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Data Access Interface for Innovation on Earth-observation Data

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Problem description:

As well as the challenging task of building, launching and operating a satellite, the success of an Earth observation mission relies on being able to ensure that the data gathered are of good quality and made readily available to users. In 2013 European Union (EU) adopted an open data policy for its Sentinel satellites of the Copernicus space programme: access to Sentinel data should be free, full and open. Data for Copernicus services are served by the core ground segment. National ground segments will include downlinked data from a local ground station as well as mirrored core data. Norwegian Meteorological Institute (MET) has the contract for developing the national ground segment in Norway.

This project will identify requirements on access to earth observation satellite data and on processing-on-demand services from different user/service categories of the Norwegian national ground segment. Identifying these requirements will be done by studying what solutions similar data access interfaces have chosen as well as through interviews and surveys. This work also aims at specifying access interface service classes and to identify interface security mechanisms for the different access classes.

A possible challenge is related to accessing data of the national ground segment. This will not be ready for testing before May at the earliest and therefore the users participating in interviews/surveys will not have any hands-on experience using the national ground segment to base their answers on. In the development plan of the national ground segment the main priority is the heaviest users. This means that the users such as start-ups and hobby-users, may not get access during the time period of this project.

The high-level goal of this project is to get a better understanding of user/service requirements on a data interface for innovation on earth observation data. Understanding these requirements and their benefits or innovation potential shall prepare for efficient prioritization of development resources.

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Abstract

European Union (EU) adopted an open data policy for the Sentinel constellation of the Copernicus program in 2013. The Copernicus program is now about to transition into its operational phase, which means that it is from now on that data will become available. Among the challenges with utilizing satellite data - facilitating data access is one of the easiest to overcome, but which also gives a high return.

This report evaluates seven satellite imagery services and their user and programming interfaces. It also compiles and extracts user requirements from a national user survey among potential Norwegian Copernicus users.

Finally, the report ends with a proposition to the development of the Norwegian National Ground Segment. What features it should include, what aspects are important with regards to its interfaces, and how development resources should be prioritized.

Sammendrag

EU innførte i 2013 et sett retningslinjer som sikrer en åpen datatilgang til Copernicus-programmets Sentinel-satellitter. Copernicus-programmet går nå inn i en operasjonell fase, noe som betyr at det er nå data vil bli gjort tilgjengelig. Det å tilrettelegge for bruk av data er en av utfordringene som er enklest å overkomme, og som samtidig gir høy fortjeneste.

Rapporten evaluerer syv satellittdata-tjenester og deres bruker- og programmeringsgrensesnitt. I tillegg tolker rapporten brukerkrav fra en nasjonal spørreundersøkelse rettet mot potensielle norske Copernicus-brukere.

Avslutningsvis gir rapporten et konkret forslag til utviklingen av det norske nasjonale bakkesegmentet. Hvilke tjenester det skal tilby, hvilke aspekter relatert til grensesnitt som er viktige, og hvordan utviklingsressursene bør prioriteres.

Preface

This report presents the work done for my thesis in the 10th semester of the Master of Science degree at Norwegian University of Science and Technology (NTNU). The work has been completed with support from Department of Telematics (ITEM) at NTNU and Norwegian Space Centre.

Supervisor and responsible professor for the project have been Kjersti Moldeklev from ITEM and Norwegian Space Centre.

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List of Acronyms

- AIS** Automatic Identification System.
- AOI** Area of Interest.
- API** Application Programming Interface.
- AQL** A Query Language.
- Atom** Atom Syndication Format.
- CGS** Core Ground Station.
- DEM** Digital Elevation Model.
- ECHO** Clearing House.
- EDRS** European Data Relay System.
- ESA** European Space Agency.
- EU** European Union.
- FD** Ministry of Defense.
- FIN** Ministry of Finance.
- GB** Gigabyte.
- GBDX** Geospatial Big Data.
- GeoJSON** Geographic JSON.
- GIO** GMES Initial Operations.
- GIS** Geographic Information System.
- GUI** Graphical User Interface.

HTTP Hypertext Transfer Protocol.

IDE Integrated Development Environment.

IETF Internet Engineering Task Force.

ISO International Organization for Standardization.

ISS International Space Station.

JSON JavaScript Object Notation.

KLD Ministry of Climate and Environment.

KMD Ministry of Local Government and Modernisation.

LMD Ministry of Agriculture and Food.

MET Norwegian Meteorological Institute.

NASA National Aeronautics and Space Administration.

NDVI Normalized Difference Vegetation Index.

NFD Ministry of Trade, Industry and Fisheries.

NGO Non-Governmental Organization.

NSC Norwegian Space Center.

OData Open Data Protocol.

OED Ministry of Petroleum and Energy.

Q&A Question and Answer.

REST Representational State Transfer.

RFC Request for Comments.

S-2 PreOpsHub Sentinel-2 Pre-operational Hub.

SciHub Sentinels Scientific Data Hub.

SD Ministry of Transport and Communications.

SOAP Simple Object Access Protocol.

SSB Statistics Norway.

UD Ministry of Foreign Affairs.

UN United Nations.

UNOSAT UNITAR's Operational Satellite Applications Programme.

URL Uniform Resource Locator.

USGS United States Geological Survey.

W3C World Wide Web Consortium.

WGS84 World Geodetic System 1984.

WKT Well-Known Text.

XML Extensible Markup Language.

YAML YAML Ain't Markup Language.

Chapter 1

Introduction

In 2008, an open data policy was adopted for the Landsat satellites [Unib]. The policy resulted in a massive increase in Landsat scenes downloaded as Figure 1.1 illustrates. United States Geological Survey (USGS) conducted a study in 2013 which found that the economic benefit for of Landsat data in the year 2011 alone was estimated to \$2.19 billion [Unic].

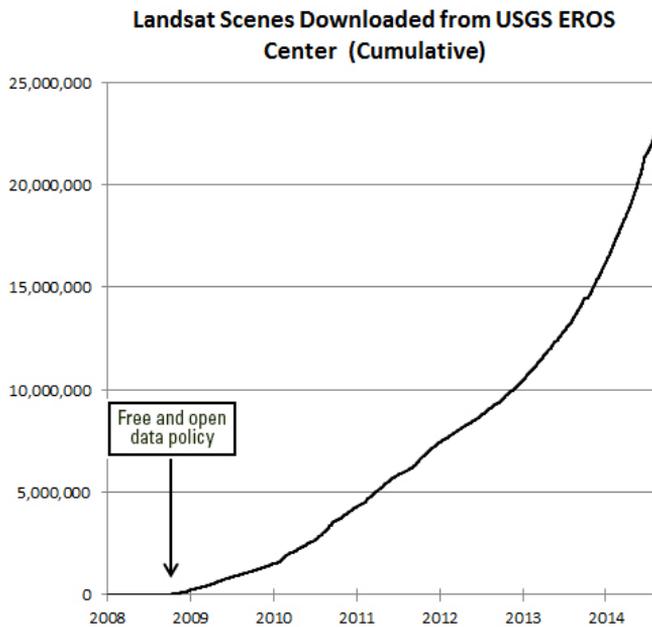


Figure 1.1: Cumulative downloads of Landsat scenes after an open data policy was adopted for Landsat data [Unic].

European Union (EU) has also adopted an open data policy for the Sentinel satellites of the Copernicus program [Eur13a]. The Copernicus program offers a vast amount of satellite data. Among the data are high-resolution radar images, high-resolution multispectral images, and other Earth-observation data. Copernicus divide services utilizing satellite data into the domains [Eurk]:

- Ocean monitoring.
- Land monitoring.
- Atmosphere monitoring.
- Emergency response.
- Security.
- Climate change.

The Copernicus program is about to transition into its operational phase, and it is now that data becomes available. Due to Norway’s geography and large sea areas, Norway will benefit greatly from the Earth-observation data. Norway plans to launch a Norwegian National Ground Segment, which will receive data from the Copernicus program through European Space Agency (ESA) and its collaborative ground segment. *Utilization of Earth-observation data - Public benefit and commercial services* [Mol15] look at the innovation possibilities following the open data policy adopted by EU for the Sentinel satellites of the Copernicus space program. Also, the report looks at the challenges with utilizing satellite data for new services. Some of the challenges include:

- Cloud cover which renders optical images unusable.
- Long shadows cast by mountains which make parts of the image too dark to use.
- Not enough light during the winter to capture optical images of Norway, meaning insufficient data and gaps in the historical data sequence.
- High demand for physical resources due to large data size and complex processing algorithms.

Utilization of Earth-observation data - Public benefit and commercial services [Mol15] concludes that high demand on physical resources is the challenge that is both easiest to overcome and at the same time gives the highest return.

As seen with the Landsat data, opening up access to satellite data can result in immense economic benefit. Consequently, the Norwegian National Ground Segment should facilitate easy data access.

1.1 Outline

Following the introduction is Chapter 2, which presents the methodology and the data basis for this report. Chapter 3 follows next and introduces theory related to the satellite imagery service aspects; features, tools, Application Programming Interface (API), and security mechanisms.

After methodology and theory come Chapter 4 which introduces the Copernicus space program, its entities, and how Norway relate to the Copernicus space program. Chapter 4 also presents the Norwegian National Ground Segment, a set of user categories with their potential users, and user requirements extracted from the user survey conducted by Norwegian Space Center (NSC).

Chapter 5 contains a comparison of the seven evaluated satellite imagery services as well as sections which map access interface features to the individual satellite imagery services. Chapter 6 presents the extensive evaluation of each of the satellite imagery services in this study. This acts as the data basis for both Chapter 5 and the proposition for the Norwegian National Ground Segment, which is found in Chapter 7.

Finally, Chapter 8 concludes this work and provides reflections and suggestions for further work.

1.2 Related Work

Few reports are studying the data access interface solutions for the Norwegian National Ground Segment. However, there are reports that study user requirements, innovation possibilities, and how one can prepare for the satellite data that will become available from Copernicus. This section presents four related works.

Utilization of Earth-observation data - Public benefit and commercial services [Mol15] look at the innovation possibilities following the open data policy adopted for the Sentinel satellites of the EU space program Copernicus and how one can utilize the satellite data.

Norsk deltaking i EU sitt jordobservasjonsprogram Copernicus (2014-2020) [Nor13] presents how Norway can benefit from being a part of the Copernicus program and why Norway should stay a member of the program. The report also presents that it is important to facilitate easy access for Norwegian users to Copernicus data.

Alt skjer på et sted - Nasjonal geodatastrategi fram mot 2025 [Sam16] introduces a national geographical data strategy towards the year 2025. The strategy aims to support the Norwegian Mapping Authority in the role as a national geographical

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data coordinator by coordinating the development in the area with new technological opportunities, requirements, and needs of the society.

Preparations for acquisition and application of optical satellite data for Norway Digital - Part 2 [KTL⁺14] studies what needs to be done to facilitate Norwegian utilization of Sentinel-2 data. The report also briefly discusses requirements for the Norwegian National Ground Segment.

The reports mentioned, contribute valuable information to this work, but this is the first report that looks at technical solutions for the Norwegian National Ground Segment.

Chapter 2

Methodology and Data Basis

This chapter will describe the methodology of this work and the data basis used in the proposition for the Norwegian National Ground Segment. This work mainly focuses on three different approaches to find and suggest solutions for the development of the National Ground Segment. These approaches are:

- Meeting persons possessing knowledge about the Copernicus architecture.
- Surveys targeting the potential end-users of the services.
- Looking at solutions chosen by similar services.

Norwegian Space Center (NSC) has connections to potential end-users and is working on conducting surveys to create a map of what user-needs exist. Because of this, this work has prioritized to study solutions chosen by similar services. The solutions might include what data the service offer, how users can access it, and what extra feature the service offers. While this work will not conduct any surveys, it will, in agreements with NSC, compile and extract information from their survey.

2.1 Meetings with Norwegian Space Centre

Meeting persons with a deeper understanding of how Earth-observation data works and its potential, can give valuable insights. The reason for this is that there are few existing satellite imagery services, and the potential end-users might not know what they can *ask for* or what they want. In fact, not all of the potential end-users have ever used a satellite imagery service. It might be necessary to apply *technology push*¹ instead of purely *market pull*² on parts of the Norwegian National Ground Segment. Meetings with employees from NSC contribute to identifying user requirements on the National Ground Segment and provides an insight into the Copernicus architecture.

¹A business strategy where a new invention is pushed through to the market as opposed to solely relies on identified needs from the market.

²A term referring to the need for a new product from the market.

2.2 User Survey

During the period of this work a survey has been conducted by NSC, that targets potential and existing users of satellite data. Appendix C contains the survey with its questions. The purpose of the survey is to identify what kind of satellite data the user needs, what kind of problems the user wants to solve and what types of satellite data and services the user already utilizes. NSC's survey will be the data basis for findings that comes directly from the users. Using an already existing survey enables this project to focus more on already existing satellite imagery services, thus prioritizing the resources available more efficiently.

2.3 Study and Use of Satellite Imagery Services

By evaluating similar satellite imagery services, one can learn from what solutions they have chosen for the different issues they have faced and thus save time by not having to reinvent the wheel. Most of the services have optical imagery as their main product; this does not affect this study noticeably as switching satellite data types is a matter of changing parameters. The services are as follows:

- Astro Digital.
- DigitalGlobe.
- Google Earth Engine.
- National Aeronautics and Space Administration (NASA)'s Clearing House (ECHO).
- Planet Labs.
- Sentinels Scientific Data Hub (SciHub).
- UrtheCast.

The services DigitalGlobe, Google Earth Engine, and NASA's ECHO have been chosen as these are services that are already well established and have been around for several years. Their Application Programming Interfaces (APIs) are well documented and have been tested by real users for several years.

Astro Digital, Planet Labs, SciHub, and UrtheCast are relatively new services. Astro Digital released their platform in June 2015 [Ast15]. As these are new services that have been able to enter the satellite imagery market at a later stage, it is expected that they have improved their services to compete with the rest of the market.

Chapter 6 presents the findings from the extensive evaluation of the seven services. Section 2.3.1 to Section 2.3.7 presents topics which relate to satellite imagery services.

All of these topics will be explored for each of the satellite imagery service included in the study.

2.3.1 Features

While many of the satellite imagery services offer the same set of features to their users, there are some features unique to each of the satellite imagery services. Some example features are processing-on-demand, access to historical data, and subscribing to notifications on newly available satellite data.

2.3.2 Web Interface

Web interfaces are, in this context, Graphical User Interfaces (GUIs) available through a web browser which enables users to browse and download satellite data without programming expertise.

2.3.3 Application Programming Interface

Each of the satellite imagery services is offering a way of interacting programmatically with their data archive. The study will look at structure and protocols for the APIs.

2.3.4 Security Mechanisms

The study will briefly discuss what security mechanisms the satellite imagery services are operating. The main focus will be on the APIs security mechanisms.

2.3.5 Documentation

The success of an API greatly depends on the quality of its documentation [Top]. Also, it is an important topic to include because it can contribute to lowering the starting barrier for users not familiar with satellite data. The latter requires that the documentation has a section on satellite data.

2.3.6 Ease of Adoption

Testing how easy or difficult it is to use the different satellite imagery services has been done by developing a sample application that utilizes all of the satellite imagery services. The code for the application can be found in Appendix D. Creating a sample application enables one to study the service from a users point of view. The objective of the application has been to use the satellite imagery service's API to download cloud-free images of Oslo, Norway. This objective has been equal at all of the satellite imagery services.

2.3.7 Challenges Encountered

For each of the satellite imagery services, the last section will contain comments on the challenges with accessing and using that specific service. These can be issues with the sign-up process, the data offered or challenges encountered during the work with the API.

Chapter 3

Theory

This chapter introduces theory related to the different aspects of satellite imagery services. The aspects; data archive, tools, API, and security mechanisms are presented in this chapter.

3.1 Data Archive

This section presents theory related to the Norwegian National Ground Segment's data archive.

3.1.1 Near-real-time and Quasi-real-time Data

Near-real-time and quasi-real-time are designations of how much time it takes from the satellite collects data until the data is available for use through the ground segments.

- *Near-real-time* data is available in less than three hours from the satellite captures the image.
- *Quasi-real-time* data is available in less than one hour from the satellite captures the image.

3.1.2 Orthorectification

Satellite data needs to go through an orthorectification process to remove the effects of image perspective and relief [OSS]. When a satellite collects an image, objects further from the center of the image may look like they are *leaning* away from the center. The orthorectification process projects the satellite image onto a Digital Elevation Model (DEM) to produce a planimetrically correct image. Figure 3.1 illustrates a satellite image being projected onto a DEM.

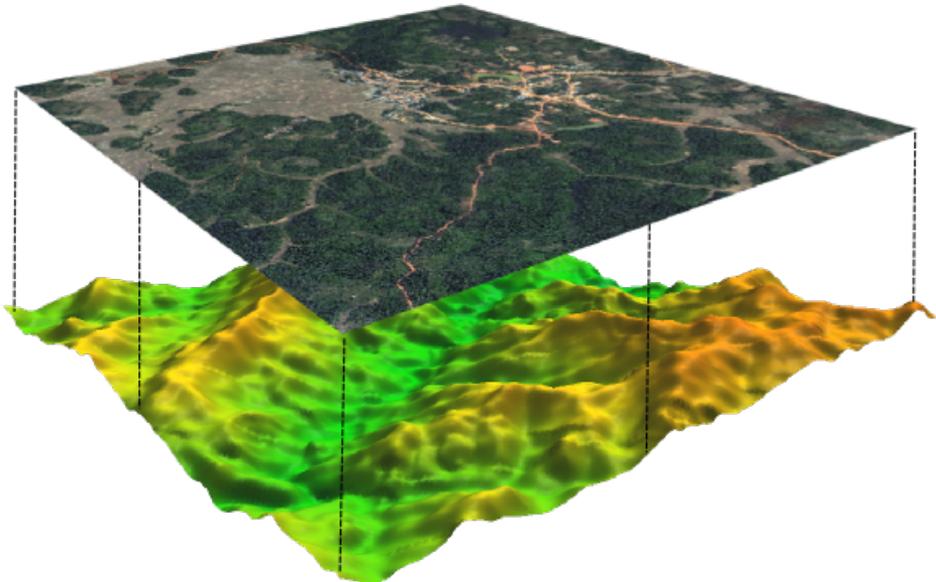


Figure 3.1: Multispectral image being projected on a DEM. Credit: Sylla Consult [Syl].

3.2 Tools

This section presents what Geographic Information Systems (GISs) are before introducing some tools available for utilizing satellite data.

3.2.1 Geographic Information Systems

GISs are designed to manage, analyze, and present spatial and geographic data [Esr]. Users can through GIS software run algorithms and user-created queries on the data, revealing new information or patterns in the data. For instance, GIS software can be used by city officials to plan the emergency response in the case of a flood by studying the topography of the town combined with the weather forecast.

3.2.2 Map Tools

In addition to GIS software, several map tools enables users to add satellite images onto a map or create map tiles. This section presents three common software tools of this type.

Google Maps JavaScript API

Google Maps JavaScript API is Google's API for using and customizing Google Maps in applications [Gooa]. The API can be used to geographically place objects, draw statistics such as heat maps, find directions and add satellite imagery. The API is available for use via a JavaScript library.

Leaflet

Leaflet is an open-source JavaScript library for interactive maps [Lea]. The library is designed to work on most devices without adding a heavy load to the application. It can be used along with satellite imagery to fill a map with tiles of satellite images.

Mapbox

Mapbox is a map platform aiming to make it easy to integrate a beautiful map design into applications. The service offers Landsat data as a base map and continues to update its base map with the newest satellite data [Map].

3.3 Application Programming Interface

This section presents theory related to APIs, and specifically theory relevant to the development of the Norwegian National Ground Segment's API.

3.3.1 Geographic Data Standards and Best Practices

This section is introducing standards and best practices commonly found when interacting with satellite imagery services through an API. These are typically related to defining dates and time or to define geographical locations.

World Geodetic System 1984

World Geodetic System 1984 (WGS84) is a coordinate system standard used in cartography, navigation and Global Positioning System (GPS). WGS84 defines a standard spheroidal reference surface where the coordinate origin is the Earth's center of mass [Wikb].

Geographic metadata

International Organization for Standardization (ISO) 19115 defines the schema required for describing geographic information and services with the help of metadata [Int14]. The standard applies to services using data that has a direct or indirect geographic extent. In practice, this means that the standard applies to most services associated with positioning on the surface of the globe. Some of the information provided by the standard is information about spatial and temporal aspects and other properties of geographic data and services.

Geographic JSON

Geographic JSON (GeoJSON) is a format where one can encode geographical features using JavaScript Object Notation (JSON) [BDD⁺08]. GeoJSON is in use in many spatial databases and web APIs related to maps. At the time of writing, GeoJSON is considered a format specification and Internet Engineering Task Force (IETF) is working on implementing a formal standardization [Int].

GeoJSON requires coordinates in longitude, latitude order for geographic coordinates. The default reference coordinate system is WGS84. A polygon around Oslo, Norway defined with GeoJSON can be seen in Figure 3.2. This polygon might seem a lot, but the standard specifies that one can use only the inner part of the object. In Figure 3.2 the optional ways of defining a GeoJSON polygon are noted as (1), (2) and (3).

```

1 { // Start (3)
2   "type": "FeatureCollection",
3   "features": [
4     { // Start (2)
5       "type": "Feature",
6       "properties": {},
7       "geometry": { // Start (1)
8         "type": "Polygon",
9         "coordinates": [
10          [
11             [10.561, 59.979],
12             [10.553, 59.847],
13             [10.907, 59.847],
14             [10.900, 59.986],
15             [10.561, 59.979]
16          ]
17        ]
18      } // End (1)
19    } // End (2)
20  ]
21 } // End (3)

```

Figure 3.2: GeoJSON: Polygon defined for Oslo, Norway.

Well-Known Text

Well-Known Text (WKT) is a markup language¹ for representing geographical features in a coordinate reference system using only strings [Wika]. WKT became an international standard in 2015 and is managed by ISO under ISO 19162 [Int15]. Figure 3.3 illustrates the same geographical polygon as the example in Figure 3.2, using WKT.

¹Markup languages are designed for definition and presentation of text.

```
1 POLYGON ((10.561 59.979, 10.553 59.847, 10.907 59.847, 10.900
           59.986, 10.561 59.979))
```

Figure 3.3: WKT: Polygon defined for Oslo, Norway.

International date and time format

With the many different ways of writing dates, ISO 8601 has been defined as an internationally accepted standard for representing dates and times [fS04]. YYYY-MM-DD is the format for a single date. Thus, April 1, 2016, would be given as 2016-04-01. ISO 8601 covers ways to write Coordinated Universal Time (UTC) and many satellite imagery services use this standard.

3.3.2 Interfaces for Requesting Data

This section presents some widely used architectural styles and protocols when developing data access interfaces, namely APIs. Both Representational State Transfer (REST) and Simple Object Access Protocol (SOAP) are in use by many web services today, while Open Data Protocol (OData) and OpenSearch are in use by SciHub [Eur16a].

Representational State Transfer

REST is a software architectural style defined by Roy Thomas Fielding in 2000 [Fie00]. The architectural style is used by web applications and exposes resources which represent data.

Figure 3.4 illustrates the *stores* resource which represents data about stores. Retrieving information about a single store is done by providing an identifier to the resource. To see information about customers belonging to the store, a sub-resource can be provided as well.

```
1 a) GET /stores/
2 b) GET /stores/{id}
3 c) GET /stores/{id}/customers
```

Figure 3.4: REST: Store and customer resources exposed by a REST API.

REST is widely in use in today's web applications and is compatible with almost any client, even a web browser. It is lightweight and supports both Extensible Markup Language (XML) and JSON. A drawback with REST is that it is not designed to issue commands on the API server. REST uses Hypertext Transfer Protocol (HTTP) for transferring data between server and client.

Simple Object Access Protocol

SOAP is a World Wide Web Consortium (W3C) standard intended for exchanging structured information in a distributed environment [GHM⁺07]. While REST exposes resources which represented data, SOAP exposes operations which represent logic. Figure 3.5 shows how a single store can be retrieved from a collection of stores.

```

1 <soap:Body>
2   <m:GetStore xmlns:m="http://www.example.com/stores">
3     <m:StoreIdentifier >{id}</m:StoreIdentifier >
4   </m:GetStore>
5 </soap:Body>

```

Figure 3.5: SOAP: Retrieving a single object.

Unlike REST, SOAP only supports XML. While SOAP is an older protocol, it is a W3C standard and has an optional security extension called Web Services Security which specifies how integrity and confidentiality can be enforced on messages [NKMHB06].

Open Data Protocol

OData defines best practices for building and using APIs built with REST. The protocol is an Organization for the Advancement of Structured Information Standards standard and helps the creator to focus on the business logic without needing to worry about headers, status codes, Uniform Resource Locator (URL) conventions and more [PHZ14].

OpenSearch

OpenSearch is a collection of simple formats for sharing search results [Ope]. The intention of OpenSearch is to help users discover a search engine and to let search client applications utilize search engines. In APIs, OpenSearch is typically used to let the user search through the resources exposed by the API.

3.3.3 Response Formats

When using APIs, the developer needs to know what format the API will respond with to be able to receive it. Most APIs let the user define what format the API response should use and most of the formats are therefore seen when interacting with APIs. This section will give an introduction to some of the most common response formats.

JavaScript Object Notation

JSON is a lightweight data-interchange format [Ecm13]. The format is both easy for humans to read and write and for machines to generate and parse. The structure

is based on a collection of name and value pairs where the first is the data key and the second is the data value. Nearly all modern programming languages are compatible with JSON. Figure 3.6 illustrates how JSON can define information about Sentinel-2A.

```

1 {
2   "satellite": {
3     "name": "Sentinel-2A",
4     "launched": "June 23, 2015",
5     "instrument": "Multispectral"
6     "orbit": "Low-polar"
7   }
8 }
```

Figure 3.6: JSON: Sentinel-2A specifications.

Extensible Markup Language

XML is a W3C recommendation defining a set of rules for encoding documents [BPSM⁺08]. As with JSON, XML is also both human and machine readable. While XML is designed for documents, it is also widely used for representing data structures, and therefore used in web services. Figure 3.7 illustrates how XML can define information about Sentinel-2A.

```

1 <satellite >
2   <name>Sentinel-2A</name>
3   <launched>June 23, 2015</launched>
4   <instrument>Multispectral</instrument>
5   <orbit>Low-polar</orbit>
6 </satellite >
```

Figure 3.7: XML: Sentinel-2A specifications.

YAML Ain't Markup Language

YAML Ain't Markup Language (YAML) is defined in 2001 [BKEdN09]. The language takes concepts from the programming languages C and Python together with ideas from XML. YAML started out as a document markup but has since then been repurposed as a data-oriented markup language. Figure 3.8 illustrates how YAML can define information about Sentinel-2A.

```

1 satellite :
2   name      : Sentinel-2A
3   launched  : June 23, 2015
4   instrument : Multispectral
5   orbit     : Low-polar

```

Figure 3.8: YAML: Sentinel-2A specifications.

Atom Syndication Format

Atom Syndication Format (Atom) is an XML format used for web feeds. Atom enables applications to check for updates published on a website and has been used by some satellite imagery services that offer the user to subscribe to notifications when new imagery is available. Request for Comments (RFC) 4287 describes Atom [NS05].

3.4 Security Mechanisms

With end-users in categories ranging from private persons to businesses and the military, the National Ground Segment will need to implement some security mechanisms to secure the API. In the following sections, some best practices in API security will be presented. IETF has published RFC 2196 – Site Security Handbook [Fra97]. In this, they suggest five steps as an approach to developing a security plan.

1. Identify what you are trying to protect.
2. Determine what you are trying to protect it from.
3. Determine how likely the threats are.
4. Implement measures which will protect your assets in a cost-effective manner.
5. Review the process continuously and make improvements each time a weakness is found.

The main focus of RFC 2196 is item four in the list above, but as with all security, one best practice is to minimize how much the user has access to, thus shrinking the attack surface for users with bad intentions. In practice, this often means to start with a completely locked application and open up single items instead of starting with an open application and locking services as you go. This security philosophy is called *Deny all*.

3.4.1 Authentication

Authentication assures that the user can prove to the system that he/she is the user he/she claims to be. The most common form of authentication is that the user

provides a username or an email along with their password. In APIs, a common practice now is that the users register online through the services own website where the user retrieves a security token. This token represents that user and the user can pass this along with the requests to the API. That way, the API server can authenticate the request. If the security token comes in the wrong hands, the user can simply request a new security token through the services website and invalidate the old security token.

3.4.2 Confidentiality

Some users might not want other users to know what products they have requested from the API, or they might not want others to be able to back trace the footsteps they have left at the service. Confidentiality is about limiting who can view what to only those with the correct permissions. Confidentiality in a system is often handled through the means of encryption. The service should not let others view another's user history.

3.4.3 Integrity

When a user requests a satellite image from the National Ground Segment, the user expects the image not to have been tampered with by anyone. It is not critical if an image has been tampered with if the user is a private person that only wants to see his house from space. However, if the user is a business whose revenue rely on correct satellite images, tampered data can be critical. The most common method of dealing with this problem is that the provider produces a checksum of an unaltered file which the user can compare with a checksum of the file received.

3.4.4 Authorization

When a user has been authenticated by the system, the system needs to control that the user does, in fact, have access to the service or data requested. The simplest way of performing authorization is to attach a set of rules to the user. For example, if the user is allowed to download satellite data, the user might have the rule "download satellite data" attached. However, in large systems, attaching all rules for all the users individually will result in large amounts of duplicate rules and increased overhead for the administrators trying to manage the system.

Instead, one can create user groups where the user groups have a set of rules attached, and the user is added to a matching group. When a user requests a file, the system will see what group the user belongs to and see if users within this group are allowed to download the file. In the case of the National Ground Segment, groups would be such as "Administrators", "Private users", "Government" and more.

A third option is to combine the two above methods of authorizing a user. This is how Amazon Web Services solves identity management [Ama]. A user can both belong to a group with a set of rules, and the administrators can attach single rules to the user. This can be a good way of allowing users temporary permission to resources.

3.4.5 Application Programming Interface Tokens

Tokens is a common way of handling authentication in APIs. The API tokens are commonly JSON Web Tokens as defined in RFC 7519 [JBS15], but there also exist other formats for the tokens. These needs to sent along with each request to the API and lets the server authenticate the user without having to check usernames and passwords. Figure 3.9 illustrates the messages sent between the server and client when requesting an API token.

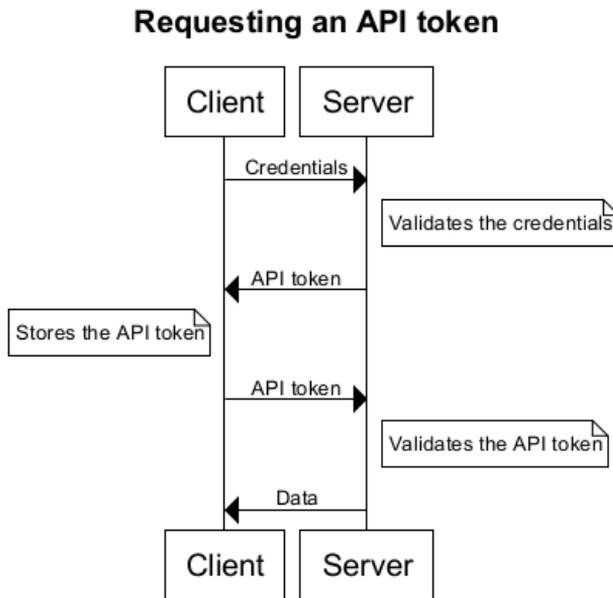


Figure 3.9: Message flow when requesting an API token.

The API token enables the server to authenticate the user without knowing the users' identity. In addition to this, a token can be set to expire after a given amount of time. The user then has to authenticate using username and password to receive a new token. If the user suspect someone else has acquired the token, the token can be made invalid by revoking it.

3.4.6 OAuth2

OAuth2 is an authorization framework defined in RFC 6749 [Har12]. This framework enables applications to obtain partial access to user accounts on an HTTP service. Figure 3.10 illustrates the authorization flow for authorizing an application to access the user's account. The client role is the application that wishes to access the user's account, and the resource owner role is the user authorizing the application. The authorization server both verifies the identity of the user and grants access to data.

Authorization Code Flow

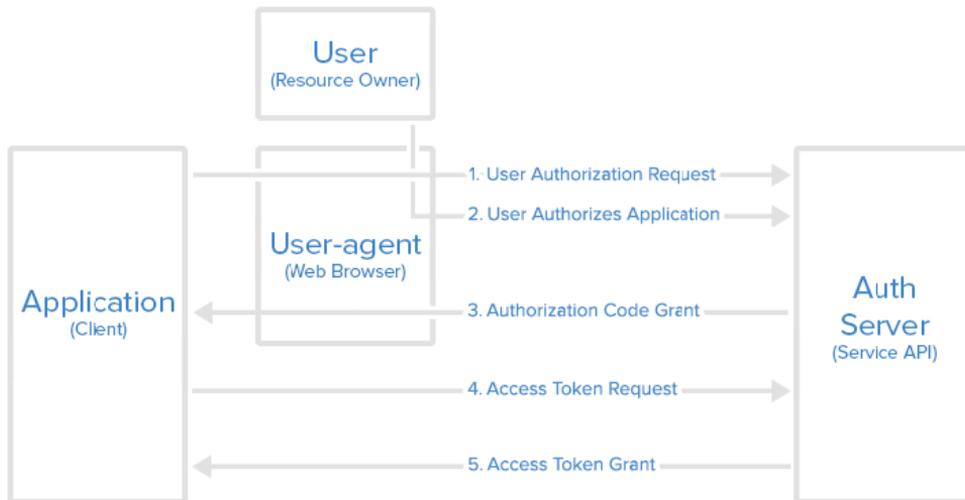


Figure 3.10: OAuth2's protocol flow when working with server-side applications. Credit: DigitalOcean [Ani14].

Chapter 4

Copernicus and Potential Users

This chapter introduces necessary information about Copernicus and its entities. The sections about the different ground segments introduce how data flows from the Sentinel satellites and to the Norwegian National Ground Segment. The chapter also includes a section on why Norway is participating in the Copernicus program.

After looking at the data flow, the chapter will introduce a set of user categories with examples of potential users within each of the category. Finally, the chapter presents user requirements which have been extracted from Norwegian Space Center (NSC)'s user survey.

4.1 Copernicus Space Program

Copernicus space program is a European system for monitoring Earth. The program is formerly known as Global Monitoring for Environment and Security and was launched in 1998 [Wik16]. The program's main objective is to monitor land, marine, atmosphere and climate changes. European Space Agency (ESA) is managing the technical aspects of the Copernicus space program.

The Earth monitoring system gathers data from upwards of 30 satellites [Eur16d]. The group of satellites consists of the dedicated constellation of satellites called *Sentinels* as well as tens of third-party satellites. Table 4.1 gives an overview of the Sentinel missions of the Sentinel constellation.

Each mission will operate in a pair of two satellites to provide robust datasets for Copernicus [Eurf]. Also, Copernicus has ordered extra satellites for each mission to continue its predecessors' tasks [Mag16]. Copernicus will provide satellite data for years to come. Appendix A contains more information about the Sentinel satellites. In addition to the satellites, the system also collects data from in-situ sensors¹.

¹Local or on-site sensors.

Mission	Launch	Monitors primarily
Sentinel-1 [Eure]	S-1A: April, 2014 S-1B: April, 2016	Land and ocean.
Sentinel-2 [Eurl]	S-2A: June, 2015 S-2B: 2016	Vegetation, forest, landscape and more.
Sentinel-3 [Eurm]	S-3A: February, 2016 S-3B: 2017	Sea level, sea color, and sea temperature.
Sentinel-4 [Eara]	S-4A: 2019 S-4B: 2027	Atmosphere and aerosols.
Sentinel-5 [Earb]	S-5A: 2020 S-5B: 2021	Atmosphere, ozone, NOx and aerosols.
Sentinel-5P [Eurh]	2016	Atmosphere.
Sentinel-6 [Euri]	2020	Ocean topography.

Table 4.1: Overview of the Sentinel constellation.

4.1.1 Copernicus Ground Segment Overview

Operating satellites, processing, and archiving data, and offering data to users requires a ground segment. This chapter will introduce the entities of the Copernicus ground segment related to the data flow. Figure 4.1 illustrates the Copernicus ground segment.

The Copernicus ground segment consists of a separate ground segment for each of the dedicated Sentinel missions as well as data from each contributing mission. Additionally, the Copernicus ground segment is complemented by the Sentinel collaborative ground segment. The components of the Copernicus ground segment are the infrastructure in which data flows from the satellites and all the way through to the Sentinel collaborative ground segment. The Norwegian National Ground Segment will retrieve data from the Sentinel collaborative ground segment.

4.1.2 Sentinel Core Ground Segment

When the satellites of the Sentinel constellation pass *in sight* of one of the Core Ground Stations (CGSs), such as the one in Svalbard, Norway, the CGS downlinks Sentinel data and generates core product in near-real-time² [Eur15b]. Additional downlink of Sentinel data is accomplished using the European Data Relay System (EDRS). EDRS works by letting the Sentinel satellites transferring data to the EDRS

²Near-real-time and quasi-real-time are introduced in Section 3.1.1.

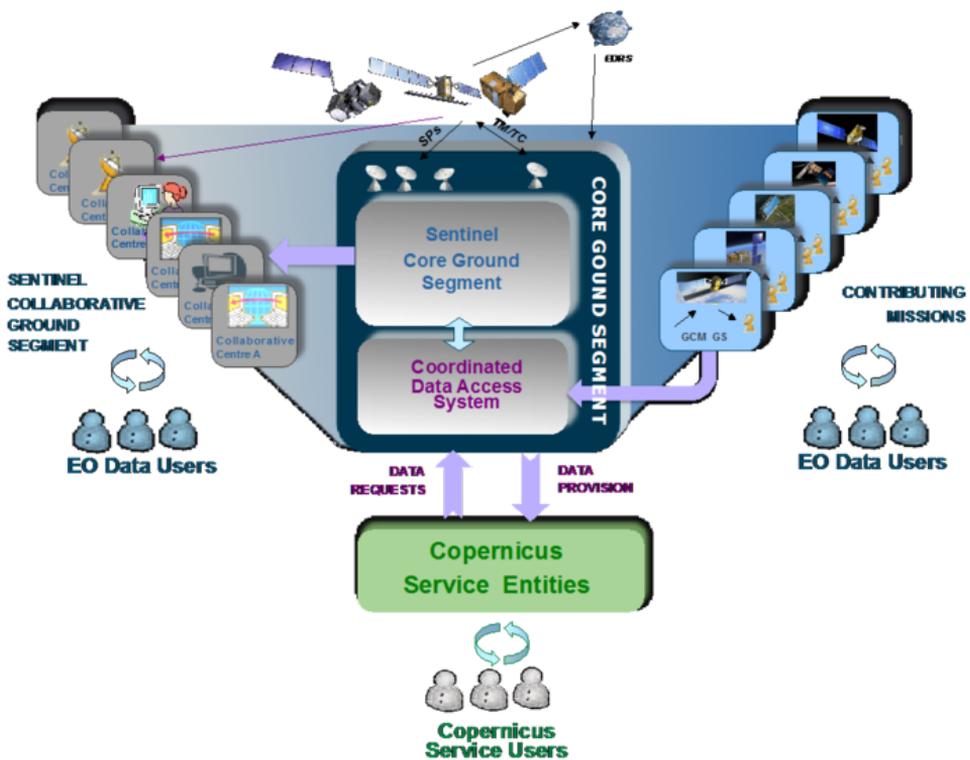


Figure 4.1: Copernicus ground segment architectural overview. Credit: European Space Agency [Eur13b].

satellites which in turn sends data to the ground stations of the EDRS [Eurb]. The Sentinel core ground segment is thus responsible for acquiring data from the Sentinel satellites as well as processing and distributing the data to the users.

4.1.3 Sentinel Collaborative Ground Segment

The Sentinel collaborative ground segment³ provides the framework for international cooperation. It is intended to enable complementary access for members of the Copernicus space program to data from Sentinel satellites and specific data products or distribution channels. While there are several objectives of the Sentinel collaborative ground segment, the following two are presented:

³Often referred to as the collaborative data hub or ColHub.

- Redistribution of Sentinel core products through mirror sites.
- Data acquisition and quasi-real-time production.

Redistribution of core products is where the largest part of data will enter the National Ground Segment. The redistribution will be done via a relay server which will be installed by ESA at Norwegian Meteorological Institute (MET) in Oslo, Norway [SNM16a]. The relay server will mirror the core products.

Data acquisition and quasi-real-time production are when local ground stations are configured to listen to the data stream from Sentinel satellites as the satellites pass *in sight* of the local ground station simultaneously as the satellite is downlinking data to a CGS. Local ground stations are different to CGSs in that the local ground stations are allowed to do this only as long as it does not conflict with operations of the CGS [Eur15a]. Norway has a contract with Kongsberg Satellite Services for a local ground station in Tromsø [Kon16]. This station listens to Sentinel-1 data as Sentinel-1 downlinks data to the CGS at Svalbard, Norway, and will provide quasi-real-time data directly to the Norwegian National Ground Segment [SNM16a].

4.1.4 Copernicus Services

The Copernicus program aims to offer services to protect the environment and natural resources. These services provide standardized information for many applications, both at national and regional levels. The Copernicus services have six main domains [Eurk]:

- Ocean monitoring.
- Land monitoring.
- Atmosphere monitoring.
- Emergency response.
- Security.
- Climate change.

For instance, a service in the emergency response domain will contribute to mitigating the effects of natural and manmade disasters [Eurk]. The development of the Copernicus services is expected to serve national, regional, and local information needs. The Copernicus services use Copernicus core data in their services.

4.2 Norway and Copernicus

Norway has been a member of ESA since 1987 [Eur16c] and has through ESA and the European Union (EU) program GMES Initial Operations (GIO) taken part in the development phase of Copernicus [Nor13]. GIO entered the operational phase in 2014 and was renamed Copernicus.

Everyone will have access to data collected by the Sentinel satellites due to the open data policy adopted by EU for the constellation [Eur13a]. However, participating in the space program enables Norway to influence the development of the program, ensure Norwegian interests [Nor13], and to have Norwegian actors competing for contracts within the program.

4.3 Norwegian National Ground Segment

In addition to the Sentinel collaborative ground segment, Norway will launch its ground segment named the National Ground Segment. MET will operate the National Ground Segment from Oslo, Norway [Nor15]. MET is Norway's national institute providing weather forecasts and are experienced with a vast amount of data. As mentioned in Section 4.1.3 a relay server containing a mirror of the core data will also be located at MET. The National Ground Segment will include core mirror data, data from the antenna in Tromsø, Norway, and other Norwegian data sources such as the Automatic Identification System (AIS) satellites [Nor16]. However, the largest part of data in the Norwegian National Ground Segment will come from redistribution of Copernicus core products through the Sentinel collaborative ground segment and the relay server.

The Norwegian National Ground Segment will provide services such as a web interface and an Application Programming Interface (API) to interact with the satellite data in National Ground Segment's data archive. The purpose of the National Ground Segment is to give Norwegian users, ranging from private persons to government agencies and the military, easy access to Earth-observation data.

A Norwegian challenge with the core product data from the Copernicus ground segment is that it uses the elevation model Planet Digital Elevation Model (DEM) with 90-meters resolution [Pla14] when *orthorectifying*⁴ data. Data from Sentinel-2 should be orthorectified using the Norwegian DEM which has a resolution of 10-meters [TGSL12]. This is one of the challenges that can be solved by developing the National Ground Segment.

⁴Section 3.1.2 briefly presents the process of orthorectifying satellite data.

ESA will prioritize data processing for the Copernicus core services and can not guarantee data delivery quicker than near-real-time [Nor13]. Norway runs the risk of not receiving necessary data for Norwegian regions as data is slowed down in ESA's data processing. The data might include data about oil spill where short delivery time is crucial. With the antenna in Tromsø, one can feed Sentinel-1 data directly into the National Ground Segment, thus delivering Sentinel-1 data in near-real-time or at best, in quasi-real-time. With some adjustments, the antenna in Tromsø will be able to collect Sentinel-2 data as well [SNM16b]. See Appendix B for more information regarding the challenges with Sentinel-2 and the antenna in Tromsø.

4.4 User Categories

The user categories of the Norwegian National Ground Segment have been categorized as the different *sectors* of the Norwegian society and industry. For each of the categories, a few potential users are presented. Note that the potential users presented are not the complete list of potential users, but examples. These users are in one way or another already using satellite data or have tasks where satellite data could contribute. The user categories presented are:

- Government
- Business sector
- Civil society
- Research and education
- Military

4.4.1 Government

The government has been chosen as a user category because many of the ministries and their agencies have areas of responsibility which require them to keep an overview of land and sea activity, biodiversity or air pollution among others. Not all the Norwegian ministries are presented here because they do not have a significant need for satellite data.

Ministry of Climate and Environment

The Ministry of Climate and Environment (KLD)⁵ is responsible for carrying out the environmental policies of the Government [Min14a]. One of the objectives of the Copernicus program is monitoring the environment and climate changes. Consequently, KLD has a use for satellite data in many areas.

One of KLD's main objectives related to biodiversity is to facilitate climate-adapted management of the biodiversity [Min15b]. For instance, wetlands can reduce

⁵Klima- og miljødepartementet

the risk of floods. The factor influencing the biodiversity on land the most is reallocating land to build infrastructure or areas for industry [Min15b]. Sentinel-1, -2 and -3 can all aid in this work.

The ice edge in the Barents Sea is rich in biodiversity and with oil drilling activity expanding further north, the need for monitoring the Barents Sea increase. In fact, 18th of May 2016, Ministry of Petroleum and Energy (OED) opened up new search areas in the Barents Sea for the petroleum industry through the 23rd licensing round [Min16b]. Oil drilling is limited to areas where there is ice less than 30% of the days in April, based on statistics for the past 30 years [Min14b]. Monitoring this can be used with data from Sentinel-1, -2 and -3 as well as historical data.

The sea ice is one of the most critical challenges in the northern regions now that the regions have been opened for the petroleum industry. The biodiversity here is vulnerable to changes, and the importance of avoiding oil spill puts pressure on the industries here. Significant development in the monitoring of sea ice and oil spill is expected in the next few years [Min14b].

Ministry of Petroleum and Energy

OED⁶ is responsible for ensuring high-value creation through effective and environment-friendly management of Norway's energy resources [Minb]. The two largest sectors OED is focusing on is the petroleum activity and the land-based energy production, which is mostly hydropower.

In the petroleum sector, oil spill detection might become the most important application utilizing data from the National Ground Segment. However, using satellites to detect oil spill will require short time from data collection till the data is available, preferably delivered in quasi-real time. Section 4.4.4 further discusses using Sentinels for oil spill detection.

Norwegian Water Resources and Energy Directorate (NVE)⁷ belongs under OED and works with monitoring glaciers, snow cover, snow melting, rivers, reservoirs and flood danger. Sentinel-1, Sentinel-2, and Sentinel-3 can contribute to the monitoring tasks.

⁶Olje- og energidepartementet

⁷Norges vassdrags- og energidirektorat

Ministry of Trade, Industry and Fisheries

The Ministry of Trade, Industry and Fisheries (NFD)⁸ is responsible for the trade, industry, and seafood policy [Min14f]. To ensure that the seafood policy is respected, NFD needs to be able to monitor the fish population.

One way of controlling the fish population is to make sure that no fishing vessels fish more than the quota they are given. Identification data from the Norwegian AIS satellites together with data from Sentinel-1 can help NFD track ships and detect ships traveling without the mandatory identification system [AIS]. Traveling without the system can indicate vessels fishing illegally.

Monitoring the fish population can also be done by looking at the sea temperature and color. In addition to this, the extent of algae blooming can give indications to how large the fish population will be for a particular year. Monitoring algae blooming can be done with data from Sentinel-2 and Sentinel-3.

Ministry of Agriculture and Food

The Ministry of Agriculture and Food (LMD)⁹ is responsible for the food and agriculture policy and covers land utilization and forestry among others [Min15a]. LMD is a potential user of Sentinel-2 to research forest health and to map the forest extent and diversity. Norwegian Food Safety Authority¹⁰ belongs under LMD and can use Sentinel-3 data to monitor the water quality in Norway.

Ministry of Transport and Communications

The Ministry of Transport and Communications (SD)¹¹ is responsible for the public roads and rail transport sector, coastal management and the marine environment [Min14g]. Consequently, SD with its underlying agencies is involved in decision making when planning new roads and infrastructure.

Some of the biggest challenges when planning infrastructure is to avoid flood and landslide risk and at the same time impact the nature as little as possible. Data from Sentinel-1 can contribute to mapping landslide risk while data from Sentinel-2 can help mapping the vegetation and biodiversity in areas where new infrastructure is planned. Sentinel-3 together with Sentinel-1 and historical data can aid in mapping the flood risk.

⁸Nærings- og fiskeridepartementet

⁹Landbruks- og matdepartementet

¹⁰Mattilsynet

¹¹Samferdselsdepartementet

Ministry of Foreign Affairs

The Ministry of Foreign Affairs (UD)¹² is responsible for securing Norway's interests internationally [Min16a]. UD might not become a big user of the National Ground Segment, but there are still some potentials.

UNITAR's Operational Satellite Applications Programme (UNOSAT) is United Nations (UN)'s program for delivering imagery analysis and satellite solutions to organizations working with humanitarian relief [Unia]. UD coordinates Norway's contributions to UN and UNOSAT, and the National Ground Segment could aid UNOSAT in their work.

Ministry of Local Government and Modernisation

The Ministry of Local Government and Modernisation (KMD)¹³ is responsible for rural and regional policy as well as national mapping and geodata policy [Min14e]. KMD is therefore presented as a user of satellite data. Data from Sentinel-1, and -2 are most relevant for KMD.

Ministry of Finance

The Ministry of Finance (FIN)¹⁴ is responsible for planning and implementing the Norwegian economic policy [Min15c]. Under FIN is Statistics Norway (SSB)¹⁵ which has, among other tasks, responsibility for area statistics in Norway [Sta15]. Through the use of Sentinel-2 data, SSB would be able to separate types of areas such as cultivated land, urban areas and forests. Thus, allowing SSB to update their area statistics more frequently. Separating types of areas would require Sentinel-2 data.

Ministry of Education and Research

The Ministry of Education and Research¹⁶ is responsible for the education sectors and research [Min14d]. Section 4.4.4 presents research and education as a user category and will introduce potential areas where the National Ground Segment can contribute.

Ministry of Defense

The Ministry of Defense (FD)¹⁷ is responsible for the formation and implementation of Norwegian security and defense policy [Mina]. FD and the Norwegian army use satellite in multiple ways. Section 4.4.5 will present the army's satellite use.

¹²Utenriksdepartementet

¹³Kommunal- og moderniseringsdepartementet

¹⁴Finansdepartementet

¹⁵Statistisk Sentralbyrå

¹⁶Kunnskapsdepartementet

¹⁷Forsvarsdepartementet

4.4.2 Business

The business sector as a user category consists of established businesses in addition to entrepreneurs. This category may become the largest one, and it will grow in number as new techniques and algorithms for satellite data are begin developed.

Established businesses

Established businesses do not necessarily use satellite data in their operations today, but have areas in their operations in which data from the National Ground Segment can contribute in the future. For instance, Statoil can use Sentinel-1 to monitor oil spill and Sentinel-5P to monitor air pollution.

Entrepreneurs

This part of the business sector includes entrepreneurs and start-ups. Analyzing and utilizing satellite data puts a high demand for physical resources [Mol15]. Consequently, starting a new business that uses satellite data in its operations can be costly.

In 2008, an open data policy was adopted for the Landsat satellites [Unib]. The open data policy resulted in a massive increase in Landsat scenes downloaded. United States Geological Survey (USGS) conducted a study on the economic benefit from the Landsat data for the year 2011. The economic benefit was estimated to \$2.19 billion [Unic]. If data from the National Ground Segment is made available at low or no cost and the National Ground Segment facilitates entrepreneurs, the entrepreneur part of the business sector user category can prove valuable.

4.4.3 Civil Society

Civil society as a user category is the user category with least demand on data and services of the categories. This category includes hobby users, organizations of different sizes, and Non-Governmental Organizations (NGOs).

Private users

Private users include everything from users that wishes to view the latest satellite image of their house to hobby astronomers or developers that want to explore the possibilities offered by the National Ground Segment.

Event planning

The event planning part of the civil society user category include users that are planning concerts, festivals, sports events, or larger events. Users here typically use Sentinel-2 data to organize the event or create emergency plans.

Non-governmental organizations

NGOs are non-profit and voluntary organizations and can exist on a national or international level. The NGOs working with the refugee crisis can, for instance, use Sentinel-2 data to keep an overview over the refugee camps. World Wildlife Fund (WWF) is working for wilderness preservation and the reduction of humanity's footprint on the environment [Wor], and can use several of the Sentinels for this purpose.

4.4.4 Research and Education

The research and education user category are most likely one of the first categories to utilize the National Ground Segment. The users in this category might already use satellite data and is familiar with the terms and tools.

Scientists

The Sentinel satellites have already acquired a significant amount of data. With new satellites becoming operational the data basis are growing rapidly. Large quantities of data with better quality than before spawns new opportunities for scientists.

In the past, many satellites have been individual projects without the continuity in the sequence of historical data. The Copernicus program will have satellites ready to replace the old ones when needed to ensure continuity in the data set. For scientists, this means that one can plan large research projects knowing that the data will be available for years to come, in the same format, without gaps. Examples of research topics where data from the National Ground Segment can contribute is:

Sea pollution

There is still not enough knowledge about the sea in Norway and how combinations of different types of pollution affect the sea [Min14c]. The historical data sequence offered by the Sentinel satellites can contribute to research on this topic.

Marine ecosystems

More knowledge about how the marine ecosystems are being affected by climate changes is needed. For instance, higher temperatures in the sea and changes in the ocean currents can force fish stocks to move. Due to this, maritime zones monitored by Norway has grown by 50% since 2003 [Min14c].

Oil spill and sea ice surveillance

As mentioned in Section 4.4.1, development in the oil spill and sea ice surveillance is expected with petroleum activity moving further north.

Additionally, data from the satellites can contribute in planning research operations and aid scientists that are in the field. For instance, research vessels operating

in the polar areas will have use of a sea ice surveillance service; both for research purposes and for planning the operations.

Education

Educational institutions have to some degree started utilizing satellite data in class. Providing a web interface or ready-to-analyze data through the National Ground Segment can increase the use of satellite data in education.

4.4.5 Military

The last user category is the military. Military operations without support from satellites are rare [EHJ⁺15]. Satellite imagery with high resolution can be used for surveillance of the enemy, civil or military infrastructure, and to monitor the conditions of the civil society as a result of war or natural disasters. Support from satellite data can also contribute to surveillance of the sea. Furthermore, satellite data can aid when planning military operations.

4.5 User Requirements

This section compiles the findings from the user survey conducted by NSC, spring 2016. The survey was sent out to 65 companies, agencies, and organizations which either uses satellite data or is a potential user of satellite data. Of the 65 recipients, only 17 responded. The reason for the few answer can be that some recipients do not know that they are a potential user. The few answers support the claim that *technology push* is necessary, as opposed to *market pull*. The survey is available in Appendix C.

4.5.1 Features

The following features have been extracted from the user scenarios described by the participants of the user survey.

Data archive

Several requirements have been revealed by the user survey regarding the data archive, the data stored in the data archive, and how one can search or browse the data archive. One already known requirement is that data in the National Ground Segments' data archive should be orthorectified using the Norwegian DEM.

Furthermore, users want to search the archive by polygons which define a geographical constraint. The search should also filter on metadata such as sensor type, platform, acquisition date, and cloud coverage. It has been mentioned that users who have previously been working with data from Sentinels Scientific Data Hub (SciHub) have been experiencing errors in the metadata catalog. Namely that when

searching for satellite data over Østfold, Norway, SciHub frequently responds with satellite data covering Sweden. Consequently, correct metadata has been mentioned as a requirement.

Finally, it has been suggested that the data archive should contain standard products with a given set of bands rather than all bands. Specifically, standard product displaying the vegetation index have been mentioned.

Area of Interest

Area of Interests (AOIs) have been mentioned frequently throughout the scenarios. Users want to be able to define AOIs both through a web interface as well as through an API. The AOIs should be defined using polygons. AOI is mentioned as a service that would make subscribing to new data easier. AOIs can also be used as a way to save a data search for later use.

Near-real-time and quasi-real-time data

Satellite data in near-real-time and quasi-real-time have been mentioned as a requirement in emergency services. For services working with monitoring oil spill or flooding, quasi-real-time is required. Near-real-time is mentioned as a requirement for services such as snow cover mapping.

Notification service

A notification service enables users to subscribe to notifications whenever new satellite data is available. The service lets users define filters for their notifications. A filter can, for example, be that the service should only notify when new satellite data within a given AOI becomes available.

Time-series

The time-series service provides a series of data within the same geographical area over a certain time span. This could, for example, be used to study movements of a glacier for the past decade by requesting a time-series of data from 2006 till 2016. The challenge with producing time-series is that it requires large amounts of data. For users, downloading and producing the time-series themselves is a time-consuming process.

Change detection

A change detection service is similar to a notification service in that users would get notified of new satellite data. However, the criterion for this service is not new satellite data, but that change is detected in the satellite data instead. For instance, say a user is subscribing to changes in the forest cover for a region. If the forest cover changes, e.g. someone has cut down areas of significant size, the change detection service would interpret the changes in forest cover by comparing old and new satellite data. The service would in turn notify the user.

Mosaics

Users want to be able to download mosaics from the National Ground Segment. The mosaics are made up of multiple satellite images which have been selected based on some criterion defined by the user. For instance, a user wants to download satellite images containing the western parts of Norway with no clouds. A mosaic would then be created by selecting cloud-free parts of satellite images in that region and merge them into one.

Processing-on-demand

As *Utilization of Earth-observation data - Public benefit and commercial services* [Mol15] concludes, there is a high demand for physical resources when working with satellite data. The reasons for this are large data size and complex processing algorithms. Through the survey, participants have expressed that algorithms should be moved to the data. In other words, users want to process data on the National Ground Segments' infrastructure before downloading ready-to-analyze data. Processing-on-demand would lower the demand for physical resources, thus could enable more users to utilize and innovate on satellite data.

4.5.2 Web Interface

The usability of the web interface has been presented as an essential requirement. The more user-friendly the data access is, the more are users going to use it. This requirement has mainly been proposed by teaching institutions who wish to use satellite data for educational purposes.

4.5.3 Application Programming Interface

A similarity in the scenarios presented in the user survey is that the users want to automate, or script, their tasks. There are three main requirements mentioned throughout the scenarios. The stability of the API is important and users expect little downtime. The API should be backward compatible, i.e. it should use versioning. Lastly, it is important that the API be thoroughly documented.

4.5.4 Summary of the Quantitative Questions

This section will present results from the quantitative questions in the user survey. Please note that in the presented questions, users could choose one or more of the alternatives. The quantitative questions were as follows:

1. What services in Copernicus do you use, or will use in the future?
2. What Copernicus data do you use, or will you use in the future?
3. Which role related to services in the supply chain do you see yourself as?
4. Which role related to data in the supply chain do you see yourself as?

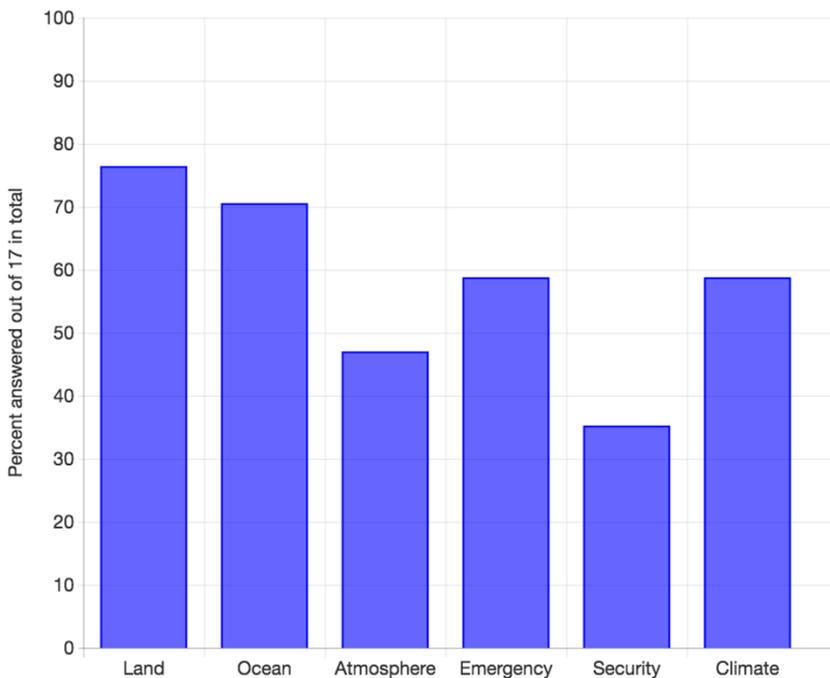


Figure 4.2: Answers to *What services in Copernicus do you use, or will use in the future?*

What services in Copernicus do you use, or will use in the future?

The results, illustrated in Figure 4.2, shows that at least 25% has chosen all of the alternatives of the respondents. However, land and ocean services are answered most frequently by the respondents with 76% answering that they use or will use land services.

What Copernicus data do you use, or will you use in the future?

When asked what types of Copernicus data users use or will use, Sentinel-2 was answered by 100% of the respondents. 94% answered Sentinel-1 of the respondents. Figure 4.3 illustrates the distribution of answers.

Which role related to services in the supply chain do you see yourself as?

When asked what service role the respondents consider themselves, 88% have answered that they consider themselves users of data from common processing routines and users of data from downstream services. Figure 4.4 illustrates the results.

Which role related to data in the supply chain do you see yourself as?

When it comes to data in the supply chain, 88% have answered that they are a data user while 65% have replied that they consider themselves a data producer or facilitator. Again, note that users can answer for more than one alternative. Figure 4.5 illustrates the results.

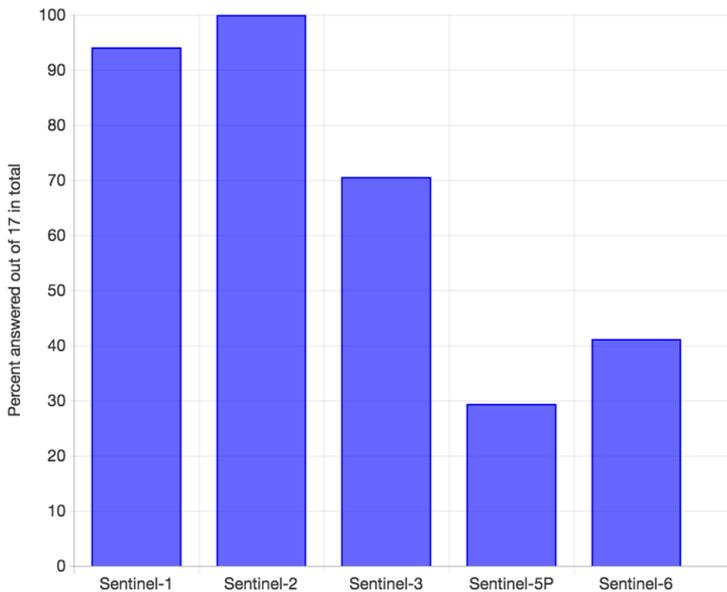


Figure 4.3: Answers to *What Copernicus data do you use, or will you use in the future?*

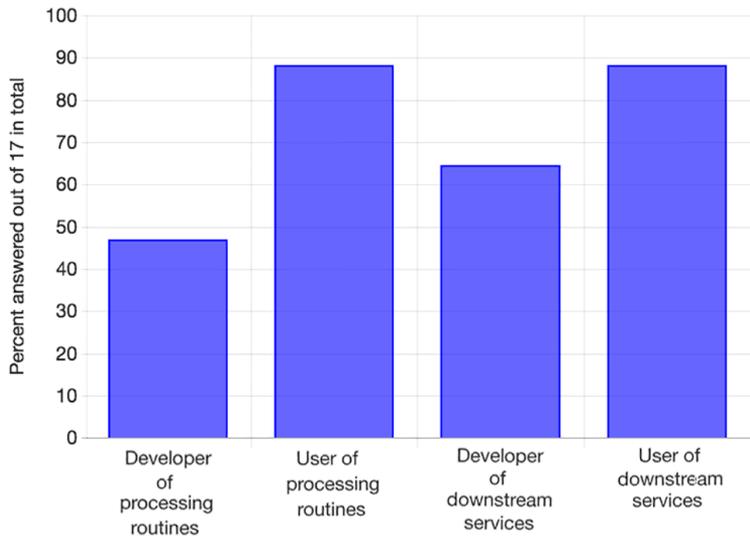


Figure 4.4: Answers to *Which role related to services in the supply chain do you see yourself as?*

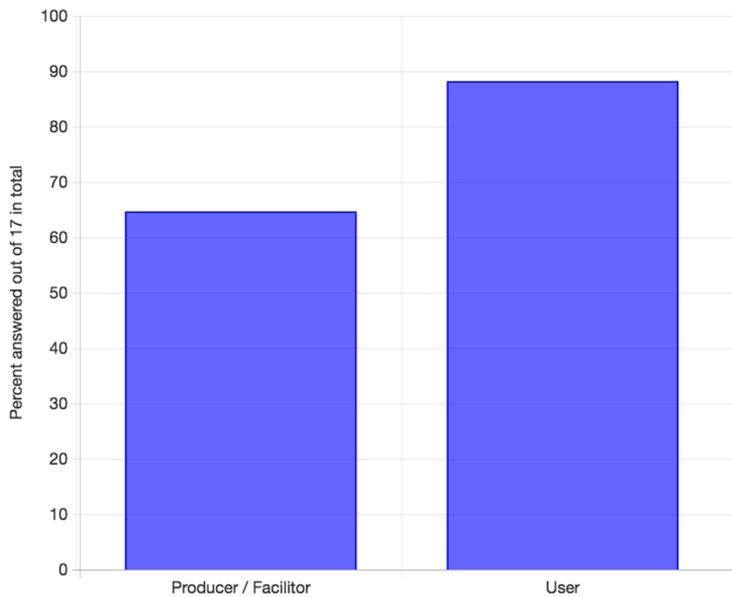


Figure 4.5: Answers to *Which role related to data in the supply do you see yourself as?*

Comparison of Satellite Imagery Services and Access Interface Features

This chapter presents a comparison of the evaluated satellite imagery services in this work. The chapter also gives an overview of a set of common features and maps the features to the satellite imagery services.

5.1 Comparison of the Services

This section summarizes the topics evaluated at each of the satellite imagery services in this study. Each service is given one to five points for each of the topics. A high score is better than a low score. Figure 5.1 shows the result for the services DigitalGlobe, Google Earth Engine, and National Aeronautics and Space Administration (NASA)'s Clearing House (ECHO). Figure 5.2 illustrates the result for the services Astro Digital, Planet Labs, SciHub, and UrtheCast.

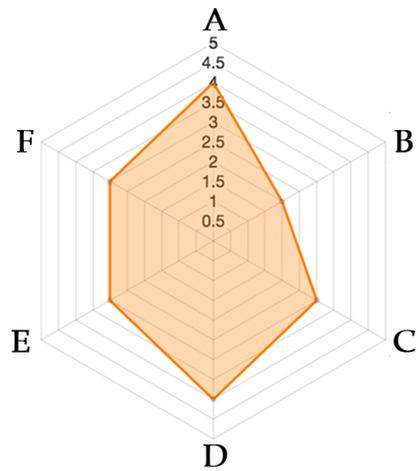
Planet Labs has the highest score in the topics; web interface, API, and documentation. Three important topics for enabling easy data access. Google Earth Engine has the highest overall score, and NASA's ECHO has the lowest overall score. Table 5.1 gives an overview of the total score for the evaluated satellite imagery services.

Service	Total score
Google Earth Engine	26
Planet Labs	25
UrtheCast	24
Astro Digital	23
DigitalGlobe	19
SciHub	15
NASA's ECHO	11

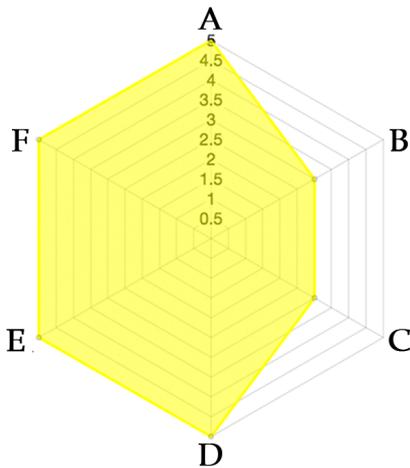
Table 5.1: Total score for the evaluated satellite imagery services.

A: Features
B: Web interface
C: API
D: Security
E: Documentation
F: Ease of adoption

DigitalGlobe



Earth Engine



NASA's ECHO

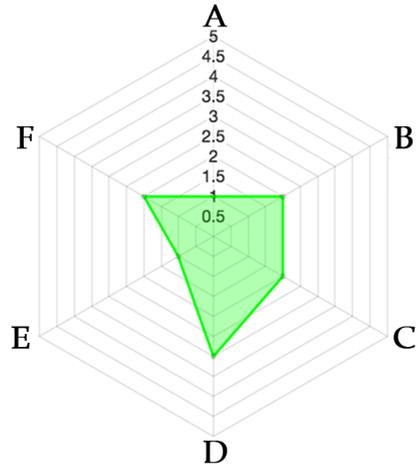


Figure 5.1: Comparison of DigitalGlobe, Google Earth Engine, NASA's ECHO, and their aspects.

A: Features
 B: Web interface
 C: API
 D: Security
 E: Documentation
 F: Ease of adoption

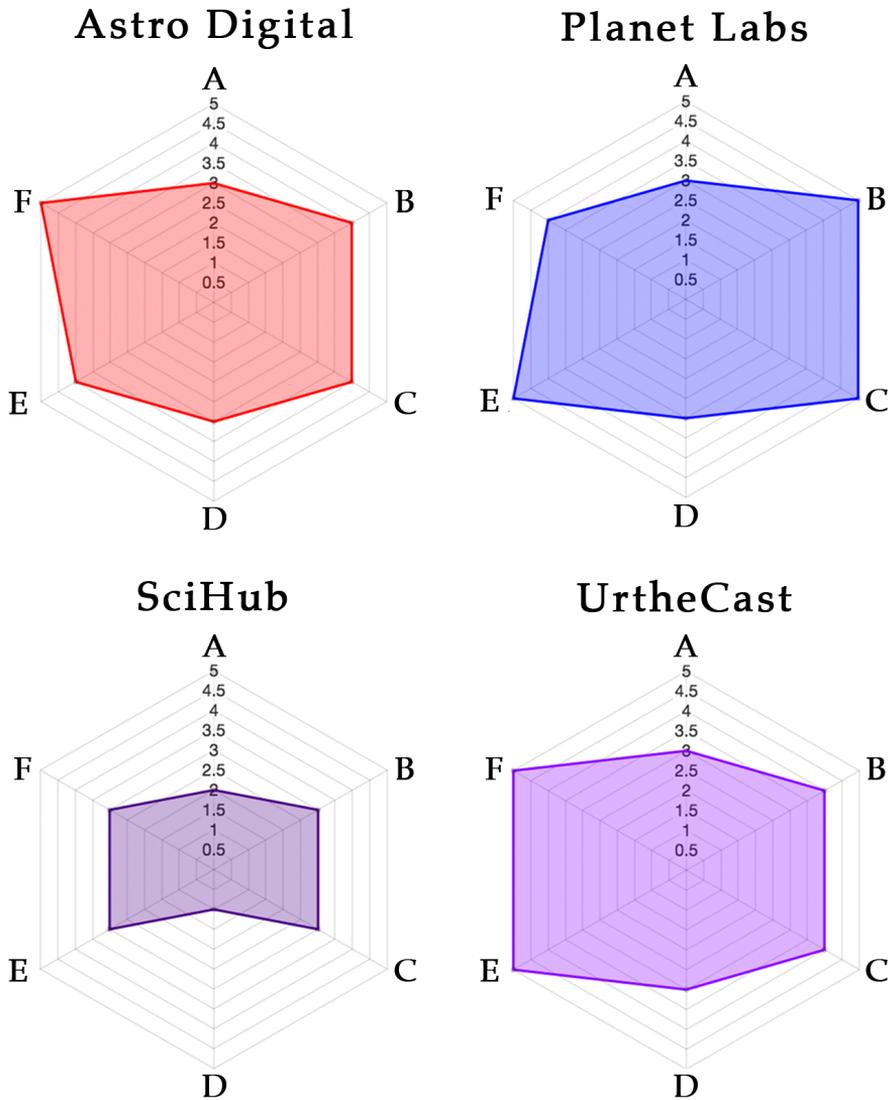


Figure 5.2: Comparison of Astro Digital, Planet Labs, SciHub, UrtheCast, and their aspects.

5.2 Data Archive

All of the satellite imagery services included in the study have a data archive in which they offer data from. The main difference between the data archives is the amount of data, and which satellites acquired the data.

5.3 Area of Interest

AOI as a service is in this context defined as geographic areas defined with either Geographic JSON (GeoJSON) or Well-Known Text (WKT), which users can save for later use. Using AOIs when interacting with the satellite imagery service's API can simplify the search process. The AOIs are defined either through the API or a web interface offered by the satellite imagery service. Table 5.2 shows which satellite imagery services offer an AOI service.

Satellite imagery service	Offers an AOI service
Astro Digital	Yes.
DigitalGlobe	No.
Google Earth Engine	No.
NASA's ECHO	No.
Planet Labs	Yes.
SciHub	Yes.
UrtheCast	Yes.

Table 5.2: Satellite imagery services offering AOIs as a service.

5.4 Near-real-time

Near-real-time is as defined in Section 3.1.1, data made available within three hours from data collection. There are few satellite services able to offer near-real-time data as a service, as seen in Table 5.3. Users working with emergency situations or oil spill detection typically needs the data available as fast as possible.

Satellite imagery service	Offers near-real-time data
Astro Digital	No.
DigitalGlobe	No.
Google Earth Engine	No.
NASA's ECHO	No.
Planet Labs	No.
SciHub	No.
UrtheCast	No.

Table 5.3: Satellite imagery services offering near-real-time data.

5.5 Monitoring an Area

A service enabling users to monitor an area. Through this service, users can enter a geographic area in which they wish to receive notifications for when new satellite data is available. The service can either do this through saved queries or AOIs. Table 5.4 gives an overview of the satellite imagery services offering a monitoring service.

Satellite imagery service	Offers monitoring of an area
Astro Digital	Yes.
DigitalGlobe	No.
Google Earth Engine	No.
NASA's ECHO	No.
Planet Labs	No.
SciHub	No.
UrtheCast	No.

Table 5.4: Satellite imagery services offering monitoring of an area.

5.6 Historical Data

Historical data allows users to search for satellite data collected in the past through date filtering in the queries. While this might sound like a service that should be included in the data archive service, some satellite imagery services restrict the period to only the past few months. Usually with the option to search further back in time available at a price. Table 5.5 shows what satellite imagery service offer this service.

Satellite imagery service	Offers historical data
Astro Digital	Yes.
DigitalGlobe	Yes.
Google Earth Engine	Yes.
NASA's ECHO	Yes.
Planet Labs	Yes.
SciHub	Yes.
UrtheCast	Yes.

Table 5.5: Satellite imagery services offering historical data.

5.7 Thumbnails

Satellite data files can be very large files and costly to retrieve. The challenge with the file size has been solved at several of the satellite imagery services by providing a thumbnail or a preview of the files before users download them. Table 5.6 show an overview of satellite imagery services providing thumbnails with their data.

Satellite imagery service	Offers thumbnails
Astro Digital	Yes.
DigitalGlobe	Yes.
Google Earth Engine	No.
NASA's ECHO	Yes.
Planet Labs	Yes.
SciHub	Yes.
UrtheCast	No.

Table 5.6: Satellite imagery services offering thumbnails.

5.8 Mosaics

Mosaics are satellite images made up of several individual satellite images. A mosaic is made by selecting satellite images based on some predefined criteria such as cloud coverage. By merging several images, one produces a cloud-free satellite image. Table 5.7 provides an overview of satellite imagery services providing a mosaic service.

Satellite imagery service	Offers mosaics
Astro Digital	No.
DigitalGlobe	Yes.
Google Earth Engine	Yes.
NASA's ECHO	No.
Planet Labs	Yes.
SciHub	No.
UrtheCast	Yes.

Table 5.7: Satellite imagery services offering mosaics.

5.9 Processing-on-demand

In this context, processing-on-demand means that a user can download ready-to-analyze satellite data from the service. Table 5.8 shows an overview of what satellite imagery services offer processing-on-demand. For some of the satellite imagery services, this means that users can download simply processed data such as cloud free mosaics or multispectral imagery with a specific set of bands. For instance, Google Earth Engine allows the user to download ready-to-analyze imagery displaying Normalized Difference Vegetation Index (NDVI).

Processing-on-demand can also be more advanced features where users can provide their algorithms for processing on the satellite imagery services infrastructure. There are also some services that let users supply their own sets for processing.

Satellite imagery service	Offers processing-on-demand
Astro Digital	Yes, simple processing.
DigitalGlobe	Yes, simple processing.
Google Earth Engine	Yes, simple processing or algorithms provided by the user.
NASA's ECHO	Yes, simple processing.
Planet Labs	No.
SciHub	No.
UrtheCast	No.

Table 5.8: Satellite imagery services offering processing-on-demand as a service.

Chapter 6

Findings from Evaluated Satellite Imagery Services

This chapter presents the findings from the evaluation of satellite imagery services similar to the Norwegian National Ground Segment. Also, an application utilizing all of the satellite imagery services has been developed. Appendix D contains the code for the application.

6.1 Astro Digital

Astro Digital is a Silicon Valley start-up founded in 2015 [Ear15] that aims to simplify how users discover and receive satellite imagery. Via a flexible API, they plan to improve the delivery of Landsat imagery and other data. They will also be handling satellite imagery from their partner Aquila Space [Ast16], who plan to launch a fleet of Earth-observation satellites¹. This section will go through the different topics introduced in Section 2.3 for Astro Digital.

6.1.1 Features

Astro Digital is, through an API and a graphical user interface, offering optical satellite imagery to their users. The following are the main features available through Astro Digital.

Data archive

Astro Digital is operating a data archive containing Landsat images. When Astro Digital's partner company Aquila Space is ready with their satellite constellation, satellite data from this constellation will also be available in the archive [Ast16].

Place orders

Users can place orders for satellite images either through the API or Astro Digital's web interface. When users place orders for satellite imagery, they can choose between

¹Aquila Space's satellite constellation Landmapper is a constellation of satellites providing worldwide multi-spectral imagery [Aqu].

single-scene processing or on-demand processing. With on-demand processing users can choose between the following options:

- *True color* which is satellite imagery with its natural colors.
- NDVI which is used to visualize vegetation health.
- Urban false image where urban areas are displayed as blue and gray areas.
- NDVI values which show an average NDVI value for the user’s AOIs.

Before confirming an order, the user can choose what format the image should be delivered in. Choices are:

- Web-ready image through Mapbox.
- Raw files delivered in the GeoTIFF format.
- Processed, ready-to-analyze image.

The user can choose to get an email notification when the image is ready to be downloaded. Ready images can also be downloaded through the API.

Area of Interests

Users can define their AOIs. These can ease the search for new data or let the user subscribe to new images within this AOI. Through the subscription service, the user can receive email notifications whenever new satellite imagery is available.

Imagery processing pipeline

Imagery processing pipeline is a service where users can have new satellite imagery delivered directly to their applications by defining AOIs.

6.1.2 Web Interface

Through Astro Digital’s web interface [Astb], users can create and modify saved searches. The searches include filters such as in what date range the images are collected, how many percentages of the image can be covered in clouds, and what AOI the images should include. Figure 6.1 illustrates a search containing the region around Trondheim, Norway. Through the web interface, users can also place orders for images as described in Section 6.1.1.

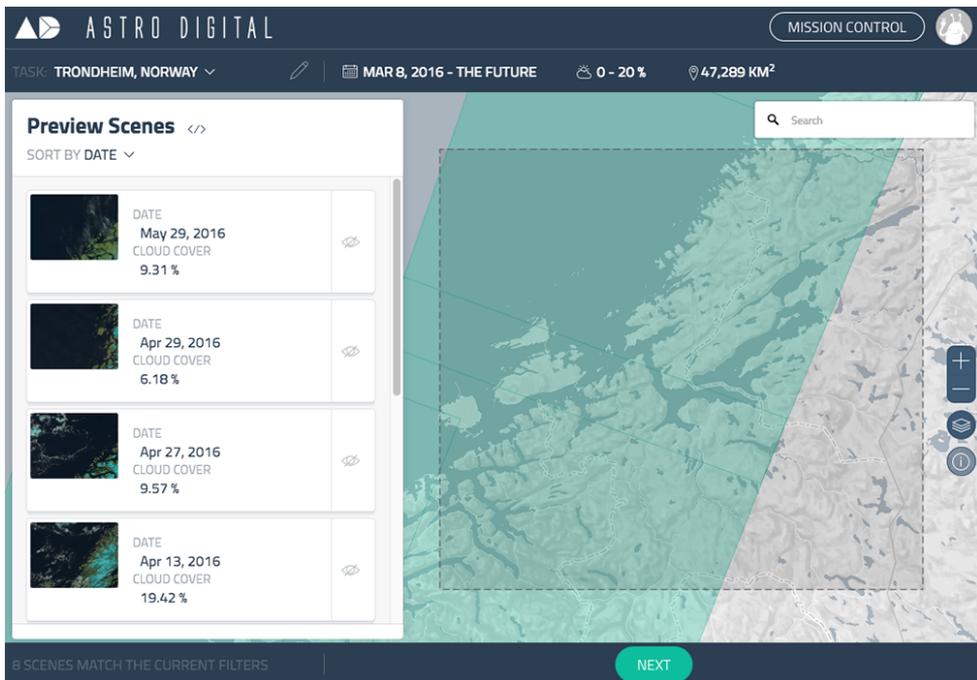


Figure 6.1: Astro Digital: Screen capture of the web interface.

6.1.3 Application Programming Interface

Table 6.1 shows an overview of the resources exposed by Astro Digital’s Representational State Transfer (REST) API.

Resource	Description
/tasks	The <i>task</i> resource is where users can place orders for satellite imagery.
/results	The <i>result</i> resource is where users can check if orders are completed and retrieve the download link for the image.
/products	The <i>products</i> resource exposes the analysis products available for users when placing orders.
/aois	Through the <i>aois</i> resource, users can create, modify and see their AOIs.
/user	The <i>user</i> resource provides authenticated user account information.
/search	The <i>search</i> resource is where users can combine queries and AOIs to find satellite imagery in Astro Digital’s archive.

Table 6.1: Astro Digital: Resources exposed by the API.

6.1.4 Security Mechanisms

To gain access to Astro Digital’s API users have to sign up through their website. When signed in, users can retrieve an API key which needs to be included in all requests to the API.

6.1.5 Documentation

Astro Digital uses a platform called *ReadMe.io* for the documentation. ReadMe.io allows documentation to be written by multiple authors and even though Astro Digital is managing the documentation, all users at Astro Digital can propose edits to the documentation. Thus, help to clarify parts of the documentation that users find hard to understand.

The *Quick Start* section of the documentation describes a demo application utilizing Astro Digital’s API and guides the user through the steps of developing the application. This walkthrough touches all the different services offered by the API. In addition to the *Quick Start* section, the documentation covers ways of embedding processed imagery to websites as well as covering all resources available via the API.

The documentation also links to a tool Astro Digital calls the *query-builder tool* [Astc]. The query-builder tool is a web interface where the users can create queries to use in their applications. Figure 6.2 illustrates a query containing Trøndelag, Norway created with the *query-builder tool*.

The screenshot displays the Astro Digital query-builder tool. On the left, a map shows a green polygon over Trøndelag, Norway, with labels for 'Trondheim' and 'Dymarka'. Below the map are two sliders: 'Cloud Cover' (0 to 100) and 'Date' (2013-02-11 to 2016-06-08). The 'Date' slider is currently set to a range from 2015-02-09 to 2016-06-08. On the right, the 'API Query' section shows a POST request to `https://api.astrodigital.com/v1/search?` with the following JSON body:

```
{
  date_from: 2015-02-09 ,
  date_to: 2016-06-08 ,
  cloud_from: 0 ,
  cloud_to: 20 ,
  intersects: [{"type":"Feature","properties":{},"geometry":
    [{"type":"Polygon","coordinates":[[[10.37109375,63.4468260563],
    [10.2996826172,63.4670775833],[10.1664733887,63.4646236159],
    [10.0360107422,63.4075095053],[10...


Below the query are buttons for 'Preview Thumbnails', 'Preview JSON', and 'Copy Query'. At the bottom, a JSON response is shown:



```
{
 "meta": {
 "found": 30,
 "name": "landat-api",
 "license": "CC0-1.0",
 "website": "https://api.astrodigital.com/v1",
 "page": 1,
 "limit": 1
 },
 "results": [
 {
 "sceneID": "LC82000152016104LGN00",
```


```

Figure 6.2: Astro Digital: Screen capture of the *query-builder tool*.

6.1.6 Ease of Adoption

The set of services offered by Astro Digital is relatively small which in turn means that the documentation does not have to cover all that much. Using the *Quick Start* section along with the *query-builder tool* makes it straightforward to get started with Astro Digital.

6.1.7 Challenges Encountered

As described in Section 3.3.1 a polygon defined using GeoJSON can either be fully stated or partly stated. Astro Digital, however, requires the full GeoJSON object to be fully stated when searching their archive. If GeoJSON is not fully stated in the query, the API responds with a message saying that there is something wrong with the polygon, but not what the error is.

6.2 DigitalGlobe

DigitalGlobe is a company that has been around since 1992 [Dig15]. Formerly under the name WorldView Imaging Corporation. The company is a commercial vendor of space imagery and geospatial content. DigitalGlobe operates a fleet of multispectral satellites containing IKONOS, GeoEye-1, and WorldView-3 amongst others. Also, DigitalGlobe operates the DigitalGlobe Maps API and the DigitalGlobe Geospatial Big Data (GBDX) API that offers satellite imagery from their fleet of satellites. This section will present what is found when going through the topics introduced in Section 2.3 for DigitalGlobe.

6.2.1 Features

DigitalGlobe is offering a map API, which utilizes their satellite imagery as a base map, and an API for their archive of satellite data. This work is only exploring the latter, as it is most similar to the National Ground Segment. DigitalGlobe offers a broad range of features, and the following is an excerpt of the main features they provide. These are the features most relevant for the National Ground Segment.

Basemap

The Basemap service enables users to implement satellite imagery collected by DigitalGlobe's satellites as a ground layer in their map applications.

Geospatial Big Data (GBDX)

The GBDX service provides access to DigitalGlobe's archive of geospatial data along with tools and algorithms for extracting useful information from the data [Digd]. The GBDX service attempts to offer a system which lowers the users' need for expensive



Figure 6.3: DigitalGlobe: Illustration of the advanced elevation series service. Credit: DigitalGlobe [Digb].

infrastructure. Section 6.2.3 presents the two APIs which constitutes the GBDX service.

Analytics

DigitalGlobe’s Analytics services are offering predictive analytics along with their image archive and expert help to attempt to pinpoint where similar events, such as flood or drought, are likely to happen in the future [Diga].

Advanced Elevation Series

The Advanced Elevation Series is DigitalGlobe’s way of providing high-resolution satellite imagery of Earth with little to no cloud coverage. The elevation and terrain information range from 2 meters to 8 meters in accuracy and resolution [Digb]. The service turns high-resolution satellite imagery into elevation data ready to be analyzed. Figure 6.3 illustrates how data from the Advanced Elevation Series can contribute when planning locations for new networking base stations.

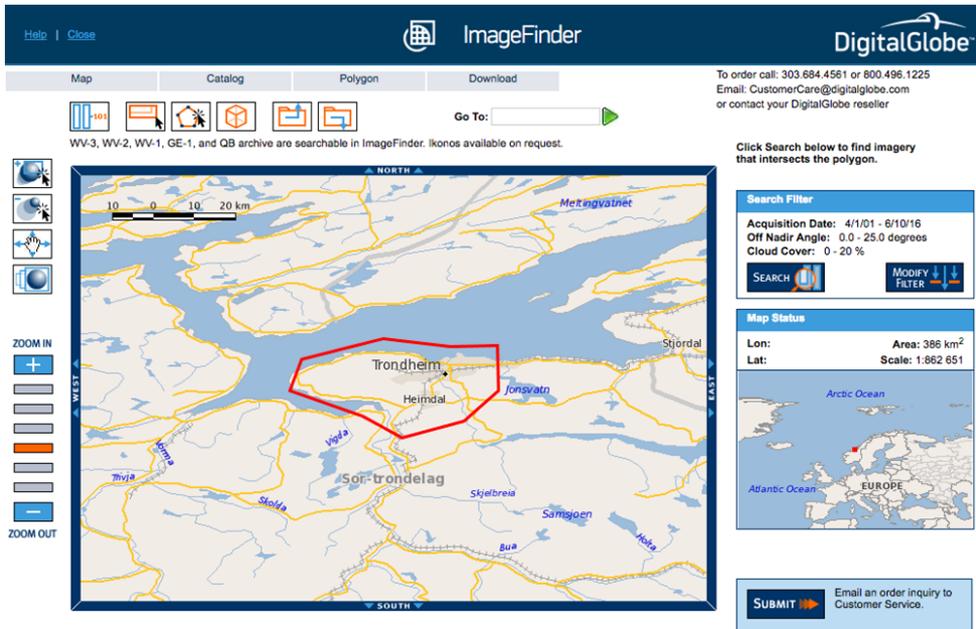


Figure 6.4: DigitalGlobe: Screen capture the web interface.

6.2.2 Web Interface

The main purpose of DigitalGlobe’s web interface is searching for imagery in their archive [Dige]. Figure 6.4 show a screen capture of the web interface. Through the web interface users can define polygons and filter images with a set of parameters before downloading the image. By altering the filters, users:

- Choose which sensor or platform acquired the image.
- Choose what frequency bands the image should include.
- Search for images collected during a given date range.
- Set a maximum threshold for cloud coverage.
- Set a maximum value for the Ground Sample Distance, a unit describing the image resolution.

6.2.3 Application Programming Interface

The GBDX services consist of two APIs. The Catalog API and the Workflow API. The Catalog API enables users to search the archive for satellite data. Images found

through the Catalog API is then assigned to a *working set*. Via the Workflow API, users can execute tasks and run algorithms on the *working set*.

The Catalog API is based on REST. Table 6.2 is an overview of services exposed by the Catalog API, and Table 6.3 is an overview of the exposed resources.

Service	Description
/search	Used to search the archive by the use of a spatial area, date range, and metadata filters.
/traverse	Lets the user traverse along the records' relationships.

Table 6.2: DigitalGlobe: Services exposed by the Catalog API.

Resource	Description
/heartbeat	Used to see if the API is operational.
/type	Exposes all parameters associated with satellite data from the archive with name and type.
/record	A record is the base entity in the archive.
/relationship	The <i>relationship</i> resource shows relations between data records in the archive.

Table 6.3: DigitalGlobe: Resources exposed by the Catalog API.

Once the wanted satellite imagery has been found using the Catalog API, users can choose to perform operations or tasks on the data. This is the Workflow API's purpose. The idea with the Workflow API is that users can chain series of tasks together where each task is an individual process. Table 6.4 contains an overview of the resources exposed by the Workflow API.

Resource	Description
/tasks	Exposes activities that perform a process.
/workflows	The <i>workflows</i> resource show the chain of individual processes to complete an action.
/workflows/{id}/events	A way for users to see if the process has started, is running or has completed.
/schemas	The <i>schemas</i> resource exposes JavaScript Object Notation (JSON) schemas used to validate user inputs.

Table 6.4: DigitalGlobe: Resources exposed by the Workflow API.

6.2.4 Security Mechanisms

To be able to utilize the DigitalGlobe GBDX APIs, users first need to sign up for the GBDX service. When signed up, users can find an API key under the account information section. With the username, password, and API key, users can retrieve an OAuth2 token. GBDX requires this token to be attached to all requests to the API. The token is valid for seven days at a time.

6.2.5 Documentation

DigitalGlobe also uses ReadMe.io to manage their documentation [Digf]. Their service offers a broad range of services which in turn means more documentation. It is worth mentioning that along with the documentation; DigitalGlobe provides a *Question and Answer (Q&A)* section. In this section, users can ask questions directly to DigitalGlobe to clarify uncertainties or get help overcoming issues in their application. The questions are visible to everyone. Hence, new users can visit the Q&A section and see if their question has been asked before.

6.2.6 Ease of Adoption

Compared to other services, it is not that straightforward to register for an account at DigitalGlobe. Even though they offer access for developers at no cost, the user has to fill out a detailed form and provide credit card information.

Once registered, the user has to retrieve an OAuth2 token. The token is necessary to make any request to the GBDX APIs. DigitalGlobe provides an authentication course for this part [Digc]. However, the token is only valid for seven days, so this procedure needs to be repeated once a week. After retrieving the OAuth2 token, it is relatively simple to follow the *Getting Started* section in the documentation and start utilizing the APIs.

6.2.7 Challenges Encountered

DigitalGlobe uses the WKT format for setting geographical filters when users are searching their archive. The most frequently observed way of handling geographical filters have been to allow both GeoJSON and WKT. Only allowing WKT is not a big problem, however, as WKT is a standard managed by International Organization for Standardization (ISO) as noted in Section 3.3.1.

Not so much a challenge, but rather a limitation is that DigitalGlobe only allows the polygons supplied when searching the archive to have a maximum size of two square degrees.

6.3 Google Earth Engine

Google's Earth Engine was developed in 2010 in partnership with USGS to place USGS's archive of earth imagery online [Gov13]. To do this, Google cataloged over 900 terabytes of USGS and NASA Landsat images. The Earth Engine is now a computing platform that allows users to run a geospatial analysis using Google's infrastructure [Goo15]. The Earth Engine is also available through an API. This section will go through the different topics mentioned in Section 2.3 for Google Earth Engine.

6.3.1 Features

As Google themselves puts it, Google Earth Engine is a platform for petabyte-scale scientific analysis and visualization of geospatial datasets [Goo15]. Following is an excerpt of the features offered through the Earth Engine.

Data archive

Google Earth Engine includes a data catalog which users can search through. The data catalog contains historical earth imagery going back more than forty years [Goo15]. Examples include all of the Earth Resources Observation Satellite Landsat catalog and data from the Sentinel-1 satellite among others.

Earth Engine Explorer

The Earth Engine Explorer is a web interface for the data archive where users can browse the archive for imagery without needing any knowledge in programming.

Earth Engine Code Editor

The Earth Engine Code Editor is a web-based Integrated Development Environment (IDE) for the Earth Engine JavaScript API [Goob]. The IDE enables users to use the Earth Engine API directly in a web browser. Included in the code editor are a script manager and documentation. By using the script manager, users can save the code for later or browse through examples.

Computation engine

While the other satellite imagery services included in this chapter typically runs on the server-side, i.e. on a local computer, Google Earth Engine is mainly a client-side API. In practice, this means that Google Earth Engine use Earth Engine proxy objects which do not contain any data, but act as handles for objects on Google's server [Goo15]. Using these Earth Engine proxy object, users can run algorithms on the data without needing the physical resources.

Specialized algorithms

Google Earth Engine provides a set of ready-to-use algorithms specialized for Landsat

and Sentinel-1 data. For instance, one of the algorithms for Sentinel-1 data is orthorectification by the use of Shuttle Radar Topography Mission 30 meter DEM [Good].

6.3.2 Web Interface

Google Earth Engine consists of two web interfaces; these are the Earth Engine Code Editor and the Earth Engine Explorer. The Earth Engine Code Editor uses the Earth Engine JavaScript API and is presented in Section 6.3.3. This section focuses on the Earth Engine Explorer web interface [Gooc].

The Earth Engine web interface enables users to browse through the Google Earth Engine data catalog without needing any programming expertise. Through the web interface, users can add layers of satellite data to the workspace. For each layer, users can modify parameters such as lowering the opacity or selecting frequency bands for the visualization.

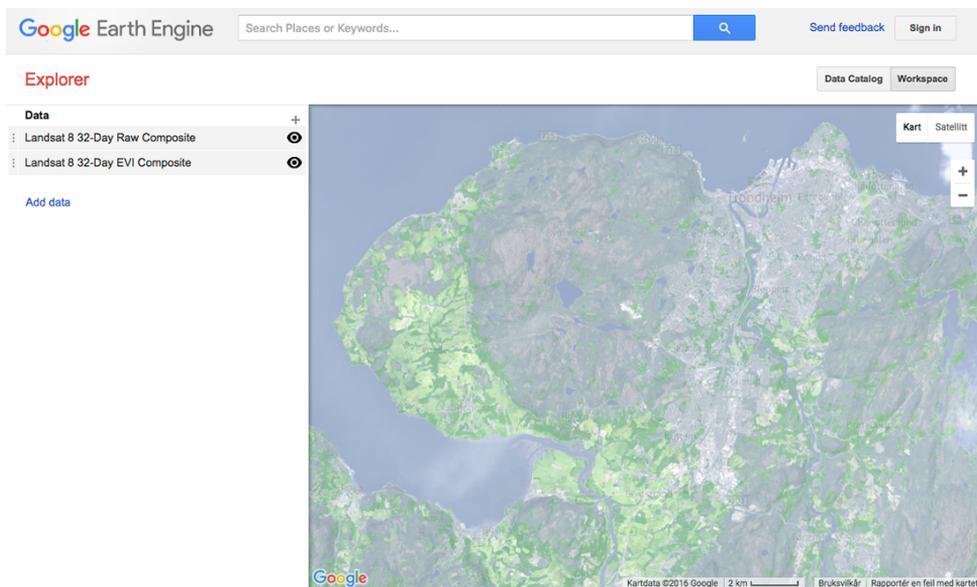


Figure 6.5: Earth Engine: Illustration of the Earth Engine Explorer.

Figure 6.5 shows two layers of Landsat 8 data added to the workspace in the Earth Engine Explorer. The top layer shows a raw multispectral image while the bottom one shows the Enhanced Vegetation Index. The bottom layer is customized to show a bright green color for areas with high vegetation index which indicates cultivated land.

6.3.3 Application Programming Interface

The Earth Engine API is available through the Earth Engine JavaScript library which consists of objects and their associated methods. The API does not expose endpoints or resources like the other satellite imagery services. Instead, objects in the JavaScript library acts as proxies to Google Earth Engine's computation engine.

The API is also available through a Python package which can be installed by following the installation guide from the documentation [Goee].

6.3.4 Security Mechanisms

To use Google Earth Engine, users are either required to be signed into the Earth Engine Code Editor, or to be authorized via the Earth Engine Python package. By inspecting the page source code for the Earth Engine Code Editor, one can see that the page uses OAuth2 for authorization. The Python package requires credentials to be set up on the users' computer. These credentials also use the OAuth2 protocol [Goee].

6.3.5 Documentation

Google Earth Engine's documentation is extensive and covers all parts of the API. Each section includes examples of use with code and inline comments. The examples can also be modified or run in the Earth Engine Code Editor [Goob]. Figure 6.6 shows a code example provided by the Earth Engine Code Editor. The red areas in the figure are higher than 1000 meters above sea level. There is also introduction videos and tutorials available in the documentation.

The Earth Engine API is mainly available through Google's JavaScript library. Hence, rather than covering API resources, the documentation covers objects with their associated methods.

6.3.6 Ease of Adoption

Anyone with a Google account can use the Google Earth Engine. Once signed in, the Earth Engine Code Editor is available right away. However, to gain access to the advanced features of the Earth Engine one has to apply through an online form provided by Google.

6.3.7 Challenges Encountered

Google Earth Engine is a powerful tool once one is comfortable with the tool. As the objects in the Earth Engine JavaScript library acts as proxies to the computation engine behind the Earth Engine, the objects put some constraints on the JavaScript

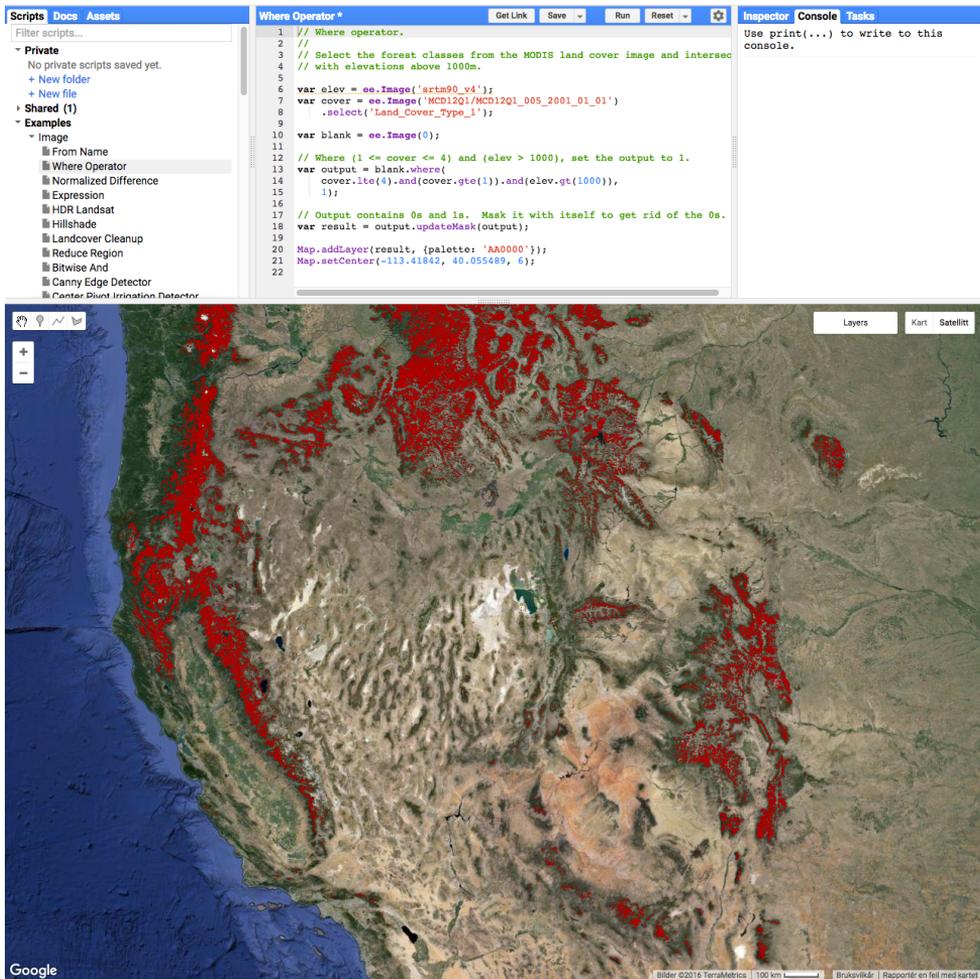


Figure 6.6: Earth Engine: Illustration of the Earth Engine Code Editor. Credit: Google Earth Engine Team [Goob].

syntax. For example, there is no console available, and it is not possible to use the standard *for-loop* syntax. However, these challenges, and how to overcome them, are well covered in the documentation.

6.4 NASA’s ECHO

NASA’s Earth Observation System ECHO is a spatial and temporal metadata registry built by NASA’s Earth Science Data and Information System [Nat16]. This system will be referred to as ECHO in this and the following sections. ECHO is a large and complex service so this section will mainly focus on the ECHO REST API and Reverb, which is ECHO’s web interface [Natd].

6.4.1 Features

This section will introduce ECHO’s data archive. Section 6.4.2 presents Reverb, and Section 6.4.3 presents the API.

Data archive

The data archive available through ECHO is big and contains large parts of NASA’s Earth-observation data. The archive contains a large number of land-, sea- and space-based platforms as well as all Landsat satellites [Nata].

6.4.2 Web Interface

Figure 6.7 shows a screen capture of ECHO’s web interface, Reverb [Natd]. The Reverb interface enables users to search through the data available in the data archive. The data available can be filtered by geographical constraints and a date range as seen at the other satellite imagery services’ web interfaces as well. Reverb also lets users filter the search by instruments, processing levels and science keywords. The science keywords can, for instance, be *agriculture*. Once a dataset is selected, the user can discover granules² of this data set before downloading the data.

6.4.3 Application Programming Interface

ECHO runs a REST API. Table 6.5 gives an overview of the API’s resources.

6.4.4 Security Mechanisms

Searching ECHO’s data archive can be done without API tokens, but the access is limited. To gain full access users need to register for an account in one of ECHO’s environments as mentioned in Section 6.4.6. After signing up, users can retrieve an API token by following ECHO’s *Creating a Token* guide [Natb]. ECHO’s API requires this API token in all requests to the API.

²The smallest aggregation of data that can be independently managed [Natc].

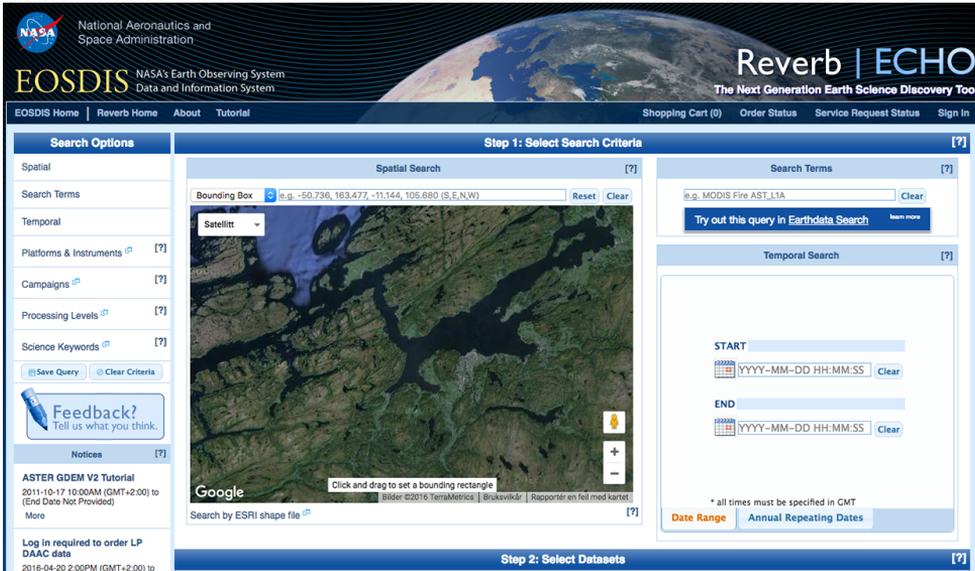


Figure 6.7: ECHO: Screen capture of the web interface.

Resource	Description
/datasets	A resource that provides user access to ECHO datasets.
/datasets/search	A resource enabling searches in datasets using A Query Language (AQL).
/granules	A resource providing user access to ECHO granules.
/granules/search	A resource enabling searches in granules using AQL.
/browses	A resource providing user access to ECHO browses.
/provider_holdings	A resource providing user access to provider holdings.

Table 6.5: ECHO: Resources exposed by the REST API.

6.4.5 Documentation

The ECHO documentation is, as the service it is documenting, vast and complex. The documentation is written with a platform called *Confluence* which is a platform for collaborating teams and their documents. While the documentation itself is understandable, it simply contains too much information. Neither is all of the documentation up to date.

For instance, there are appendices attached to the API documentation. In *Appendix C* of ECHO's API documentation, one can find an appendix named *Full*

API Documentation. Many of the links within *Appendix C* results in a *404 Not Found* message. However, this is where the clearest documentation for ECHO's API resources are located.

Finding the correct documentation can be a hassle and one often ends up at a whole other part of ECHO. The documentation also lacks examples and a *Getting Started* section.

6.4.6 Ease of Adoption

To gain access to ECHO, users needs to sign up online through ECHO's website. ECHO is running in three operational environments, *Operations*, *Partner Test* and the *Testbed* environment [Natb]. The difference between environments is what data is available and what functionality is available. ECHO requires users to create their account within the same environment as they plan to use. Most users will want to sign up for the *Operations* environment. Table 6.6 shows ECHO's environments with their belonging websites.

Name	Website	API URL
Operations	https://urs.eosdis.nasa.gov	https://api.echo.nasa.gov
Partner Test	https://beta.urs.eosdis.nasa.gov	https://api-test.echo.nasa.gov
Testbed	https://alpha.urs.eosdis.nasa.gov	https://testbed.echo.nasa.gov

Table 6.6: ECHO: Overview of the operational environments.

Once signed up for the right environment and the right documentation is found, it is not that difficult to start utilizing ECHO's API. Additionally, Reverb is usable without an account.

6.4.7 Challenges Encountered

The first impression with NASA's ECHO is that they assume that users visiting their service already know the different terms associated with satellite data. It is a high barrier for new users to get started with their service. Even with a few year of experience working with APIs one must expect to meet some challenges with ECHO.

By operating three different environments which all require separate accounts at three different websites, ECHO is separating users and underlying infrastructure, but at the same time confusion users with unclear guides and documentation. In addition to this, ECHO requires API tokens for some of its services without clarifying where this apply.

The way of defining geographical constraints in searches to the data archive does not use any standards. Both GeoJSON and WKT has been used by similar satellite imagery services and should have been employed by ECHO as well.

6.5 Planet Labs

Planet Labs, Inc. is a company based in California, United States that operates a fleet of nearly hundred miniature satellites called Doves [Mar14]. The Doves along with five RapidEye satellites constitute the data basis for Planet Labs satellite imagery data [Pla16]. The satellite imagery can be accessed either online using Planet Labs web interface or by using their API. This section will go through the different topics covered in Section 2.3 for Planet Labs.

6.5.1 Features

Planet Labs is offer three ways of interacting with their image archive. It can be done through their API or through one of the two web interfaces they operate. Namely the Scene Explorer and the Mosaic Explorer. In addition to these features is the Labs service which is where Planet Labs showcase experiments and ideas.

Image archive

The image archive is Planet Labs' data archive and contains data collected by the RapidEye satellites, Planet Labs' satellites and Landsat satellites [Plab]. Planet Labs is still in the early phases as a satellite imagery provider, and currently only provides satellite data for California, United States.

Scene Explorer

The Scene Explorer is Planet Labs' web interface for discovering individual images from their image archive.

Mosaic Explorer

The Mosaic Explorer enables users to browse composited maps of the data from Planet Labs' image archive.

Labs

In the Labs service, users can browse through experiment and demonstrations of the API provided by Planet Labs.

6.5.2 Web Interface

Planet Labs provides two web interfaces to interact with their image archive. These are the Scene Explorer and the Mosaic Explorer as mentioned in Section 6.5.1. This section will introduce the Scene Explorer first, then the Mosaic Explorer afterward.

The Scene Explorer web interface can be seen in Figure 6.8 and lets users browse through the image archive for individual images. The search area can be filtered using polygons and a date range. Users can then download images by adding them to the cart.

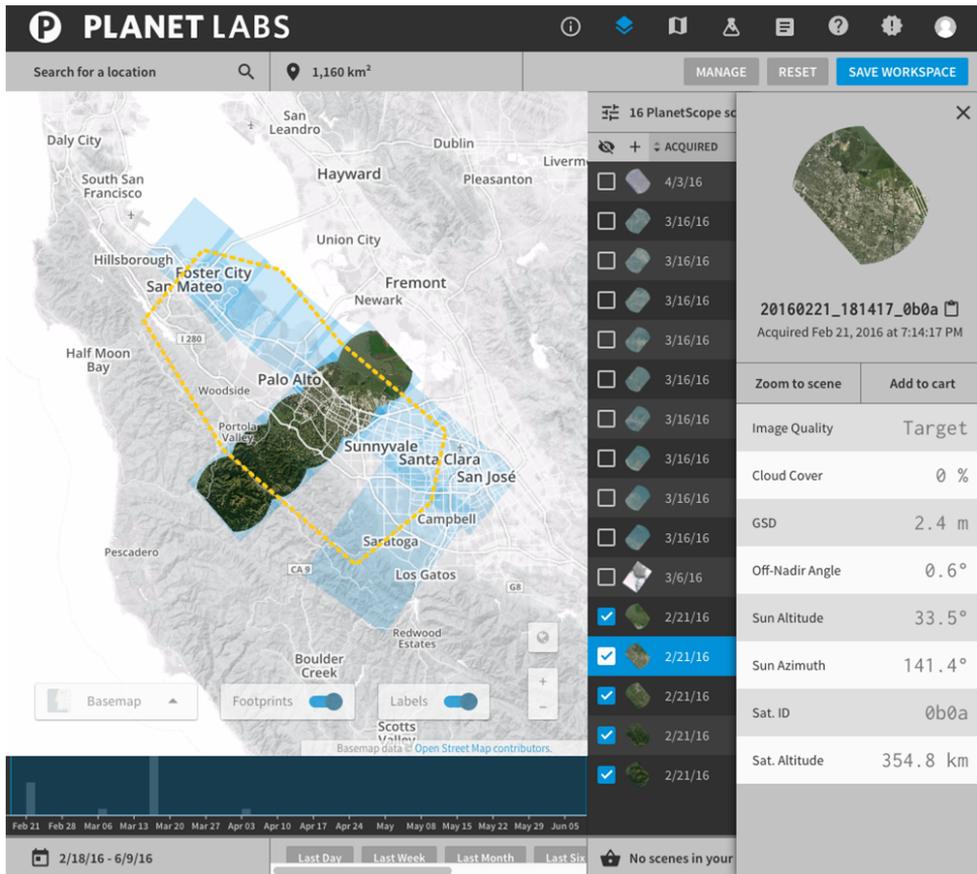


Figure 6.8: Planet Labs: Screen capture of the Scene Explorer web interface.

The Mosaic Explorer web interface can be seen in Figure 6.9 and lets users select predefined tiles which are made up of multiple images to produce a result with no clouds. The images contributing to the mosaic can be seen on the right-hand side of

the figure. Planet Labs offer different mosaic settings such as the *Landsat 8 Mosaic* and the *RapidEye California Summer Mosaic*.

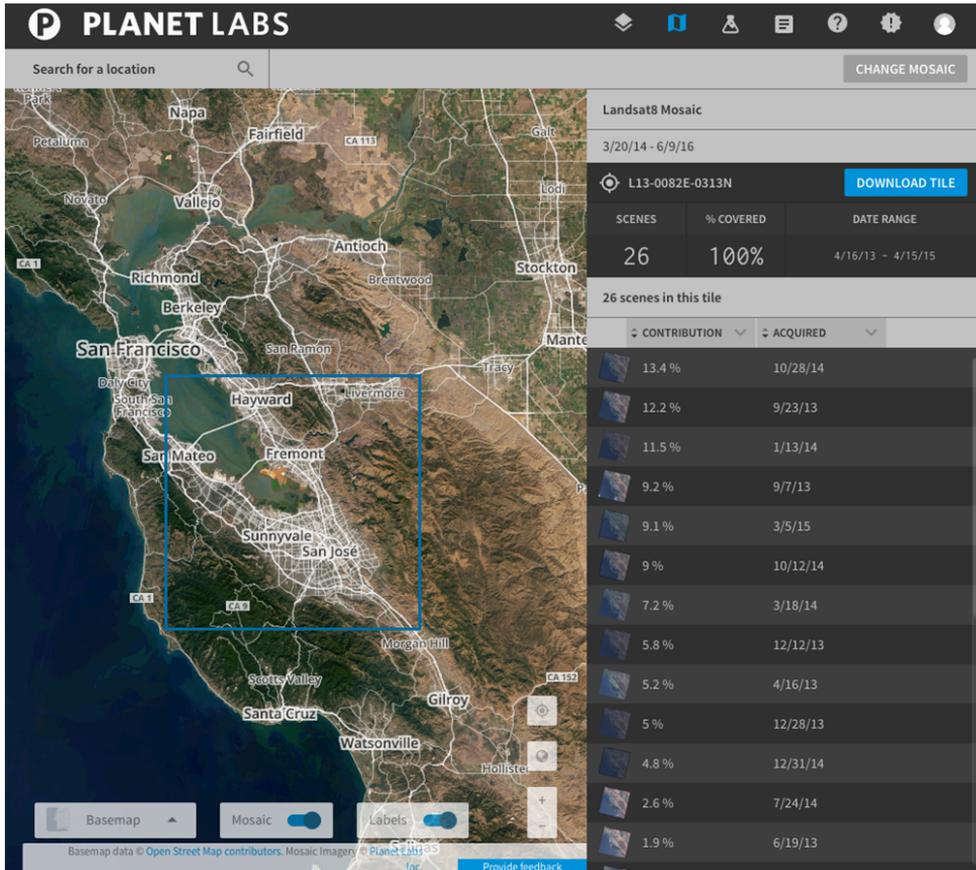


Figure 6.9: Planet Labs: Screen capture of the Mosaic Explorer web interface.

6.5.3 Application Programming Interface

Planet Labs has a REST API, which exposes the resources seen in Table 6.7.

6.5.4 Security Mechanisms

To gain access to Planet Labs' API services, users need to send in an application to Planet Labs. Once approved, an API token can be retrieved from the account information page through Planet Labs website. The API token needs to be attached to all requests to the API.

Resource	Description
/scenes	Resources that allows for searching and downloading scenes with their associated metadata.
/scenes/landsat	The resource used for Landsat scenes.
/scenes/ortho	The resource used for Planet Labs scenes.
/scenes/rapideye	The resource used for RapidEye scenes.
/mosaics	A resource that allows for searching and downloading mosaics. It also contains information about the scenes that constitutes the mosaic tile.
/orders	Endpoint used to manage multiple downloads of Planet Labs' images.
/aois	A resource that allows for creating and modifying AOIs which can be used when searching for imagery.
/workspaces	Using the <i>workspaces</i> resources, users can save searches for later use.

Table 6.7: Planet Labs: Resources exposed by the REST API.

6.5.5 Documentation

Planet Labs' documentation covers all APIs offered by them and the associated resources. The documentation includes a *Tutorials and Guides* section where they present ways of using their API. Users can also choose to see examples in one of the two programming languages: Python and JavaScript. However, the documentation is missing search functionality to find information quicker.

6.5.6 Ease of Adoption

Planet Labs is still in a beta phase and to sign up one needs to apply for the Planet Explorer program [Plaa]. Receiving an invite from Planet Labs might take up to a week from the application has been sent in.

When signed up one can find an API key under the account information and start using the API. Planet Labs presents several use cases and the documentation is filled with code examples which makes starting with their service easy.

6.5.7 Challenges Encountered

The main challenge with Planet Labs is that it is brand new and does not yet provide satellite data for any other regions than California, United States. Planet Labs do not provide any information about when one could expect other regions to open up. Their gallery contains satellite imagery from all over the world, so it comes down

to making it available. The API is still at *version 0* which could indicate that they wish to improve the API before opening up more areas.

6.6 Sentinels Scientific Data Hub

SciHub is ESA's data hub for satellite imagery acquired by the satellites of the Sentinel constellation [Eur16b]. SciHub released its first products in May 2014 [Eur14] and is adding more data as the Sentinel satellites are becoming operative. This section will go through the topics introduced in Section 2.3 for SciHub.

6.6.1 Features

SciHub is still under development, and new data types become available when new satellites become operational. Due to this, some of the features such as the Sentinel-2 Pre-operational Hub (S-2 PreOpsHub) are temporary features. This section presents features provided by SciHub.

Data Hub archive

SciHub's Data Hub archive consists, at the time of writing, of Sentinel-1 and Sentinel-2 products. Data is added continuously as new satellites become operational.

Scientific Hub

The Scientific Hub is SciHub's web interface to their data archive. Section 6.6.2 further introduces the web interface.

S-2 PreOpsHub

The S-2 PreOpsHub is a temporary feature which provides pre-operational access for all users to Sentinel-2 data. The S-2 PreOpsHub is a web interface similar to the Scientific Hub.

API Hub

The API Hub is SciHub's API to the Data Hub archive and Section 6.6.3 further introduces the API Hub.

6.6.2 Web Interface

SciHub's web interface as seen in Figure 6.10 allows users to search through their Data Hub archive without the need for programming knowledge. Through the web interface users can filter searches geographically by use of a polygon and by altering search parameters. The parameters can be cloud coverage, sensor mode, relative orbit number or product type among others. Once an image has been found, users can download the raw image directly.

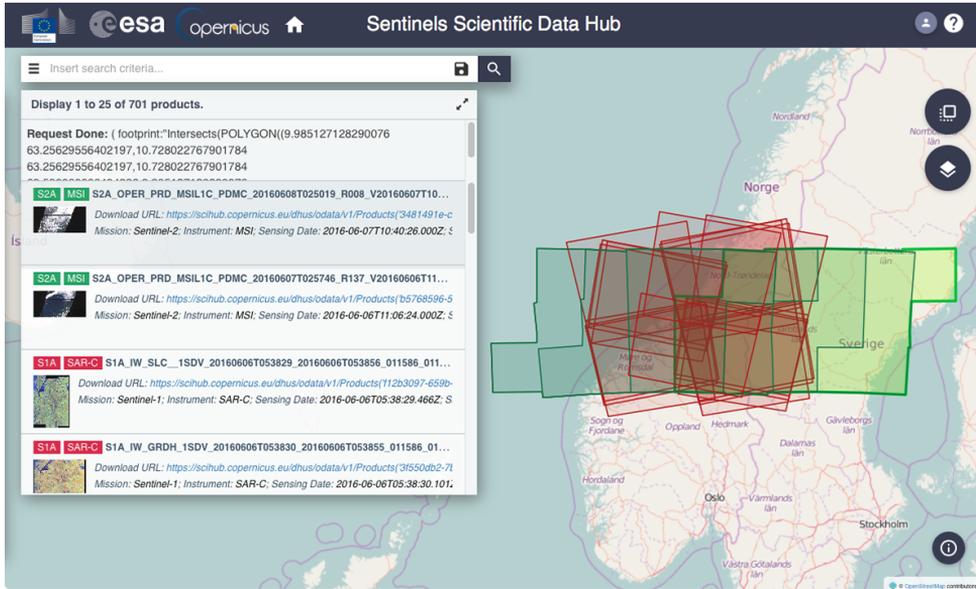


Figure 6.10: SciHub: Screen capture of the web interface.

6.6.3 Application Programming Interface

SciHub is running two APIs. One is built using Open Data Protocol (OData), which enables the creation of REST-based data services. The other API is an OpenSearch API. The sample application developed during this work is using OpenSearch to search SciHub’s archive. The OData API exposes the resources seen in Table 6.8. The OpenSearch API exposes the resources seen in Table 6.9. OpenSearch is complementary to the OData API and is possible to use as the query aspect of OData [Eur16a].

Resource	Description
/products	A resource that includes the records of all the products stored in the Data Hub archive.
/collections	A resources that expose a collection of products.

Table 6.8: SciHub: Resources exposed by the OData API.

Resource	Description
/search	A resource for searching for products in SciHub’s Data Hub.

Table 6.9: SciHub: Resources exposed by the OpenSearch API.

6.6.4 Security Mechanisms

The only requirements for using SciHub's API Hub is that the user registers for an account through SciHub's websites. The username and password for the account need to be sent with all requests going to either of the two APIs in the API Hub. SciHub is, at the time of writing, not using API tokens.

6.6.5 Documentation

The first impression with the documentation for SciHub API is that they expect users that come to their website to already possess quite a bit of knowledge about satellites data. The documentation lacks a *Getting Started* section for new users.

While there are some examples of API use, the documentation would benefit from more examples which could help users getting started in shorter time. The documentation focuses more than necessary on explaining the protocols in use and too little on the actual API and its resources.

Additionally, not all parts of the documentation are updated. The part of the documentation explaining SciHub's web interface is not updated since 2014 [Eurd] and still provides explanations for the old web interface, as Figure 6.11 illustrates. Figure 6.10 shows SciHub's current web interface.

6.6.6 Ease of Adoption

To start using SciHub, users need to sign up through SciHub's *Self Registration* form. Once registered, SciHub is ready to be utilized. While getting the initial access to SciHub is a simple process, getting started with the service can be a hassle, even for experienced programmers. The documentation is heavy and lacks examples and a *Getting Started* section.

6.6.7 Challenges Encountered

The first challenge encountered with SciHub is that the entry barrier is too high. It appears as a service which expects all of the users to possess some knowledge of satellite data. As mentioned in Section 6.6.5, the documentation is heavy and with few examples.

In addition to this, SciHub uses OpenSearch for their product discovery API. OpenSearch uses strings as queries and where other satellite imagery services accept multiple parameters to be sent with the request, OpenSearch requires a long and complicated query to be passed as a single parameter. From a programmer's perspective, this results in more formatting of parameters in the applications and possible pitfalls.



Figure 6.11: SciHub: Explanations for the old web interface. Credit: European Space Agency [Eur].

The satellite images available through SciHub’s Data Hub typically range from five to seven Gigabytes (GBs) in file size. Also, there seems to be some connection problems with SciHub because the connection frequently breaks in the middle of a download with no possibilities to continue where it broke.

6.7 UrtheCast

Based in Vancouver, Canada, UrtheCast is a company that focused on geospatial analysis both with using their applications and through an API they offer. UrtheCast operates a fleet of high-resolution multispectral satellites and with the use of a camera onboard the International Space Station (ISS) offers live-streaming of the Earth [Urta]. This section will go through the different topics introduced in Section 2.3 for the satellite imagery service UrtheCast.

6.7.1 Features

UrtheCast is offering an API as well as a web interface which can be used to interact with their data archive [Urtf]. This section presents UrtheCast's features. Section 6.7.2 presents the web interface and Section 6.7.3 presents the API.

Archive

UrtheCast's data archive contains satellite data from the Deimos satellites, the Theia satellite, and the Iris sensor which is stationed on the ISS [Urtb]. The Iris sensor can capture 1-meter resolution Ultra-High-Definition video [Urtb]. The videos are not available straight out of the box, but users can request a sample from UrtheCast.

Area of Interests

The AOI service offered by UrtheCast enables users to create and save AOIs which can be used in the other features provided by UrtheCast.

Live

UrtheCast is streaming live video from the ISS at their website [Urta]. Although there is no practical use of this, it is a way of showcasing their camera. Through this service, users can see the sun rise and set 16 times a day.

Satellite Tracker

The Satellite Tracker service lets users see where the satellite is located at a given time, and its purpose is to enable users to predict and plan imaging opportunities.

Events

The Events service together with the AOI service lets users subscribe to a feed of changes and updates to satellite imagery whenever they occur in a chosen AOI.

Map Tiles

The Map Tiles service enables users to visualize and render Earth imagery in their applications.

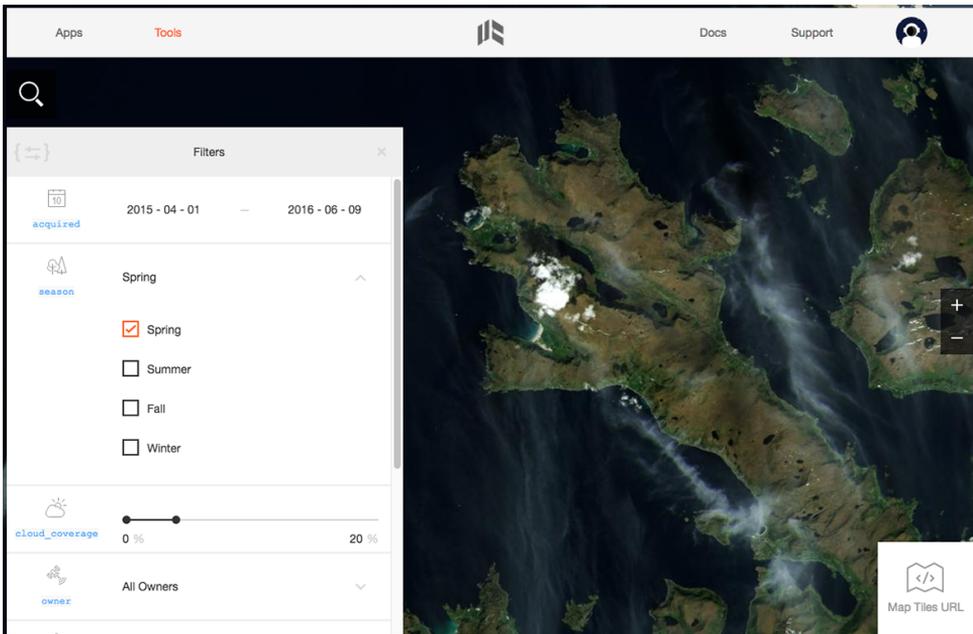


Figure 6.12: UrtheCast: Screen capture of the web interface.

6.7.2 Web Interface

Figure 6.12 shows UrtheCast’s web interface. Through the web interface, users can search UrtheCast’s data archive for satellite imagery [Urte]. The searches can be filtered by dates, cloud coverage, render type, and sensor. Additionally, users can select what season of the year they want images to have been acquired. Naturally, this has to be somewhat synchronized with the dates. UrtheCast then builds up a *map tile* with images matching the chosen settings. When a *map tile* has been found, users can copy the link and implement the *map tile* in their web service.

6.7.3 Application Programming Interface

UrtheCast’s API is built upon the REST software architectural style and exposes the resources from Table 6.10.

6.7.4 Security Mechanisms

When signed into UrtheCast’s website, users can retrieve their API secret and API key at the user account page. The API secret and API key needs to be included in all requests to UrtheCast’s API.

Resource	Description
/satellite_tracker/satellites	A resource used to track satellites.
/archive/scenes	Used by users to search through UrtheCast's data archive.
/consumers/apps/me/aois	Used by users to create and modify their AOIs.
/event_streams/events	Resource used to track changes in the resources offered by the UrtheCast API.
/ordering/orders	The <i>orders</i> resource acts as a shopping cart when placing orders for satellite imagery.
/ordering/orders/{id}/line_items	The <i>line items</i> resource used to add individual images to order.
/ordering/deliveries	The <i>deliveries</i> resource is used to retrieve orders.

Table 6.10: UrtheCast: Resources exposed by the API.

6.7.5 Documentation

UrtheCast's documentation is comprehensive and covers all parts of UrtheCast's features. The documentation contains a *Getting Started* section for new users, a *Concepts Overview*, which describes what roles different parts of the API play and an introduction to satellite imagery.

The introduction to satellite imagery lowers the barrier for starting with UrtheCast for new users. An introduction to satellite imagery has not been seen at any of the other satellite imagery services. To exemplify, Figure 6.13 demonstrates how UrtheCast explains the difference between good and poor absolute geolocation accuracy in satellite imagery. The left half has a good accuracy while the right half has a poor accuracy [Urtc].

The documentation also includes an interactive API presentation [Urtcd] which goes through all of UrtheCast's services, how they can be used, and how satellite imagery can be utilized. The users have to be signed up and need to have retrieved their API key to view the presentation.

The presentation together with the *Getting Started* section of the documentation indicates that UrtheCast wants to attract users from outside the scientist and researcher user category.



Figure 6.13: UrtheCast: Comparison of good and poor absolute geolocation accuracy. Credit: UrtheCast [Urtc].

6.7.6 Ease of Adoption

UrtheCast offers a free tier for developers and signing up can be done through their website. Once signed up users can retrieve their API key and API secret from the account information page. After doing this, UrtheCast offers several ways of learning about the API and satellite imagery in general. UrtheCast’s *Getting Started* makes UrtheCast an easy service to use.

6.7.7 Challenges Encountered

Querying for scenes within an AOI seems to fail sometimes. There is no error message which makes it hard to debug. Other than that there has not been any particular challenges with UrtheCast.

Proposition for the Norwegian National Ground Segment

Requirements and solutions to data access interface features, processing-on-demand services, and interface security mechanisms have been studied throughout this work. The main sources for this have been the extensive evaluation of similar satellite imagery services as well as requirements extracted from the user survey conducted by NSC. This chapter will present a proposition to the development of the Norwegian National Ground Segment.

7.1 Features

The features presented during this section are features that contribute to the requirements posed by users. Variations of these features have also been seen frequently in the evaluated satellite imagery services.

7.1.1 Data Archive

The most frequently mentioned requirement on data in National Ground Segment's data archive is that the data should be orthorectified using the Norwegian DEM. This requirement is already known to NSC.

Further on, users working with disaster management and security have posed that they need satellite data in near-real-time and in some cases in quasi-real-time. Sentinel-1 data can be delivered in quasi-real-time with help from the antenna in Tromsø as mentioned in Section 4.1.3. Sentinel-2 data is at the time of writing not possible to deliver in quasi-real-time.

In addition to these requirements, users have, in the survey, mentioned that the National Ground Segment should contain a set of standard products. These products should have been processed with the most common processing routines and contain ready-to-analyze data. An example of a standard product is NDVI. NDVI displays the greenness, i.e. the relative density and health of vegetation [Unid]. Leaves reflect

wavelengths of near-infrared light which can be used to convert raw images into NDVI products.

7.1.2 Area of Interests

AOI as a service enables users to create geographical constraints that can be saved for later use. The AOIs should be definable through both a web interface and an API. Users should be able to define AOIs by using GeoJSON or WKT formats. Users should also be able to filter searches in the data archive with their AOI. The AOI can be integrated with the other services offered by National Ground Segment as well.

7.1.3 Notifications

A notification service would allow users to subscribe to new satellite data within a geographical area that also matches a filter defined by the user. Whenever new satellite data becomes available, the user would then receive an e-mail notification containing a link to either download the satellite data or view the satellite data in National Ground Segment's web interface.

7.1.4 Time-series

Producing time-series with satellite data require large amounts of data within the same geographical area over a given time span, usually several years. The large quantities of data put a high demand for physical resources on the users. Transferring the raw satellite data from the National Ground Segment to the user would also be a time-consuming process. A time-series service would enable the user to request a time-series for a given time span and have the National Ground Segment do the processing. Letting the National Ground Segment do the processing would lower the demand for physical resources as well as lower the amount of data transferred.

7.1.5 Change-detection

The change-detection service lets users subscribe to changes in data within an AOI defined by themselves. Whenever some predefined criterion notices a change in the satellite data of the specific AOI, users would get notified. The service can be exemplified with a user monitoring the extent of his forest. Through the change-detection service, the user has chosen to receive notifications by e-mail whenever the change-detection service notices a change in the forest cover for his AOI. The user can then choose to download the satellite data for further analysis. The change-detection service differs from the notification service in that the change-detection only notifies users if a change in satellite data is detected. The notification service notifies whenever new satellite data is available.

7.1.6 Mosaics

Through a mosaics service, users should be able to merge multiple satellite data files into one based on some chosen criterion. For instance, a user wants satellite imagery over Oslo, Norway with no clouds. The user would then request a mosaic over the given area with cloud coverage below a certain threshold. The National Ground Segment would then merge multiple images into the wanted result before delivering the product to the user.

7.1.7 Processing-on-demand

Processing-on-demand is a service that enables users to process and run algorithms on data using the National Ground Segment's infrastructure. The processing can take a long time, and the service should notify the user when the data is ready to be downloaded. The notification can, for example, be sent via e-mail. Offering the processing-on-demand service to users would lower the demand for physical resources, thus increasing the amount of potential users for the National Ground Segment. This, in turn, would increase the potential for innovations in satellite data coming from the National Ground Segment.

7.2 Web Interface

The National Ground Segment should have a web interface, allowing users with little to no programming experience to utilize the available satellite data. As requested by learning institutions in the user survey, the usability of the web interface is important and highly affects how much they will use the service.

Through the web interface, users should be able to search and browse the satellite data archive. The user should also be able to set geographical constraints for the search by drawing a polygon on an interactive map. The search should be filterable by which satellite acquired the data, when the data was acquired, and other available metadata. Examples of user-friendly interfaces are as follows:

- Astro Digital's web interface, as seen in Section 6.1.2.
- Planet Labs' web interface, as seen in Section 6.5.2.
- UrtheCast's web interface, as seen in Section 6.7.2.

7.3 Application Programming Interface

Companies and organizations who want to use satellite data in their operations usually want to automate their tasks. There is little doubt that the National Ground Segment needs to be accessible through an API. The purpose of this section is to

introduce some of the most valuable findings from the evaluated satellite imagery services and suggest recommendations based on these findings.

7.3.1 Structure

The REST software architectural style is commonly used in large web services today and is used by six of the seven satellite imagery services included in this study. Consequently, this proposition for the structure of the API will assume that REST is chosen for the National Ground Segment. Table 7.1 shows a proposition for the structure of the resources in the National Ground Segment's API.

Resource	Description
/aois	Through this resource, users can create, modify or delete their AOIs.
/change-detections	Resource enabling users to set up filters for the change-detection service.
/mosaics	Users can search through existing mosaics or place order for their mosaics.
/notifications	Lets the user create, modify or delete notification preferences for the notification service.
/orders	Through this resource, users can check the status for orders placed via the other resources. Orders that are completed should come with a link to where the file can be downloaded.
/products	Exposes the set of standard products available in the data archive.
/search	Used by users to search the National Ground Segment's data archive.
/tasks	By providing the identifier for a satellite data file, users can use this resource to create tasks for the processing-on-demand service.
/time-series	Resource enabling users to place order for time-series.

Table 7.1: Proposed structure for the Norwegian National Ground Segment's API resources.

7.3.2 Search Parameters

The API should allow queries to filter on most of the available satellite metadata. The metadata is most frequently given in one of the data types *integer*, *float*, and *string*. Parameters related to dates or geographical coverage are more complex.

```

1 # Astro Digital
2 <api_url>/?cloud_from=0&cloud_to=10
3
4 # DigitalGlobe
5 <api_url>/?filters=[cloudCover < 10]
6
7 # ECHO
8 <api_url>/?cloud_cover [min]=0&cloud_cover [max]=10
9
10 # Planet Labs
11 <api_url>/?cloud_cover.estimated.lt=10
12
13 # SciHub
14 <api_url>/?q=cloudcoverpercentage:[0 TO 10]
15
16 # UrtheCast
17 <api_url>/?cloud_coverage_lt=10
18
19 # <api_url> is the Uniform Resource Locator (URL) for the given
    API.

```

Figure 7.1: Code illustrating ways of using range operators to filter on metadata in an API.

Date format parameters should follow the ISO 8601 standard as described in Section 3.3.1. When it comes to parameters concerning the geographic extent of the satellite data, the API should allow parameters using either GeoJSON or WKT¹.

The user might want to use *range operators* on the metadata, e.g. when searching for satellite imagery that contains less than 10% clouds. Figure 7.1 illustrates the different ways *range operators* are handled by satellite imagery services. Google Earth Engine is not included as it is available through programming libraries.

It appears as if there are no agreed standards when it comes to range operators. The way Astro Digital and UrtheCast uses range operators makes sense. However, there is no clear way of knowing if Astro Digital includes the end boundaries or not. Table 7.2 illustrates the different range operators used by UrtheCast.

7.3.3 Stability and Consistency

The API should be backward compatible, meaning that when the API updates with new features, applications already utilizing the API will not break. A common method for solving this challenge is to use versioning. When the API add new features

¹Section 3.3.1 defines GeoJSON and WKT

Operator	Mathematical symbol	Description
<code>_lt</code>	$<$	Less than.
<code>_lte</code>	\leq	Less than or equal to.
<code>_gt</code>	$>$	Greater than.
<code>_gte</code>	\geq	Greater than or equal to.

Table 7.2: API range operators used by UrtheCast.

or modify parts of a feature, the updated API should increment its version number while the old version should still be available for a given period. Thus allowing users to update their applications to the new version before the old API version is shut down. *Version 1* of an API is denoted with *v1* between the API Uniform Resource Locator (URL) and the resource as Figure 7.2 illustrates.

```
1 <api_uri>/v1/search?
```

Figure 7.2: API versioning.

7.3.4 Security

The security aspect of the National Ground Segment’s API is a stricter requirement. As with all online services, there are security threats. Hence, the API should implement a well-established security standard. Google Earth Engine and DigitalGlobe uses OAuth2 for the security mechanisms in their API and so should the National Ground Segment.

One can not assume that the users are familiar with API keys, API secrets, and tokens. The National Ground Segment should, therefore, provide examples and a tutorial explaining how one retrieves an API token. As seen in Section 6.2.6, DigitalGlobe provides a brief authentication course for new users.

7.4 Documentation

The documentation should cover all resources provided by the API. The quality of the documentation greatly affects the usability of the API. No matter how good an API, it will not get used without proper documentation [Blo06].

UrtheCast provides a *Concept Overview* section as the front page for the documentation. This page explains how the API is structured and where in the documentation the user should start. The *Concept Overview* section makes it easier to start with the service.

For users new to in the satellite data field, there should be an introduction section where satellite data, its properties, and its associated lingo is explained. An introduction to satellite data would contribute to lowering the starting barrier for new users. Not all users are experts within the field.

The documentation at similar satellite imagery services that have been easiest to read and understand have all had code examples next to the documentation. These examples have been available in one of the three programming languages: Python, JavaScript, and Shell. The user can choose one of the programming languages for the examples.

Lastly, a *Q&A* section or a forum would enable users to interact with each other. The *Q&A* section could reduce the workload for those working with support in the National Ground Segment. Also, over a longer period, the section will grow into a knowledge base where users can see if anyone have had similar problems as the user is facing.

7.5 Ease of Adoption

A goal for the development of the API should be that users should be able to get up a basic implementation utilizing the API in less than 15 minutes. This section proposes tools that could contribute to reaching the 15 minutes goal.

7.5.1 Query-builder Tool

As presented in Section 6.1.5, Astro Digital has a web interface they call a *query-builder tool*. Through this service, users can draw a polygon on an interactive map which makes up a geographical constraint for their query. Additionally, the service lets users modify parameters based on the available metadata. When the user is done modifying the query, the query can be copied as a JSON object. The query is usable by users in their application.

The National Ground Segment should either implement a service similar to the *query-builder tool* or refer to a service with the same functionality. For instance, <http://geojson.io> can be used to create GeoJSON objects quickly.

7.5.2 Interactive Tutorials

Interactive tutorials should be available along with the regular documentation. The tutorial should introduce users to the service, what one can do using the service, and basic satellite data knowledge.

For instance, Astro Digital have a *Quick Start* section which guides the user through a use case and how one should set up the platform to automate the tasks presented in the use case. The use case presented by Astro Digital is that they has a field of Arugula on the other side of town, and they want to monitor the health of the field without having to drive across town [Asta].

UrtheCast's way of introducing their service is through an online presentation which introduces code examples and the result of the code when executed. This interactive presentation requires the user to provide an API token.

7.5.3 Language-specific Programming Libraries

Not all users are comfortable dealing with requests and responses when interacting with an API. The solution to this can be language-specific programming libraries. For instance, instead of handling the requests themselves, users could use an already existing programming library where the interaction with the API would be in the form of calling methods on classes. There exists software, such as Alpaca, which can automatically generate these libraries based on the API's resources [Pro].

7.6 Prioritization

The proposition includes several aspects and features of the National Ground Segment. It will be costly to develop all of the features, hence, it is required to do some prioritization. Developing an AOI service is, for instance, less complicated than developing a processing-on-demand service. The priority of the National Ground Segment is to get data out to the users. As a first version, this work recommends an API with belonging documentation and an AOI service. The API will enable programmatic access to the National Ground Segment. Thus, allowing users to start developing applications and explore the data offered.

Chapter 8

Conclusion and Further Work

This report provides a proposition to the development of the Norwegian National Ground Segment. The proposition includes what features the Norwegian National Ground Segment should include, what aspects are important, and how development resources should be prioritized. The proposition is based on an extensive evaluation of seven satellite imagery services and the compilation and extraction of a national user survey among potential Norwegian Copernicus users.

8.1 Reflections

It seems that there is a high barrier for new users to use, or even talk about satellite data. Maybe people think that satellite data has to be a very complicated theme - when, in fact, satellite imagery is not that difficult. It all comes down to how the data is presented and that easy data access if facilitated. The high barrier might very well be the hardest challenge for the Norwegian National Ground Segment when it comes to acquiring users from outside the satellite data culture.

The extensive evaluation of satellite imagery services has resulted in valuable information for this work. However, the study of satellite imagery services could have benefitted from a more structured plan when it comes to how the services are evaluated. Creating a sample application utilizing satellite imagery services has contributed in that the API part of the study has been highly structured. The work could have benefitted with a structured plan to explore the web interfaces of the satellite imagery services as well.

The interface security part of the satellite imagery services is a complex topic. Consequently, this work has only explored the security mechanisms briefly as there has been a limited amount of time available. Studying the interface security mechanisms would be interesting, but could result in a report in itself. The work has, however, mapped what security mechanisms are applied to the evaluated satellite imagery services and can point the Norwegian National Ground Segment in the right direction.

Overall, the work has been fascinating and has opened my eyes for satellite data services. There are clearly some *up-and-coming* services out there, and I think the use of satellite data will explode in the next few years. Learning about the topic at an early stage is exciting.

8.2 Further Work

The reason for weighing the findings from the evaluated satellite imagery services so heavily is that it has proven difficult to get engaged with potential users. Only 17 of the 65 recipients answered the NSC's survey. It could prove valuable to conduct a new user survey after the National Ground Segment has been active for at least a year. The recipients might then know a bit more about the potentials of satellite data, and the survey can refer to the National Ground Segment.

While this report has looked at Astro Digital, DigitalGlobe, Google Earth Engine, NASA's ECHO, Planet Labs, SciHub, and UrtheCast, it would be interesting to see what other member countries of the Copernicus program are doing. France already has the *Sentinel Product Exploitation Platform* and Greece has the *Hellenic National Sentinel Data Hub* [Eurc]. Both services are utilizing data from the Sentinel collaborative ground segment. These were not included in this report because SciHub already represents a service utilizing Copernicus data and it is interesting to look at satellite imagery services that differ more from SciHub.

Lastly, it could prove valuable to look at services whose main focus is not optical satellite imagery, but, for example, radar imagery. This report has had optical satellite imagery as its main focus. Looking services utilizing other types of satellite data might reveal more features that the Norwegian National Ground Segment could benefit from.

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Appendix

An Introduction to the Sentinels

The following is an overview of the different satellites of the Sentinel constellation in the Copernicus space program.

A.1 Sentinel-1

The prime objectives of the Sentinel-1 mission are land and ocean monitoring. The satellite carries a C-band SAR sensor which offers medium- and high-resolution radar imaging in all weather conditions. This allows for detecting small movement of the ground, which makes it useful for land and sea monitoring. Sentinel-1 is also well-fitted for observing ships, oil spill and sea-ice.

Sentinel-1A was launched into orbit 3rd of April 2014, and Sentinel-1B was launched 25th of April 2016 [Eure]. Sentinel-1B is expected to stay in a pre-operational phase for three months from launch before it starts delivering data.

A.2 Sentinel-2

The Sentinel-2 satellites both carry a multispectral instrument that allows the satellites to capture high-resolution optical imagery. This allows Sentinel-2 to observe changes in vegetation, forest, landscape and more. The Sentinel-2 mission provides a coverage of the Earth's land surface every ten days with one satellite and every five days with two satellites [Eurl]. Table A.1 gives an overview Sentinel-2's technical specifications.

Sentinel-2A was launched 23rd of June 2015, and Sentinel-2B is planned to follow in the second half of 2016 [Eurl].

Mission features	Data
Mission lifetime	15 years
Number of satellites	2
Nominal in orbit satellite lifetime	7.25 years with consumables for additional 5 years
Nominal orbit	Sun synchronous 786 km (mean altitude)
Land coverage	-56° to +84°
Satellite revisit time	< 5 days
Swath width	290 km
Spatial resolution (panchromatic)	12 m
Spatial resolution (multispectral)	20 m
Spatial resolution (thermal)	60 m

Table A.1: Technical specifications for the Sentinel-2 mission [Eurg].

A.3 Sentinel-3

The Sentinel-3 mission uses multiple sensing instruments to accomplish its mission which is primarily an ocean mission. Sentinel-3 will observe sea level, sea color, and sea temperature as they vary over the seasons.

Sentinel-3A is planned for 16th of February 2016; Sentinel-3B is planned for 2017 and Sentinel-3C is planned for launch before 2020 [Eurm].

A.4 Sentinel-4

The Sentinel-4 mission focuses on monitoring gas concentrations and aerosols in the atmosphere to support air-quality and climate monitoring. The Sentinel-4 mission is a payload on the geostationary Meteosat Third Generation satellites [Eurj].

Sentinel-4A is planned for 2019 with Sentinel-4B following in 2027 [Eara].

A.5 Sentinel-5

The Sentinel-5 missions are to monitor the atmosphere from a polar low Earth orbit, and the instruments can observe levels of ozone, NO_x and aerosols. The Sentinel-5 mission is not a satellite itself, but a payload on the polar-orbiting MetOp Second Generation satellite [Eurj].

Sentinel-5A is planned for 2020 and Sentinel-5B is planned for 2021 [Earb].

A.6 Sentinel-5P

The Sentinel-5P (Precursor) is a mission intended to provide data continuity and fill what would be a five-year gap between the Envisat and Aura missions and the launch of Sentinel-5 [Eurh]. The mission will perform atmospheric monitoring at high temporal and spectral resolution.

Sentinel-5P has a planned launch during 2016.

A.7 Sentinel-6

The Sentinel-6 mission will provide observations of the topography of the ocean. This information contributes to monitoring changes in sea level [Euri]. Sentinel-6 is planned to operate in the 2020 - 2030 time frame [Eura].

Appendix **B**

Meetings with Anja Strømme and Ola Nordbeck

The following sections are summaries of meetings with Anja Strømme and Ola Nordbeck from Norwegian Space Center.

B.1 Meeting on 11th of February 2016

The following is a summary of the topics discussed during a meeting with Anja Strømme and Ola Nordbeck at NSC on 11th of February 2016.

B.1.1 Antenna in Tromsø

Norway has an antenna located in Tromsø which collects data from Sentinel-1 as the satellite passes by. This allows data to be collected and fed into the National Ground Segment in near-real-time.

B.1.2 User Survey

NSC has created and is planning to send out a user survey to potential users of the National Ground Segment. This survey aims to detect user requirements for the National Ground Segment.

B.1.3 Relay Server at Norwegian Meteorological Institute

ESA will finance and install a relay server in Norway which will be located at MET. This relay server will act as the Norwegian user in the collaborative ground segment (collaborative data hub). MET will also operate the servers for the National Ground Segment, and data will be downloaded from the relay server and into the National Ground Segment.

B.1.4 Challenges with the Elevation Model

The data from the Copernicus ground segment is orthorectified using Planet DEM, a DEM with 90-meter resolution. Norway has a 10-meter resolution DEM which would be preferred. Two possible solutions to this challenge are either implementing the Norwegian DEM in the Copernicus ground segment so that core data will be orthorectified with the Norwegian DEM, or by downloading raw Sentinel-2 data and orthorectifying it in the National Ground Segment.

B.1.5 Norway Part of a Test Case Running in Italy

ESA is currently running a test case in Italy for processing-on-demand. The test case being run is orthorectifying satellite imagery of Norway using the Norwegian 10-meter resolution DEM.

B.1.6 Importance of Moving Users to the Data

Satellite data is typically large files with optical images being somewhere between five and seven GBs. This means that requirements for physical resources for users are high. A way of lowering the requirements for physical resources would be to move the users to the data instead of vice versa. This could be accomplished by offering users to run algorithms and calculations on the servers for the National Ground Segment.

B.2 Meeting on 28th of April 2016

The following is a summary of the topics discussed during a meeting with Anja Strømme and Ola Nordbeck at the NSC on 28th of April 2016.

B.2.1 Update on the User Requirements Survey

The number of responses on the user requirement survey sent out by the NSC has been relatively low. Around one-third of the 65 establishments and enterprises answered the survey. Several participants in the survey are already cooperating, or in dialog with NSC and NSC already know what needs these users have. While the survey shows some trends in what type of satellite data the user needs, it is hard to draw a conclusion from the survey due to few responses.

B.2.2 Norwegian National Ground Segment

The priority of the National Ground Segment is to deliver satellite data to users. Before a web interface and/or a data access interface is ready, satellite data requests from users will most likely be handled manually by simply sending the requested

data to the users. Later in the development cycle of the National Ground Segment a data access interface or an API will be needed.

The National Ground Segment will also need a Graphical User Interface (GUI) for searching and downloading data, but as the major users of the National Ground Segment are going to want to automate their tasks, this is not a priority. There might be a graphical user interface such as the one used by SciHub as a temporary solution.

It is unlikely, and not intended that the National Ground Segment should offer more functionality and data than Google Earth Engine and other similar services. The major advantage for the National Ground Segment will be the matter of data quality. By orthorectifying the satellite imagery using the Norwegian DEM, the National Ground Segment can offer the best satellite data over Norway. This data will be possible to overlay geographically with non-Earth observation data as vector data as well as other orthorectified imagery.

While users of the National Ground Segment will know that the data origins from the Copernicus space program, the National Ground Segment is a success if the users do not need to know that they are using Copernicus data. Users should only have to worry about the part of the data flow which is between the user and the National Ground Segment. This will require that establishments and enterprises facilitate data transfer from the National Ground Segment and adapt the data structure to the users' data and management systems.

B.2.3 Application Programming Interface

An API is required for the National Ground Segment as a major part of the users are going to want to automate the process of retrieving data. This API might include several APIs where users choose API based on the user's needs and expertise. The development work on the data access interface is likely to be outsourced to a company with extensive knowledge with API development.

B.2.4 Processing-on-demand

The users should be able to request ready-to-use (or ready-to-analyze) data. This could be solved by letting the users run simple or more complex processing on data at the National Ground Segment before transmitting the data back to the user. For example, the user should be able to request data limited to the geographical area chosen by the user and not have to download the full satellite image.

If the user should be able to supply their data set into the data processing, the system will have different requirements and needs to be looked into. This could be a

potential start-up business, offering merging of user data sets and data sets from the National Ground Segment.

B.2.5 Sentinel-2A and the Antenna in Tromsø

The antenna located in Tromsø is, at the time of writing, only collecting data from Sentinel-1. This antenna could potentially collect Sentinel-2A data and feed it into the National Ground Segment, but Sentinel-2A is transmitting some needed start- and end parameters which it only transmits once it begins dumping data and upon completion. Sentinel-2A is in reach of the antenna in Tromsø when Sentinel-2A is dumping data to the core ground station located at Svalbard. However, the antenna does not “see” Sentinel-2A at both start and end of the data dumping. Thus, it misses out on the start- and end parameters. This is an issue that could be solved by having the Sentinel-2A satellite transmitting these parameters continuously, but this is not a priority for ESA.

Figure B.1 illustrates the issue where the antenna in Tromsø does not see both start and end of the data transmission from Sentinel-2A. Due to the curvature of the earth, the core ground station of Svalbard can see section A and B in the figure while the antenna in Tromsø can see section B and C.

B.2.6 Digital Elevation Model

NSC is working with Finland and Sweden to see if it is possible to create a common Digital Elevation Model (DEM) for Norway, Sweden and Finland. Norway, and Finland have DEM with a 10-meter resolution while Sweden has a 50-meter resolution DEM and is working on a 2-meter resolution DEM. This DEM could be implemented in the Copernicus core ground segment so that the core data is orthorectified using a DEM with 10-meter resolution. Currently, the core data is orthorectified using Planet DEM, which has a 90-meter resolution.

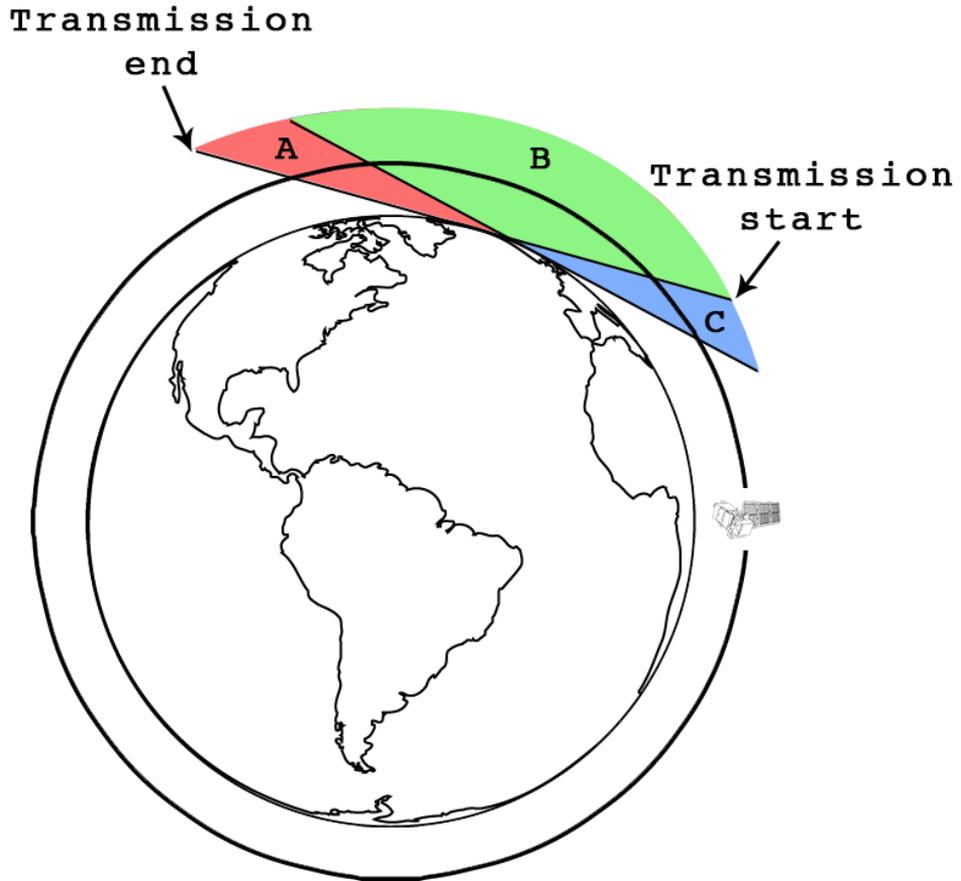


Figure B.1: Illustration of Sentinel-2 and the antenna in Tromsø, Norway.

Appendix

User Survey Conducted by Norwegian Space Center

The following pages are the user survey sent out to potential users of the National Ground Segment. The user survey is created, and conducted by the Norwegian Space Center.

Nasjonalt Bakkeselement – Brukerundersøkelse

Introduksjon

Copernicus programmet for jordobservasjon og overvåking er et europeisk program som ledes av EU. Det gir brukerne pålitelig og oppdatert informasjon gjennom en serie av data og tjenester knyttet til miljø- og sikkerhet. Programmet består av et komplekst system som samler inn data fra flere kilder: Sentinel-jordobservasjonssatellitter og in-situ sensorer. All data og informasjon blir gitt gjennom en fri og åpen datapolitikk.

For å sikre norske brukerne rask og enkel tilgang til satellittdata og basistjenester utvikler nå Norsk Romsenter i samarbeid med nasjonale aktører det nasjonale bakkeselementet (NBS).

En del av det nasjonale bakkeselementet vil fungere som et speil ("mirror site") av det Europeiske kjernebakkeselementet for å hente inn og samle Sentinel data over norske interesseområder. Dataene blir her lagret og tilrettelagt for videre distribusjon til nasjonale brukere. De satellittdata som skal distribueres er:

- Satellittdata i kvasi-sanntid (<1 time fra opptak)
- Satellittdata i nær-sanntid (<3 timer fra opptak)
- Satellittdata i rullerende arkiv (3-24 timer fra opptak)
- Arkiverte historiske data (>24 timer fra opptak)

For å sikre at NBS lagrer, tilrettelegger og distribuerer data på en tilfredsstillende måte ønsker Norsk Romsenter (NRS) å få oppdatert nasjonale brukerbehov. Nedenfor følger spørsmål som baserer seg delvis på EU-Kommisjonens Copernicus brukerundersøkelse ("Call for Interest"¹), men også på en bruksmønsterundersøkelse utført av Faggruppen for Satellittdata i Norge Digitalt².

Norsk Romsenter er per i dag kjent med mange brukeres behov og dette ligger til grunn for det innledende arbeid som er påbegynt. Gjennom denne undersøkelsen ønsker vi få et bedre bilde av behovene for tilrettelegging (fellesprosessering) og tilgang (distribusjonsløsning) til data.

Basert på resultater fra undersøkelsen vil NRS prioritere oppgaver på kort og lang sikt som vil bli kommunisert tilbake til brukerne våren 2016. Målsettingen er en felles forståelse av:

- hva systemet kommer til å omfatte
- hvor godt integrert systemet blir med ulike brukertiløsninger
- hvordan og hvor raskt systemet må levere

¹ <http://www.copernicus.eu/copernicus-call-for-interest>

² <http://kartverket.no/geodataarbeid/Geodatasamarbeid-prosjekter/Satellittdata/>

Spørsmål

1. Virksomhetens navn

Fyll her i virksomhetens navn

2. Hvilke fellestjenester i Copernicus bruker du i dag/vil du bruke i fremtiden? (kan velge flere)

1. Land
2. Hav
3. Atmosfære
4. Katastrofehåndtering
5. Sikkerhet
6. Klima

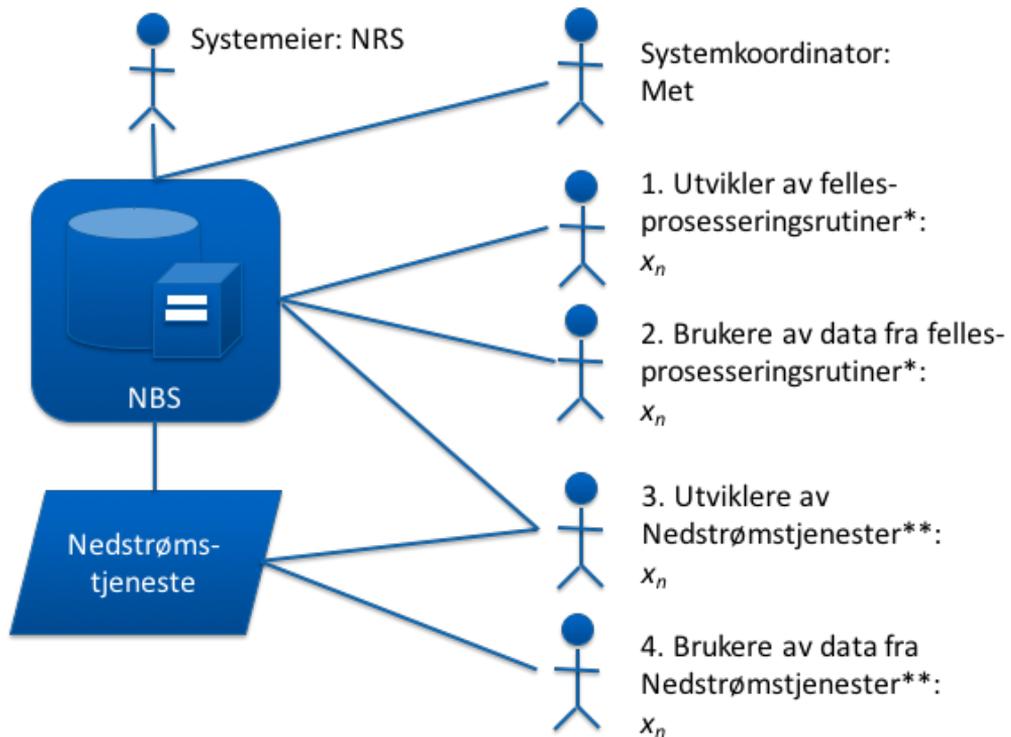
Fyll her i den/de tjenester som er av interesse og utdyp hvis mulig

3. Hvilke Copernicus data bruker du/kommer du til å bruke?(kan velge flere)

1. Sentinel-1 (radar, 5x20 m) Oljesøl, skipsdeteksjon, sjøis, fjellskred, bre-bevegelse, snø, is, flomfare, avskoging
2. Sentinel-2 (optisk, 10x10 m) Hyppig dekning, verneområder og biologisk mangfold, arealdekke, skogskader og avskoging, klimarelaterte endringer i vegetasjon og isbreer, avrenning til elver og innsjøer, urban grønnstruktur, pollenvarsling
3. Sentinel-3 (hav og land) Havnivå, bølgehøyde, havtemperatur, havfarge – alger, global vegetasjon
4. Sentinel-5p (luftforurensning) Aerosol-partikler, klimagasser, SO₂, NO₂, ... , Ozon og UV-varsling
5. Sentinel-6 (hav, 2020) Havnivå, bølgehøyde, vind over hav
6. Annet (beskriv)

Fyll her i den/de Copernicus data som er av interesse

4. Når det gjelder tjenester i verdikjeden (se figur nedenfor), hvilken/hvilke roller anser du at du kan ha?



*Fellesprosesseringsrutiner: prosessering av data til et definert nivå

**Nedstrøms-tjenester: tilrettelegging av data for spesifikke behov

Fyll her i den rolle/roller som du/dere anser å ha

5. Når det gjelder data i verdikjeden hva anser du å være din rolle?

1. Dataprodusent/-tilrettelegger til andre portaler
2. Databruker

Fyll her i den rolle som du/dere anser å ha

Mal for bruksmønster (Use case)

Nedenfor følger en mal for bruksmønster med forklaring. Forklaringen under "beskrivelse" er ment som veiledning og skal bli erstattet med din beskrivelse. Hvis du har et ønske om å beskrive flere bruksmønster som er av betydning for det Nasjonale Bakkeselementet så kan dere kopiere, fylle i og levere inn flere bruksmønster med ulike navn.

Bruksmønster	Beskrivelse
Bruksmønster navn	<i>Gi et kort beskrivende navn for bruksmønsteret som kan bli brukt som en unik identifikator. Det er hensiktsmessig å bruke et navn som viser til formålet med bruksmønsteret. For eksempel: "Interaktivt søk etter data".</i>
Mål	<i>Målet beskriver kort hva brukeren har for hensikt med dette bruksmønsteret. For eksempel: "Å gjøre det mulig for brukere å interaktivt finne informasjon om relevante data og/eller produkter".</i>
Sammendrag	<i>Gi et kortfattet sammendrag av bruksmønsteret som gir en rask oversikt over mål og hovedaktøren. For eksempel: "Hvordan få tilgang til data fra metadatakatalogen for å få tilgang til en serie av nedlastbare data".</i>
Aktører	<i>List opp aktører, personer eller ting utenfor systemet (her Nasjonal bakkesegment) som agerer mot (acts on) systemet (primære aktører) eller som blir håndtert (is acted) av systemet (sekundære aktører). Primære aktører kan være en institusjon, portaler og relevante dataressurser. For eksempel: "1. Primær aktør: Databrukere".</i>
Forutsetninger (Preconditions)	<i>Oppgi forutsetninger for at et bruksmønster skal initieres. Eventuelle forutsetninger med andre nærliggende systemer kan også oppgis her. For eksempel: "En eksisterende Metadata Katalog som er tilgjengelig for "browsing" eller søk"</i>
Primær arbeidsflyt (Main success scenario/Normal flow)	<i>En beskrivelse av bruksmønsterforløpet fra start til slutt. Eventuelle feil eller alternative forløp skal ikke beskrives her. Dette gir en rask oversikt (en liste i punktform) over arbeidsflyten. For eksempel: "1. Databrukeren gjør et søk ved hjelp av begreper som vitenskapelige søkeord, geografiske og tidsmessige begrensninger etc. 2. søket blir videresendt til katalogen. 3. katalogen svarer med en sortert liste som beskriver de aktuelle datasettene og produktene, inkludert online henvisning til datasett ."</i>
Alternative forløp (hvis relevant)	<i>Oppgi alternative scenarios som kan oppstå. Kan omfatte scenarios som resulterer i feil eller scenarios som faller utenfor det grunnleggende scenariet.</i>
Etterbetingelser (Post conditions)	<i>Oppgi betingelser i omgivelsen og tilstanden som må være oppfylt etter utføring av en test eller en samling tester. Resultater som programmet garanterer. For eksempel: "Brukeren får nødvendig informasjon for å velge og laste ned relevante data eller produkter".</i>
Ikke-funksjonelle krav	<i>Et krav som ikke går på funksjonalitet, men på egenskaper som for eksempel pålitelighet (oppetid mm.), vedlikehold etc.</i>
Kompletterende informasjon (Notes and issues)	<i>Det er alltid nødvendig informasjon som ikke hører hjemme under de andre kategoriene og her er det mulig å gi kompletterende informasjon.</i>
Bruksmønster diagram	<i>Her er det mulighet for å legge til et diagram som viser til forløpet av hendelser som gir bruksmønsteret hos dere. Teksten kan være en bedre måte å beskrive bruksmønsteret, men ofte gir et bilde en god oversikt. Her er det ønskelig med et UML (Unified Modelling Language) diagram.</i>
Dato	<i>ÅÅÅÅ-MM-DD</i>
Navn på utfyller	<i>Navn</i>

Appendix **D**

Application Utilizing Satellite Imagery Services

An application has been developed during the evaluation of the seven satellite imagery services. The source code for this application is too long and not suitable for paper. Due to this, this appendix will link to the Github repository containing the source code. The repository also includes instructions on how to install and run the application. The repository is located at:

<https://github.com/oyvindym/earth-observation-api>.