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SENTINEL DATA ACCESS ANNUAL REPORT (01/12/2015 – 30/11/2016)

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FOREWORD

Frascati, 27 March 2017



It is with pleasure that I introduce to you the 2016 Sentinel Data Access Annual Report. This report follows on from the first Sentinel Data Access Annual Report, released on 27 April 2016, and highlights the tremendous growth which took place during the course of the last twelve months, in terms of the volume of data published on the Sentinel Data Access System, user registrations and the number of products which were disseminated during the year.

The uptake of Sentinel products within 2016 far exceeded our targets and our most optimistic expectations. The extent to which Sentinel data is being used within and beyond Europe became apparent at the Living Planet Symposium

held in Prague in May 2016. This major event in the Earth Observation calendar provides a system perspective on state of the art in the field of Earth Observation research and exploitation. With a record 3,000 participants, and an overwhelming display of posters and presentations related to the Sentinels, the EU Copernicus programme has had an immediate and highly significant impact on the Earth Observation community. Moreover, the uptake and re-distribution of Sentinel data by GMES and Copernicus Participating States, via their collaborative ground segments, our international partners and by commercially oriented organisations, illustrates well the global interest in this EU-led initiative.

This Annual Report has been prepared by the Serco SpA/GAEL consortium, which is responsible for the development and operations of the Sentinel Data Access System. As such, it contains detailed statistics and analysis regarding the uptake of Sentinel data during the year, as well as an inside view on the challenges faced by the Data Access operations team, as they adapted to the ever increasing amount of data which the system was required to publish and disseminate.

While for the users the Sentinel Data access and distribution remains the most visible element of the system, one must not forget that the success of the overall Copernicus Space Component depends on the skills and capabilities of hundreds of engineers, scientists, and operators ensuring the day-to-day functioning of centres and facilities distributed across Europe and beyond.

On behalf of ESA, I would like to extend my sincere thanks to these professionals for their dedication and outstanding performance, making a major contribution to the success of the Copernicus programme.

Per Bergellini

Pier Bargellini





→ Document Scope

The Sentinel Data Access Annual Report 2016 is a deliverable of the "Sentinels Rolling Archive User Access, Operations, Maintenance and Evolutions" contract (n.: 4000116830/16/I-BG) between the European Space Agency (ESA) and the consortium led by Serco S.p.A as Prime Contractor. This document provides an annual report of the Sentinel Data Access Service operated by the consortium as part of the Copernicus programme.

Definitions

Data Dissemination	Refers to the access and retrieval of Copernicus Sentinel data by end users
Data Ingestion	Refers to the indexing, storage and publication on the data dissemination infrastructure of the Copernicus Sentinel data
Data Publication	Refers to the provision of products available on-line for download by users
Rolling Archive	A Rolling Archive is the collection of data which remains accessible to users <i>online</i> . Each Rolling Archive is governed by a policy which dictates when products will be removed from the online collection.

Conventions

In this report, the following conventions have been used:

- the SI approved unit symbols KiB, MiB, GiB, TiB and PiB are used to report data volumes: 1KiB= 2^{10} bytes, 1 MiB= 2^{20} bytes, 1GiB= 2^{30} bytes, 1 TiB = 2^{40} bytes and 1 PiB = 2^{50} bytes.
- unless otherwise noted, the volume figures refer to the compressed product volumes as published and downloaded via the data hub access points.



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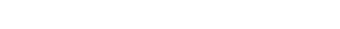
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1. INTRODUCTION

Copernicus is a European Union programme which provides operational information on the world's land surfaces, oceans and atmosphere, to support environmental and security policymaking and meet the needs of citizens and service providers. Under the Space Component of the Copernicus programme, ESA is



developing a family of dedicated satellites, called the Sentinels, to serve the programme's Earth Observation requirements. The data acquired from these

missions is systematically downlinked and processed to operational user products by the Sentinel ground segments. ESA's Sentinel Data Access System is designed to retrieve the Sentinel-1, -2, -3 (land) and -5P products from the relevant ground segment and make the products available for users to download from dedicated access points.

On 3 October 2014, the Sentinel Data Access System began the operational supply of data products from the Copernicus Sentinel-1A satellite mission. Since 2014, the Data Access System has been continually evolving, to keep pace with the rapid growth both in the amount of Copernicus Sentinel data available for distribution and in user demand for that data.

On 27 April 2016, the data access service provider Serco SpA released an annual report, analysing the performance of the Data Access System since the start of operations and public uptake of Copernicus Sentinel data¹. This 2016 annual report takes up from where the 2015 report left off, and tracks the system's performance and user activity during the period **1 December 2015 to 30 November 2016**.

Throughout this document, **Y2016** will be used to refer to the current reporting period of 1 December 2015 to 30 November 2016; and **Y2015** will be used to refer to the previous reporting period of 3 October 2014 to 30 November 2015.

1.1 Evolution of the Data Access System architecture

The Sentinel Data Access System provides to different user typologies free and open access to Copernicus Sentinel data products. The System is developed and managed as a service, by a consortium led by Serco SpA. The service includes the management of the infrastructure, supporting applications and procedures, and expert staff who tailor the publication of products to the operational scenarios and respond to user enquiries.

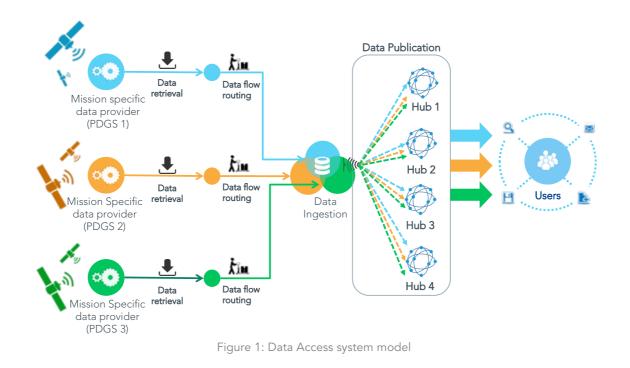
As depicted in the figure below, the Data Access System automatically retrieves products from ESA's Sentinel ground segments (PDGSs) and publishes them online, on a series of dissemination points known as hubs. Accessing these hubs, users are able to explore the data collections and download products, either through an interactive web interface or automatically, using a scripting interface. All of the products retrieved from the Sentinel PDGS are published on each of the hubs.

¹ https://sentinel.esa.int/documents/247904/685154/SPA-COPE-ENG-RP-066-00-

03_SENTINELS_DATA_ACCESS_ANNUAL_REPORT_final_ver sion.pdf







Due to the flexible architecture on which the Data Access System is based, the consortium is able to expand the hub configuration to accommodate an ever-widening user base and the different operational data access requirements of the various stakeholders involved in Copernicus.

At the end of Y2015, the system operated two hubs through which users could access the data products: the **Copernicus Open Access Hub** (COAHub, formerly known as SciHub)² and the **Collaborative Hub** (ColHub). In Y2016, the number of hubs grew to four, with the addition of the following two hubs which are designed to support specific Copernicus user typologies: On 2 December 2015, the **International Hub** (IntHub) was opened. This hub provides a direct data link for the international partners who have signed cooperation arrangements with the European Commission and technical operating arrangements with ESA.

Currently these partners are: Geoscience Australia (GA), the National Oceanic and Atmospheric Administration (NOAA - US), the National Aeronautics and Space Administration (NASA – US), and the US Geological Survey (USGS – US).

 On 29 January 2016, the Copernicus Services Hub (ServHub) was opened. This hub provides dedicated access for the Copernicus Services, in line with their key role in the Copernicus programme. During Y2016, this hub was progressively opened to additional users from EU institutions.

At the end of the reporting period, therefore, the Sentinel Data Access System operates four data hub instances through which different user typologies can access Copernicus Sentinel data. This is summarised in the following diagram:



² In November 2016, on the basis of feedback from the Commission's outreach activities, ESA asked Serco SpA to change the name of the Scientific Data Hub (SciHub) to "Copernicus Open Access Hub", to reflect the fact that Sentinel data is disseminated under a full, free and open data policy for the benefit of *all* users, and not only the scientific community.



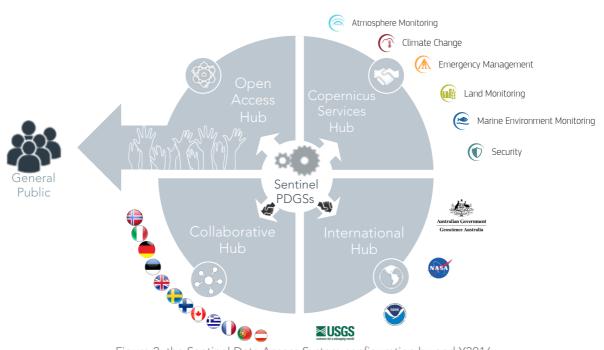


Figure 2: the Sentinel Data Access System configuration by end Y2016

Each of the four hubs has been configured specifically to the needs of its target community:

• The Copernicus Open Access Hub is the hub which offers to *all* users free, full and open access to Copernicus Sentinel data. Accordingly, there are no restrictions on who can register to download products. Due to the high number of users active on the hub at any one time, and the need to ensure bandwidth remains available for all users, the number of concurrent downloads which users are entitled to make is configured to two.

Currently no policy is in place for removing products from the online access according to criteria such as the age of the product (known as a Rolling Policy).

 The Copernicus Services Hub, which guarantees free and full access to Sentinel data for all Copernicus Services, also does not operate a Rolling Policy. It serves a lower number of users than the Copernicus Open Access Hub, so users are entitled to make up to 10 concurrent downloads.

• Use of the Collaborative Hub and the International Hub is limited to those who have signed a technical arrangement with ESA or an international arrangement with the European Commission, so the number of users is restricted and the two hubs are also configured to support 10 concurrent downloads.

It assumed that the partners accessing the Collaborative Hub and the International Hub will download the Sentinel data products as they are published on the hub, and then redistribute the products from their own storage and data access points. Accordingly, each hub operates a Rolling Policy, through which products which have been on the hub for more than 30 days are automatically removed from the hub.

These differences between the hubs are summarised in the figure below.







Figure 3: Sentinel Data Access System hub characteristics

1.1.1 Specific Data Hub Evolutions

During Y2016, the Copernicus Open Access Hub and the Collaborative Hub were expanded, with ad-hoc instances deployed to deal with specific data flows (e.g. during mission ramp-up phases) or to improve the number of access points available for the users.

Copernicus Open Access Hub

A key feature of the Data Access System is that each hub provides scripting interfaces (APIs) which enable users to browse and access the available products in an automated way, seamlessly integrating the data access services into their own workflows. In 2015, it was recognised that a large number of users of the Copernicus Open Access Hub were benefitting from these capabilities. In order to assist this category of user in time for the open distribution of Sentinel-2A data products, a separate instance of the Copernicus Open Access Hub was released in November 2015, dedicated to the scripting interface (the so-called APIHub). The APIHub was initially only intended to disseminate the latest data from the Sentinel missions. In Y2016, however, the APIHub was extended so that it would maintain

the entire data archive, as for the rest of the Copernicus Open Access Hub.

In the initial phases of the Sentinel operations (i.e. the "ramp-up phase"), adjustments are more likely throughout the processing chains. The mechanism developed to give the operations team the flexibility to modify or upgrade the delivered datasets during the rampup phase, without impacting the routine dissemination of data for the operational missions, is to deploy dedicated "pre-operations hubs" which serve as independent access points for the newly qualified datasets.

In Y2016, two of these dedicated and temporary pre-operational hubs were deployed on the Copernicus Open Access Hub, to support the distribution of Sentinel-2 and Sentinel-3 products in their rampup phases:

S2preops Hub

Activated from the start of the Sentinel-2A mission ramp-up phase, this hub distributed Sentinel-2 products in parallel to the Open Access Hub interfaces. The hub was decommissioned on 19 September 2016, when the dissemination of Sentinel-2 single-tile products on the Open Access Hub was announced. More details on the Sentinel-2 single-tile dissemination are provided in Section 1.2.1 below.





S3preops Hub

Activated on 20 October 2016, the Sentinel-3 Pre-Operations Hub is the current ESA access point for downloading Sentinel-3 products. At the end of the mission ramp-up phase (scheduled for mid-May 2017), the Sentinel-3 product dissemination will be transferred to the standard Open Access Hub interfaces.



Figure 4: First Sentinel-3A image distributed on the Sentinel-3 Pre-Operations Hub

Collaborative Hub

The Collaborative Hub was initially setup in order to provide a dedicated access point for the ESA Member states participating in the GMES programme, to enable them to create their own mirror archives, or download data covering national areas of interest.

In Y2016, after agreement with the European Commission that the hub should also be open to all Copernicus participating states, access to the hub was expanded to all GMES/Copernicus participating states, on signature of a technical arrangement with ESA.

In order to support the increase in demand, a second dissemination node for the Collaborative Hub was established, this time on the same infrastructure as the one which hosts the Copernicus Open Access Hub. This second node was put in operation on 9 May 2016.

Data Hub Relays

Initially conceived as an additional support to ESA's GMES Participating States, a network of Data Hub Relays was designed to provide a distributed set of dissemination points from which multiple collaborative ground segments could download the Sentinel products. The main goal behind the initiative was to increase the overall capacity to re-disseminate data at the national level, while reducing the overall load on the primary data access nodes. In general, these Data Hub Relays are located in facilities that have a favourable connectivity to a "local" collaborative ground segment, and are used primarily to serve that local collaborative ground segment, although they can actually serve any collaborative ground segment instance.

During 2016, five such Data Hub Relays were established on the Collaborative Hub, and initial qualification activities commenced. Each Data Hub Relay re-uses the software system of the main data hub nodes and is supported within the overall operations context.

1.1.2 Network Evolutions

All the Data Access Hubs are hosted on a 10 Gb/s access point, with exception of the Collaborative Hub Node 2 which is hosted on a 3 Gb/s access point.

On 3 May 2016, a dedicated interconnection with the European GÉANT network (<u>http://www.geant.org/</u>) was successfully transferred to operations. The impact of this connection on the data flow is discussed in detail in Section 6.2 below.

1.2 Main Mission developments

1.2.1 Sentinel-1

At the end of Y2015, Sentinel-1A data products were already being disseminated to users through both the Copernicus Open Access Hub and the Collaborative Hub on a routine operation basis. When the International Hub and Copernicus Services Hub were opened, routine





dissemination of Sentinel-1A products began immediately on those hubs.

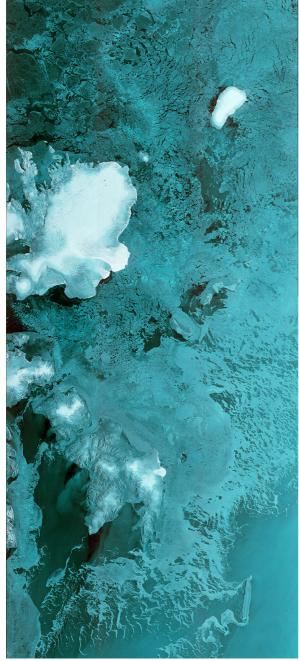


Figure 5: First Sentinel-1B image published on the Copernicus Open Access hub

Sentinel-1B was launched on 22 April 2016, and routine dissemination of the Sentinel-1B data products began on all the Data Access Hubs at the end of September 2016, after successful completion of the satellite Commissioning Phase on 14 September 2016.

1.2.1 Sentinel-2

Routine dissemination of Sentinel-2A products started at the beginning of Y2016, on 3 December 2015.

Initially, each Sentinel-2A product was distributed as a compilation of elementary granules of fixed size (called tiles), at fixed intervals along a single orbit. The volume of one of these multi-tile products, which comprised a grid of some 3 by 3 tiles, was up to 8GB. This was found to be problematic for many users with limited bandwidth available on their side, who experienced network time-outs and interruptions during their downloads, and were often forced to restart a download in order to obtain the complete product. Moreover, the preparation and loading of data from the Sentinel-2 PDGS towards the data hubs was found to be affected by occasional drop-outs, meaning a delay in publication of the full Sentinel-2 production.

How much faster is the download of Sentinel-2 products in tiles?

The table below gives an indication of the improved download times achieved as a result of the new single-tile format.

User Bandwidth (Mbps)	Time to download an average-sized S2 multi-tile product	Time to download an average-sized S2 single-tile product
16	1 hour	3.3 mins
56	10 mins	57 secs
120	5 mins	26 secs

Table 1: Indication of time spent for downloading a typical S2 multi-tile product and a typical single-tile product

The table compares, for a series of standard bandwidth rates available on the user side, the time it would take to download an average sized multi-tile product and the time it would take to download an average sized single-tile product. As can be seen, even with a low 16Mbps bandwidth, **downloading a single-tile product takes a fraction of the time it took to download a multi-tile product**.





Recovery from these drop-outs was typically achieved within a few days after the sensing, with a subsequent impact on the overall timeliness of a (small) percentage of products.

Responding to this feedback from users, ESA carried out a series of optimisations within the Sentinel-2 PDGS, to be able to repackage Sentinel-2A products as single-tile products, which have a much lower volume and are therefore easier to download.

To support users before the products could be distributed as single tiles, dedicated batch scripts were provided to the users to illustrate how to extract and download single tiles automatically from the multi-tile products, and ease the downloading process. It is important to note, however, that extracting a portion of a product in this way is not considered by the system as a complete download, and so none of the downloads of single-tiles or granules extracted from a larger product have been included in the statistics presented in this report.

Routine dissemination of the new single-tile products began on 27 September 2016.

The pictures in Figure 6 and Figure 7 below give an idea of the difference the change to singletile products made, in terms of product size and coverage. Figure 6 shows an example of a data strip divided into the original multi-tile products. Figure 7 shows an example of the same data strip divided into the new single-tile products.

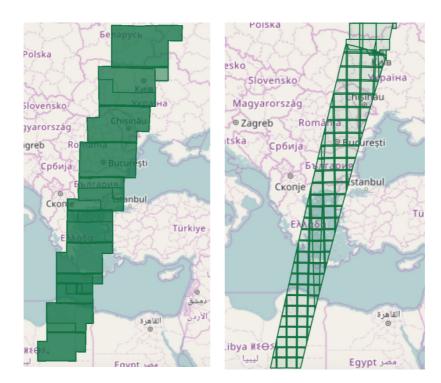


Figure 6: Example of a footprint of Sentinel-2 disseminated in multi-tile products (before 27 September 2016)

Figure 7: Example of footprint of Sentinel-2 disseminated in single-tile products (after 27 September 2016)





1.2.2 Sentinel-3

On 16 February 2016, the Sentinel-3A satellite was launched. Routine dissemination of the Sentinel-3A OLCI products (OLCI Level 1 Full Resolution and OLCI Level 1 Reduced Resolution product types) began on 20 October 2016, on the Sentinel-3 Pre-Operations Hub.

The release of the OLCI products was followed shortly afterwards by the routine dissemination of SLSTR products (SLSTR Level 1 Radiance and Brightness Temperatures), which began on 17 November 2016.

Given that publication of Sentinel-3A products began so near to the end of the reporting period, the quantities of data which were published and downloaded within the period do not compare to quantities of data which were published and downloaded for Sentinel-1 and Sentinel-2A. Accordingly, to avoid distorting the scales used in the graphs presenting data for the other two missions, the statistics for Sentinel-3A are dealt with in a dedicated section of the report (see Section 7.1).



Figure 8: Sentinel-3 PDGS team on prelaunch meeting at ESA's centre for Earth Observation (ESRIN) on 4 February 2016

1.3 Summary of Y2016 Major Achievements

In brief, Y2016 was a year of massive growth for the Sentinel Data Access System, which doubled the number of hubs it supports and went from disseminating data from one satellite alone, to disseminating data from four satellites, all on a routine operational basis.

The major achievements and milestones for Y2016 are summarised in the figure below.

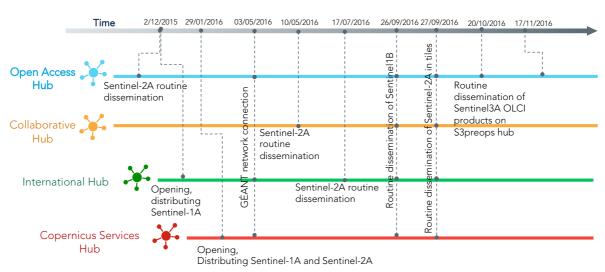


Figure 9: Timeline of the major achievements for Y2016



2. DATA ACCESS SERVICE GROWTH

In Y2016, the number of user registrations, and the volume of Sentinel products which were published and disseminated towards end users greatly increased with respect to Y2015. In this chapter, each of these increases is examined in more detail.



2.1 User take-up

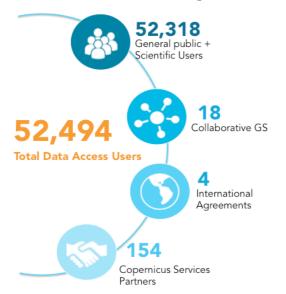


Figure 10: Number of registered users per hub

Figure 10 shows the distribution of users across the different hub instances. These numbers are

the total number of user accounts which have been opened on the hubs since the start of each hub being operated³.

Given that only the Copernicus Open Access Hub is open to the public for self-registration, and access to the other hubs is provided on a pre-registration basis, this section looks only at the numbers of registrations on the Open Access Hub.

2.1.1 User registrations

The number of users registered on the Copernicus Open Access Hub in Y2016 has increased by 320% with respect to the previous year: at the end of Y2015, there were 12,447 users registered worldwide on the Hub; by the end of Y2016 this number had risen to 52,318.

³ It is highlighted that, for the sake of accuracy, whenever the same email is used for more than one user registration, the accounts are taken to be duplicated so the information for each account is added together and considered as coming from just one account in the calculations provided in this report.





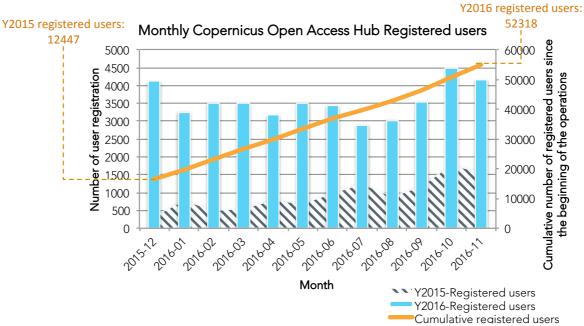


Figure 11: Trend of user registrations on the Copernicus Open Access Hub

It is interesting to note that the **monthly trend** of new user registrations continued to be linear during Y2016, as it was in Y2015. This indicates that interest in Sentinel data has been increasing in a steady and consistent way throughout the two years in which the data has been made available to the general public.

The graph in Figure 11 above shows the monthly number of users who registered for access to the Copernicus Open Access Hub during Y2016, and the cumulative number of registered users since the start of operations; those values are compared with the monthly user registrations performed during Y2015. From this graph, it can be seen that the number of new registrations per month was almost constant throughout Y2016, with an average of 3,300 new registrations per month.

It is also interesting to note that the peaks in user registrations in December 2015 and October 2016, correspond with the start of publication of Sentinel-2A and Sentinel-1B products respectively.

2.1.1 Copernicus Open Access Hub user demography⁴

Although Europe still has the largest usercommunity, with 21,476 registered users by the end of Y2016, the growing awareness of and interaction with the Copernicus Open Access Hub has by no means been limited to Europe. In the diagram in Figure below, the increase in user registrations since Y2015 is broken down by continent. These figures show that the most remarkable increase in user registrations

⁴ When users register to access the Copernicus Open Access Hub, they provide information from pre-defined lists such as their country, the thematic domain for which they intend to use the data, and the type of use (research/commercial etc.) for which they intend to use the data. There is no active verification of the information entered, so the statistics presented here rely on the assumption that the information provided by users is truthful.





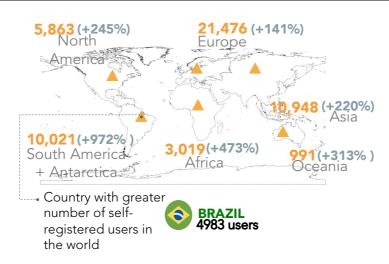


Figure 12: Number of registered users per continent since the beginning of the operations and the percentage increase in the number of registrations per continent since Y2015

in Y2016 actually took place in South America + Antarctica and in Africa, with an increase of 972% and 473% respectively.

Breaking the figures down even further by country, it emerges that Brazil was the country with the largest number of users in the world by the end of Y2016, with 4,983 self-registered users.

Focussing more specifically on Europe, the diagram in Figure 13 illustrates, on the top, the density of registered users in the ESA and European Union Member States. On the bottom, the top 5 ESA and European Union Member States in terms of the number of registered users are shown, and how this has changed with respect to Y2015 (i.e. whether the country is now in an equal, lower or higher position than in Y2015).

Within Europe, therefore, it is still Germany which has the largest number of users registered on the Copernicus Open Access Hub. German user registrations increased by 200% since Y2015, reaching a total number of 3,981 selfregistered users at the end of Y2016.

User activity on the hubs is analysed in Chapter 3 below.



1000 – 2000 Registered Users < 100 – 200 Registered Users < 100 Registered Users 500 – 1000 Registered Users

2000-3000 Registered Users 200 – 500 Registered Users 200 – 500 Registered Users Not ESA member state

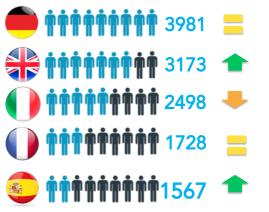


Figure 13: Copernicus Open Access Hub registered user distribution in EU and ESA member states





2.2 Product Publication

By the end of Y2016, Sentinel-1A and -1B and Sentinel-2A products were being routinely published on all the data access hubs. This section presents the statistics for the publication of those products during Y2016.

2.2.1 Publication growth

By the end of Y2016, a total of **1,154,049** Copernicus Sentinel products had been published on the Copernicus Open Access Hub since the start of operations on 3 October 2014⁵, with a total data volume of **1.23 PiB**. The table below breaks these totals down by Sentinel, and Figure 14 compares the total volume published at the end of Y2015 with the total volume published at the end of Y2016.

MISSION	Number of products published since the start of operations	Volume (PiB) of products published since the start of operations
S1	884,628	0.77
S2A	269,421	0.46
ALL	1,154,049	1.23

Table 2: overall number and volume of published products on each of the Data Access hubs since the start of the operations

As underlined in Figure 14, the cumulative volume of Sentinel products published by the end of Y2016 was more than 2.5 times the cumulative volume of products published by the end of Y2015. 60% of the total volume published since the start of operations was published in Y2016, and in the last 3 months of Y2016 alone, the Data Access System

⁵ Throughout this report, start of operations is taken to be 3 October 2014, the date on which the Copernicus Open Access Hub was opened to the public with the routine data flow of Sentinel-1A data. published the same volume of products as was published in the whole of Y2015. These figures give a good indication of how quickly the volumes of data are increasing, and that the system is coping with data volumes which are unprecedented for Earth Observation missions.

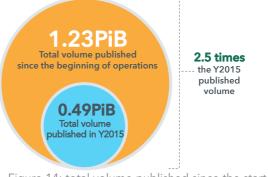


Figure 14: total volume published since the start of operations and comparison with Y2015 published volume

Looking at what the publication volumes mean on a daily basis, it can be seen that by November 2016, the average daily volume of data being published by the Data Access System was more than 3 times the average daily volume which was published during November Y2015 (see Table 3).

MISSION	Daily average volume (TiB) published in November 2015	Daily average volume (TiB) published in November 2016
S1	1.33	3.45
S2	n/a	1.13
ALL	1.33	4.58

Table 3: average volume of products published per day in the last month of Y2015 and Y2016

At the end of Y2016, the majority of products being published were Sentinel-1 products, reflecting the fact that both Sentinel-1A and -1B were in orbit, and products from each satellite were already being disseminated to the public on a routine operational basis. With an average daily publication volume of 3.45 TiB per day in November 2016, Sentinel-1 products constituted 75% of the total average daily publication volume (see Figure 15 above), and by the end of Y2016 Sentinel-1





products constituted two-thirds of the total volume of products which had been published since the start of operations.



Figure 15: Y2015 and Y2016 average daily publication per mission

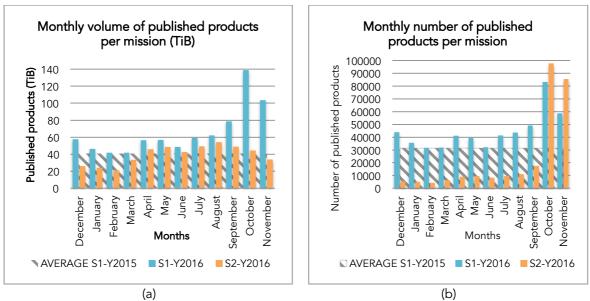
2.2.2 Publication trends

The following graphs show, per Sentinel, the monthly volume (graph a) and number (graph b) of products which were published on the data access hubs during Y2016, compared with the average values recorded for Y2015.

Sentinel-1A production remained stable during Y2016 and, following the successful completion

of the Sentinel-1B Commissioning Phase, Sentinel-1B data was made seamlessly available through the same interfaces as Sentinel-1A data. The corresponding peaks seen in the graphs above, in the number and volume of Sentinel-1 products published during October and November 2016, are also partially due to the retrospective processing campaign of SLC Sentinel-1A products, which is described in more detail in Section 5.2.1 below.

The Sentinel-2A operation capacity increased throughout Y2016, in line with the mission rampup, and the average daily volume of Sentinel-2A products published on each hub rose from 0.8TiB per day in December 2015 to 1.13TiB per day by the end of Y2016. In Figure 16 (b), a dramatic increase in the *number* of Sentinel-2A products published can be seen to have taken place in October and November 2016, and this is explained by the switch to disseminating the products as single-tile packages. It is highlighted that while the number of products increased tenfold, the *volume* of data published remained fairly constant.









In this section, the overall publication figures are broken down by product type (for Sentinel-1 only) and geographical coverage.

Publication per product type

For Sentinel-2, the products which are currently published are Level 1C, and no further analysis by product type is relevant.

For Sentinel-1the following product types are published:

- Level 0 (L0)
- Level 1 Ground Range, Multi-Look, Detected: Medium Resolution (L1-GRDM)
- Level 1 Ground Range, Multi-Look, Detected: High Resolution (L1-GRDH)
- Level 1 Single-Look Complex (L1-SLC)
- Level 2 Ocean (L2-OCN)

On the right of the diagram in Figure 17, the total number of Sentinel-1 products published in Y2016 is split down into the percentage published per product type. From this it can be seen that the most frequently published Sentinel-1 products during Y2016 were Level 1 products (62%), and that at least one L1-GRD product type is available for each available L0 product.

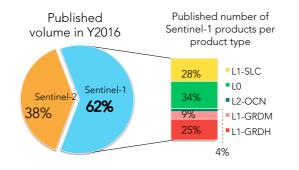


Figure 17: Y2016 Published products per product type

The percentage of SLC products increased from 18% of the overall Sentinel-1 publication in Y2015, to 28% in Y2016. This increase is related to the fact that SLC products have been systematically made available over land and ice masses since July 2016, and also to the retrospective processing of Sentinel-1A Interferometric Wide Swath data to SLC products, which was performed during Y2016 (see Section 5.2.1 below for details about this retrospective processing campaign).

Geographical coverage of published products

The geographical areas over which the Sentinels gather data are determined by the observation scenarios for each mission, which are available online via the following links: https://sentinels.copernicus.eu/web/sentinel/mis sions/sentinel-1/observation-scenario for S1, https://sentinels.copernicus.eu/web/sentinel/mis sions/sentinel-2/acquisition-plans for S2. These scenarios are in turn governed by the overarching Sentinel High Level Operations Plan, which is a document agreed between ESA and the European Commission and also available online from the Document Library at https://sentinel.copernicus.eu.

Figure 18 below is a heatmap which shows the geographical coverage of the Sentinel-1 products published during Y2016. The colour scale illustrates the different numbers of products which were published for each area; purple and red zones are the areas for which the greatest number of Sentinel-1 products were published. It should be highlighted, however, that the Level 2 OCN products, which are available over oceans and coastal zones, are not shown in this heatmap, due to the different footprint used in the OCN products which prevents the same calculation from being applied to the product count.

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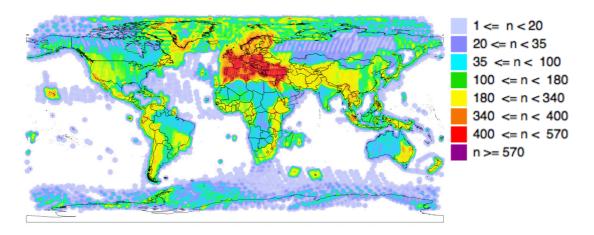


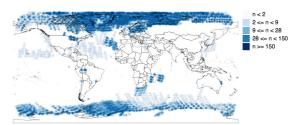
Figure 18: Heat map of Sentinel-1 products published during Y2016

The heatmap shows the global coverage of the Sentinel-1 data published in Y2016, with the highest number of products available over Europe and maritime monitoring areas. Other hot spot (red) areas correspond to calibration sites and places of interest for particular campaigns, such as active tectonic areas.

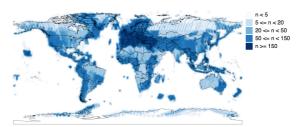
It is interesting to break the overall Level 1 geographical coverage down further to show the coverage per product type, because different Sentinel-1 product types are suitable for different geographical areas.

The HLOP determines which Sentinel-1 products will be available for which area of the world, and the maps in Figures 19 above illustrate that in Y2016:

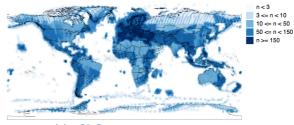
- GRDM products are mostly available for sea ice and marine areas;
- GRDH products are mostly available over land masses;
- SLC products are also mostly available over land masses.



(a) : **GRDM**



(b) : **GRDH**



(c) : **SLC**

Figures 19: Heat maps of Sentinel-1 products published during Y2016 per product type: (graph a) Ground Range, Multi-Look, Detected: Medium Resolution (graph b) Ground Range, Multi-Look, Detected: High Resolution; (graph c) Single-Look Complex





While the Sentinel-1 heatmap shows a variable density acquisition rate over different geographical areas, the heatmap in Figure 20 shows that Sentinel-2A is aimed at achieving more evenly spread global coverage, although during the ramp-up phase particular emphasis was focused on European and African land masses.

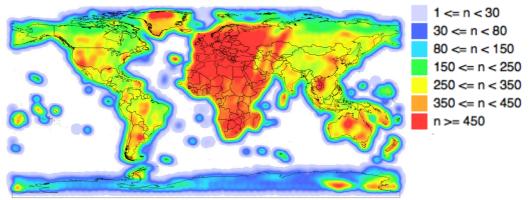


Figure 20: Heat map of Sentinel-2A products published during Y2016





2.3 Product Downloads

This section presents the statistics for Sentinel-1 and Sentinel-2 user downloads during Y2016.

It is important to repeat that, as briefly mentioned at Section 1.2.1 above, **one download refers to an uninterrupted download of a complete data product** and partial downloads or failed transfers are not considered. The data hubs support other download capabilities – i.e. by "byte range" (a feature exploited by many download managers to assist also in the pause/resume of longer downloads) and by sub-product components, allowing the extraction of one or more files of interest without downloading the full product.

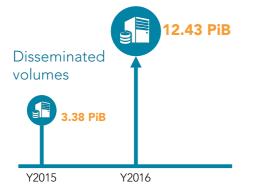


Figure 21: Total volume disseminated at the end of Y2015 and at the end of Y2016 (from the beginning of the operations) However, since these partial downloads are difficult to distinguish from an interrupted download, they are not taken into account in any of the statistics presented in this report.

2.3.1 Download growth

Y2016 was a year of remarkable growth in terms of the number and volume of downloads made by users from the Data Access System. During Y2015, the total number of products downloaded by users was 2,920,593, with a total volume of 3.38PiB. In Y2016, this volume increased by **268%** and the total volume of data disseminated to users since the beginning of the operations reached **12.43 PiB**.

To give an example of what this jump in data volume means, the volume of downloads performed during the last three months of Y2016 (3.94 PiB) is greater than the total volume of downloads performed during the whole of Y2015.

Figure 22 below breaks these totals down per mission, and compares the total volume of data downloaded by the end of Y2016 with the total volume which had been downloaded by the end of Y2015.

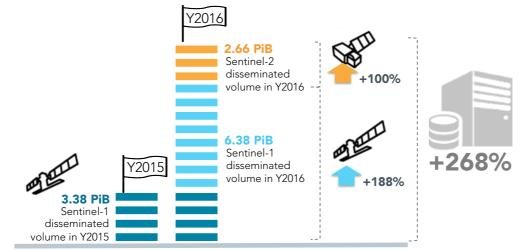


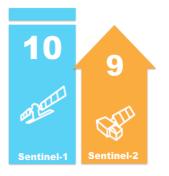
Figure 22: Total volume of products downloaded since the start of operations, differentiated by year and by mission





These figures demonstrate an eager uptake of Sentinel-2 data during the first year of operations, and that a high level of interest in Sentinel-1 data was sustained throughout the year: 3.38 PiB of Sentinel-1 products had been downloaded by users by the end of Y2015, and by the end of Y2016 this had risen by 188% to a total of **9.76 PiB of Sentinel-1 products downloaded since the start of operations**.

User interest levels can be monitored more directly by looking at the "Archive Exploitation Ratio". The Archive Exploitation Ratio shown in Figure 23 was computed at the end of Y2016, as the total number of user downloads made from all of the hubs since the start of operations, divided by the total number of products which had been published on any one of the hubs since the start of operations.



This ratio shows that by the end of Y2016, even though as many as 884,628 Sentinel-1 products had been published, users had already managed to download 10 times that amount. This ratio of 1 product published: 10 products downloaded for Sentinel-1 has in fact not changed since Y2015, indicating that the level of interest in Sentinel-1 data is keeping pace with the huge quantities of data being published.

The ratio for Sentinel-2 products is 1:9, i.e. by the end of Y2016, users had downloaded 9 times the nearly 300,000 Sentinel-2 products which had been published during the year. This uptake appears particularly impressive when it is recalled that for most of Y2016, Sentinel-2 products were published in the multi-tile packages, with volumes as high as 8GB, which for users with low bandwidths proved difficult to download.

It is also interesting to note that these archive exploitation ratios indicate that the Sentinel-1 and Sentinel-2 user groups were almost equally active by the end of Y2016.

Figure 23: Archive exploitation ratio at end Y2016



2.3.1 Download trends

	Number of products downloaded since the start of operations	Volume (PiB) of products downloaded since the start of operations
Open Access Hub	7,118,949	8.13
Collaborative Hub	2,916,673	3.21
International Hub	880,042	0.89
Copernicus Services		
Hub	179,172	0.19
ALL hubs	11,094,836	12.43

Table 4: Number and volume of products downloaded since the start of operations, per hub.

In Table 4 above, the overall numbers of product downloads are broken down per hub, to show the different levels of user uptake on each hub.

Not surprisingly, the biggest contributor to the dissemination of Sentinel products since the beginning of the operations is the Copernicus Open Access Hub, which has managed 65% of the overall volume of downloads.

However, as can be seen from Table 5 below, use of the Collaborative Hub increased dramatically during the year and by the end of Y2016, the average volume of data being downloaded on a daily basis was actually higher from the Collaborative Hub than from the Copernicus Open Access Hub. Table 5 also shows again that the increase in the volume of downloads since the previous reporting period was impressive: by the end of Y2016, the Copernicus Open Access Hub was handling twice the daily volume of downloads it had been handling at the end of Y2015, and the Collaborative Hub went from supporting a daily download volume of 1.1 TiB to a daily volume of 21.0 TiB.

Hub	Daily average volume (TiB) downloaded in November 2015	Daily average volume (TiB) downloaded in November 2016	% Increase since Y2015 in average daily volume published
Open Access Hub	8.2	16.8	+105%
Collaborative Hub	1.1	21.0	+1813%
International Hub	n/a	5.3	n/a
Copernicus Services Hub	n/a	1.7	n/a
ALL hubs	9.3	44.8	+383%

Table 5: volume disseminated per day during the last month of Y2015 and Y2016





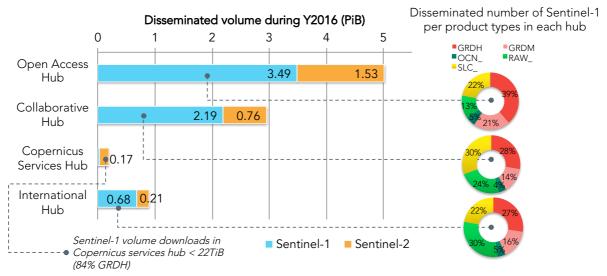


Figure 24: Sentinel-1 and Sentinel-2A disseminated volume during Y2016 per hub and per product type

Focussing more specifically on user downloads during Y2016, the graphs in Figure 24 show the volume of products which users downloaded from each hub *per mission* during Y2016. The Sentinel-1 figures are further broken down to show the percentage of each product type which was downloaded per hub.

On the Copernicus Open Access Hub, the Collaborative Hub and the International Hub, over 70% of the volume disseminated from the hub consisted of Sentinel-1 products. On the Copernicus Services Hub, on the other hand, less than 22 TiB of Sentinel-1 data was downloaded and the overwhelming majority of products downloaded from the hub were from Sentinel-2. In this context, it is recalled that there is an additional and tailored dissemination point for delivering Sentinel-1 Near Real Time products to the Copernicus Marine Environment Monitoring Service (CMEMS). Details of the volume of products disseminated via this dedicated access point are provided in Section 2.3.1 below.

Looking at the breakdown per product type, it can be seen that GRDH products were the most

popular Sentinel-1 products for users of the Copernicus Open Access Hub (39%) and the Copernicus Services Hub (84%). Users of the Collaborative Hub and the International Hub showed more evenly distributed interest in the GRDH, SLC and RAW products, with the highest interest (30%) being shown for SLC products by Collaborative Hub users and for RAW products by International Hub users.

Clearly, the overall volume of downloads made from the Copernicus Services Hub and the International Hub is low compared to the volume of downloads made from the Copernicus Open Access Hub or the Collaborative Hub. However, It can be seen from the following graphs in Figure 25 below, which show the monthly volume (graph a) and number (graph b) of downloads made from each hub during Y2016, that after an initially slow start, activity on both hubs increased on the hub towards the end of the year, with the number of downloads on the International Hub reaching as many as 237,551 in November 2016.





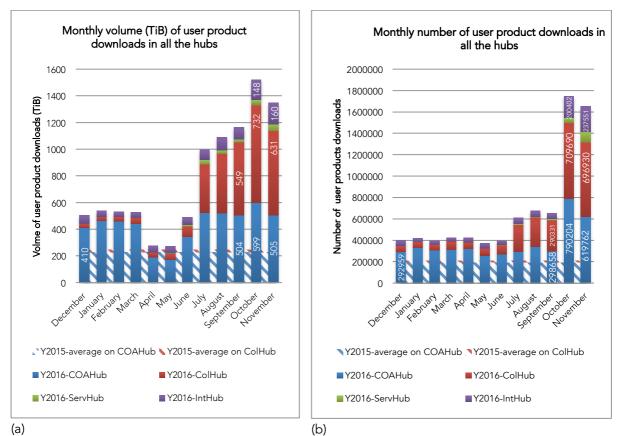


Figure 25: Dissemination trend during Y2016 compared with the average disseminated volumes in Y2015

A significant increase in activity can also be seen on the Collaborative Hub from July 2016 onwards. More details on Collaborative Ground Segment activities are presented in Section 4 below, and this increase in user activity is discussed there.

For the Copernicus Open Access Hub, two points are worth highlighting from the graphs in Figure 25:

- Graph (b) shows a rapid increase in the number of downloads in October and November 2016. This is mostly attributed to the release of Sentinel-2 products in the new single-tile format, which not only made it easier for users to download the products, but also meant users could more easily select the specific area or cloud-free zone in which they were interested.
- On the other hand, graph (a) clearly shows an apparent drop in user downloads in April and May 2016. The lower figures recorded for those months are caused by a software

anomaly which, between 23 March and 16 June 2016, affected the system responsible for generating the statistics presented in this report. This anomaly has permanently affected the data collected for the affected period, and has artificially reduced the data download numbers presented for Y2016 throughout the report.

The anomaly was not immediately spotted because at the time it occurred, the apparent decline coincided with two notable developments:

- the wider publication of scripts which made it possible for users to extract single tiles from the Sentinel-2 products; and
- the opening of third party Sentinel data mirror sites acting as re-distribution points.

At first glance, therefore, it appeared as if the decrease in product downloads from the Copernicus Open Access Hub could be







attributed both to the success of the mirror sites and, given that the data dissemination statistics do not count downloads of portions of data extracted by users, also to Sentinel-2 users preferring to download extracted tiles from products. With those assumptions made, a thorough investigation into the issue was deferred, to enable the operations team to deal with other higher priorities.

Detailed investigations were instead carried out during June 2016. The tests revealed that in fact a software error had been introduced in the Data Access System software version upgrade which was installed on 23 March 2016, and that this error was preventing the system from recording successful downloads of any core product whose size was greater than 2GB. The result was that the system advertised a far lower number of product downloads than users had actually made. In reality, therefore, a higher number and volume of products was downloaded during the affected period than is shown in these graphs, but throughout the report only the number and volume of products which was actually recorded by the system will be shown, in order to avoid introducing estimates into the statistics.

2.3.2 Fresh vs old products

The overall download figures can be further broken down to analyse the average age of products in which users of each hub are most interested.

The table below shows, per Sentinel, the percentage of downloads made in Y2016 across

a series of temporal ranges. The temporal ranges are the amount of time between the date on which the product was published on the hub and the date on which the user downloaded the product.

The table shows that most activity on the hubs during Y2016 was aimed at downloading freshly published products. In particular, Sentinel-1 users on the International Hub and the Collaborative Hub showed a very high interest in the new products, with 66% and 78% of Sentinel-1 products being downloaded up to only 2 days after they were published on the hub.

However, there was still notable interest in the older Sentinel-1 data available. On the Copernicus Open Access Hub, as much as 20% of the Sentinel-1 downloads were of products which were more than 3 months old. Even more striking, on the Copernicus Services Hub the overwhelming majority (62%) of Sentinel-1 downloads were of products more than 3 months old, while only 2% of downloads were for Sentinel-1 products up to one week old.

For Sentinel-2, the same interest in the older products is not visible: only 2-3% of Sentinel-2 products downloaded from the Copernicus Open Access Hub or the Copernicus Services Hub in Y2016 were of products more than 3 months old, whereas 74-77% of downloads were of products up to only one week old.

Sentinel-1				Sentinel-2								
	<2d	2d< to <1w	1w< to <1m	1m< to <3m	3m< to <6m	>6m	<2d	2d< to <1w	1w< to <1m	1m< to <3m	3m< to <6m	>6m
Open access Hub	48%	12%	12%	8%	8%	12%	59%	15%	19%	5%	1%	1%
Copernicus Services Hub	0%	2%	7%	29%	42%	20%	48%	29%	16%	4%	2%	1%
Collaborative Hub	66%	13%	21%	rolling	rolling	rolling	58%	17%	25%	rolling	rolling	rolling
International hub	78%	13%	9%	rolling	rolling	rolling	54%	29%	17%	rolling	rolling	rolling

Table 6: percentage of Sentinel-1 and Sentinel-2 downloads per temporal ranges per hub during Y2016 (d=day, w=week, m=month)







2.3.1 Copernicus Marine Environment Monitoring Service (CMEMS) dedicated access point

During the Commissioning Phase for Sentinel-1A, a dedicated dissemination point was set up for the Copernicus Marine Environment Monitoring Service (CMEMS), to ensure delivery of the products to CMEMS with sufficient timeliness right from the start of data dissemination activities. CMEMS established its operational interfaces around this dedicated access point (ftp server), and the ftp service has been maintained throughout the data access operations.

During Y2016, 654,474 Sentinel-1 products were published on this ftp server dedicated to the specific needs of CMEMS. This is more than 9 times the number which was published during the previous year, and constitutes a total volume of 92 TB of Sentinel-1 data. Within CMEMS, multiple teams access these products via shared user accounts and elaborate different kinds of parameters from the same data.

CMEMS downloaded a total volume of 311 TB of products from the ftp server during Y2016.

The archive exploitation ratio during Y2016 was 1:5.6.

The graphs below show the monthly trend in the number of published and downloaded products on the dedicated access point.

As can be seen from these graphs, there was a significant increase in terms of both publication and downloads on the dedicated access point during Y2016. This can be partially attributed to the contribution of Sentinel-1B, but there is also a natural variation in the number of products sensed and published depending on the seasonal time-windows of interest to CMEMS.

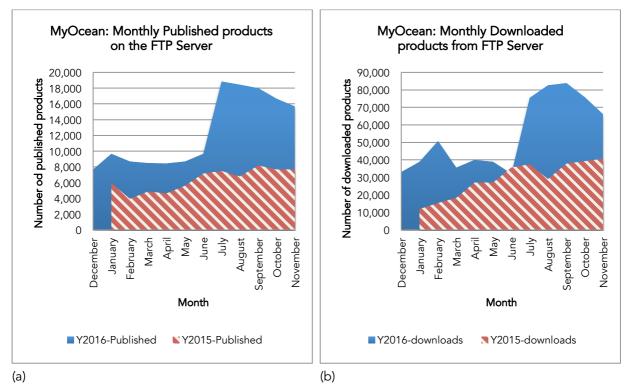


Figure 26: Publication and dissemination trends in FTP Copernicus Marine Environment Monitoring Service in Y2016 compared to Y2015







3. USER ACTIVITY

3.1 Active users

In the current analysis, registered users who perform at least one complete product download during the specified period are defined as "active users".

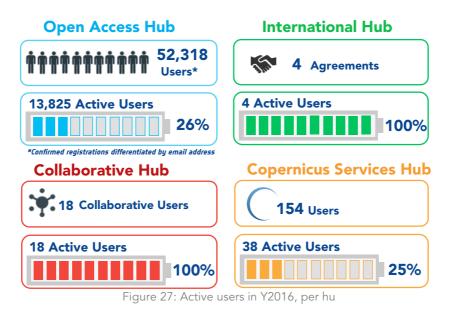
However, this does not mean that the other users, who did not perform any complete download in the same period, were necessarily "inactive". As already explained, if a user is only interested in part of an image and chooses to extract just a specific granule or tile from the product, this download is not counted by the system as a complete download and so the user who made the partial download would not be counted as an active user. Moreover, users may have downloaded only product metadata from the Sentinel archive, for instance to create an independent catalogue for future use.

The percentage of active users during Y2016 (i.e. users who made one or more complete download during Y2016) are shown for each hub in the diagram below.

These percentages reflect the different natures of the hubs. Given that the Collaborative Hub and the International Hub were established for national institutions, and only one user account is opened for each partner institution, it was expected that the partners would make this 100% use of their user accounts.

The Copernicus Open Access Hub, on the other hand, is open to the world at large and anyone who wishes to explore the site can open an account. It is also not unexpected, therefore, that 26% of registered users on the Open Access Hub were active during Y2016: many people will have opened an account who did not have an immediate need for Sentinel data; many will have made partial downloads only from the site, particularly in the months before the release of Sentinel-2 products in single-tiles; and some may have used their accounts to explore and extract information from the metadata. Overall, the number of users registered on the Copernicus Open Access Hub in Y2016 was 4 times greater than the number registered in Y2015, and the number of active users on the Hub doubled, rising from 6,579 in Y2015 to 13,825 in Y2016.

Broken down per mission, there were 9,888 active users of Sentinel-1 products on the Copernicus Open Access Hub in Y2016, and 6,644 active users of Sentinel-2 products.







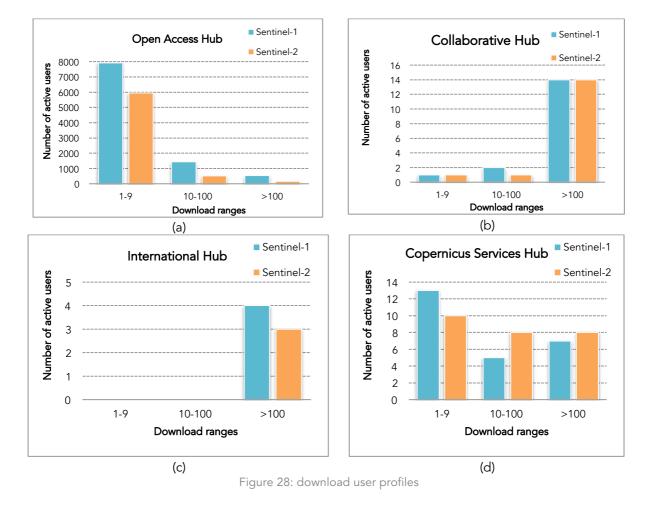
3.2 User downloads profile

A greater insight into user activity on each hub can be gauged by looking at the average number of downloads made by the users of each hub during Y2016. Table 7 shows the average download numbers per hub, and also per mission.

From this table, it can be seen that not only are 100% of the Collaborative Hub and International Hub users active, they are also using their accounts to download a high proportion of the products which have been published

HUB	Sentinel-1	Sentinel-2
Open Access Hub	111	58
Collaborative Hub	104,069	37,372
International Hub	258,447	272,528
Copernicus Services Hub	806	3,398

Table 7: average number of downloads per active user per hub, during Y2016



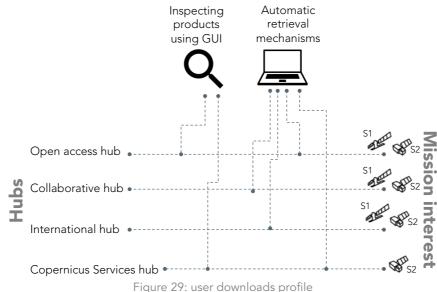




The greatest variety of activity levels is among the Copernicus Services users. Looking also at the graphs in Figure 28, which group active users according to the number of downloads they made during Y2016, it appears that the majority of Copernicus Services Hub users used their accounts to browse the data collections and make 1-9 carefully selected downloads during the year. However, almost as many users made full use of their accounts for downloading products. Closer analysis shows that this class of users is in fact very active, on average downloading far in excess of 100 products, causing the average number of downloads for Copernicus Services Hub users to even out at the relatively high number shown in Table 7 .The Copernicus Open Access Hub supported the highest number of users who made more than

100 downloads: 506 Sentinel-1 users and 149 Sentinel-2 users. Another interesting finding from this data is that the overwhelming majority of both Sentinel-1 and Sentinel-2 active users on the Copernicus Open Access Hub made between 1-9 downloads during Y2016. Again, it is assumed that the majority of these users were exploring the products through the graphical user interface, which enables the inspection of the product metadata before download, and carefully selecting the precise product(s) which they wished to download.

The figure below is a graphical representation of the way the majority of users typically used each hub during Y2016.



3.2.1 Effective bandwidth

Another way to gauge the variety of users supported by each hub is to look at the range of 'effective bandwidths' in which the users were operating during Y2016.

The effective bandwidth is calculated using the time it takes to download a product and the volume of that downloaded product. The effective bandwidth depends on many factors, such as the actual network bandwidth available to the user, the performance required to save the product on a disk, as well as the concurrent activities on the hub at the time the download is made. The range of effective bandwidths provides an indication of the variety of competing user requests experienced on the side of the hub and the variety of download rates experienced on the user side.

The table below presents the percentage of completed downloads performed in Y2016 for the following four effective bandwidth ranges: <10Mbps, 10-50Mbps, 50-100Mbps and >100Mbps.



Hubs vs effective bandwidth ranges	<10 Mbps	10-50 Mbps	50-100 Mbps	>100 Mbps
Open Access Hub	5%	52%	30%	13%
Collaborative Hub - node1	0%	32%	28%	40%
Collaborative Hub – node2	0%	40%	23%	37%
International Hub	10%	50%	29%	11%
Copernicus Service Hub	0%	32%	47%	21%
All Hubs	3%	41%	31%	24%

Figure 30: percentage of completed downloads performed in Y2016 per bandwidth range, per hub

The table in Figure 30 shows that each hub supported a wide variety of effective bandwidths, ranging from 10 Mbps to as much as over 100Mbps. This indicates that there was a great diversity in the facilities available to users of each hub. The primary effective bandwidth in which users of the Collaborative Hub operated, for instance, was over 100Mbps, while on the Copernicus Open Access Hub, the majority of downloads were made with an effective bandwidth of 10-50Mbps.

3.3 Copernicus Open Access Hub user focus

The following sections focus on the Copernicus Open Access Hub users.

3.3.1 Monthly active users

The graph in Figure 31 shows, per Sentinel, the numbers of *monthly* active users on the Copernicus Open Access Hub during Y2016 (i.e. the number of users each month who made at least one complete download during the month).

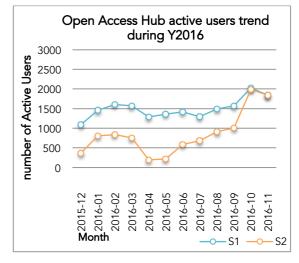


Figure 31: active user trend per mission in Y2016

A gradual increase in the number of Sentinel-1 monthly active users took place during the year, rising from just over 1,000 active users per month, to just under 2,000 active users per month by the end of Y2016.

The number of monthly active users for Sentinel-2 rose more dramatically during the year, increasing from 366 users in December 2015 to 1,841 in November 2016, so that by the end of Y2016, there was an equal number of active users for both Sentinel-1 and Sentinel-2.





In particular, a sharp increase in the number of monthly active users took place after dissemination of Sentinel-2 data as single-tile products began on 27 September 2016. This indicates that many more users started downloading Sentinel-2 data once it became easier for them both to make the download and to select the precise region or cloud free zone in which they were interested.

The apparent drop in the number of active users which appears to take place in April and May 2016, is linked to the software anomaly described in detail at Section 2.3.2 above, which prevented the monitoring system from recording downloads of products with a volume greater than 2GB.

3.3.1 Active users per continent and country

The shows the number of active users per continent in Y2015 and in Y2016, together with the percentage increase between the two years.

The continent with the largest number of active users was again Europe, but the region which experienced the greatest increase in the number of active users since Y2015 was South America + Antarctica, which saw a 378% increase in the number of people actively downloading products with respect to the previous year.

Examining the geographical spread of active users in more detail, the tables below list the top 10 countries in terms of the number of active users per Sentinel in Y2016. In the second column, the percentage of registered users who were active during Y2016 is also shown.

As might be expected, the countries with the highest numbers of registered users also appear among the countries with the highest numbers of active users: the top 5 Copernicus Participating States in terms of the number of registered users are all present in this top 10, as is Brazil, which was the country with the greatest number of registered users by the end of Y2016.

It is interesting to note that in the top 10 countries listed here, there are also countries

which are actively operating national mirror sites (e.g. Italy, the United Kingdom, and France each operate a national Collaborative Ground Segment mirror site, and the United States has three national sites for disseminating Sentinel data). This reflects the width of the EO user communities existing in these countries, but also shows that the existence of a national dissemination site in a country does not automatically reduce the number of users from that country who make active use of the Copernicus Open Access Hub, suggesting that the Hub remains a useful complement to the national initiatives.

Continent	Number of active users in Y2015	Number of active users in Y2016	% increase
Europe	3,959	7,366	86%
Asia	1,257	2,497	99%
North America	791	1,624	105%
South America + Antarctica	340	1,625	378%
Africa	140	473	238%
Australia	87	238	174%

Table 8: Number of Active users per continent in Y2015 and Y2016, and percentage increase







Sentinel-1			Sentinel-2		
Country	Total no. of S1 Active Users in Y2016	% of registered users who were active in Y2016	Country	Total no. of S2 Active Users in Y2016	% of registered users who were active in Y2016
Germany	834	21%	Germany	770	19%
Italy	642	26%	Italy	455	18%
United	621	20%	United	411	12%
Kingdom			States		
United States	621	19%	United Kingdom	387	12%
China	533	18%	Spain	341	22%
Brazil	427	9%	France	267	15%
France	393	23%	Brazil	260	5%
Spain	301	19%	Netherland s	206	20%
Canada	293	26%	Poland	186	16%
Russian Federation	283	32%	Mexico	155	12%

Tables 9: top ten countries in terms of the number of Open Access Hub active users, per mission, from the start of operations, and the percentage of registered users per country who were active during Y2016.

3.3.1 Geographical areas of interest

The following heatmaps show, for each Sentinel, the areas over which the greatest number of downloads were performed by *Copernicus Open Access Hub* users during Y2016. The distinct red spots on the maps mark the areas for which the highest number of downloads were made. For ease of reference, the publication density heatmaps are shown again next to the download heatmaps.

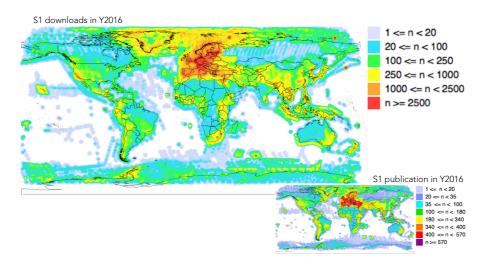


Figure 32: heatmap showing areas of interest for Sentinel-1 users in Y2016

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For Sentinel-1, there is a clear correlation between the areas over which the greatest numbers of products are published and the areas of high downloads, with a marked concentration of both published products and downloaded products over Europe. Nonetheless. there are notable some variances between the two heatmaps: in particular, the high intensity of downloads made over Greenland and the Arctic zones relative to the amount of data published for those zones, and the comparatively low intensity of downloads over the Middle East and the Andes. Moreover, the four areas where the red spots occur, showing maximum download intensity, are areas for which only a medium to low number of products were published.

For Sentinel-2, there is also a strong correlation between the publication and download heatmaps, and for the most part the areas with the highest density of published products are also the areas of highest download activity. The two areas where the high intensity red spots occur, however, are again partly unexpected areas, for which only a medium to low number of products were published. It is also noticeable that the uptake ratio for Sentinel-2 products over Asia, Canada and certain parts of Africa and Antarctica, appears to be close to 1:1, which is out of step with the higher exploitation ratios observable elsewhere.

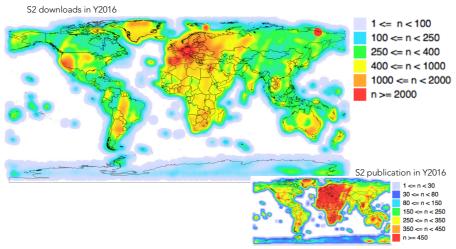


Figure 33: heatmap showing areas of interest for Sentinel-2 users in Y2016





3.3.1 Users per declared usage type and thematic domain

A broad overview of the type of users accessing the Copernicus Open Access Hub, and the end-use for which they are downloading Sentinel data is set out below. It is recalled, however, that these statistics are based on the information which users provide when they register for access to the hub and there is no independent verification of this data. The diagram in Figure 34 analyse user activity in terms of the user's declared field of activity. In graph (a), the total number of registered users on the Copernicus Open Access Hub is broken down to show the distribution of users across the different domains by the end of Y2016. In graph (b), the total number of downloads made in Y2016 is separated out according to the declared domain of the users downloading the products.

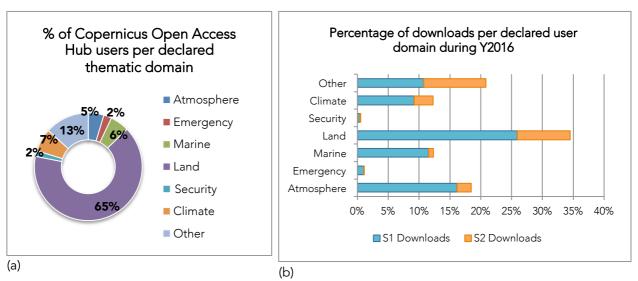


Figure 34: percentage of Copernicus Open Access Hub users per declared thematic domain at the end of Y2016 (graph a), and the percentage of downloads performed per mission for each thematic domain during Y2016 (graph b).

As was the case at the end of Y2015, the vast majority of registered users by the end of Y2016 were users who had declared their field of activity to be 'Land'. Land users were also the user group which downloaded the greatest number of products in Y2016, and almost 4/5 of the downloads they made were downloads of Sentinel-1 products.

Although seemingly a small user group at only 5% of the total registered users, the 'Atmosphere' users downloaded the second highest amount of Sentinel-1 products during Y2016.

For Sentinel-2, it was the users who fell into the 'Other' category who downloaded the highest number of products in Y2016, followed closely by the Land user group.





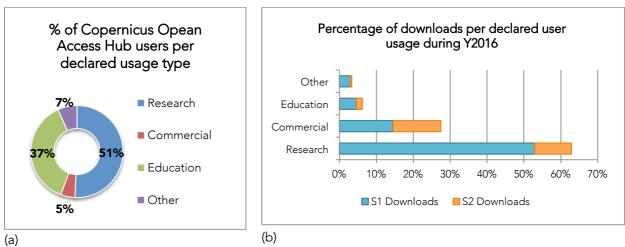


Figure 35: percentage of Copernicus Open Access Hub users per declared usage type at the end of Y2016 (graph a), and the percentage of downloads performed per mission for each usage type during the reporting period (graph b).

From graph (a) in Figure 35, it can be seen that the majority of registered users by the end of Y2016 were users who had declared their use of the data to be for 'Research'. From graph (b) it can be seen that the majority of products downloaded by this research user group were Sentinel-1 products.

The number of users who declared their use of the data to be 'Commercial' increased considerably during 2016: in 2015 this commercial user group represented only 6% of the user community; by the end of Y2016, it had

come to represent as much as 37% of the total number of registered users.

The commercial user group was also very active during Y2016, performing a total of 28% of product downloads from the Copernicus Open Access Hub. It is also interesting to note that this group downloaded more Sentinel-2 products than were downloaded by the larger research user group, and overall downloaded almost equal amounts of Sentinel-1 and Sentinel-2 products.





4. DATA DISSEMINATION PARTNERS

Building on the data dissemination provided under the Copernicus programme, Participating States, international partners and commercial actors are developing complementary national and commercial services for the exploitation of Copernicus Sentinel data.

Among other objectives, these services address the redistribution of Sentinel products, as well as the creation of additional data sets or complementary products, such as regional datasets or higher level products.

- The activities of GMES and Copernicus participating states are described in Section 4.1.
- The activities of international partners are described in Section 4.2.
- Two examples of commercial redistribution are described in Section 4.3.



Figure 36: Atomium monument, Brussels.

4.1 Collaborative Ground Segment Agreements

GMES and Copernicus Participating States are complementing the exploitation of the Sentinel missions and supporting the redistribution of Sentinel products by developing new products and establishing additional data access points (mirror sites), adding to a network known as the Collaborative Ground Segment.

A total of 12 Collaborative Ground Segment agreements have been signed with ESA. Following signature of the formal agreement, ESA provides a username and a password to the national contact point for accessing the Collaborative Hub.

The Collaborative Ground Segment partners replied to an annual questionnaire released by ESA on the use of Sentinel data on their national sites. Not all of the national services planned under the Collaborative agreements were operational by the end of Y2016, so the statistics presented are based on the input of the 7 partners whose national initiatives were active in Y2016.

Table 10 summarises the status of the 12 Collaborative Ground Segment agreements, listed in order of the date the agreement was signed with ESA. Where no information was provided, this is shown as "-".

By the end of the reporting period, 69% of the Collaborative Ground Segment partners had opened their national mirror sites. Of these, 4 were opened during the first half of 2016, and one in the second half of 2016. The sites that were already open in 2015 (i.e. Greece, UK, France and Canada) experienced an impressive average increase in publication and download volumes during Y2016 of:

- publication: +482%
- dissemination: +2,046%

Table 10 presents information about the numbers of registered and active users on the national mirror sites. It is recalled that the values reflect the answers provided by the Collaborative partner in response to the annual questionnaire.





Progressiv	CollGS	CollGS	Opened	Operation	National site link
e number	partner	agreement signature date	mirror site	stat date	
1	Greece	May-14	yes	06-Feb-15	http://sentinels.space.noa.gr/
2	Norway	Sep-14	-		
3	Italy	Oct-14	yes	28-May-16	http://collaborative.mt.asi.it/
4	Germany	Nov-14	no		http://www.code-de.org
5	Finland	Jan-15	yes	24-May-16	http://finhub.nsdc.fmi.fi
6	UK-16	Mar-15	yes	01-May-15	http://www.ceda.ac.uk/;
	UK-2	Mar-15	yes	09-Sep-16	http://sedas.satapps.org.uk
7	France	Mar-15	yes	11-Sep-15	http://peps.cnes.fr
8	Sweden	Jun-15	yes	April-16	https://saccess.lantmateriet.se/p ortal/saccess_se.htm
9	Canada	Sep-15	yes	22-Sep-15	ftp://ftp.neodf.nrcan.gc.ca
10	Portugal	Oct-15	-		
11	Austria	Feb-16	yes	31-May-16	http://www.sentinel.za mg.ac.at/
12	Estonia	Sep-16	no		

Table 10: Collaborative Ground Segment mirror sites summary

CollGS partner	overall number of registered users since	increase since	% of registered users from the		% of registered users who were active in
	start of operations	Y2015	national country	in Y2016	Y2016
France	1,282	400%	50%	_7	-
Austria	860		89%	470	55%
Greece	380	126%	73%	65	10%
UK-2	169		94%	169	100%
Finland	128		79%	63	50%
Sweden	77		-	77	100%
UK-1	67	335%	85%	52	85%
Italy	21		100%	8	38%
Canada	10	60%	100%	7	70%

Table 11: Summary of national mirror site users

⁶ The UK's Collaborative Ground Segment consists of two mirror site initiatives: UK-1 indicates the site operated for the academic community; UK-2 indicates the site operated independently and aimed at commercial users.

⁷ CNES reported that unfortunately, due to an anomaly in relation to the dissemination of products from the French mirror site, this information is not available for the French Collaborative Ground Segment.





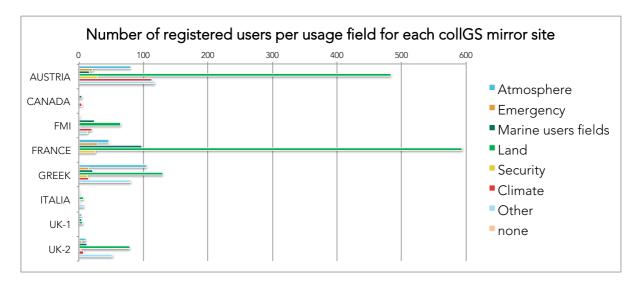


Figure 37: Distribution of users by usage field on each mirror site

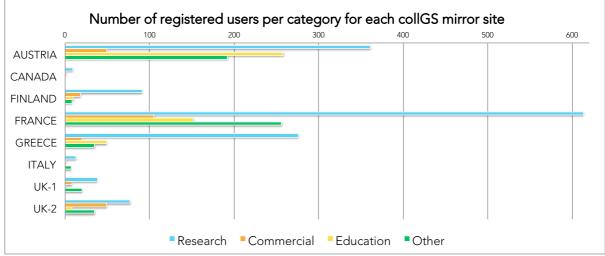


Figure 38: Distribution of users by user category on each mirror site

It is interesting to note that although most mirror site users are nationals of the country providing the service, a proportion of users on most mirror sites comes from outside the country.

In line with the agreements signed with ESA, the Collaborative Ground Segment partners categorise their own users according to the same fields used by ESA. The graph below shows for each mirror site the breakdown of users according to their declared usage field.

It can clearly be seen from this graph that, as for Copernicus Open Access Hub users, 'Land' is the most common usage field overall for

the mirror site users, by a considerable margin.

From the graph below, it can be further seen that the majority of mirror site users intend to use the Sentinel data for 'Research', with 'Education' and 'Other' forming the next most popular uses. Nonetheless, **a** notable proportion of the users on each mirror use the data site intend to for 'Commercial' purposes and on the UK-2 site and Finland's site, commercial users actually constitute the second highest user group.







The Table 12 below reports the volume of Sentinel data which was published and downloaded from the mirror sites in Y2016, together with an indication of the increase with respect to Y2015.

From these figures it appears that a large amount of Sentinel products were made available on the mirror sites during Y2016, but that user activity by the end of Y2016 had not yet kept pace with the amount of data which was published.

Finally, some of the Collaborative Ground Segment partners were also able to provide statistics on the uptake of data from their mirror sites per product type, and this information is set out in the Table 13 below.

From this table, it can be seen that the Sentinel-1 GRDH and SLC products constituted a high percentage of the Sentinel-1 products downloaded by mirror site users in Y2016 (34% and 48% respectively), as was the case on each of the Sentinel Data Access Hubs. However, the 'Level 0' products were not nearly as popular with the mirror site users as they were with the users of the Sentinel Data Access System. This suggests that some finetuning of the data offer on the Collaborative Hub could be made, in order to optimise the use of resources.

It is also worth highlighting from this table that the total volume of Sentinel-2 products downloaded from the mirror sites during Y2016 is equivalent to the total volume of Sentinel-1 products which was downloaded (306.76 TB).

Copernicus participating states	Y2016 published Volume [TB]	Increase [%]	Y2016 Volume [TB] of products downloaded	Increase of volume downloaded with respect to Y2015 (yes/no)
Austria	980		146.00	n/a
Canada	17	365%	8	Yes
Finland	24.8		0.71	Yes
France	913.46	659%	_8	-
Greece	123.51	100%	5.00	Yes
Sweden	-		6,04	n/a
UK-1	789.3	455%	399.12	Yes
Total [TB]	2,848.07		558.83	

Table 12: Publication and dissemination volumes on mirror site

⁸ CNES reported that unfortunately, due to an anomaly in relation to the dissemination of products from the French mirror site, this information is not available for the French Collaborative Ground Segment.



Total [TB]

0.2



Collaborative	Sentinel 1	Sentinel 1 L1	Sentinel 1 L1	Sentinel 1 L1	Sentinel	Sentinel 2
Ground	Level 0	Ground Range,	Ground Range,	Single-Look	1 L2	L1C
Segment	[TB]	Multi-Look,	Multi-Look,	Complex [TB]	Ocean	[TB]
partner		Detected:	Detected: High		[TB]	
		Medium	Resolution [TB]			
		Resolution [TB]				
Austria	0.2	1.5	13	39	0.1	92
Canada		3.7	4.5			
Finland		0.04	0.57			0.03
Italy	0.0015	0.00017	0.166	0	0	0.003
Sweden						6.04
UK-1		24.18 (S1A; EW)	86.73 (S1A; IW)	(S1A)108.57 +(S1B) 0.02		209.11

104.97 Table 13: Volume disseminated in Y2016 from the mirror sites per product type;

147.59

0.1

307.18

29.42





4.2 International Technical Arrangements

The European Commission and ESA have agreed with NASA, the National Oceanic and Atmospheric Administration (NOAA), the US Geological Survey (USGS) and Geoscience Australia (GA) to make Copernicus Sentinel data available to them via a dedicated access point, the International Hub.

These agencies transfer the data to their own dissemination points, for use by their own user communities.

4.2.1 Redistribution statistics

Feedback was received from NASA and GA on use of their sites during Y2016, via replies to the annual questionnaire released by ESA.

GA opened its regional Copernicus data hub on 26 June 2015, with the aim of providing free and open access to data from the Copernicus Sentinel satellites for the South-East Asia and South Pacific region. The project is operated collaboratively by GA, the New South Wales Office of Environment and Heritage, Queensland Department of Science Information Technology and Innovation and the Commonwealth Scientific Industrial Research Organisation. The National Computational Infrastructure (NCI) in Canberra is contracted to implement and operate the hub.

The regional hub can be accessed from the following website: http://www.copernicus.gov.au/. At the end of Y2016, there was no user interface for browsing the catalogue or downloading the products but GA was planning to release a graphical user interface which would allow user registration and an interactive and custom search of the archive by early 2017.

During Y2016, GA disseminated both Sentinel-1 and Sentinel-2 data from the hub. The products published on the hub were the original products as supplied by ESA.

NASA started distributing Sentinel-1 products from its Alaska Satellite Facility data portal, Vertex (https://vertex.daac.asf.alaska.edu/), on 12 December 2015. The aim of its mirror site is to re-use and re-disseminate Sentinel products, to increase distribution capacity, and maximise the benefits to Earth Science research and applications. During the reporting period, NASA distributed only Sentinel-1 products from its site.

The table below sets out the overall statistics for these two international dissemination points for Copernicus Sentinel data.

It is interesting to note that while 77% of GA's user community is Australian, only 18% of NASA's registered users are from the United States and the remaining 82% come from 100 different countries across the world. Notwithstanding this high number of international users, however, 66% of the downloads made from NASA's site were made by American users, and the diagram below shows the different US user groups which together constituted this 66% of the total downloads.

Partner	Start of operations date	Number of users in Y2016	% of registered users from the national country	Published Volumes (TB)	Volume of products downloaded (TB)
GA	26-Jun-15	121	77%	190.5 (S1: 130.4 S2: 60.1)	22.5 (S1: 0.3 S2: 15.8)
NASA	12-Dec-15	2,555	18%	1,327	687.86

Table 14: NASA and GA sites information

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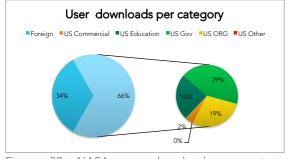


Figure 39: NASA user downloads per category percentage

The declared usage fields for which the highest numbers of downloads were made from NASA's site were:

- Geophysics (33%);
- Land Processes (16%); and
- Cryospheric Studies (11%).

A further 26% of the total downloads were made by users who registered 'Other' as their usage field.

As is also possible from ESA's Data Access System, NASA's dissemination point enables the download of metadata and browse images of the Sentinel-1 holdings. This additional download information is grouped together under 'Other' in the following table, which sets out the user take-up per product type from NASA's dissemination point during Y2016.

Product Type	No. of products downloaded in Y2016	Percentage of number of downloads per products type	Vol. of products downloaded [TB] in Y2016	Percentage of volume of downloads per products type
Level 0	19,640	2%	12.86	2%
L1 Ground Range, Multi- Look, Detected: Medium and High Resolution	315,362	35%	171.12	25%
L1 Single-Look Complex	451,453	50%	503.86	73%
L2 Ocean	2,201	0%	0.01	0%
Other	120,727	13%	0.0075	0%
Total	909,383		687.86	

Table 15: user take-up per product type from NASA's dissemination point during Y2016





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4.3 Commercial Redistributors

Another development during Y2016 was the growth of commercial services which are systematically downloading the complete collections of Sentinel-1 and Sentinel-2 data from the Sentinel Data Access System and redistributing the data to an expanding user base. As with the national initiatives, these services are fostering the uptake of Copernicus Sentinel data and are encouraging the downstream exploitation of the information the data provides.

Information about their activities during Y2016 was available for this annual report from two of these commercial redistributors, Sinergise and Cloudferro, and this information is briefly summarised below.

4.3.1 Sinergise

The Slovenian company Sinergise Laboratory for Geographical Information Systems, Ltd (Sinergise) has developed tools which enable users to browse through the complete collection of Sentinel-2 data in full resolution, and provide streamlined access to the data, especially for machine-to-machine services (http://sentinel-pds.s3-website.eu-central-1.amazonaws.com/).



Sinergise not only re-publishes the core Sentinel products which it sources from the Copernicus Open Access Hub, it also adds to its data offering value-added products which are created from the Sentinel core products. In total, Sinergise published **1,251,491 products** on its site during Y2016, reaching a total volume of approximately **0.5 PB**.

Users of Sinergise's services are able to download either full Sentinel-2 products or parts of products and the system supported a significant volume of user downloads in Y2016, receiving **3.6 billion requests** for Sentinel-2 files and **distributing around 2 PB** of data.

Sinergise is working on introducing a similar archive for Sentinel-1 data in 2017.

4.3.2 CloudFerro

In July 2016, the Polish company CloudFerro sp. z o.o. opened its EO Cloud platform, on which it offers services which enable commercial and scientific users to obtain and process data from Sentinel-1, Sentinel-2, Sentinel-3, Landsat and Envisat

(http://www.cloudferro.com/en/eocloud/).



CloudFerro reported 76 registered users, with 70% of them coming from Poland.

During Y2016, **549.85 TB** of Sentinel products were published on the EO Cloud. Of these:

- 8,977 were Sentinel-1 products, with a total volume of 38.87 TB,
- 358,520 were Sentinel-2 products, with a total volume of 510.98 TB.

In the period between the platform going online in July 2016 and the end of Y2016, **183 TB** of data was downloaded from the site.





5. DATA ACCESS SYSTEM PERFORMANCE ANALYSIS

Performance analysis plays a key role in the continuous improvement of the Data Access Service. Operations of the Sentinel Data Access System are constantly monitored, and the results are collected and regularly analysed to check the system's performance. The approach and the results from this continuous analysis are described in this Section.

It is also highlighted that throughout the year, statistics covering a 24h sliding window and showing the number of published products and completed downloads, together with the number of user searches made on the hub have been made continually available to all users on the Copernicus Open Access Hub entry page. The statistics were intended to give users an instant view of the system activity and highlight when potential issues might be affecting the system.

5.1 Availability

Availability is defined as the percentage of time it is possible for users to search the catalogue and retrieve products from the system.

The following table sets out the overall availability values collected during Y2016. For the hubs which offer users more than one access point, the availability values are calculated using the combined availability of the access instances: the Copernicus Open Access Hub availability is calculated as the average availability of the graphical user interface and the API interface; and from October 2016, the Collaborative Hub availability value is calculated as the average between the Node 1 and Node 2 values. It is also worth noting that the availability of the International Hub and the Copernicus Services Hub did not start to be monitored until July 2016, when the operations phase of the Data Access Service contract began.

Hub	Y2016 Availability
Copernicus Open Access Hub	95.11%
Collaborative Hub	98.19%
International Hub	99.59%
Copernicus Services Hub	99.35%

Table 16: Overall availability of each hub during Y2016

The following chart breaks these overall figures down into the monthly availability figures for each hub.





MONTH	Acc	Dpen ess Hub ilability [%]		aborative Hub ailability [%]		rnational Hub ailability [%]	Serv	pernicus vices Hub ailability [%]
2015-12	\bigcirc	92,74		96,92	n/a		n/a	
2016-01		97,20		99,70	n/a		n/a	
2016-02		99,48		98,14	n/a		n/a	
2016-03		99,12		98,72	n/a		n/a	
2016-04		92,48		98,89	n/a		n/a	
2016-05		98,72		99,50	n/a		n/a	
2016-06		99,09	\bigcirc	99,87	n/a		n/a	
2016-07		96,78		96,87		99,71		99,85
2016-08		96,09	\bigcirc	94,68		99,51		99,41
2016-09	\bigcirc	93,58		98,81		99,26		99,16
2016-10		85,03		96,90		99,65		98,88
2016-11		91,06		99,33		99,83		99,42
Year availability		95,11		98,19		99,59		99,34

Table 17: monthly availability for each hub: the green bubble means that the average availability towards the users during the week was more than 95%, the yellow bubble means that it was between 90% and 95% and the red bubble means it was lower than 90%.

The International Hub and the Copernicus Services Hub achieved consistently high availability during the period in which they were monitored.

The availability of the Collaborative Hub also remained strong throughout the year, despite the fact that use of the hub increased considerably during the year. A drop in availability was noted in August 2016, when the network Data Hub Relay performance assessment activities began, occasionally placing a higher stress on the Hub than it was able to support. As a result, each Relay was introduced to the Collaborative Hub on a gradual basis, and the availability of the Hub was not affected by any further major disturbance, while the number of downloads continued to increase.

At over 95%, the overall availability of the Copernicus Open Access Hub for Y2016 is impressive, considering the ever-increasing load of user searches and downloads which it supported throughout the year. However, there were periods in Y2016 in which the availability of the Hub was unpredictable, and this resulted in significant disruption for users trying to download products and the lowest availability value for the year of all the hubs. Detailed explanations for this reduced performance are presented below.

5.1.1 Copernicus Open Access Hub focus

The figure below reports the weekly availability of the graphical user interface of the Copernicus Open Access Hub.

In December 2015, the availability was <90% for two consecutive weeks. This event was related to infrastructure patching and to transferring a new software version to operations on 14 December 2015.

Another critical event occurred on 22 January 2016. Due to a site configuration issue, all the virtual machines ceased to function properly (including the hot redundancy service). The anomaly occurred on a Friday afternoon, but the Copernicus WAN service provider (T-Systems) was able to restart the hosting service in the evening. The data access service was fully restored at 09:56 UTC the next day.

In the period between February 2016 and April 2016, even though the overall availability of the Copernicus Open Access Hub was relatively and the frequency of these events was







orting period			pernicus Open Access Hub I interface availability
03 December 2015	2015 WN 49	0	
10 December 2015	WN 50	-	
17 December 2015	WN 51	-	
24 December 2015	WN 52	\bigcirc	
31 December 2015	WN 53	-	
07 January 2016	2016 WN 01	-	
14 January 2016	WN 02	-	
21 January 2016	WN 03	-	
28 January 2016	WN 04	-	
04 February 2016	WN 05	-	
11 February 2016	WN 06	-	Legend
18 February 2016	WN 07	-	Legend
25 February 2016	WN 08	-	👿 availability >= 95%
	WN 08	-	90 <= availability <
03 March 2016		-	availability < 90%
10 March 2016	WN 10	-	
17 March 2016	WN 11	-	
24 March 2016	WN 12	-	
31 March 2016	WN 13	-	
07 April 2016	WN 14	-	
14 April 2016	WN 15	-	
21 April 2016	WN 16	\bigcirc	
28 April 2016	WN 17	\bigcirc	
05 May 2016	WN 18	\bigcirc	
12 May 2016	WN 19		
19 May 2016	WN 20	\bigcirc	
26 May 2016	WN 21	\bigcirc	
02 June 2016	WN 22	\bigcirc	
09 June 2016	WN 23	\bigcirc	
16 June 2016	WN 24	\bigcirc	
23 June 2016	WN 25	\bigcirc	
30 June 2016	WN 26	\odot	
07 July 2016	WN 27	\bigcirc	
14 July 2016	WN 28	0	
21 July 2016	WN 29	-	
28 July 2016	WN 30	6.2	
04 August 2016	WN 31	-	
11 August 2016	WN 32	-	
18 August 2016	WN 33	6.2	
-	WN 33	-	
25 August 2016	WN 34	-	
01 September 2016		6.2	
08 September 2016	WN 36		
15 September 2016	WN 37		
22 September 2016	WN 38	6.2	
29 September 2016	WN 39	0	
06 October 2016	WN 40	-	
13 October 2016	WN 41	-	
20 October 2016	WN 42	\bigcirc	
27 October 2016	WN 43	\bigcirc	
03 November 2016	WN 44	\bigcirc	
10 November 2016	WN 45	\bigcirc	
TO MOVEMber 2010			

Figure 40: Weekly Open access hub availability in Y2016 associating a coloured bubble according the availability rage: the green bubble means that the average availability towards the users during the referred week was more than 95%, the yellow bubble means it was between 90% and 95% and the red bubble

high, occasional short downtimes were noted particularly significant in the period between 11 April and 21 April 2016. Analysis identified that these downtimes were associated to particular user requests that were sub-optimally handled and required performance tuning. The Data Access System software was modified to include a means of better managing this type of user request. The resulting software upgrade was successfully installed on 19 April 2016, and was followed by an optimisation of the quota control configuration on 22 April 2016. These interventions successfully restored the stability of the service for 12 consecutive weeks.

During the period between 15 July 2016 and 25 August 2016, a series of downtimes occurred outside normal working hours and particularly during the night. Most of the downtimes were caused by the activity of specific users who were using the graphical user interface to request in batch mode the bulk download of parts (e.g. granules or tiles) of Sentinel-2 products. This disproportionately onerous load on the system was managed in the short-term by instructing the users on how to use the API interface, which is better designed for making massive product downloads. Investigating the issue within the software itself, it was discovered that the support library used for Sentinel-2 product handling was sub-optimal and prone to creating conditions of memory resource exhaustion. This problem was ultimately resolved by the adoption of an alternative software library.

During the same period, two security patching activities were carried out on the infrastructure, on 20 July 2016 and 3 August 2016. These provoked extended periods of unavailability during the days on which they were performed, significantly reducing the overall weekly availability value. Moreover, firewall maintenance was carried out at the end of August, and this led to further downtimes which affected user downloads.

In the last quarter of Y2016, the problem of system overload on the Copernicus Open Access Hub reached its peak and the availability during the quarter was significantly reduced.

On 19 September 2016, the Sentinel-2 Pre-Operations Hub was decommissioned, and all of the pre-Operations Hub users transferred their activities to the graphical user and API interfaces of the Copernicus Open Access Hubs. This created a surge of requests which was not easily absorbed by the system. In particular, the majority of users on the Pre-Operations Hub were using scripts to download parts of Sentinel-2 products and, in terms of CPU usage, the resources needed to satisfy the download of a





single part of a product are much higher than the resources needed to satisfy a full product download. This additional stress had not been factored into the calculations, so when these users transferred their activities, the additional peak was greater than expected and not wellsustained by the system. This extra stress was removed one week later, however, as soon as the Sentinel-2 products started to be distributed operationally as single-tile products from the Hub, removing the need to make partial downloads using dedicated scripts, and the availability of the system was restored in the short-term.

Nonetheless, publication of the single-tile Sentinel-2A products, together with the publication of the Sentinel-1B data, attracted even more activity on the Copernicus Open Access Hub, and the number of user searches and download requests which the system had to manage correspondingly increased. The combination of these factors (more users, more products, more searches and more downloads) stretched the system to an extent that was no longer sustainable with the existing level of scalability, and the Hub was again beset by a series of downtimes. Several temporary measures were adopted and were successful in re-establishing a good level of service reliability between 21 October 2016 and the beginning of November 2016.

The root causes of the architectural limitations had, however, already been identified and fundamental improvements to the scalability of the solution had already been developed, in order to fix the problem on a long-term basis. This major software upgrade was being validated during the final months of the reporting period and is set to be fully operational at the beginning of 2017. The new solution will provide far greater scalability, include an evolution to cope with the further increase of data arriving with the Sentinel-3A products, and make it possible for the operations team to perform maintenance work without requiring a complete shutdown of the service, by removing a server individually from

the pool of servers and managing the user sessions on the remaining servers (exceptional maintenance may still require temporary suspension of the service).

However, in order to start configuring this new scalable system, extraordinary maintenance activities were required during November 2016 and this caused further disruption to the Hub's availability, accounting for the three weeks of sub-optimal performance at the end of Y2016.

5.2 Publication Timeliness

Publication timeliness is a measure of the time it takes from the end of the data being sensed by the satellite to the product being published on the hub. The timeliness depends on the end-toend design of the mission, from the geographical position of the receiving antenna to the priority given to each product in the publication chain.

Products are categorised as either Near Real Time (NRT) products or Non-Time Critical (NTC) products. NRT products are delivered to the users less than 3 hours after acquisition of the data by the sensor. The expectation for NTC products is that they will be published within 24 hours from sensing.

The figure below shows for Sentinel-1 (blue) and Sentinel-2 (red) NTC products the average publication timeliness on each hub during Y2016, and the percentage of published NTC products which fell within that average timeliness. Only products which were published within 7 days of sensing were included in the calculation, to remove as far as possible retrospectively processed data, which is discussed in detail in the following section. The size of the bubble does not indicate any statistical value.

As expected, given the different designs of the two missions, Sentinel-1 products are published within a shorter time from sensing than Sentinel-2 products.



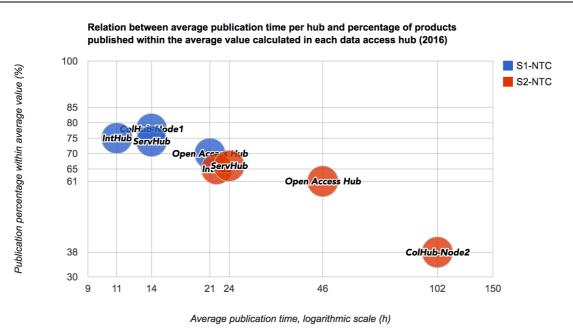


Figure 41: Average publication timeliness per hub

In general, the hubs which are reserved to a restricted community received the data more quickly than the Copernicus Open Access Hub, and this can partially be attributed to the better overall availability of the dedicated hubs discussed above. However, the publication timeliness for Sentinel-2 products on Node 2 of the Collaborative Hub was much lower than expected, with an average delay of 102 hours (outlier red bubble in the graph), and this was the result of a problem in the publication chain. Node 2 of the Collaborative Hub is outside the perimeter of the overall Wide-Area-Network (WAN) dedicated to the Sentinels, and the data public is transferred via internet. The synchronisation service which manages the transfer was found to be inefficient for the publication management, especially during the period in which Sentinel-2 single tiles were being published at the same time as multi-tile products from the Commissioning Phase. A significant improvement for the management of Node-2 is planned for the beginning of 2017.

As outlined in Section 2.3.1 above, Sentinel-1 NRT products are provided to the Copernicus Services via their dedicated access points, and this provides the timeliest access to the NRT data.

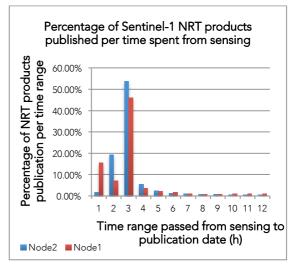


Figure 42: Histogram of the percentage of NRT products distributed per time ranges calculated from the sensing date of the satellite to the publication date in the ColHub nodes

During Y2016, the NRT products were also provided to the Collaborative Ground Segment partners via both nodes of the Collaborative Hub. The histogram in Figure 42 illustrates the publication timeliness for Sentinel-1 NRT products on the two nodes.

From this graph, it can be seen that the overwhelming majority of NRT products were







delivered via both nodes to the Collaborative Ground Segment partners within 3 hours from sensing. The slightly slower overall publication rate for Node 2 is again attributable to the Node being outside the dedicated Sentinel WAN.

5.2.1 Publication of retrospectively processed products

In addition to the Sentinel-1 and Sentinel-2A routine production, several supplementary processing campaigns were undertaken and resulted in additional publication flows which the Data Access System managed in parallel to the routine data flows.

The most significant batch of additional data for Sentinel-1 was generated by a major retrospective processing campaign aimed at generating SLC products which were not foreseen in the initial operations concept for Sentinel-1. This major retrospective processing campaign was completed in November 2016, providing access to SLC products for all Interferometric Wide Swath Mode data acquired over land masses since October 2014.

The graph below shows the monthly distribution of Sentinel-1A SLC products which were sensed during Y2015 and published in Y2016 as a result of the SLC retrospective campaign. Given the large effort involved in carrying out such a major reprocessing campaign, the processing and publication was scheduled around the availability of the operators involved and the largest volumes of data started to be published from September 2016 onwards.

In total, 78.8 TiB of additional Sentinel-1A SLC products which were sensed during Y2015 were published during Y2016.

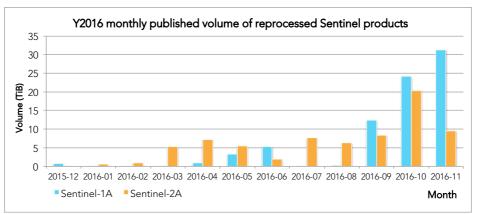
For Sentinel-2, several reprocessing campaigns were performed during Y2016, and the figure below also shows the monthly volume of reprocessed Sentinel-2A products published on the Copernicus Open Access Hub during Y2016.

The first reprocessing campaign for Sentinel-2A products started in March 2016, with the aim of reprocessing the data acquired during the Sentinel-2A Commissioning Phase, before the instruments were fully calibrated. In particular, it was considered useful to generate qualified products for the 2015 summer period.

The publication of this reprocessed data was interrupted in June 2016, when the PDGS discovered a failure in the input products and aborted the reprocessing campaign. The problem was fixed in July 2016 and the publication of reprocessed products was still ongoing at the end of the reporting period.

Additionally during Y2016, the PDGS identified some anomalies in published products. Campaigns were accordingly launched to delete these products and reprocess them once the anomaly had been identified and resolved.

A total volume of 73.9 TiB of Sentinel-2A reprocessed products was published during Y2016.





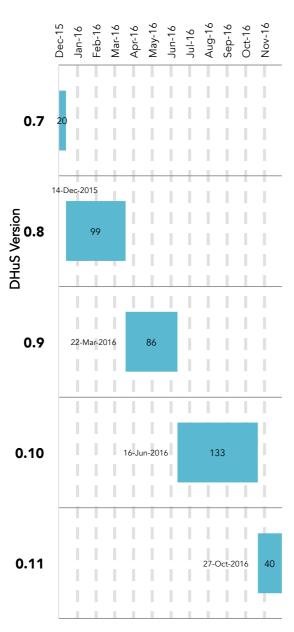






5.3 Hub Software improvements

During Y2016, 5 major software upgrades were put into operation in the data access hubs.



Open Access Hub: DHuS Operational History

Figure 44: History of software upgrades on the Copernicus Open Access Hub in Y2016

Figure 44 shows the dates on which the software versions were transferred to operations on the Copernicus Open Access Hub during Y2016. The number in the bar is the number of days which passed between each software upgrade.

For each major version upgrade, at least one significant new feature was added:

- version 0.8 series introduced the Sentinel-3 ingestion capacity,

- version 0.9 series introduced the interface for the remote product synchronization dedicated to the OSF users,

- version 0.10 series improved the security measures and the software functions for supporting the Data Hub Relay network tests,

- version 0.11 series improved the OData performance and, as consequence, the synchronization and response performance.

The Data Hub software performances are continuously analysed to identify the necessary performance enhancements to optimise the user experience. The growing amount of products and users requests challenging the operational instances makes this optimization process a key task.

5.3.1 Publication performance

A series of optimizations were also applied to the Data Hub Software since version 0.8, to speed up the publication process.

During Y2015, a distinct correlation between a high number of user requests and a slowing down in the publication rate had been noted. This was due to the fact that the system internal requests (e.g. for data publication) were impacted by external requests from the users. It was for this reason that in Y2015, some accounts which were performing huge quantities of requests had been temporarily locked, to prevent them from blocking the download activity of all users.

In Y2016, the Data Hub software was upgraded to separate better the handling of internal system requests from user requests.

Moreover, the publication process itself was optimized, through an improvement of the product registration and metadata indexing, and

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a significant enhancement of the data synchronization process between the hub instances managing product ingestion and those managing user queries was implemented.

5.3.2 Response time

The Data Hub APIs exposed to the users, OData and OpenSearch, were optimized during Y2016 (in particular in version 0.8 and 0.11), to guarantee better performance in responding to user requests.

OData: the introduction and optimization of a cache reduced the time spent to satisfy an OData request using filters. In the frame of the Data Hub testing campaigns, an average decrease in the response time of up to 41% was measured.

Sentinel-2 Nodes inspection: The product nodes inspection of Sentinel-2A products (via the OData API) was optimized to respond to the user need of downloading tiles.

The processing time of this kind of query decreased by 80% (from 2,5 sec to 0,5 sec).

Open Search: The OpenSearch implementation in DHuS was also upgraded to provide faster response to user requests. Specific implementation was provided to avoid deadlocks causing resource exhaustion, and a timeout setting was introduced.



"News guy wept when he told us Earth was really dying Cried so much that his face was wet Then I knew he was not lying."

From: 'The Rise and Fall of Ziggy Stardust and the Spiders From Mars' (1972)





6. USER EXPERIENCES

6.1 User feedback

User feedback is constantly taken into account in order to check if the Data Access Service is meeting the users' needs. Users are invited to write to the email address **eosupport@copernicus.esa.int**, which is the contact point for all issues concerning Copernicus satellite data. From this coordination point, all emails regarding data access are filtered out and forwarded directly to the Sentinel Data Access System operations team for resolution.

6.1.1 Copernicus Open Access Hub and Copernicus Services Hub user feedback

Feedback and requests received from users of the Copernicus Open Access Hub and Copernicus Services Hub are tracked via a "ticketing" system. During Y2016, 1,334 user tickets were managed (almost 4 times the total number of tickets opened and managed during Y2015).

The Data Access Service provider has been routinely reporting on the resolution of these user tickets since 1 July 2016, when the Service moved into routine operations. In the period 1 July 2016 to 30 November 2016, users raised 773 tickets and 100% of these were resolved within the period. The average initial response time for these tickets was 1 hour 40 minutes 03 seconds, and the maximum initial response time recorded was 8 hours 02 minutes 09 seconds.

As was the case for Y2015, the most frequent request from the users of the Copernicus Open Access Hub was for a reminder/reset of username or password or for unsuccessful login on the hub (90% of which were due to the selfregistration procedure not having been completed).

The next most frequent type of request was for API usage support, especially on the filter usage.

In the second half of Y2016, some changes in the API interface were introduced, mostly intended to enhance the robustness of the system and protect it from excessive searches and download requests. These changes resulted in an increased number of requests for support and some complaints from the users; especially those who were performing queries in order to retrieve automatically the entire metadata catalogue. An evolution of the DHuS software is planned for early 2017, in order to support better these types of users.

During the first half of Y2016, before the change to distributing the Sentinel-2A products as single-tiles was made, a significant number of users also raised tickets to report problems with completing Sentinel-2 downloads. As explained at Section 1.2.1 above, to support these users before the switch to single-tile products took place, dedicated batch scripts were provided to shows users how to extract and download automatically single-tiles from the multi-tile products, and ease the downloading process.

6.1.2 Collaborative Ground Segment partner feedback

As part of the questionnaire sent to them by ESA, the Collaborative Ground Segment partners were invite to provide feedback on their experience of downloading products from the Sentinel Data Access System.

Overall, the partners reported that the Collaborative Hub was the most efficient access point for their purpose, and that the Copernicus Open Access Hub was not as consistently reliable.

The change to distributing Sentinel-2 products as single-tiles was greatly appreciated, because it was easier to manage a download of the lower product volume and fewer download interruptions and transfer issues were experienced. On the other hand, as previously outlined in this report, Sentinel-2 distribution in single-tiles from the Collaborative Hub led to a







period of poor publication timeliness, so satisfaction with the change was tempered by frustration with the slow product publication.

The partners participating in the Data Hub Relay network reported confidence that an increase of performance in this context could lead to an optimization of the distribution of Sentinel products from the national sites.

For completeness, the detailed feedback received from the Collaborative Ground Segment partners on data retrieval from the Sentinel Data Access System has been summarised in the table below.

Collaborative Ground Segment partner	Feedback on data retrieval from the Sentinel Data Access System
CANADA	Reported a series of errors connecting, searching and downloading from the Collaborative Hub.
ESTONIA	Also reported problems with the stability of the connection with the Copernicus Open Access Hub due to the large number of users who try to download the data
FRANCE	Reported problems with availability of the hubs (as discussed in section 5.1.1), confirming that they frequently found it necessary to download from the different access points.
GERMANY	Reported progress with the Data Hub Relay operations, with concerns for transfer rates achieved and the backlog of Sentinel-2 production within the ColHub (as discussed in section 5.2), also in response to frequent maintenance activities and some inefficiencies in the synchronisation. The German Collaborative Ground Segment identified the need for reporting product deletions, and the need for better ways to verify the overall completeness of the transferred data from multiple sources. These issues have been discussed with ESA in order to identify improvements for the Data Hub Software to be rolled into operations in early 2017.
ITALY	Reported that they were downloading data from both from ColHub and COAHub. Downloading from ColHub was reported to be smooth and successful, whereas for COAHub there were difficulties with speed, disconnections and wrong checksums (as discussed in section 5.1.1).
UK_1	Reported challenges in keeping on top of the high data rates (especially considering the retrospective processing of data as reported in section 5.2.1). The UK_1 partner also positively noted that the smaller Sentinel-2 files have resulted in fewer drop-outs, and transfer issues.





UK_2	Reported issues of timeliness of data being made available in the ColHub and COAHub (as discussed in section 5.2) and on the overall availability (as section 5.1.1). They also noted a high variability in the search response time on the COAHub. They suggested a KML/Shp import function in the COAHub, and this function will be planned for Y2017. The change to the Sentinel-2 single-tile product format was seen as an important improvement, although it was noted that the footprints are an irregular shape and feel unconventional. The UK_2 partner also commented on difficulties in automating some tasks based on the published Sentinel acquisition plans. The UK_2 partner suggested that providing geocoded quick looks would be extremely useful.

Table 18: Feedback from the Collaborative Ground Segment partners on data retrieval from the Sentinel DataAccess System International partners feedback

The international partners were also invited in the questionnaire sent to them by ESA to provide feedback on their experience of downloading data from the Sentinel Data Access System. The feedback received is reported in full in the table below.

In order to identify the elements reducing the end-to-end performance of the system for the international partners, tests were designed and are being performed by the Copernicus Network team in collaboration with the NASA, USGS, and GA network teams. These tests are still ongoing at the time of writing the report, and it will only be possible to derive a final conclusion after completion of the planned tests.

It can already be reported, however, that the tests which had been performed by the beginning of December 2016 indicated that there were issues on some specific GÉANT nodes in the path between Europe and overseas users.

NASA	"Our data access experience has been very positive. There have been intermittent time periods where data retrievals and connectivity to the data hubs have been uneven and the NSG was not able to achieve the expected daily throughput rates. However, ESA's operational/technical support team has been responsive, and the teams have been working together to improve the data access experience"
GA	"We continue to experience low download bandwidth and data corruption during the transfer from all ESA hubs. We are focusing our effort on working with ESA to address both issues. This has inevitably caused delay for other development activities of our regional hub. We have also struggled with adapting to changes of ESA hubs' API and user configurations, especially when these changes are often announced shortly before implementation or after the fact. We appreciate the help we received from the ESA teams and believe it's important to continue communications that help us understand how ESA hubs operate and vice versa."







Responding to the tickets raised by users who reported difficulties with download speed revealed that the problems with limited bandwidth were for the most part on the user side, and that there is a direct link between low bandwidth capacity on the user side and a high risk of download failure. The time spent downloading Sentinel products also increases significantly with lower bandwidths, creating another cause for user frustration. For instance, the download of a Sentinel-1 Single Look Complex product of 4GB would vary from 27 minutes at 20Mbps to 5 minutes at 100Mbps.

A series of steps were taken in Y2016 to assist users with their network connections:

• On 3 May 2016, a dedicated interconnection with the European GÉANT network was successfully transferred to operations, to assist research and education users.

As expected, research and education users quickly adapted to the dedicated connection to GÉANT, and benefitted from the much faster bandwidth speeds offered by the major high speed network. By the end of Y2016, around 64% of the available bandwidth (10Gbps) was being successfully used in routing the data to the GÉANT and commercial links, resulting in an average volume of traffic of around 6.4 Gb/s. Figure 45 below shows that of this total traffic of 6.4Gbps, as much as 4Gbps (63%) was then onwards routed through the GÉANT network, with the remaining 37% being routed through the commercial network.

As an indication of the extent to which the GÉANT bandwidth rates helped users, it was noted that tickets on the topic of failed downloads quickly decreased after the connection with GÉANT was established.

- As already discussed in detail throughout the report, a decision was made to change the size of Sentinel-2 products by repacking the multi-tile products as single-tile products, to assist users with lower bandwidths in particular.
- For African academic users who highlighted a problem with bandwidth capacity, ESA organized and promoted a specific ad hoc service, through which the users are sent hard disks containing the requested products.

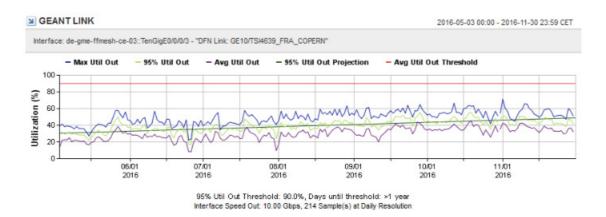


Figure 45: GÉANT link outbound network utilization





OUTLOOK 7.

7.1 Sentinel-3A **Beginnings**

By the end of Y2016, a total volume of 10.40 TiB of Sentinel-3A data had been published on the dedicated Sentinel-3 Preoperations Hub, and a total volume of 66.20 TiB had been downloaded by users. This means that by the end of the reporting period, users had already downloaded over 6 times the amount of products which had been published.

The following graphs show the weekly trend to the end of Y2016 in the number of Sentinel-3 products which were published and downloaded

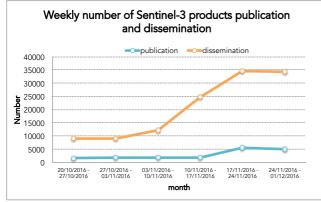
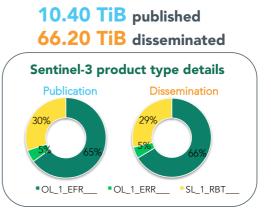


Figure 46

from the Sentinel-3 Pre-operations Hub, and the total volumes of published and downloaded products broken down per Sentinel-3 product type.

It can be seen from the weekly trend graph that the Sentinel-3 user group became increasingly active towards the end of Y2016. It is also interesting to note that the distribution per product type is almost identical for published products and downloaded products, which suggests that users have so far been downloading all of the available products, without showing any distinct preference for one product type over another.







7.2 Short term planned development

The figure below shows the main activities planned for the short term (i.e. to be completed by the end of December 2016) and these activities are briefly discussed in the following sections.

7.2.1 Scalability

A major evolution of the Data Hub Software is set to be transferred to operations in December 2016, to increase the scalability of the data distribution system, and introduce redundancy to ensure fewer service interruptions during maintenance activities. The main feature of this software enhancement is that the system will be able to parallelize the user queries and downloads across a larger pool of servers

This will also make it possible for the operations team to perform routine maintenance by removing a server individually from the pool of servers and managing the user sessions on the remaining servers, reducing the effect of any individual downtime and no longer requiring a complete shutdown of the service. Nevertheless, exceptional maintenance may still require a temporary suspension of the service.

7.2.1 Sentinel Data Dashboard

The Sentinel Data Dashboard, which is being developed to give the European Commission direct access to statistics concerning the performance of the Data Access System and uptake of Sentinel data, is being tested to ensure its stability, and is set to be opened for operational use in Y2017.

7.2.1 Open source release

The Data Hub development team is set to announce a new Open Source release of the Data Hub Software.

The new version (called 0.12.5-6) will support Sentinel-1A and B, Sentinel-2A and Sentinel-3A missions, fix issues present in the previous release and introduce some new features and performance improvements.

A restyling of the user interface for the open source portal is also planned.

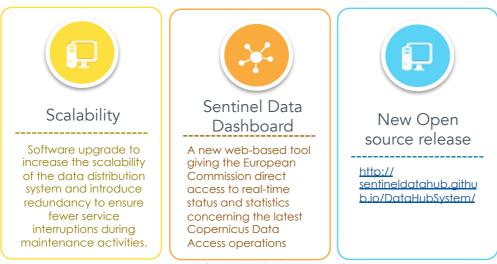


Figure 47: Short-term development plan





7.3 2017 Outlook

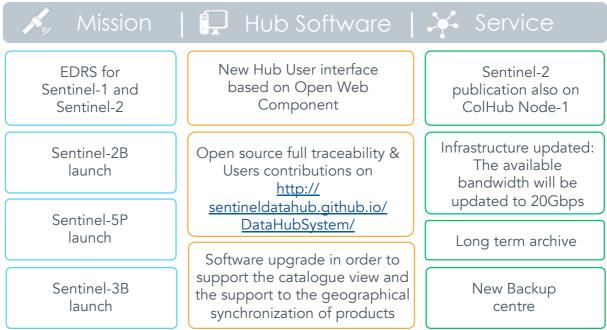


Figure 48: 2017 outlook

As summarised in Figure 48, during the next reporting period the following enhancements to the Sentinel missions, Hub software and Data Access Service will be implemented:

Sentinel missions

Data availability from the Sentinel satellites will be enhanced with the start of operations of the EDRS⁹ service. This will be an important step in increasing the system's ability to relay large volumes of data very quickly from Sentinel-1 and Sentinel-2 satellites to the PDGS ground station, and increasing the possibilities for receiving data in Near Real Time.

The Sentinel-2 and Sentinel-3 mission configurations will be completed with the

launches of the twin satellites Sentinel-2B and Sentinel-3B.

The Sentinel-5P mission is expected to be launched, and will add to the data collection atmospheric data products for monitoring air quality, climate forcing, ozone and UV radiation.

Hub software

A new user interface based on latest technologies for Open Web Components will be released. This will allow each user to customise the user interface to meet their own needs.

The open source portal ¹⁰ dedicated to the Data Hub Software will be opened to accept external contributions, providing full traceability of the software development story.

9

¹⁰ http://sentineldatahub.github.io/DataHubSystem/



http://www.esa.int/Our_Activities/Observing_the_Ea rth/Copernicus/Sentinel-1/Laser_link_offers_high-speed_delivery



External users who re-use the Data Hub Software for their own initiatives (such as the Data Hub Relay partners and Collaborative Users) will be supported by the development of new features, such as synchronization of products covering a predefined geographical area of interest, or a catalogue view (visualization of the list of all the products present in the hub via API).

Data Access Service

Both of the Collaborative Hub nodes will publish Sentinel-2 products, in order to increase the reliability of the service and optimize the network connectivity with the Data Hub Relays.

The overall dissemination infrastructure will be upgraded to provide an available bandwidth of 20Gbps, doubling the current network capacity. Two major changes in the Hub operations will be introduced:

- The Hub instances that are currently storing the entire history of Sentinel data starting from the qualification of the respective datasets will start a rolling policy (deleting the oldest products from the online archive). This change will be transparent for the users. Access to the removed products will be possible on demand from the Long-Term Archive.
- A secondary back-up centre will be operated on an independent infrastructure, to minimise the risk of unavailability in case of major failure of the primary infrastructure.

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- Collaborative Hub: https://cophub copernicus.eu/, http://colhub.esa.int
- International Hub: <u>https://inthub.copernicus.eu/</u>
- Copernicus Services Hub: <u>https://cophub.copernicus.eu/</u>
- Data Hub open source portal: <u>http://sentineldatahub.github.io/DataHubSystem/</u>
- GitHub open source framework: <u>https://github.com/SentinelDataHub/DataHubSystem</u>

