentinel satellites further fuel the discussion how an appropriate infrastructure providing access to respective archives and processing capabilities should be designed. To find answers to this challenge the COPERNICUS program has recently, as part of its Integrated Ground Segment, started to fund a series of Data Information and Access Systems (DIAS) which are supposed to fill the gap between data provision and product generation by means of coordinated cloud based infrastructures. The functional requirements[9] are summarised in Figure 7.

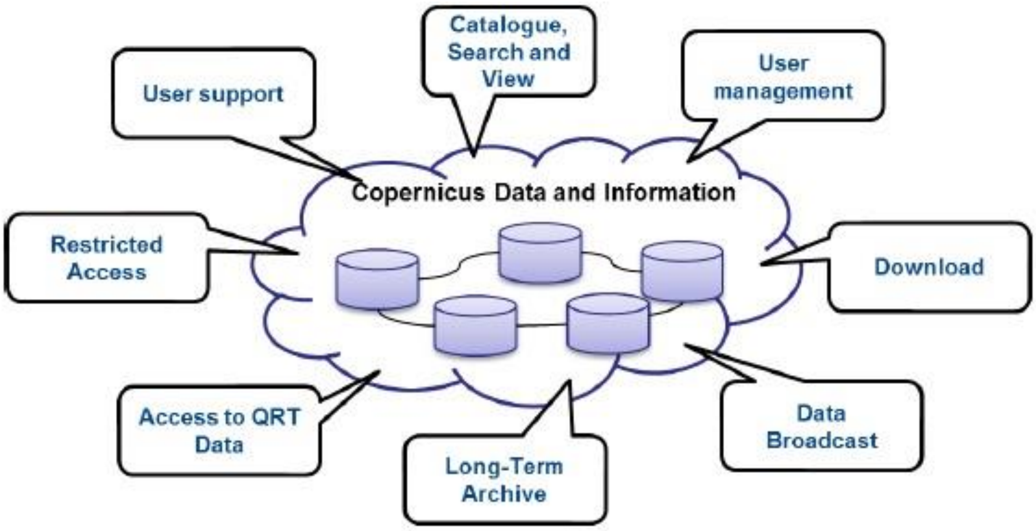


Figure 7 Required functionalities of the Copernicus distribution services. Source:ESA

A key concern of the DIASs are their User Interfaces which will play a decisive role in the user acceptance of the offered data and services. The Sentinel-2 web platform described in this report can thereby be considered as a pilot and due to its open-source basis also as a testbed which would enable an almost instantaneous basic functionality on a wide range of possible existing cloud based archive and storage infrastructures. Most of the required technical functionalities regarding the SW interface such as Catalogue search and view, Download, and User management are already implemented or could be easily added. The open-source policy is thereby an important factor allowing the mandatory interoperability between the various implementations.

[9] http://copernicus.eu/sites/default/files/documents/News/Data_Access_Functional_Requirements_Dec2016.pdf

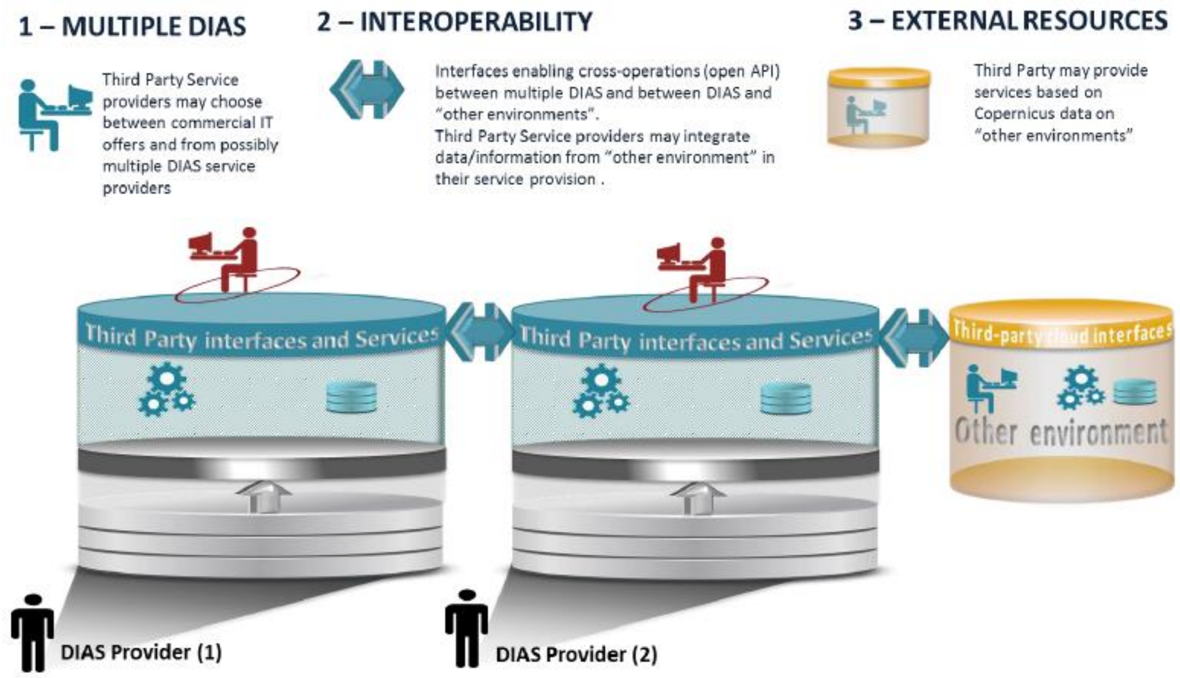


Figure 8 Multiple Dias and interoperability. Source: ESA

Future extensions could envisage to allow for local as well as remote processing and storage of data or even a combination such that processing times and data transfer loads could be optimised according to resources available at each end and for the transfer in between.

7 Conclusions

Compared to existing Sentinel-2 data browser, the JRC solution offers improved image screening capabilities exposing the full resolution imagery acquired over the tropical belt and Europe from late 2015. Online computing and tailored made output might drastically reduce processing and downloading time, enabling ReCaREDD partners to better cope with the frequent problem of internet capacities and stability at their institutions.

JRC is furthermore offering free of charge WMS/WPS services to partners in order to add Sentinel2 imagery directly into desktop GIS application (ArcGIS, QGIS) or any other web-based solutions.

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List of abbreviations and definitions

IFORCE	International Forest Resources and Carbon Emissions
JEODPP	JRC Earth Observation Data and Processing Platform
ESA	European Space Agency
REDD+	Reducing Emission from Deforestation and forest Degradation
ReCaREDD	Reinforcement of Capacities for REDD+

Annexes

Annex 1. Military Grid Reference System and Sentinel-2 tiles

Sentinel-2 data is delivered in the Military Grid Reference System7 (MGRS). MGRS is derived from the Universal Transverse Mercator (UTM) grid system and the universal polar stereographic (UPS) grid system, but uses a different labelling convention. The MGRS is used for the entire earth (UTM up to -80 degrees and below +84 degrees and UPS for the two polar regions. In the case of Sentinel-2 data, only the UTM component of the MGRS is used since all data takes fall in the range [−56o,+84o]. The 5 character 100 km tile names are in the form ZZABC where ZZ refers to the UTM zone number (i.e., ZZ ∈{01,02,...,60}, A to the UTM latitude band (with A ∈ {C,D,...,X} \{I,O})8, and BC to the column and row index of the tile within the zone (with B ∈{A,B,...,Z} and C ∈{A,B,...,V}\{I,O}). The Sentinel-2 MGRS implementation is not fully compliant with the official MGRS system because a tile of zone ZZ overlapping the zone ZZ + 1 is delivered in UTM zone ZZ + 1 if and only if this is necessary to avoid create gaps in the data. This is illustrated in Figure 9 where the tile 30PZT overlaps the zone 30 but the MGRS tile 31TBH does not exist for its footprint is fully covered by 30TY N. This non-symmetric treatment creates irregular patterns in the Sentinel-2 tiling system that can also be observed in Figure 9 at the boundaries between adjacent UTM zones.

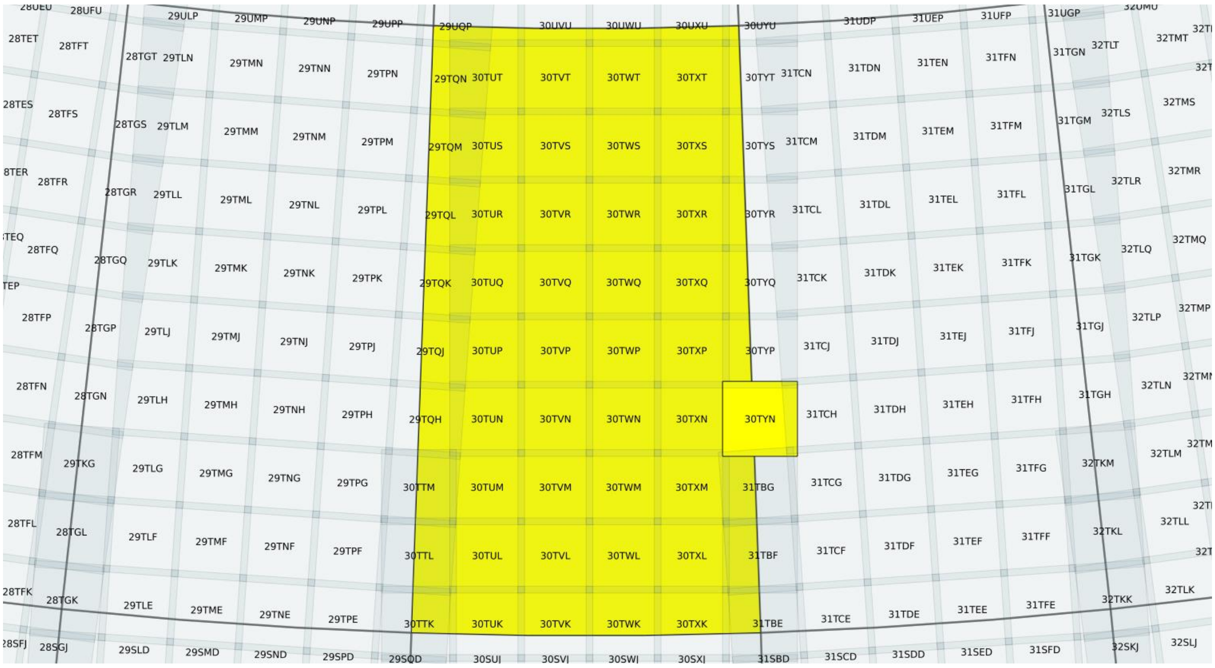

Figure 9 The S2A MGRS-based tiling system: close-up highlighting the asymmetry at the UTM zone borders.

KJ-NA-28658-EN-N

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Publications Office

doi:10.2760/790249
ISBN 978-92-79-69733-3