Global Lakes Sentinel Services

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GLaSS Training material, Lesson #1

EO Data handling

What are the specifications of Sentinel 2, 3 and other high resolution sensors regarding temporal, spatial, spectral characteristics and access mechanisms and what tools are available for analysing?

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Lesson summary

The Sentinel 2 and 3 data handling session introduces the spatial, temporal, spectral and format specifications of the european multispectral high resolution sensors Sentinel 2 and 3 of the Copernicus programme as well as for Landsat operated by USGS. The lesson provides information about access mechanisms and image importing software solutions, all demonstrated with exercises on selected test data sets in order to learn how to select and handle satellite data for water quality monitoring purposes.

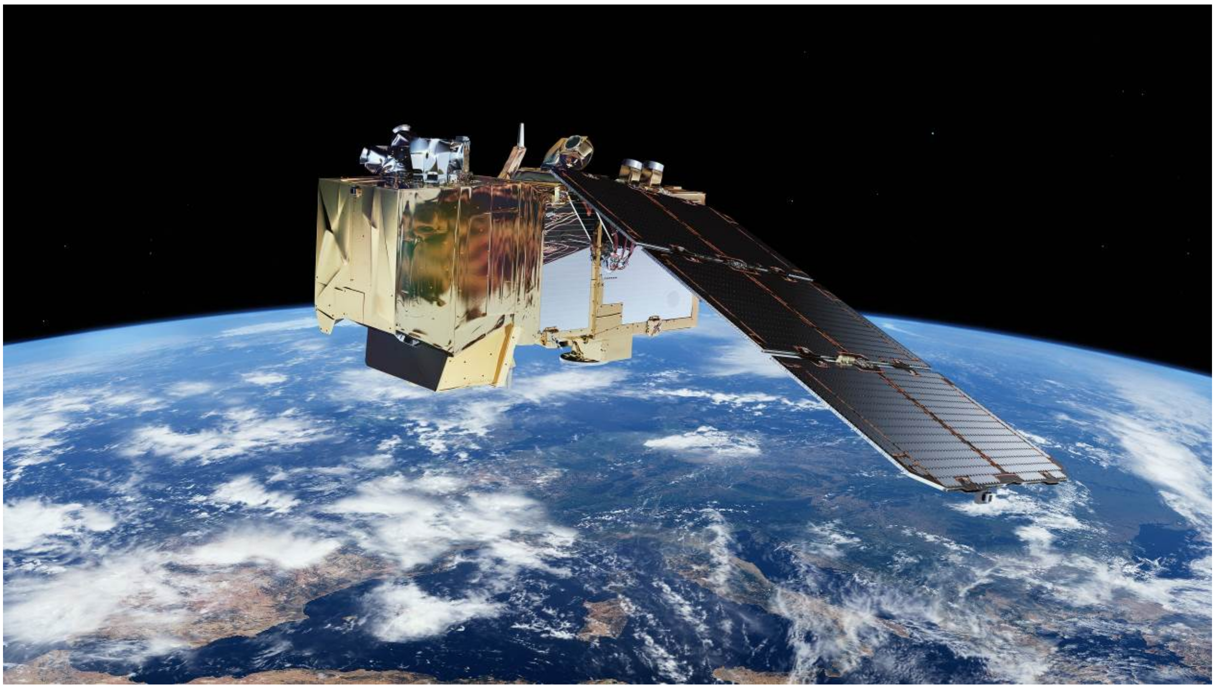

Figure 1 Sentinel 2 satellite © ESA/ATG medialab

GLaSS training material outline

This lesson is part of the GLaSS training material. The complete training material outline is listed on http://data.waterinsight.nl/GLaSS/trainingmaterials/GLaSS_lesson_outline.pdf.

Note that the lessons logically follow up on each other, the later lessons might require skills that can be acquired during the earlier lessons.

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List of abbreviations

Abbreviation	Description
DN	Digital Numbers
DORIS	Doppler Orbit Radio positioning system
ETM	Enhanced Thematic Mapper
FPA	Focal Plane Assemblies
FR	Full resolution
GNSS	Global navigation satellite system
IOCR	In-Orbit Commissioning Review
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LRR	Laser Retro-Reflector
MGRS	US Military Grid Reference System
MLST	Mean Local Solar Time
MSI	MultiSpectral Instrument
MWR	Microwave Radiometer
OLCI	Ocean and Land Colour Instrument
PAR	Photosynthetically Active Radiation
POD	Precise Orbit Determination
RR	Reduced Resolution
SLSTR	Sea and Land Surface Temperature Instrument
SNAP	Sentinel Application Platform
SRAL	SAR Radar Altimeter
SWIR	Shortwave infrared
TIRS	Thermal Infrared Sensor
TOA	Top of Atmosphere
TSM	Total Suspended Matter
USGS	United States Geological Survey
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VNIR	Visible and near infrared
WRS	Worldwide Reference System
XML	Extensible Markup Language

1 Introduction

In the present unit the Sentinel 2 and 3 satellites as well as Landsat 8 are introduced. The GLaSS project was developed with focus on the Sentinel project; however, the Sentinel 2 was launched only a few months before the end of the project and the Sentinel 3 launch is still on hold until further notice (January 2016). This was the reason why Landsat 8 imagery has been used in the project as a proxy for Sentinel 2 MSI imagery and MERIS as a proxy of Sentinel-3 OLCI. The tools for examining and analysing the Earth Observation data are still adapting to the requirements brought up by the new sensors (MSI and OLCI) and in the present unit we will show you which of these tools, in some case still under development, will be operative within the next few months to work with the new data formats.

The Sentinel Application Platform (SNAP) is one of those tools that is available to work with Sentinel data and that will be further improved and updated in the near future. The common architecture for all Sentinel Toolboxes is being jointly developed by Brockmann Consult, Array Systems Computing, and C-S and it is called SNAP. The Sentinel toolboxes contain some functionalities of historical toolboxes such as BEAM, NEST and Orfeo Toolbox that were developed over the last years. Because SNAP is currently under development not all functionalities coming from BEAM are still in place. Nevertheless, the Sentinel-2 data readers are already functional, and they are not included in the last BEAM distribution (BEAM 5). For this reason we will use the Sentinel SNAP reader to open and understand the contents of the MSI data, but in all other units of the GLaSS training pack BEAM 5, http://www.brockmann-consult.de/cms/web/beam/, will be used as the tool for the data analysis (for MERIS and Landsat images).

1.1 Data formats

1.1.1 Sentinel 2

SENTINEL-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. The full mission specification of the twin satellites flying in the same orbit but phased at 180°, is designed to give a high revisit frequency of 5 days at the Equator.

SENTINEL-2 will carry an optical instrument payload that will sample 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. The orbital swath width will be 290 km.

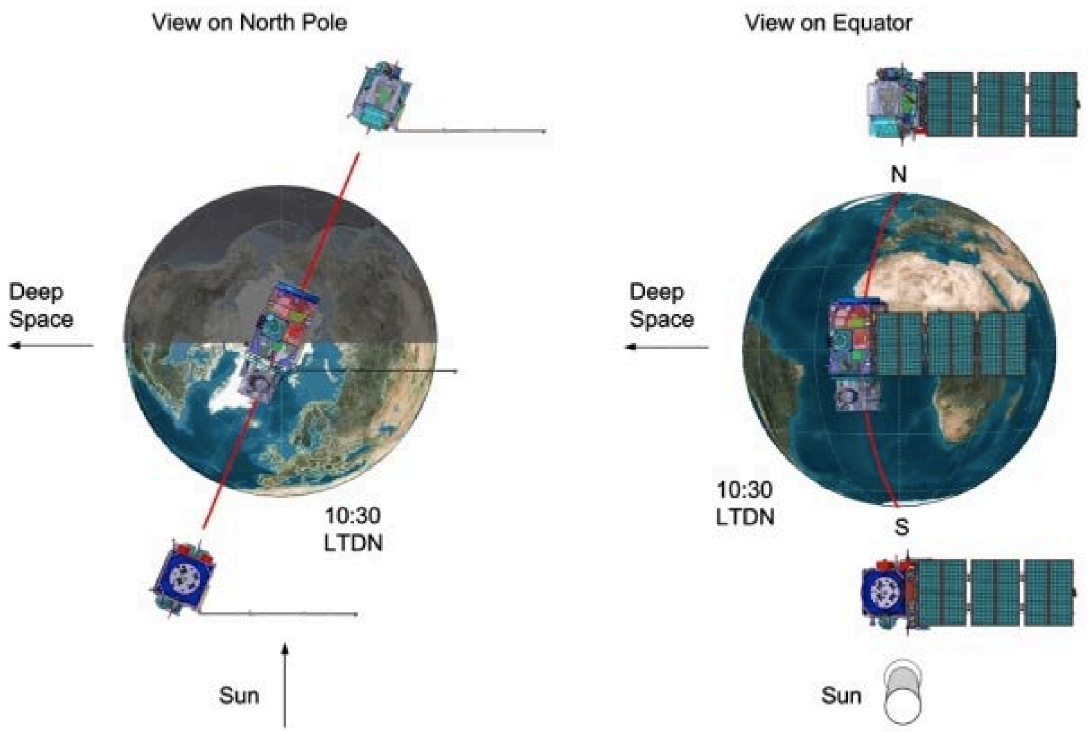

Figure 2 The Twin-Satellite SENTINEL-2 Orbital Configuration (courtesy Astrium GmbH, through ESA webpage)

The twin satellites of SENTINEL-2 will provide continuity of SPOT and LANDSAT-type image data, contribute to ongoing multispectral observations and benefit Copernicus services and applications such as land management, agriculture and forestry, disaster control, humanitarian relief operations, risk mapping and security concerns.

The mean orbital altitude of the SENTINEL-2 constellations is 786 km. The orbit inclination is 98.62° and the Mean Local Solar Time (MLST) at the descending node is 10:30 (am).

The Multi Spectral Instrument (MSI)

The MultiSpectral Instrument (MSI) uses a push-broom concept. A push-broom sensor works by collecting rows of image data across the orbital swath and utilises the forward motion of the spacecraft along the path of the orbit to provide new rows for acquisition. The average period of observation over land and coastal areas is approximately 17 minutes and the maximum period of observation is 32 minutes.

Light reflected up to the MSI instrument from the Earth and its atmosphere is collected by a three-mirror (M1, M2 and M3) telescope and focused, via a beam-splitter, onto two Focal Plane Assemblies (FPAs): one for the ten VNIR wavelengths and one for the three SWIR wavelengths.

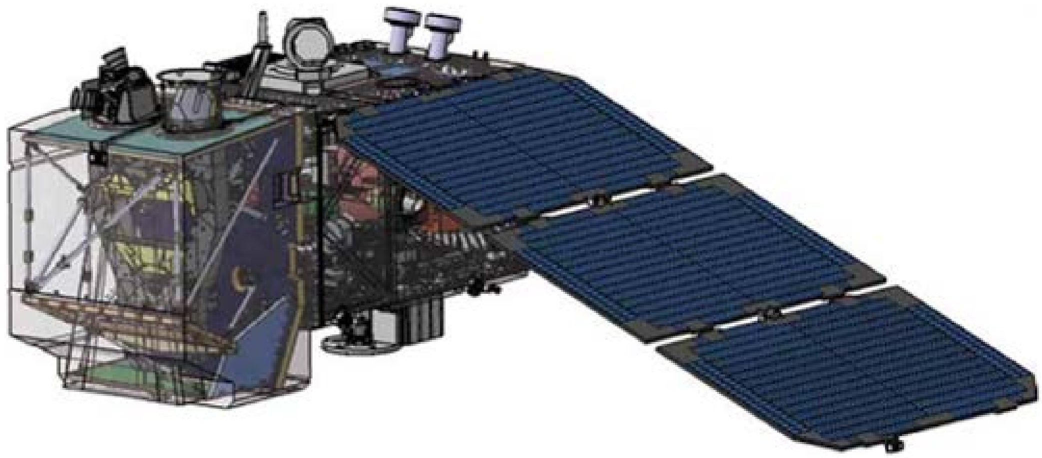

Figure 3 SENTINEL-2 Satellite. (Astrium GmbH, Germany, through ESA webpage)

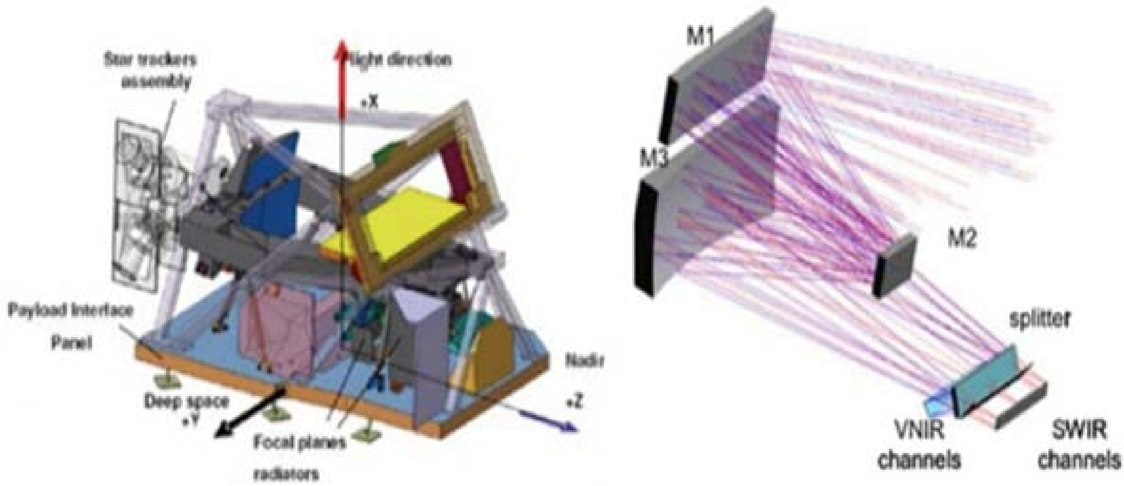

Figure 4 MSI internal configuration

The MSI measures the Earth's reflected radiance in 13 spectral bands from VNIR to SWIR (Table 1).

Table 1. Spectral bands for the Sentinel-2 MSI sensor

Band number	**Central wavelength** (nm)	**Bandwidth** (nm)	**Spatial resolution** (m)
1	443	20	60
2	490	65	10
3	560	35	10
4	665	30	10
5	705	15	20
6	740	15	20
7	783	20	20
8	842	115	10
8a	865	20	20
9	945	20	60
10	1380	30	60
11	1610	90	20
12	2190	180	20

MSI Data Products

SENTINEL-2 products will be made available to users in SENTINEL-SAFE format, including image data in JPEG2000 format, quality indicators (e.g. defective pixels mask), auxiliary data and metadata.

The SAFE format has been designed to act as a common format for archiving and conveying data within ESA Earth Observation archiving facilities. The SAFE format wraps a folder containing image data in a binary data format and product metadata in XML. This flexibility allows the format to be scalable enough to represent all levels of SENTINEL products.

A SENTINEL-2 product refers to a directory folder that contains a collection of information (Figure 4). It includes:

- a *manifest.safe* file which holds the general product information in XML
- a preview image in JPEG2000 format
- subfolders for measurement datasets including image data (granules/tiles) in GML JPEG2000 format
- subfolders for datastrip level information
- a subfolder with auxiliary data (e.g. International Earth Rotation & Reference Systems (IERS) bulletin)
- HTML previews

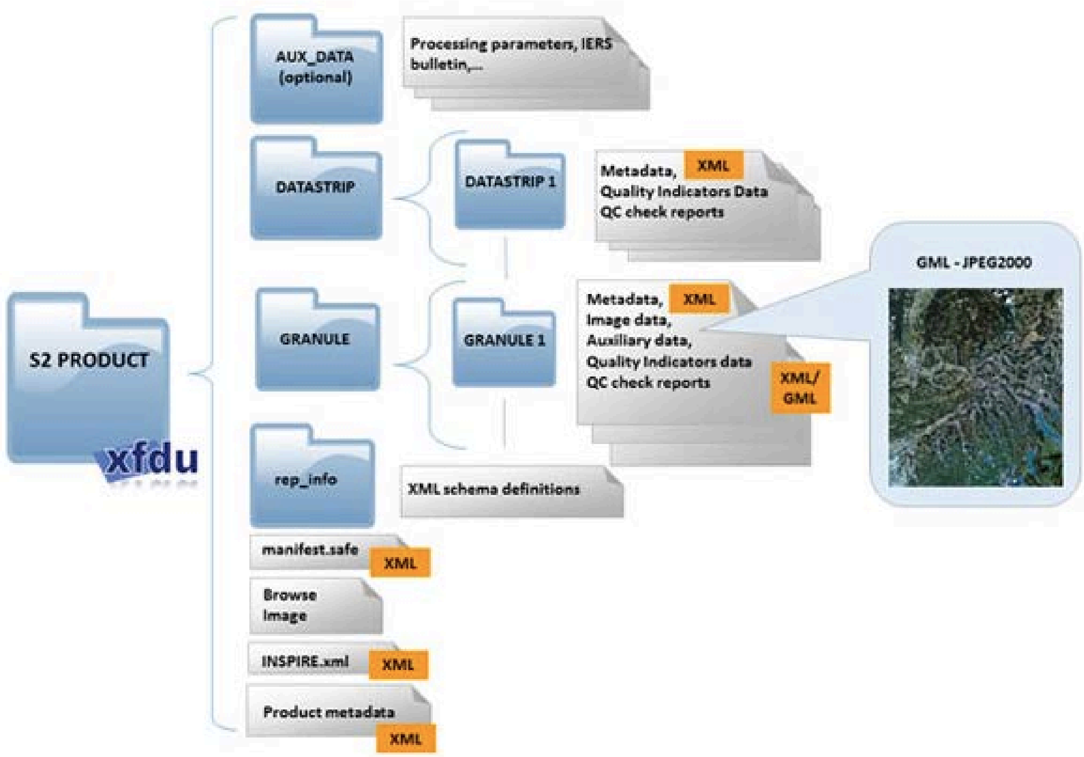

Figure 5 Sentinel-2 product physical format

The elementary levels of the MSI products are granules of a fixed size. The granule size is dependent on the product level.

For Level-0, Level-1A and Level-1B products: these granules are sub-image of a given number of lines along track and separated by detector. They are 25 km across track and 23 km along track in size.

For orthorectified products (Level-1C and Level-2A): the granules (also called tiles) consist of 100 km by 100 km squared ortho-images in UTM/WGS84 projection. There is one tile per spectral band.

<u>L1B and L1C Data Formats</u>

All data acquired by the MSI from the Sentinel-2 constellation will be systematically processed from Level-0 up to Level-1C, as cascading from data reception on-ground in a systematic manner.

Level-0 data processing operations will be performed in real-time during the data-reception operations. Level-1 processing includes a three-step processing to generate Level-1A, Level-1B and Level- 1C data starting from the consolidated Level-0 data. These three levels correspond respectively to the S2MSI1A, S2MSI1B and S2MSI1C data-products.

The Sentinel-2 User Product is composed by a set of granules which are called tiles for L1C User Product. A Tile consists of 100 km x 100 km squared ortho-images in cartographic reference frame UTM/WGS84 (Universal Transverse Mercator / World Geodetic System 1984) projection.

Ortho-rectified product are systematically projected on UTM-UPS/WGS84 projection and tiled. The UTM tiling follows the US-MGRS (US-Military Grid Reference System):

- The vertical UTM boundaries and horizontal latitudinal band boundaries define 6° X 8° Grid Zones.
- Each Grid Zone is filled by 100,000-meter grid squares. The MGRS is derived from the UTM grid system and the UPS (Universal Polar Stereographic) grid system, but uses a different labelling convention. The MGRS is used for the entire earth.

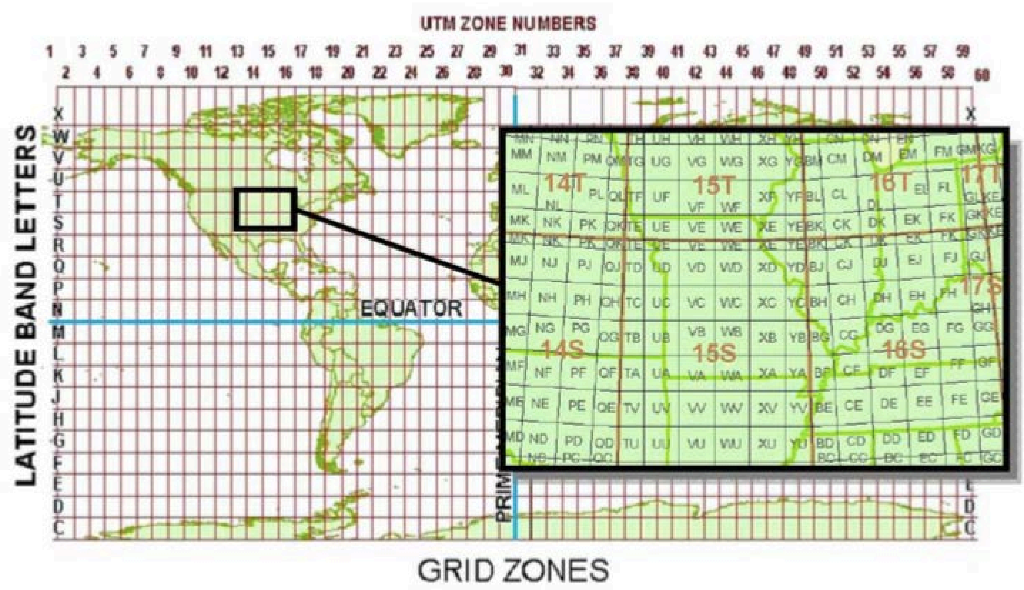

Figure 6 Example of tiling (100 x 100 km) within the UTM15 zone

The ortho-rectified products (Level-1C) are tiled according to this grid (approximately 100 km x 100 km). The UTM zone is selected according to each Tile of the product.

The naming convention for MSI products is quite complex and depends on the level of processing of the data. For L1C products the name is something similar to (for details refer to the S2-MSI Product Specifications document in the sentinel user guide[1]:

S2A_OPER_MSI_L1C_TL_MTI__20141104T134012_A123456_T15SWC_N11.11.tar

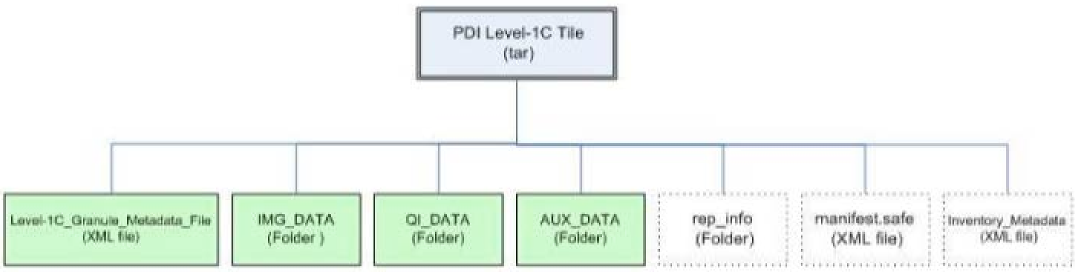

Figure 7 Contents of the S2-MSI higher folder level

[1] https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/document-library/-/asset_publisher/Wk0TKajiISaR/content/sentinel-2-level-1-to-level-1c-product-specifications

1.1.2 Sentinel 3

The main objective of the SENTINEL-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission definition is driven by the need for continuity in provision of ERS, ENVISAT and SPOT vegetation data, with improvements in instrument performance and coverage.

The SENTINEL-3 mission will be jointly operated by ESA and EUMETSAT to deliver operational ocean and land observation services.

The spacecraft carries four main instruments:

- OLCI: Ocean and Land Colour Instrument
- SLSTR: Sea and Land Surface Temperature Instrument
- SRAL: SAR Radar Altimeter
- MWR: Microwave Radiometer.

These are complemented by three instruments for Precise Orbit Determination (POD):

- DORIS: a Doppler Orbit Radio positioning system
- GNSS: a GPS receiver, providing precise orbit determination and tracking multiple satellites simultaneously
- LRR: to accurately locate the satellite in orbit using a Laser Retro-Reflector system.

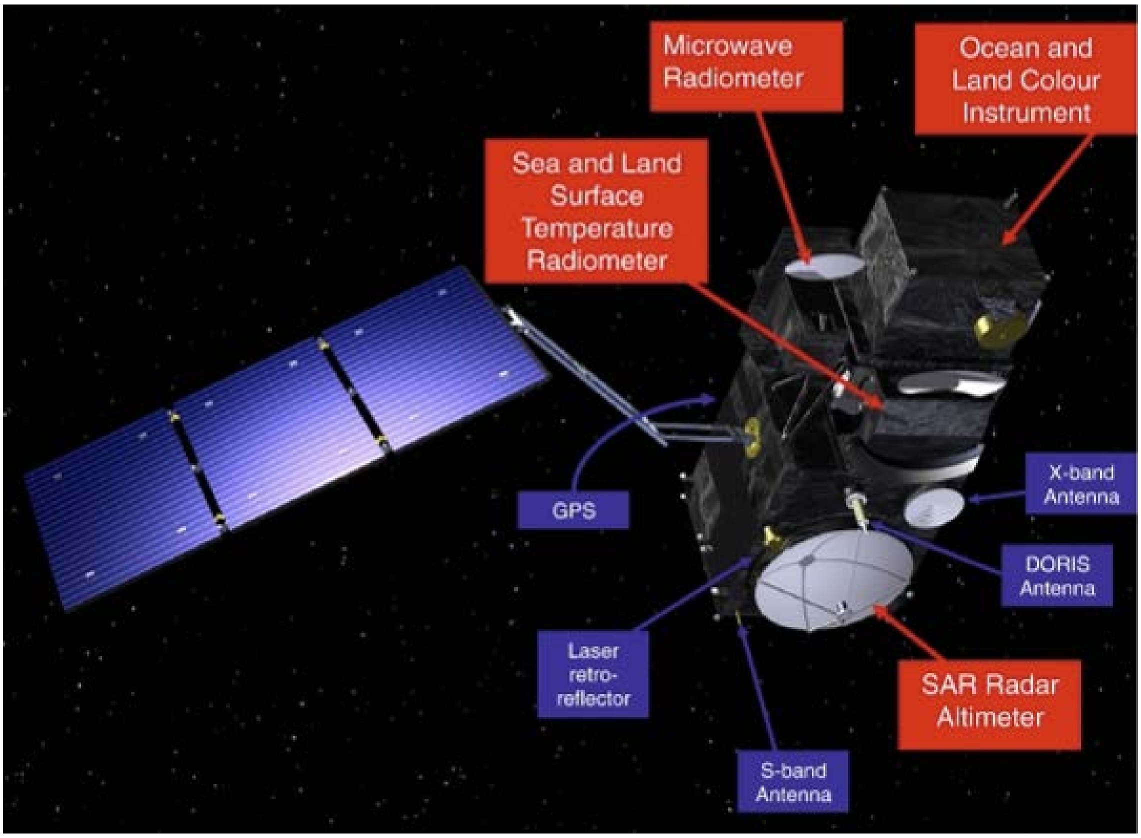

Figure 8 SENTINEL-3 Satellite and Payloads (Credit: ESA)

<u>OLCI Specifications</u>

The OLCI instrument baseline is the successor to ENVISAT MERIS. The OLCI is a push-broom instrument with five camera modules sharing the field of view. Each camera has an individual field of view of 14.2° and a 0.6° overlap with its neighbours. The whole field of view is shifted across track by 12.6° away from the sun to minimise the impact of sun glint. With 21 bands, compared to 15 bands on MERIS, a design optimised to minimise sun-glint and a resolution of 300 m over all surfaces, OLCI marks a new generation of measurements over the ocean and land. The swath of OLCI and nadir SLSTR fully overlap.

This "native" acquisition resolution of approximately 300 m is the one used to compute the product grid of Full Resolution (FR) product. A Reduced Resolution (RR) processing mode provides Level-1B data at sampling rates decreased by a factor of four in both spatial dimensions resulting to resolution of approximately 1.2 km.

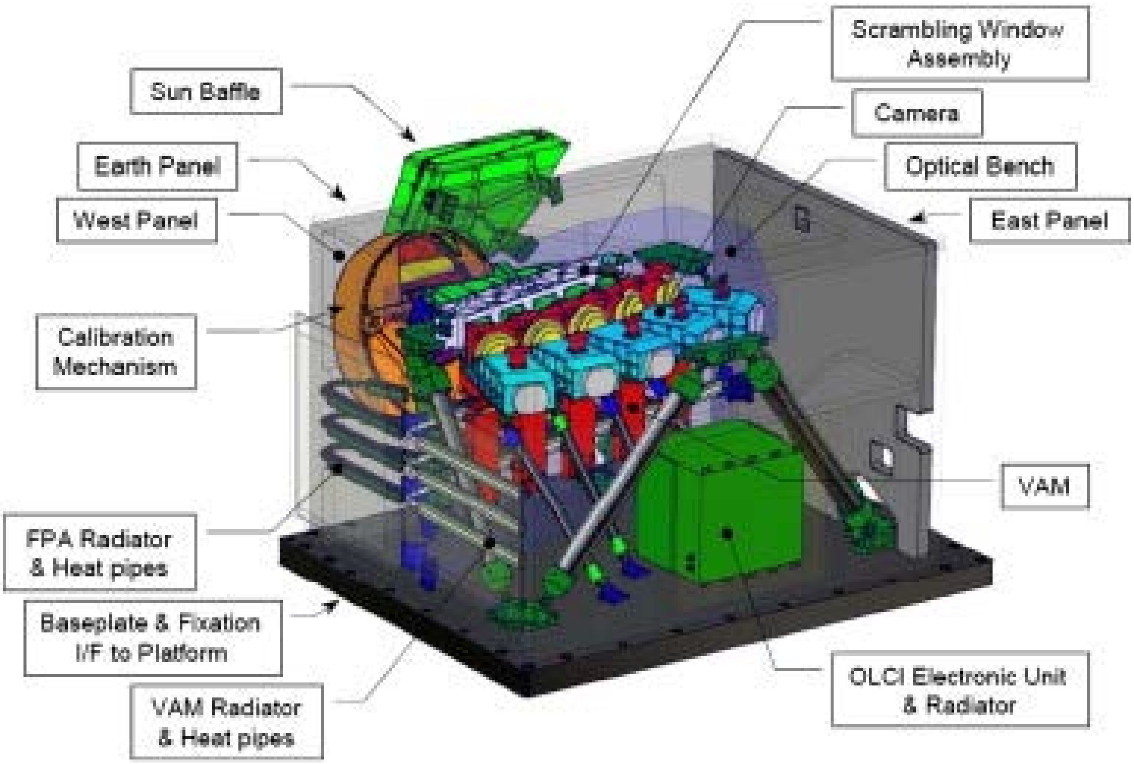

Figure 9 OLCi instrument (Credit: ESA)

Table 2. Technical characteristics of OLCI

Swath	1 440 km
SSI at SSP (km)	300 m
Calibration	MERIS type calibration arrangement with spectral calibration using a doped Erbium diffuser plate, PTFE diffuser plate and dark current plate viewed approximately every 2 weeks at the South Pole ecliptic. Spare diffuser plate viewed periodically for calibration degradation monitoring
Detectors	ENVISAT MERIS heritage back-illuminated CCD55-20 frame-transfer imaging device (780 columns by 576 row array of 22.5 µm square active elements).
Optical scanning design	Push-broom sensor. Five cameras recurrent from MERIS dedicated Scrambling Window Assembly (SWA) supporting five Video Acquisition Modules (VAM) for analogue to digital conversion
Spectral resolution	1.25 nm (MERIS heritage), 21 bands.
Radiometric accuracy	< 2% with reference to the sun for the 400-900 nm waveband and < 5% with reference to the sun for wavebands > 900 nm. 0.1% stability for radiometric accuracy over each orbit and 0.5% relative accuracy for the calibration diffuser BRDF.
Radiometric resolution	< 0.03 W m-2 sr-1 mm-1 (MERIS baseline)
Mass	153 kg
Size	1.3 m3
Design lifetime	7.5 years

Table 3. OLCI bands characterization (Pelloquin and Nieke, 2012)

Band	Center wavelength (nm)	Full width at half maximum (nm)	Solar in-band irradiance (mW/m2/nm)	Integrated solar irradiance (mW/m2)
Oa01	400.28	14.63	1485.28	19776.80
Oa02	412.69	9.80	1711.16	16352.40
Oa03	442.49	9.91	1865.25	18198.00
Oa04	490.98	9.94	1934.08	19126.00
Oa05	510.90	9.94	1922.50	19037.60
Oa06	560.74	9.95	1799.40	17880.30
Oa07	620.64	9.98	1649.76	16397.00
Oa08	665.62	9.99	1530.72	15186.30
Oa09	674.36	7.48	1495.98	11147.40
Oa10	681.86	7.51	1470.28	11020.40
Oa11	709.37	9.98	1405.20	13930.50
Oa12	754.39	7.49	1266.20	9468.05
Oa13	761.89	2.65	1249.19	3412.14
Oa14	764.40	3.76	1242.39	4699.20
Oa15	768.15	2.65	1227.68	3352.24
Oa16	779.41	14.99	1175.70	17511.80
Oa17	865.73	19.93	958.88	18548.90
Oa18	885.73	9.95	929.95	9096.45
Oa19	900.74	9.96	895.46	8756.14
Oa20	940.74	19.81	825.14	15040.90
Oa21	1024.67	23.89	700.63	16537.80

Data formats

The OLCI product types that will be distributed to users are divided into three main products.

1. Level-1B product, output from the OLCI Level-1 processing. The Level-1 product provides reflectance for each pixel in the instrument grid, each view and each OLCI channel, plus annotation data associated to OLCI pixels.
2. Level-2 land products, output from the OLCI Level-2 processing. The level-2 land product provides land and atmospheric geophysical parameters computed for full and reduced resolution.
3. Level-2 water products, output from the OLCI Level-2 processing. The Level-2 water product provides water and atmospheric geophysical parameters computed for full and reduced resolution.

Level 1 B

From the three processing modes of the OLCI Level-1 processor (Earth Observation (EO), radiometric calibration and spectral calibration) and the two available resolutions in EO (full and reduced resolution), four different Level-1B products can be obtained:

- OL_1_EFR: processing mode for full resolution
- OL_1_ERR: processing mode for reduced resolution.
- OL_1_RAC: radiometric calibration mode (internal products not disseminated to SENTINEL-3 users).
- OL_1_SPC spectral calibration mode (internal products not disseminated to SENTINEL-3 users).

The Level-1B products in EO processing mode contain calibrated, ortho-geolocated and spatially resampled Top Of Atmosphere (TOA) radiances for the 21 OLCI spectral bands. The associated error estimates are also contained in the measurement data files. In full resolution products (i.e. at native instrument spatial resolution), these parameters are provided for each re-gridded pixel on the product image and for each removed pixel. In reduced resolution products (i.e. at a resolution four times coarser), the parameters are only provided on the product grid.

In addition to measurement datasets, annotation datasets provide:

1. Time stamps for each line of the product grid
2. Geolocation information for each pixel (and for each removed pixel in case of OL_1_EFR)
3. Quality flags, concerning surface or cloud identification, invalid or cosmetically filled pixels
4. Meteorological variables for each tie-point (defined on a specific grid: every 16 pixels for RR and every 64 pixels for FR products)
5. Geographical information and angles associated with each tie-point
6. Instrument features and settings needed in further processing such as detector index or OLCI channels, central wavelength and bandwidths.

Level 2 Water

The OLCI Level-2 water reduced or full resolution products, OL_2_WFR and OL_2_WRR respectively, are outputs from the OLCI Level-2 processor and contain water and atmospheric geophysical products at full and reduced resolution. Note that all pixels flagged as cloudy are discarded from OLCI Level-2 processing.

The only difference between the OL_2_WFR and OL_2_WRR products is the spatial resolution.

Each product provides, as measurement data files: (fully described in the table below):

1. Water-leaving reflectance (Rxxx) for all bands except those dedicated to measurement of atmospheric gas. Two types of reflectance are distinguished: the BAC reflectance for "Baseline Atmospheric Correction algorithm" (MERIS heritage) or AAC reflectance for "Alternative Atmospheric Correction algorithm" (based on a neural network procedure). BAC is used for the operational output of the reflectance in this product package but in cases where reflectances are computed and AAC is needed, a setting has been defined in the configuration file to switch between algorithms.
2. Ocean colour products such as algal pigment (chl_oc4me and chl_nn, in two separated bands), Total Suspended Matter (TSM_NN) concentrations and transparency characterisation based on the Diffuse Attenuation coefficient (KD490_M07).
3. Neural network water-inherent optical properties such as CDM absorption (ADG_443_NN).
4. Atmosphere by-products such as Photosynthetically Active Radiation (PAR), Aerosol Optical Depth /Aerosol Angstrom exponent (gathered in one file and noted respectively as T865 and A865) and Integrated Water Vapour (IWV) column. Note that this last variable also contains information for water pixels and is identical to the one included in OL_2_WRR and OL_2_WFR.
5. Error estimates for all the products.

Several associated variables are also provided in the annotations data files:

- Classification, quality and science flags (WQSF)
- Common data such as the ortho-geolocation of land pixels, solar and satellite angles, atmospheric and meteorological data, time stamp or instrument information. These variables are inherited from Level-1B products.

Table 4 Contents of the L2 Water scenes

Variables	Description	Units	Input Bands
Rxxx	Surface directional reflectance, corrected for atmosphere and sun specular reflection.	dimensionless	all except Oa13, Oa14, Oa15, Oa19 and Oa20
chl_oc4me and chl_NN	Chlorophyll-a concentration, computed using "OC4Me" or Neural Network algorithms.	mg (chl a) m^{-3}	- Oa3 and Oa6 - Oa1-Oa12, Oa16, Oa17 and Oa21
TSM_NN	Total suspended matter concentration.	$g.m^{-3}$	Oa1-Oa12, Oa16, Oa17 and Oa21
KD490_M07	Diffuse attenuation coefficient for down-welling irradiance, at 490 nm.	m^{-1}	Oa4 and Oa6
ADG_443_NN	Absorption of coloured detrital and dissolved material at 443 nm.	m^{-1}	Oa1, Oa12, Oa16, Oa17, Oa21
PAR	Quantum energy flux from the sun in the spectral range 400-700 nm.	µEinstein.m^{-2}.s^{-1}	-
T865 and A865	Aerosol load, expressed in optical depth at a given wavelength (865 nm) and spectral dependency of the aerosol optical depth, between 779 and 865 nm.	dimensionless	Oa5, Oa16 and Oa17
IWV	Integrated Water Vapour column	$kg.m^{-2}$	Oa18, Oa19

1.1.3 Landsat

Started in 1972, Landsat satellite missions have been a collaborative project of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). USGS is responsible for the operation of the satellites and manages all activities concerning data receiving, data access, product generation as well as the dissemination.

The primary Landsat 1-3 missions, launched from 1972 to 1978, offered a spatial resolution of about 80m, covering four spectral bands from green to infrared. With Landsat 4 (1982-2001) and 5 (1984-2013) the spatial resolution increased to 30m and further bands were added as e.g. a blue-green, shortwave infrared and thermal band. With Landsat 7 ETM+ also a 15m panchromatic band was introduced. The latest mission is Landsat 8, launched in February 2013.It carries tow sensors on board: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), having a 12bit radiometric quantization of the data. The spectral response functions of the Landsat 7-8 are visualized in Figure 10:

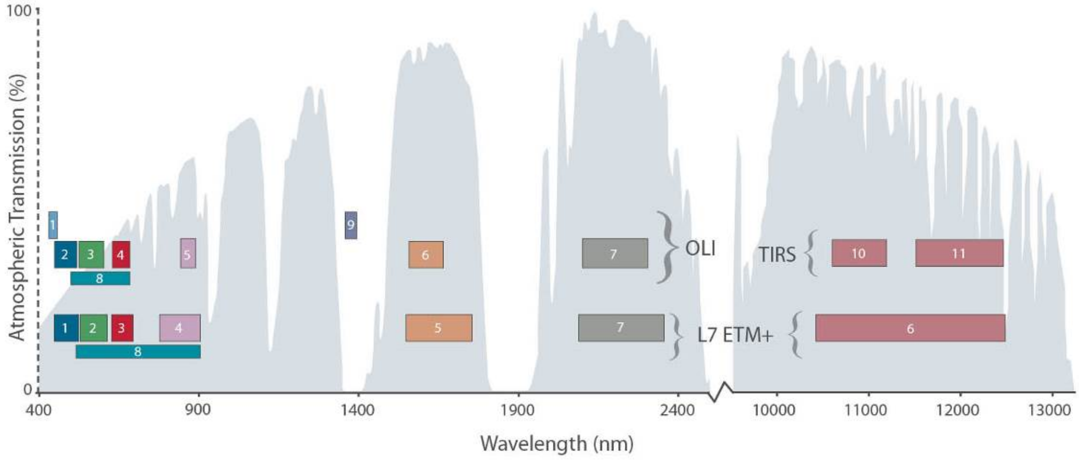

Figure 10 Landsat 7 ETM+ and Landsat 8 OLI spectral bands (source: landsat.gsfc.nasa.gov)

Since 2003, Landsat 7 has to face a problem in the Scan Line Corrector (SLC), resulting in data gaps, increasing from the scene center to the image border.

Available Landsat products are Level 1T terrain corrected GeoTIFF data with cubic convolution resampling. Map projection is Universal Transverse Mercator (UTM in World Geodetic System (WGS) 84 datum. Landsat 8 products offer 16-bit pixel values with an approximate scene size of 1 GB (USGS 2013). Using the radiance scaling factors provided in the metadata files, the final level 1 products can be converted to spectral radiance or TOA reflectances. The formula used to calculate the spectral radiance and TOA reflectances values in case of Landsat 8 data are

$$L_\lambda = M_L * Q_{cal} + A_L$$

where L_λ = spectral radiance

M_L = radiance multiplicative scaling factor for the band

A_L = radiance additive scaling factor for the band

Qc_{al} = Level 1 pixel value in DN

and

$$\rho_{\lambda'} = M_\rho * Q_{cal} + A_\rho$$

where $\rho_{\lambda'}$ = ToA planetary spectral reflectance

M_ρ = reflectance multiplicative scaling factor for the band

A_ρ = reflectance additive scaling factor for the band

Qc_{al} = Level 1 pixel value in DN

For further details please visit http://landsat.usgs.gov.

Some image processing software tools either convert the Digital Numbers directly into TOA reflectances/radiances (e.g. SNAP Toolboxes) or they provide functions to perform the conversion (e.g. ENVI)

Moreover, a provisional Landsat surface reflectance product exists with different algorithms applied for Landsat 4-7 using Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) and Landsat 8 using L8SR (USGS 2015).

1.2 Data Access

1.2.1 Sentinel data hub

The Sentinels Scientific Data Hub (SciHub) provides free and open access to a rolling repository of Sentinel-1 and Sentinel-2 user products, starting from the In-Orbit Commissioning Review (IOCR).

There are three access points: the scientific hub, the API hub, and the Sentinel-2 preoperational hub. The scientific and the API hubs are operated in parallel. The API hub access a point for API users with no graphical interface and it is currently available only for users registered on the SciHub before the 21st of December 16:46 UTC. The API Hub may be accessed through the URL:

https://scihub.copernicus.eu/apihub/

The API Hub is managed with the same quota restrictions, ie. a limit of two parallel downloads per user. The site is publishing precisely the same data content as the Scientific Data Hub, with all new data from the 16th November.

Some characteristics of the SciHub concerning Sentinel-2 data are:

- The Sentinel-2 data offer for the Scientific Data Hub will consist of Level-1C user products.
- The Scientific data Hub maintains a rolling archive of the latest months of products for download via HTTP.
- Search query on the products stored on the rolling archive and filtering of results via a full-text search bar.
- Online inspection of the searched products by browsing and pre-viewing the product metadata and measurements without downloading it.
- A maximum of 2 concurrent downloads per user is allowed in order to ensure a download capacity for all users.
- The Data Hub exposes the Open Data Protocol (OData) interface for accessing the EO data stored on the rolling archive.
- Automatic E-mail notification is offered to the users for informing about the availability of new EO data matching the user defined saved search query. E-mail frequency is predefined.

Self-registration can be performed by the user itself following these steps:

1. Click on the “Register” button in the Scientific Data Hub home page
2. Fill in all fields of the registration form. The "Register" button turns active and click on it.

3. The Data Hub user notification service will send an automatic e-mail to the provided e-mail address containing a link for registration confirmation.

4. Following the confirmation by the user, the new account is automatically active with "Search" and "Download" rights.

The graphical user interface (Figure 11) contains several search options: the "full text search bar", "advanced search options" and a "map tool". In Section 3 there is an exercise explaining the use of the SciHub to download Sentinel-2 images.

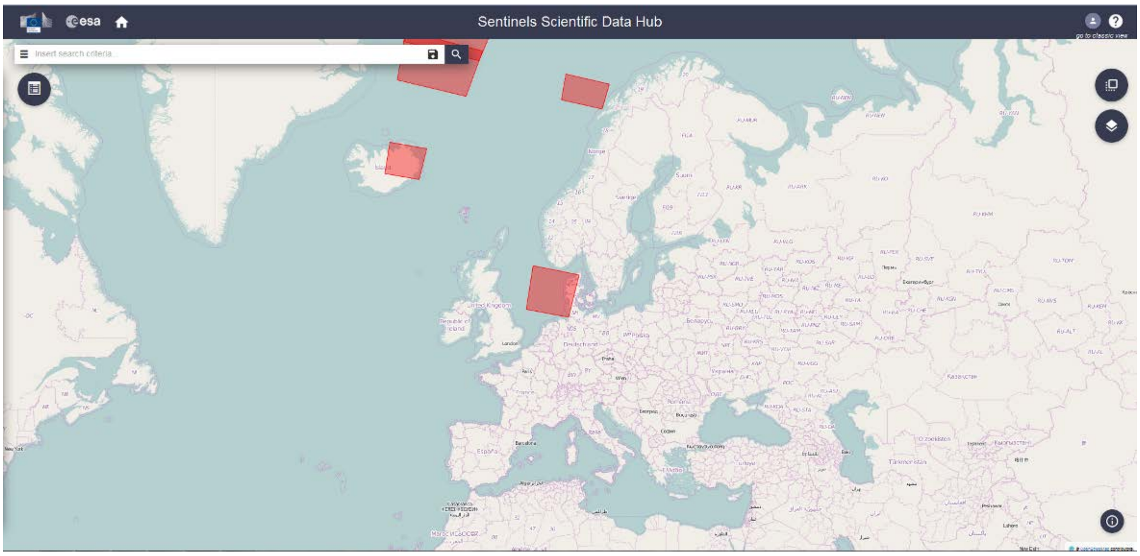

Figure 11 The graphical user interface

For automatic download of the rolling archive, the Data Hub exposes two dedicated Application Program Interfaces (API) for browsing and accessing the EO data. The APIs are:

- Open Data Protocol (OData)
- Open Search (Solr)

The OData interface is a data access protocol built on core protocols like HTTP and commonly accepted methodologies like REST that can be handled by a large set of client tools as simple as common web browsers, download-managers or computer programs such as cURL or Wget .

OpenSearch is a set of technologies that allow publishing of search results in a standard and accessible format. OpenSearch is RESTful technology and complementary to the OData. In fact, OpenSearch can be used to complementary serve as the query aspect of OData, which provides a way to access identified or located results and download them.

For more details please visit: https://scihub.copernicus.eu/userguide/5APIsAndBatchScripting

1.2.2 Landsat via USGS

All available Landsat 4/5/7/8 scenes, back up to 1984, can be browsed at http://earthexplorer.usgs.gov or at http://glovis.usgs.gov/ (see figure 12) by either clicking on the map for our required AOI, entering path row numbers or Latitude and Longitude coordinates. The selected scenes can be downloaded via the USGS Bulk Download Application, which needs to be installed on your workstation. The software can be accessed here: http://earthexplorer.usgs.gov/bulk/

To download it, you have to sign in with your account. If you don't have one, you will first have to create it.

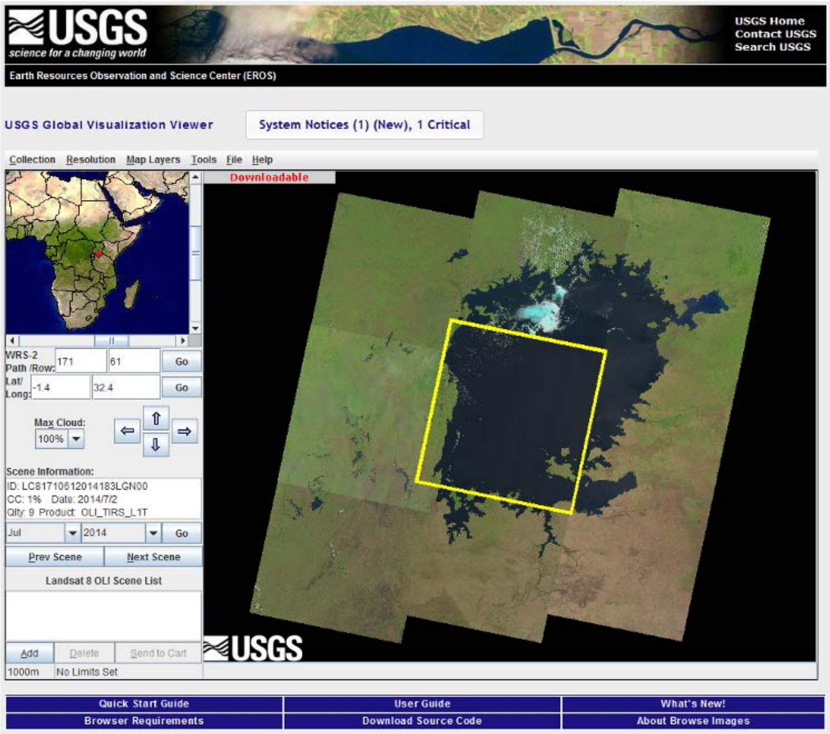

Figure 12 Screenshot of the USGS Global Visualization (GLOVIS) Viewer for search and selection of suitable scenes. At this example you can see a Landsat 8 tile of lake Victoria (Path/Row: 171/61) recorded at the 2 July 2014.

For the Landsat data, a global notation system called Worldwide Reference System (WRS) divides the world into paths and rows, see Figure 13. WRS-1 has been applied for Landsat 1-3 and WRS-2 for Landsat 4-8.

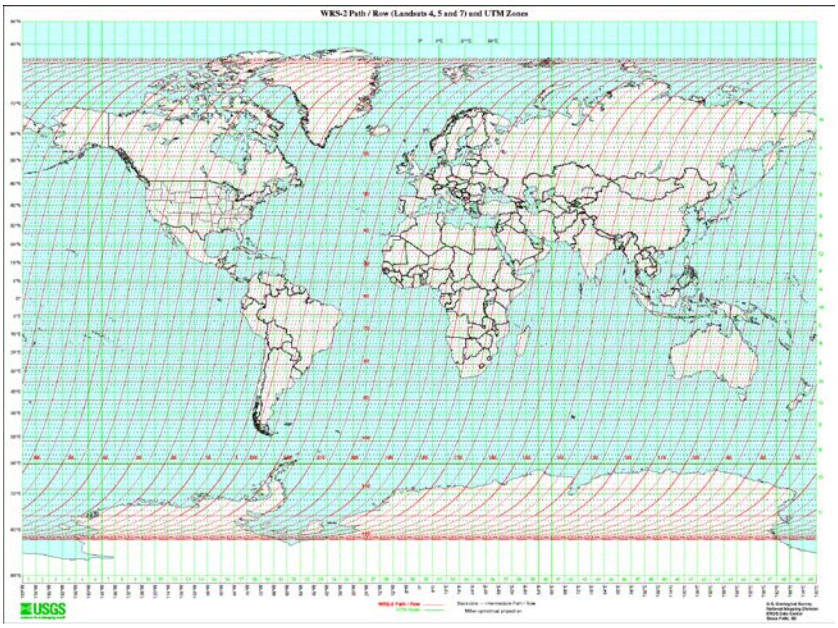

Figure 13 Landsat WRS-2 Path and Rows(source: http://landsat.gsfc.nasa.gov)

1.2.3 Sentinel 2 and Landsat via GlaSS Core System

The GLaSS core system at BC automatically ingests the Landsat 8 and Sentinel-2 scenes from the pickup point into a data input repository. The scenes in this case arrive already ordered by lakes, i.e. in subdirectories for each lake. The processing chain in the GLaSS core system for each scene comprises

- subsetting of the complete Landsat 8 scene to the respective lake bounding box, including consistency check of the input product (i.e. completeness of the .tar.gz file)
- subsetting of the Sentinel-2 tiles to the respective lake bounding box, separated in the respective UTM zones.
- formatting including quicklook generation and metadata extraction
- archiving of the lake subsets and quicklooks in the online archive accessible by the partner systems
- catalogue registration in the GLaSS core system catalogue for data discovery by the partners

After this process the Landsat 8 and Sentinel-2 scene subsets are available in the catalogue and in the online archive for discovery and access by the partners. Figure 14 shows the Landsat 8 collections and their geographic distribution.

Figure 14 GLaSS Core System catalogue with Landsat 8 collections for the Task 4.1 lakes. The lake footprint bounding boxes are shown on the map. One selected quicklook of a subset of some Landsat 8 scene is shown in the list.

Figure 15 shows search results for one lake. The cloud coverage criterion applied is tested against the metadata value from the complete Landsat 8 scene because a cloud identification processor is not yet in place.

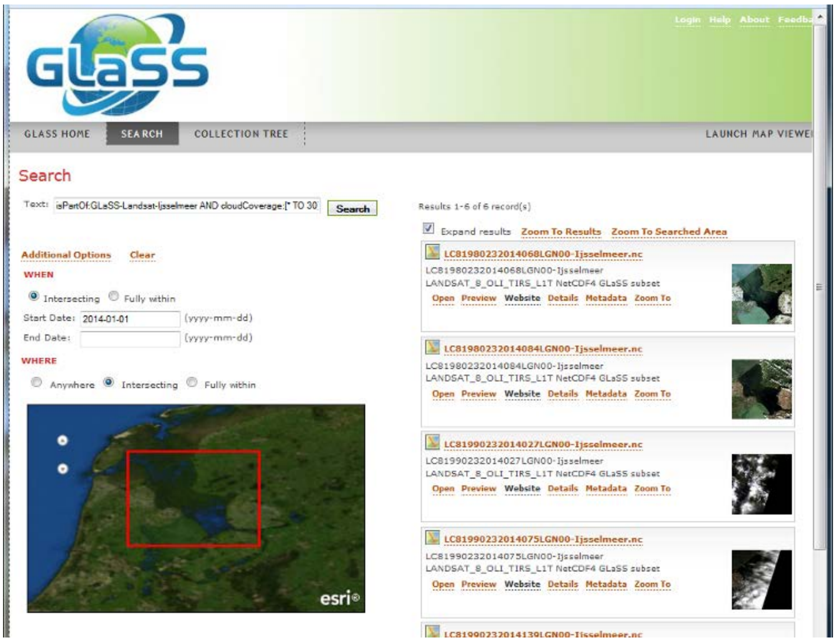

Figure 15 Landsat 8 granules of the Ijsselmeer collection with additional metadata search criteria

Details for one Landsat 8 subset entry with metadata and quicklook are shown in Figure 16.

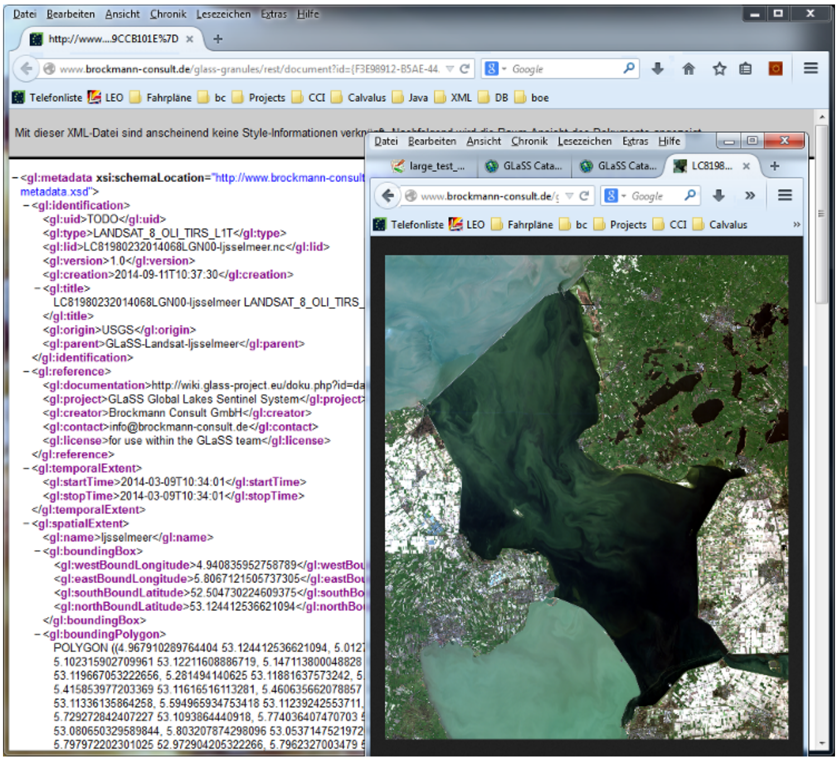

Figure 16 Metadata and quicklook of one granule of the Landsat 8 Ijsselmeer collection

While single product files can be downloaded directly from the catalogue other protocols are available for the access to the complete collections. Figure 17 shows FTP access with FileZilla.

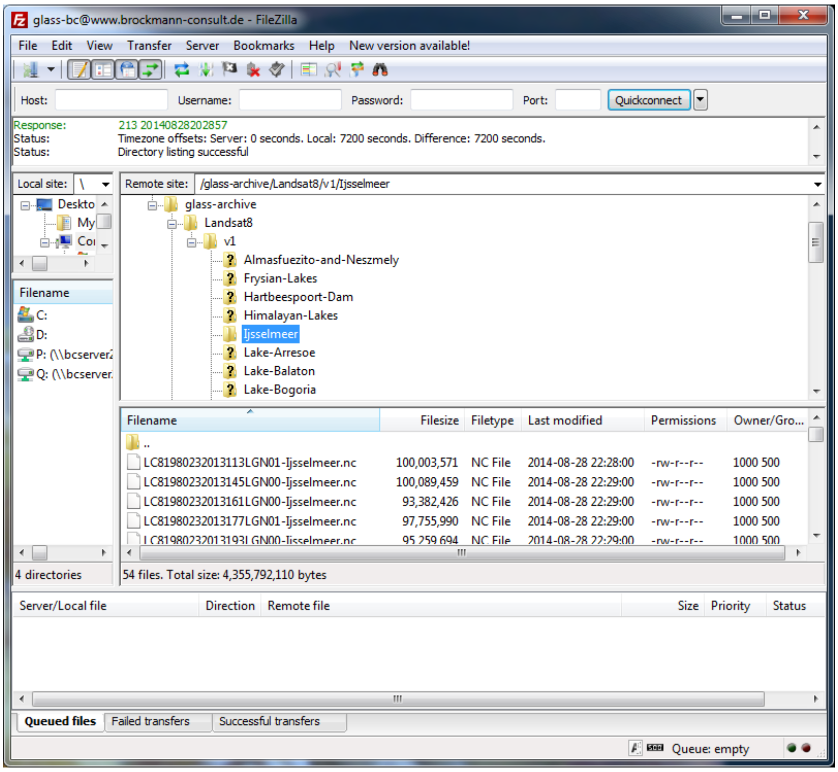

Figure 17 FTP access to the online archive with Landsat 8 collections and their subset files. Bulk download is possible with this interface.

The other interfaces OPeNDAP and WMS are also available for the Landsat 8 data.

1.3 Software Tools

1.3.1 SNAP

The common architecture for all Sentinel Toolboxes is being jointly developed by Brockmann Consult, Array Systems Computing, and C-S and it is called the Sentinel Application Platform (SNAP).

The installer of SNAP can be downloaded from ESA: http://step.esa.int/main/download/

Here, the access to the current installers for the most common platforms (Windows, MacOS, Linux) are provided. During the installation process you can select to download and install the Sentinel-1, Sentinel-2, Sentinel-3, or SMOS Toolbox or even all of them.

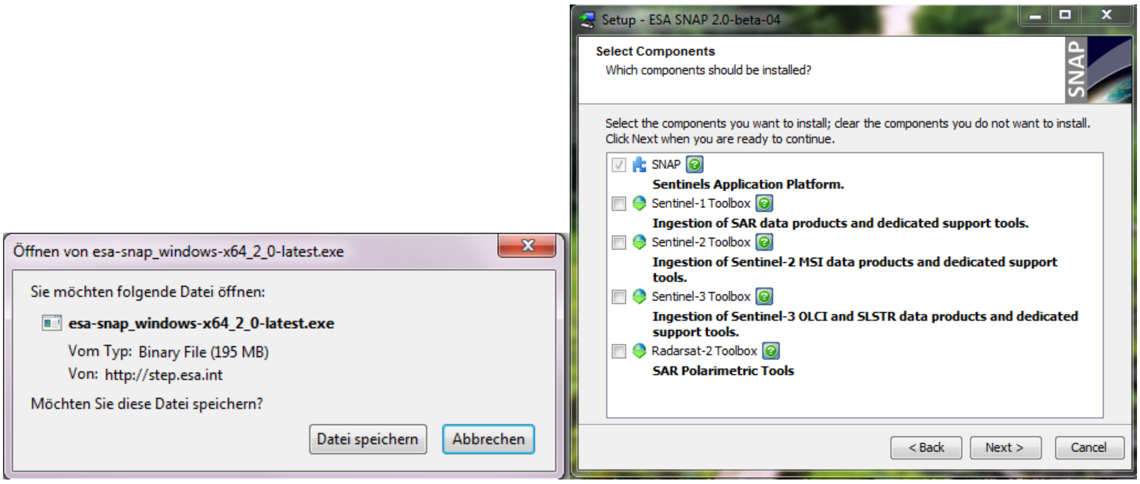

Figure 18 Installation of SNAP in a Windows environment

Sentinel-2 Toolbox

The Sentinel-2 Toolbox consists of a rich set of visualisation, analysis and processing tools for the exploitation of optical high-resolution products including the Sentinel-2 MSI sensor. As a multi-mission remote sensing toolbox, it also provides support for third party data from RapidEye, SPOT, MODIS (Aqua and Terra), Landsat (TM) and others.

The Sentinel-2 Toolbox is being developed for ESA by CS in partnership with Brockmann Consult, CS-Romania, Telespazio Vega Deutschland, INRA and UCL.

Sentinel-3 Toolbox

The Sentinel-3 Toolbox consists of a rich set of visualisation, analysis and processing tools for the exploitation of OLCI and SLSTR data from the upcoming Sentinel-3 mission. As a multi-mission remote sensing toolbox, it also supports the ESA missions Envisat (MERIS & AATSR), ERS (ATSR), SMOS as well as third party data from MODIS (Aqua and Terra), Landsat (TM), ALOS (AVNIR & PRISM) and others. The various tools can be run from an intuitive desktop application or via a command line interface. A rich application-programming interface allows for development of plugins using Java or Python.

The Sentinel-3 Toolbox is being developed for ESA by Brockmann Consult in partnership with the University of Reading, C-S France, ACRI-ST and Array.

The Sentinel toolboxes have a user-friendly interface similar to all toolboxes (Figure 19). The interface offers a wide range of image processing and analysis tools.

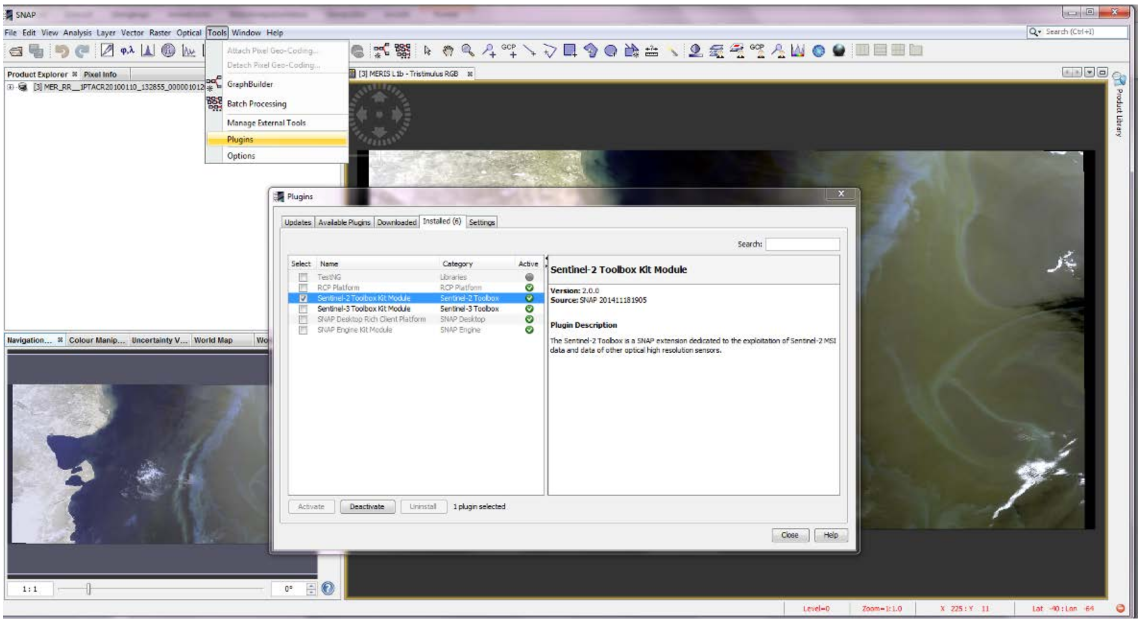

Figure 19 SNAP overview of the desktop and installation of plugins.

They are all based on the graph processing framework, and many of the SNAP functions are implemented as operators that can be invoked on both, the SNAP desktop or on command line. There exists the possibility to compile processing chains configuring xml files by means of the graphical Graph Builder. Execution of the xml chains can also be done using the GPT command line tool. Many of the SNAP function are generic, in the sense that they can be used for all toolboxes and a wide range of data.

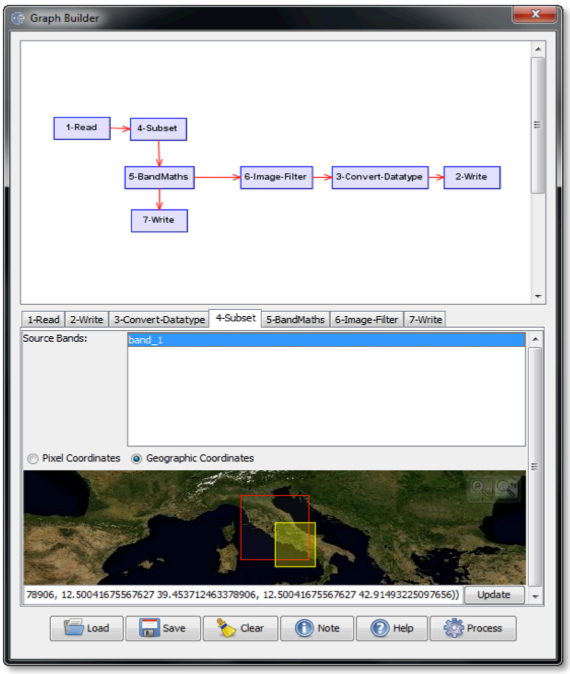

Figure 20 View of the Graph Builder

SNAP counts with interesting web resources, like a forum for the community and tutorials for new users.

http://forum.step.esa.int/c/s3tbx
http://step.esa.int/main/doc/tutorials/

Figure 21 Sentinel 3 Forum and main links to the tutorials

SNAP comes with dedicated product reader for the different Sentinels. Sentinel-2 bands come in different spatial resolutions. The products are stored in SAFE format. For opening a product, you need to select the *productname.xml* file within the SAFE folder in order to open a product.

Go to the Sentinel-2 MSI file stores in the data folder and open the .xml file with SNAP:

S2A_OPER_MTD_SAFL1C_PDMC_20151203T0385851_R047_V20151203T041742_20151203T041742

In the SNAP File label select Open Product (Figure 22) and from the folder where the file is stored select the .xml file.

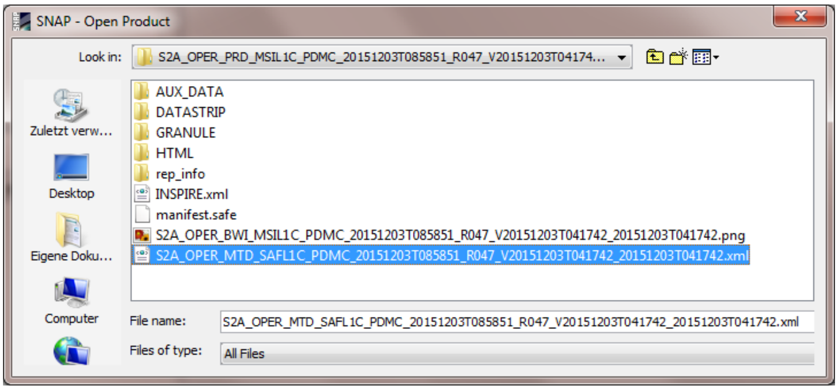

Figure 22 opening dialog for Sentinel-2; select the xml file within the SAFE container for opening the product.

The product used for this exercise comprehends two different UTM zones, zone 44 and zone 45. The product reader for Sentinel-2 offers different options to open the product; either in the native resolution of the bands (3 multi-resolution products) or opening all bands with the same resolution (10, 20 or 60m). As the tiles come in different UTM zones, the user needs to select one of them for opening a product. Depending on how many UTM zones the tile is covering, the number of choices increases (2, 4, 8 or 12)

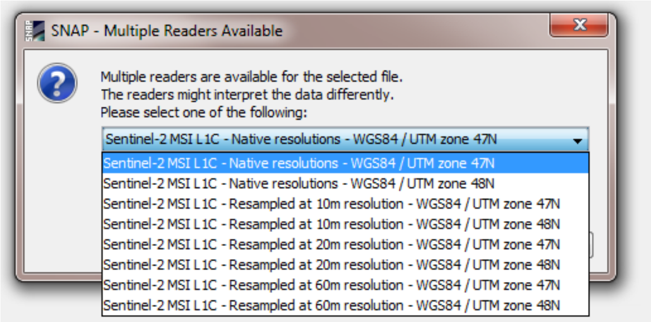

Figure 23: Options for opening a Sentinel-2 Level 1C product with SNAP

Not all functions are still ready to use when the product is opened with the multi-resolution option, You will get a message informing about this limited functionality. Another known problem is the length of the product name. When working with the Windows sytem.

1.3.2 QGIS

Quantum GIS (QGIS) is a user friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, and Windows and supports numerous vector, raster, and database formats and functionalities. Detailed information about QGIS can be found at: www.qgis.org. With QGIS basic functionalities like image display, creation of RGB composite, value identification or transects are available, e.g. to get a first overview about the data quality or suitability of the scenes.

1.4 Summary

In the above chapters different sensors with their specifications concerning spectral, spatial or temporal resolution as well as the connected data access mechanisms have been introduced.

A summary of the specifications can be found in Table 5:

Table 5 Overview of specifications of Sentinel 2/3, Landsat 7/8

	Sentinel 2	**Sentinel 3**	**Landsat 7**	**Landsat 8**
Optical Instrument	Multi Spectral Instrument (MSI)	Ocean and Land Colour Instrument (OLCI) Sea and Land Surface Temperature Radiometer (SLSTR)	Enhanced Thematic Mapper Plus (ETM+) SLC off since 2003	Operational Land Imager (OLI) Thermal Infrared Sensor (TIRS)
Spectral resolution (in nm)	Band center wavelength in nm with band width in brackets B1: 443 (20)	Band center wavelength in nm with band width in brackets Oa1: 400 (15)	Band center wavelength in nm B1: 483	Band center wavelength in nm (except for TIRS in µm) B1: 442

	B2 490 (65) B3 560 (35) B4: 665 (30) B5: 795 (15) B6: 740 (15) B7: 783 (20) B8: 842 (115) B8a: 865 (20) B9: 945 (20) B10: 1380 (30) B11: 1610 (90) B12: 2190 (180)	Oa2: 412 (10) Oa3: 443 (10) Oa4 490 (10) Oa5 510 (10) Oa6: 560 (10) Oa7: 620 (10) Oa8: 665 (10) Oa9: 673 (7.5) Oa10:681 (7.5) Oa11: 753 (10) Oa12: 753 (7.5) Oa13: 761 (2.5) Oa14: 764 (3.75) Oa15: 767 (2.5) Oa16:778 (15) Oa17:865 (20) Oa18: 885 (10) Oa19: 900 (10) Oa20: 940 (20) Oa21: 1020 (40)	B2: 560 B3: 662 B4: 835 B5:1648 B6: 11335 B7: 2206 B8: 706	B2: 482 B3: 561 B4: 655 B5: 865 B6: 1609 B7: 2201 B8: 589 B9: 1373 B10: 10.9 µm B11: 12.0 µm
Spatial resolution	10 m (B2-B4,B8) 20m (B5-B7,B8a, B11-B12)) 60m (B1, B9-B10)	300m (OLCI FR) 1200m OLCI RR, SLSTR)	30 m (B1-B7) 15 m (B8) 60 m (B6 until Feb 2010)	30 m (B1-B7,B9) 15 m (B8) 100 m (B10,11)
Temporal resolution	10days repeat cycle (5 days after launch of Sentinel-2B)	Complete global coverage after 1-2- days	16 days repeat cycle	16 days repeat cycle
Product Level	L1C	L1B, L2 (separated for land and water)	L1T	L1T
Data format	Sentinel SAFE Image format itself: JPEG2000	Sentinel SAFE	GeoTIFF	GeoTIFF
Data type	12 bit	16 bit	8 bit	16 bit
Size	4-6 GB		~ 600 MB	~ 1GB
Projection/ Datum	UTM/WGS84, separated data sets for each UTM zone		UTM/WGS 84	UTM/WGS 84
Access	ESA Science Hub	EUMETCAST, EMETSAT Data	http://earthexplorer.usgs.gov http://glovis.usgs.gov	http://earthexplorer.usgs.gov http://glovis.usgs.gov

2 This lesson

2.1 Research question

Lesson on Sentinel 2, 3 and other high resolution sensors

What are the specifications of Sentinel 2, 3 and other high resolution sensors regarding temporal, spatial, spectral characteristics and access mechanisms and what tools are available for analysing?

2.2 Training objectives / skills to gain in this lesson

Learn what are the specifications of Sentinel 2, 3 and Landsat, how to access them and which tools are available in order to select suitable satellite images for water quality monitoring purposes

1. Being able to access the data, open the data to prepare further analysing activities
2. Knowing about the specifications of Sentinel 2, 3 and Landsat in terms of spatial, temporal and spectral resolution and data formats

2.3 Required software and data

Software and tools

To complete this lesson tasks, the following tools and software are required or suggested:

- SNAP toolbox – Sentinel-2 Toolbox (required, described in the lesson)
- QGIS (required, described in the lesson)

Downloadable files

- GLaSS_Training_Lesson1.pdf
  The main document of the lesson including exercises and questions.
- GLaSS_Training_Lesson1_Answers.pdf
  A document containing answers to all questions proposed in the exercises.
- GLaSS_Training_Lesson1_DataAndTools.zip
  Supplied data and tools, described below.

The zip-file with supplied data and tools contain:

- Landsat 8 data from 2014-08-04 covering Lake Constance:
  LC81940272014216LGN00.tar.gz
- Sentinel 2 data:
  S2A_OPER_MTD_SAFL1C_PDMC_20151203T0385851_R047_V20151203T041742_20151203T041742

3 Exercise

Part 1 Access to Sentinel 2, 3 and Landsat

Depending on the water body you want to monitor, different spatial resolutions can be considered as suitable. For example, in case of homogeneous distribution with no small scale dynamics of e.g. sediment inflows or algae blooms, coarser satellite missions, such as Sentinel 3 will provide you with reasonable information with a very high temporal coverage. Small water bodies, e.g. rivers, need to be monitored with a higher spatial resolution, offered by e.g. Sentinel 2 (up to 10m) or Landsat (up to 30m). Using different Landsat missions (5-8) data from 1984 onwards are available for long time series assessments. For a selection of images, the different online portals need to search through and selected data has to be downloaded.

How to download Sentinel 2 images

Go to the SciHub clicking on the following link or copying it into a web browser:

https://scihub.copernicus.eu/dhus/#/home

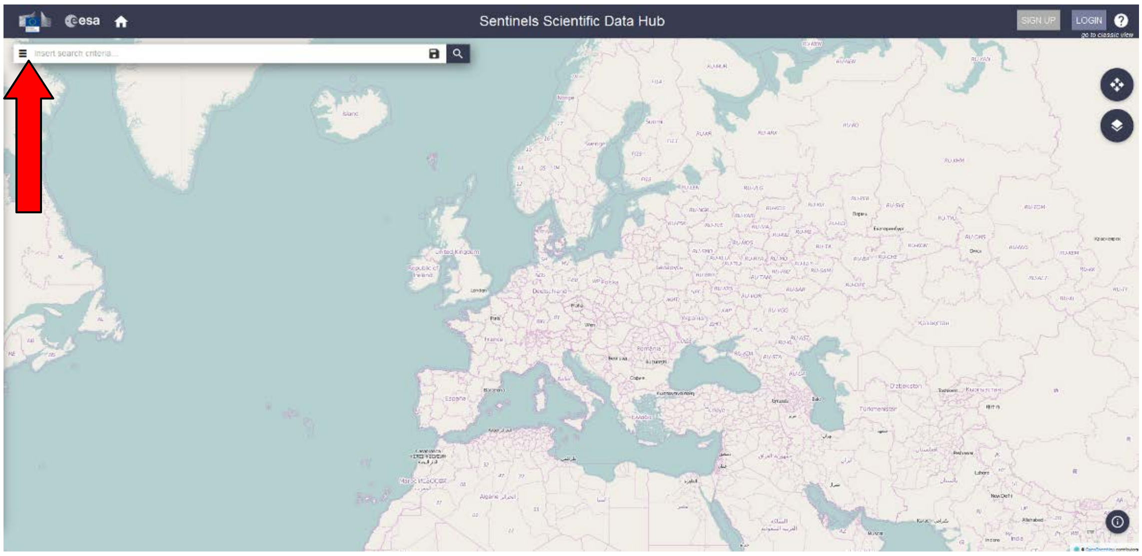

Figure 24 SciHub main window

The full text search bar is located in the upper left corner of the GUI (Figure 24), in Figure 25 the dialog window of the Advance Search is shown in detail. There is a general search by dates (for sensing or ingestion periods), and a particular Sentinel 2 search by cloud cover in percentages.

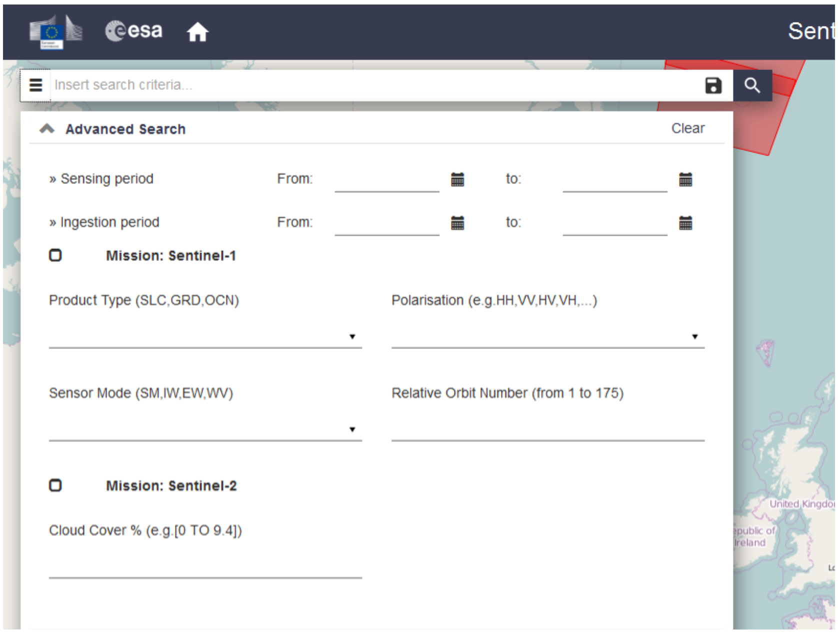

Figure 25 Advanced search dialog window

- *If you want images with at least 75% of clear pixels, which cloud percentage would you indicate for the cloud cover filter?*

The easiest thing to do if you are working on a specific region is to define the Region Of Interest. This is done by clicking on the “navigate on map” icon and drawing manually a ROI (Figure 26).

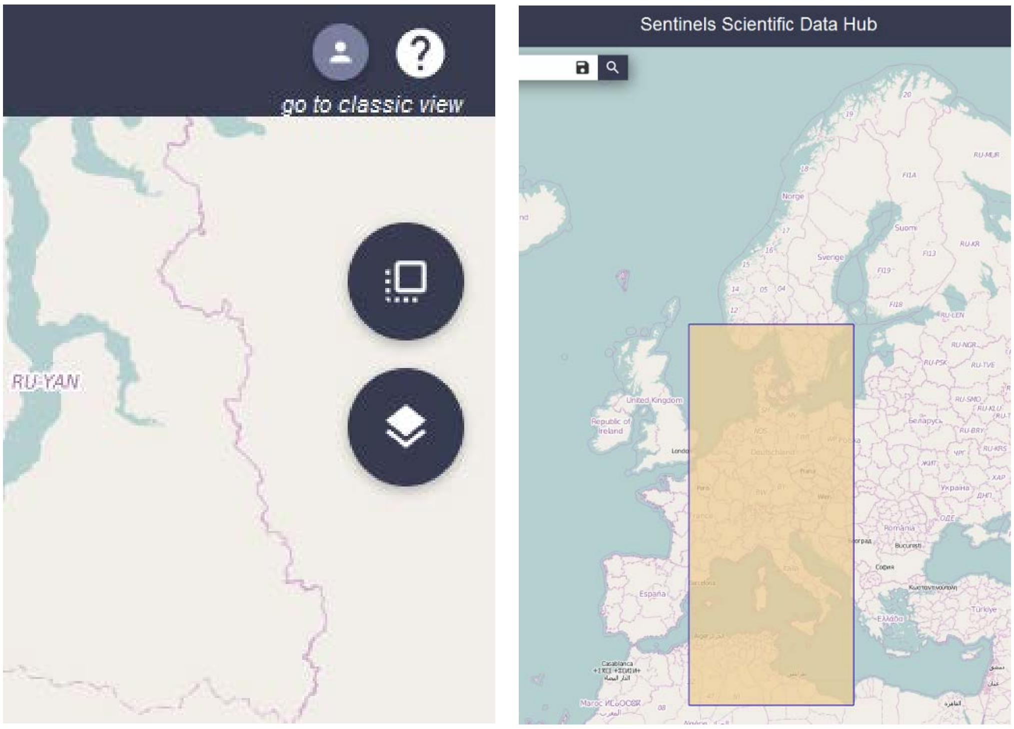

Figure 26 Navigation and drawing of ROIs

You have to define later the “advanced search” criteria, for instance by sensing date (like one month period, for instance). By clicking on the "Search" button the Data Hub will search for any product whose footprint intersects the selected ROI. See results of the example above in the Figure 27.

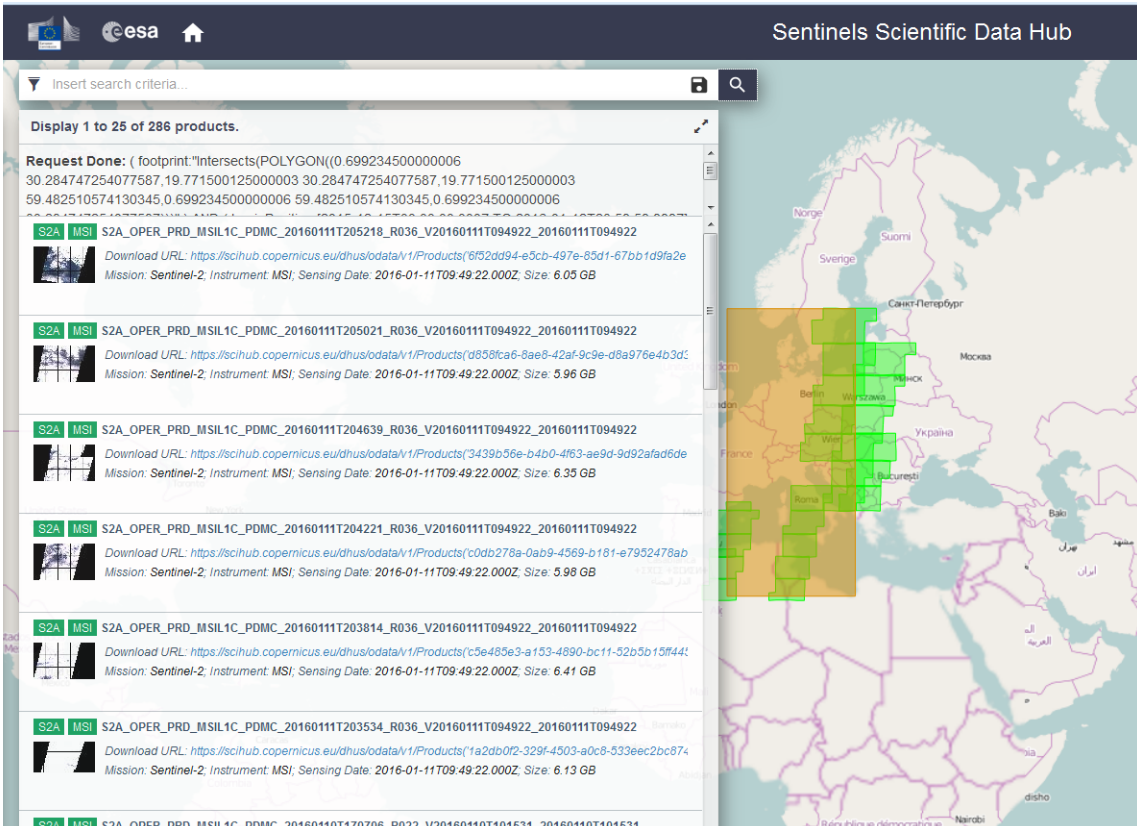

Figure 27 List of products inside ROI

To select the product of interest, just click on list that shows up after the search. The visualisation of the product details is shown clicking on the icon on the bottom right of the selected product (Figure 28).

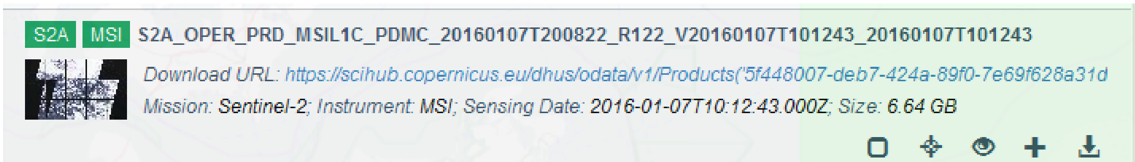

Figure 28. Detail of product name and URL, and icons for viewing product details, zoom to product, add product to cart and download options

- o *Could you identify in the name of the file below, when the Sentinel two data was taken? You can search for help in the S2-MSI Product Specifications document.*

  S2A_OPER_PRD_MSIL1C_PDMC_20160112T200934_R051_V20160112T110648_20160112T110648

The product details contain information about the product's origin (instrument, satellite, date and size), about the characteristics of the product itself (cloud coverage, degraded data, coordinates of the footprint, format, generation time, ingestion date, processing level), information about the instrument and about the satellite. The product can be downloaded directly from this window (see download icon in the bottom right of Figure 29), or add to the shopping cart to be downloaded later using the plus icon in the product list.

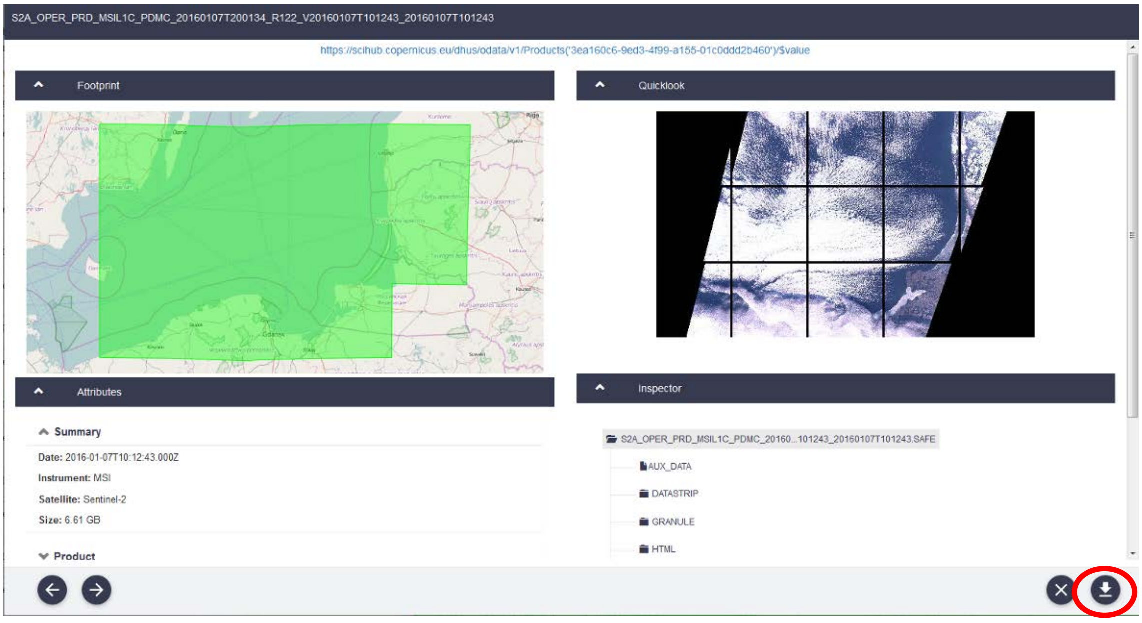

Figure 29 Selected product details

When clicking on the download icon the product is immediately downloaded and saved on your local disk.

How to download Landsat images

Field measurement of chlorophyll and turbidity has been made at several stations at Lake Constance and at Lake Illmensee on 2014-08-04. In order to be able to process images for water quality retrieval, available images must be identified and assessed.

Activities:

- Search for Landsat 30m resolution products for small lakes
- Go to http://glovis.usgs.gov/ and select your region of interest Lake Constance and Illmensee.

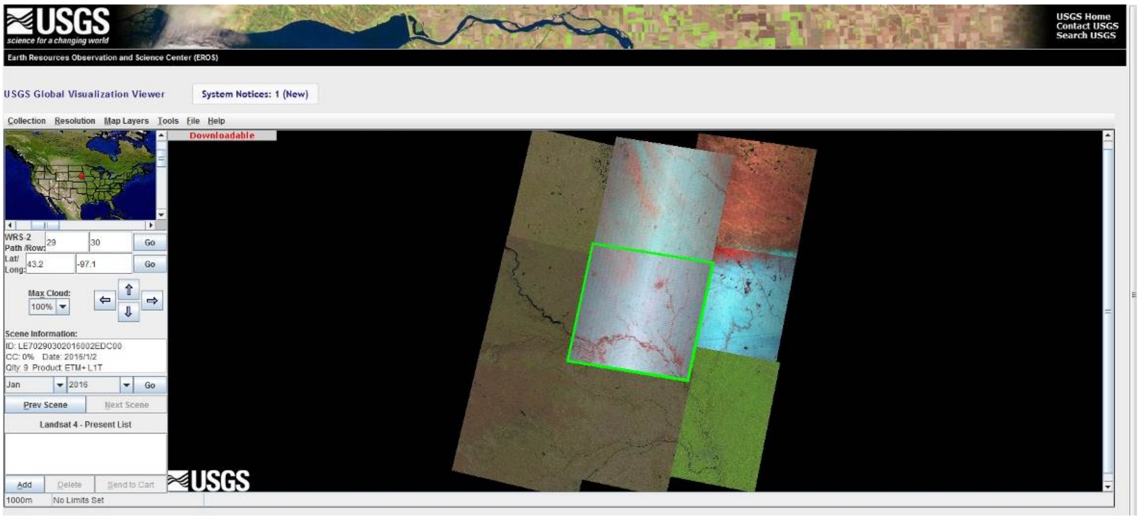

Figure 30 USGS Global Visualization Viewer

- *On which path/row can you find these lakes in one scene?*

<u>Download of the product</u>

After identifying and checking for acceptable cloud coverage (visual for your AOI), the image needs to be added to the scene list and the sent to the item basket (‘Send to cart’) of your account. In case you do not have an account, please register yourself and create an account.

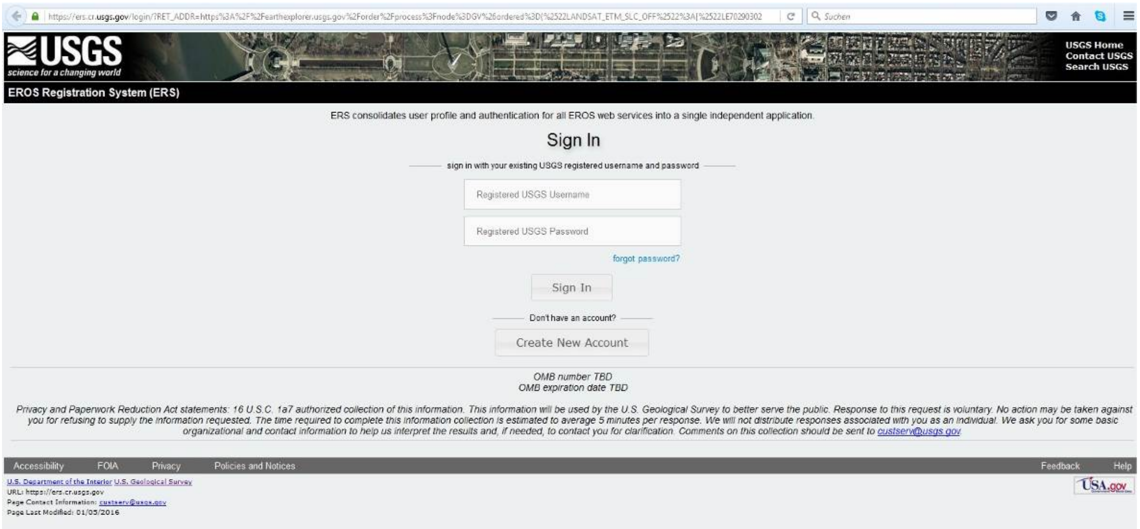

Figure 31 USGS EROS registration System Login page

The downloaded image is stored in a compressed .tar.gz file, e.g. LC81940272014216LGN00.tar.gz, containing the individual band GeoTIFFs (e.g. _B1.TIF), a metadata file (_MTL.txt) and a quality band file (_BQA.TIF) in case of Landsat 8. The metadata file contains information about e.g. geometric conditions at recording like sun azimuth, cloud coverage, radiance and reflectance factors.In order to access the single bands and load them e.g. to your GIS, you'll need software to unzip the data, like 7Zip.

- *What is the cloud coverage of the Landsat 8 image from 2014-08-04 as specified in the metadata file?*

Part 2 Discover the specifications of Sentinel 2, 3 and Landsat

After downloading the images, the data need to be opened in specific visualization and analysing software or tools, like SNAP or QGIS. Helpful information about recording time, flags and further metadata can be accessed with these tools.

Opening Sentinel-2 in SNAP

Sentinel-2 comes in different resolutions and therefore, the opening process offers a number of alternatives:

- Opening all bands in their native resolution (10, 20, 60m)
- Opening the product by resampling all bands to one of the resolutions (10, 20, 60m)

Furthermore, if an original Sentinel-2 L1C product is opened, it is asked for the UTM zone to be opened.

Open the product in “Sentinel-2 MSI L1C –Native Resolution – WGS84/UTM zone 44”.

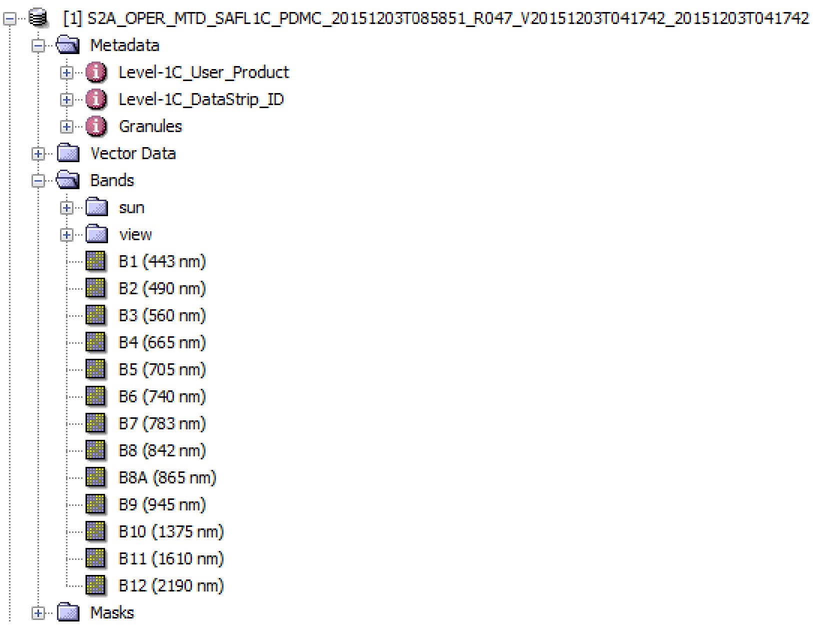

Figure 32 Sentinel-2 L1C product displayed in the Product Explorer of SNAP

The products contain all information needed for further analysing and processing. The product is listed in the product explorer and different containers exist for the Metadata, Vector data, Masks and the Bands.

Once the product is on the Product Explorer view (Figure 32)you can click the right button in your mouse and select Open RGB Image Window. Accept the default band combination (Figure 33).

Further important information about a product and its quaity is provided with the flags, which are prepared ready to use in the mask manager (tabulator at the right of the display window). Refer to Figure 33.

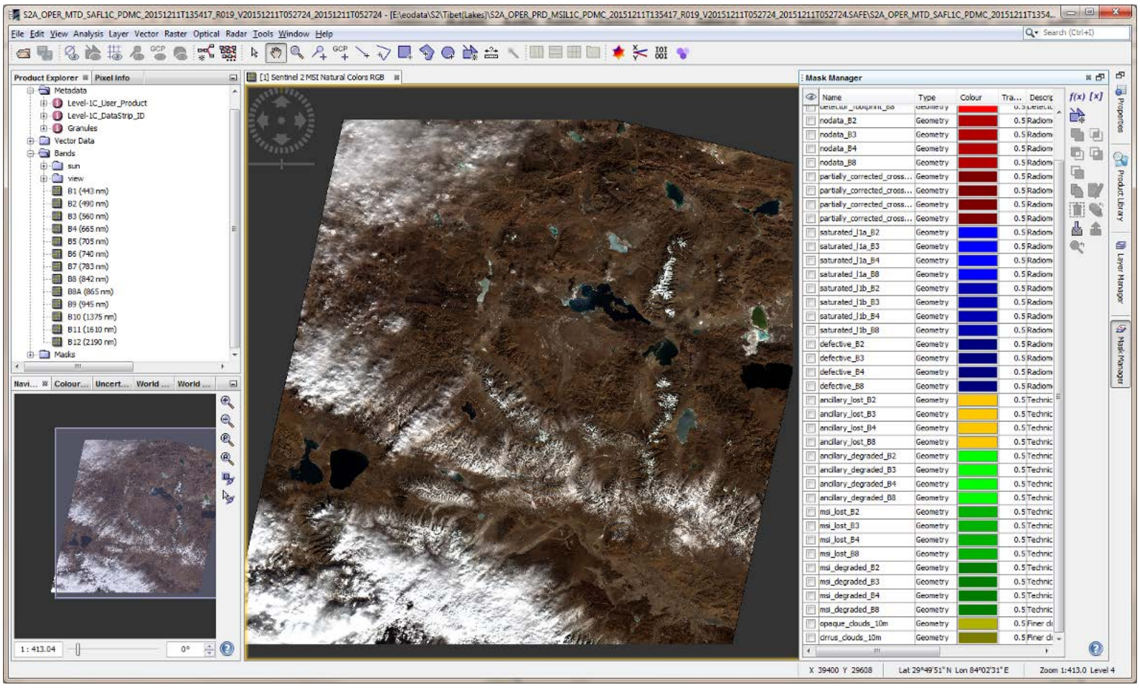

Figure 33 SNAP interface with a Sentinel-2 product opened: Product Explorer, Navigation window, Display window, mask manager.

Open a product in multi-resolution mode.

- o *Where can you find in the data and which one is the product start time?*

On the RGB overlay the pixels flagged as cloud with the cloud mask. For doing this you can open the Mask Manager (View/Tool Windows/Mask Manager) and click in the “opaque_clouds” masks at the end of the list.

- o *Which surfaces are flagged as cloud?*

Opening the product in QGIS

For further detailed checking of e.g. the image quality and the spatial coverage you can open the single GeoTIFFs with QGIS either via drag & drop or using the ‘open’ command.

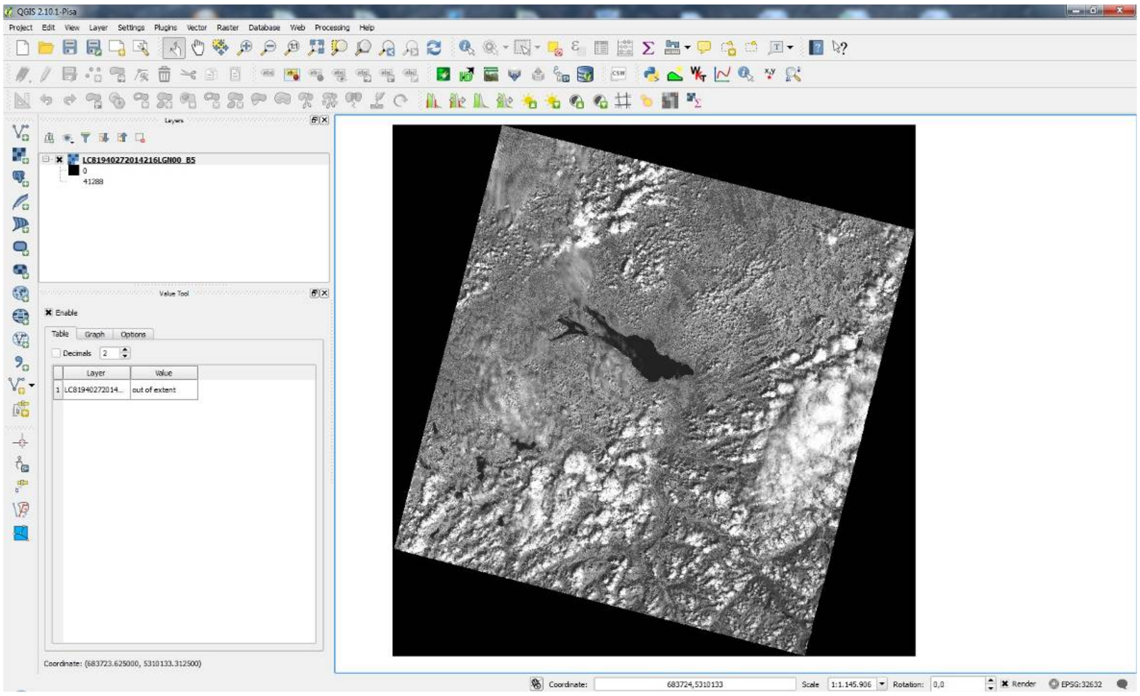

Figure 34 QGIS

In QGIS you can also have a look at the metadata with right click on the layer, selecting 'properties'. You can also change the 'Style' of the image by changing the stretch settings.

- *What is the Top of Atmosphere Radiance of the pixel coordinate UTM 32N 552695 E, 5264153 N (Lat /Lon WGS 84:47°31'43.1976" N, 9°42'0.2124" E)?*

4 More information and further reading

This lesson is based on the following report:

- GlaSS Deliverable 2.3, 2014. Global Lakes Sentinel Services, D2.3 System implementation report. BC, WI, EOMAP
- GlaSS Deliverable 2.4, 2014. Global Lakes Sentinel Services, D2.4 Interfaces. WI, BC, EOMAP, SYKE, BG, VU/VUmc, TO
- GLaSS Deliverable 3.2, 2014. Global Lakes Sentinel Services, D3.2 Harmonized atmospheric correction method. Available via: www.glass-project.eu/downloads
- GLaSS Deliverable 4.1, 2015.. TO, SYKE, WI, CNR, BC, VU/VUmc. Available via: www.glass-project.eu/downloads

For more information on GlaSS, and to download all public reports: www.glass-project.eu.

References

- ESA 2015: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/document-library/-/asset_publisher/Wk0TKajiISaR/content/sentinel-2-level-1-to-level-1c-product-specifications
- USGS 2013: Factsheet Landsat- A Global Land-Imaging Mission, http://pubs.usgs.gov/fs/2012/3072/fs2012-3072.pdf, accessed 05.11.2015)
- USGS 2015: Product Guide: Provisional Landsat 8 Surface Reflectance Product. Version 1.8 http://landsat.usgs.gov/documents/cdr_sr_product_guide.pdf, accessed 08.01.2016

Colophon

Global Lakes Sentinel Services

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Grant number 313256

GLaSS Training material, Lesson #1

EO Data handling

What are the specifications of Sentinel 2, 3 and other high resolution sensors regarding temporal, spatial, spectral characteristics and access mechanisms and what tools are available for analysing?

Karin Schenk (EOMAP), Philip Klinger (EOMAP), Ana Ruescas (BG), Kerstin Stelzer (BC)

2016

GLaSS Consortium

No	Name	Short Name
1	WATER INSIGHT BV	WI
2	SUOMEN YMPARISTOKESKUS	SYKE
3	EOMAP GmbH & Co.KG	EOMAP
4	STICHTING VU-VUMC	VU/VUmc
5	BROCKMANN CONSULT GMBH	BC
6	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR
7	TARTU OBSERVATORY	TO
8	BROCKMANN GEOMATICS SWEDEN AB	BG