FACULTY OF GEO-INFORMATION SCIENCE
AND EARTH OBSERVATION

ITC

SENTINEL EO4SD TOOLBOX V2

INSTALLATION, CONFIGURATION AND USER GUIDE OF THE SENTINEL EO4SD Toolbox

Version 2

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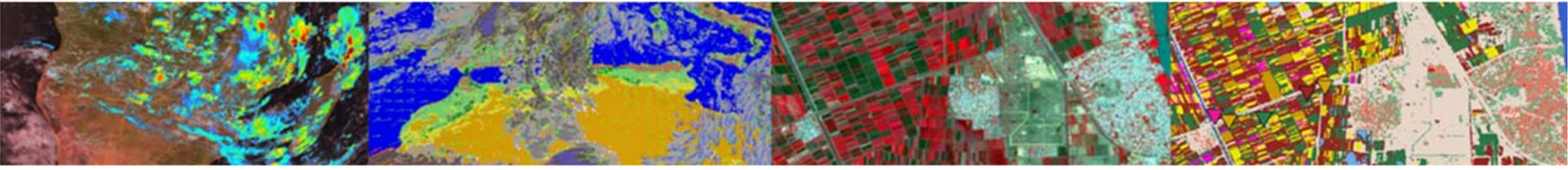
Department of Water Resources (WRS)

November 2020

UNIVERSITY OF TWENTE.

ITC



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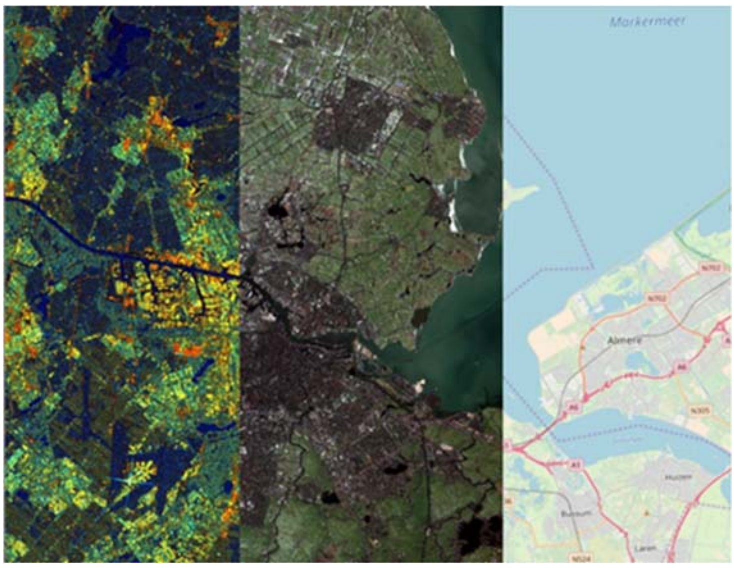
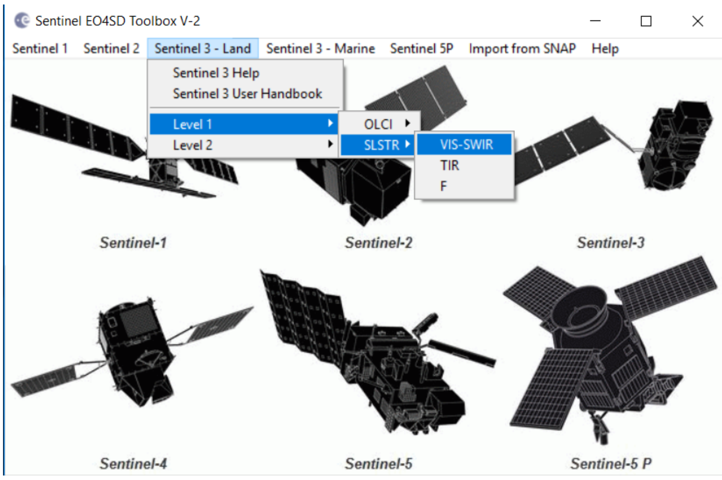
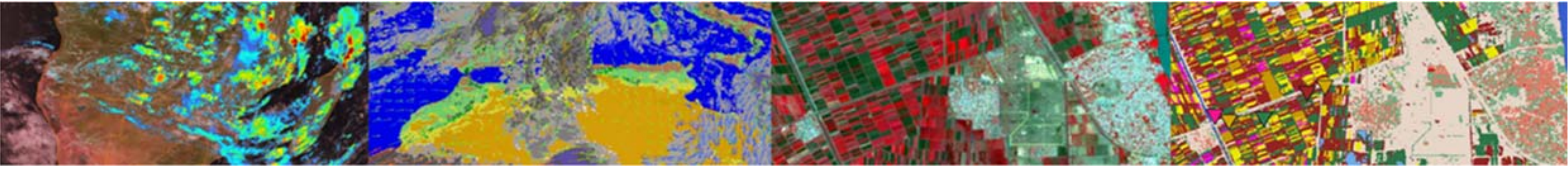




CHANGE RECORD

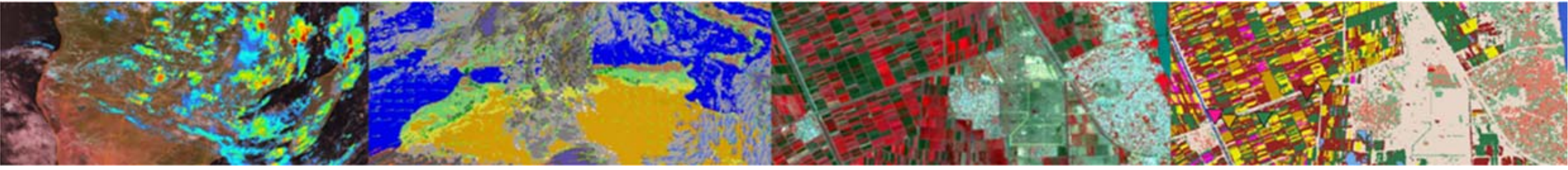
Date	***Page(s)***	***Change record***	***Version***
26.02.2018	52	First version	1.0
10.08.2020	55	Version 2 – updated for S5P	2.0
25.11.2020	55	Version 2 – reviewed and check on exercises because of software changes	2.0



Release notes

Following comments have to be taken into consideration with respect to the release of this Sentinel EO4SD Toolbox, Version 2:

1. This is an updated release and utmost care was taken to ensure appropriate operation of the routines developed but some defects might still be included and should be reported to the corresponding author to be included in a new release;
2. For the release of this toolbox version all Sentinel 1, 2 , 3 and 5P data sources used have been checked. If any pre-processing problems are encountered please report these to the corresponding author. On the other hand, some new products might be added to the data portal(s). If you need assistance building import routines please report them as well;
3. The Toolbox assumes a 64 bits Windows Operating System;
4. No liability can be accepted for use of the Sentinel EO4SD Toolbox by the toolbox developers;
5. When using the Sentinel EO4SD Toolbox you agree and comply with the conditions of the software utilities used as well as the terms and conditions stipulated by various Sentinel data providers and Copernicus for the use or references to the source of the data;
6. When not familiar with ILWIS386 a tutorial and a manual with exercises and exercise data is available at: http://filetransfer.itc.nl/pub/52n/ILWIS386/Tutorial/. It is strongly encouraged to consult these documents prior to start with the toolbox exercises described later within this manual. Here it is assumed that the user has a basic knowledge of GIS and remote sensing and ILWIS386 in particular.
7. Due to the transient nature of the internet some links provided in the document my no longer be active.



Abstract

This document describes the training package developed for the Water Resource Management (WRM) component of the European Space Agency (ESA) initiative '*Earth Observation for Sustainable Development (EO4SD)*' which aims at increasing the uptake of EO-based information in regular development operations at the national and international level.

The EO4SD project on water resource management will provide Earth Observation demonstrations on a large-scale in Africa (Sahel, Africa Horn and Zambezi), Asia (Myanmar and Lao PDR) and Latin America (Bolivia and Peru), and within water related operations of major IFI's including World Bank, Asian Development Bank, Inter-American Development Bank and the Global Environmental Facility. The CD efforts will utilize the capacity offered by the new family of missions called Sentinel, developed specifically for the operational needs of the Copernicus program and carry a range of technologies such as radar, multi-spectral imaging instruments for land, ocean and atmospheric monitoring.

The satellite data and various derived products are freely available through a number of data portals like the '*Copernicus Open Access Hub*' (https://scihub.copernicus.eu/dhus/#/home). Sentinel 3 Marine Products are available through the Copernicus Online Data Access (CODA) Portal (https://coda.eumetsat.int) or for certain marine products even through EUMETCast, a DVB based telecommunication data dissemination system or through the EUMETSAT Data Centre.

In order to easily ingest the online and EUMETCast delivered satellite information a small open toolbox has been developed, the so called '*Sentinel EO4SD Toolbox*', allowing the ingestion of the currently available satellite images from Sentinel 1, 2 and 3 land and marine products into free and open GIS/RS processing software like ILWIS and QGIS.

The main reason for development of this specific toolbox is based on the fact that in many of the countries targeted by the EO4SD Capacity Development effort, the available band width is limited and download of the full scenes (given their large file size) might be problematic. The toolbox allows processing of pre-selected spectral channels downloaded only, e.g. only 3 selected spectral channels out of the 14 available Sentinel 2 MSI instrument scene image data set to create a color composite instead of the full scene download. This reduces the overall download requirement substantially.

The toolbox is developed using Python scripts in conjunction with an ILWIS Objects Python extension and Version 1 supports the pre-processing of Sentinel 1, 2 and 3 OLCI and SLSTR images and the available Level 2 land and marine products.

The training package consist of an introduction of Copernicus and the Sentinels, provides the required sensor and image data details of the various Sentinels, discusses how to obtain the data from online portals, how to obtain the software tools used and how to install these. Later on a set of exercises is presented on the use of the Sentinel data, the pre-processing, visualization and basic analysis applying the tools provided.

Within version 2 also routines to import and preprocess the level 1B and 2 data from Sentinel 5P have been included for the following parameters: CO, HCHO, CH4, NO2 and SO2, as well as their quality masks. Also additional information on S5P is provided and relevant references.

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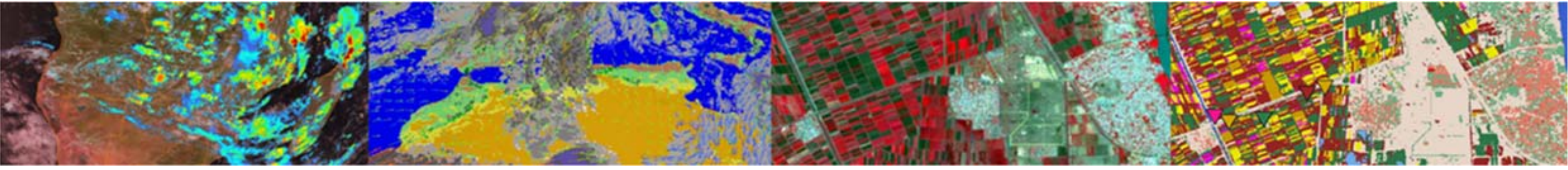
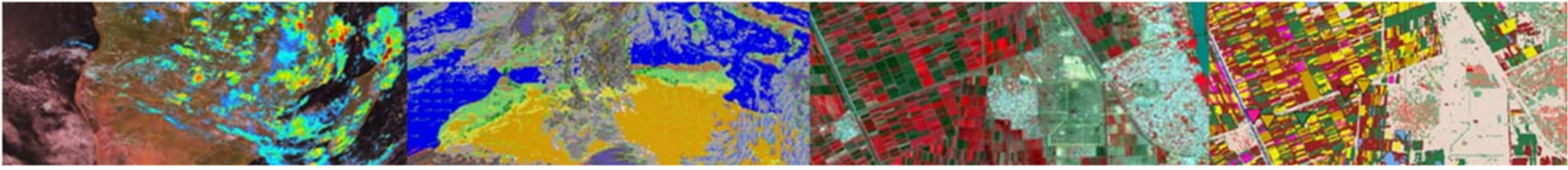
November 2020



LIST OF ACRONYMS AND ABBREVIATIONS

CS	Client States
EO	Earth Observation
FR	Full Resolution
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GIS	Geographical Information Systems / Geographical Information Science
GUI	Graphical User Interface
HH	Horizontal transmit, Horizontal receive SAR polarization
HR	High Resolution
HV	Horizontal transmit, Vertical receive SAR polarization
IFI	International Financial Institution
IR	Infra-red
ITC	Faculty ITC, University of Twente
L0	Level 0
L1	Level 1
L2	Level 2
L3	Level 3
LRM	Low Resolution Mode
LST	Land Surface Temperature
LWIR	Low Wave Infra-red
MR	Medium Resolution
MWIR	Medium Wave Infra-red
MWR	Microwave Radiometer
NetCDF	Network Common Data Form
NRT	Near real Time
OC	Ocean Colour
OLCI	Ocean and Land Colour Instrument
RR	Reduced Resolution
S1	Sentinel 1
S2	Sentinel 2
S3	Sentinel 3
S5P	Sentinel 5 Precursor
SAR	Synthetic Aperture Radar
SLR	Single Look Complex
SLSRT	Sea and Land Surface Temperature Radiometer
SM	Strip Map
SST	Sea Surface Temperature
UTC	Universal Time Code
UTM	Universal Transverse Mercator
VH	Vertical transmit, Horizontal receive SAR polarization
VIS	Visible
VNIR	Visible and Near Infra-red
VV	Vertical transmit, Vertical receive SAR polarization
WRM	Water Resources Management
WST	Water Surface Temperature
WV	Wave Mode



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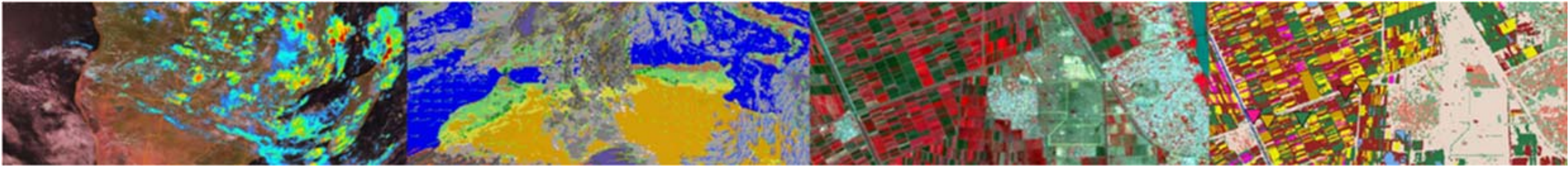


1. THE COPERNICUS PROGRAM AND THE SENTINELS

1.1 INTRODUCTION

The Sentinel Satellites are developed for the specific needs of the Copernicus programme. Copernicus, formerly Global Monitoring for Environment and Security, is the European programme to establish a European capacity for Earth observation designed to provide European policy makers and public authorities with accurate and timely information to better manage the environment, and to understand and mitigate the effects of climate change. Through satellite and in situ observations, the Copernicus services deliver near-real-time data on a global level which can also be used for local and regional needs, to help us better understand our planet and sustainably manage the environment. The Copernicus Services transform this wealth of satellite and in situ data into value-added information by processing and analysing the data acquired. Datasets stretching back for years and decades are made comparable and searchable, thus ensuring the monitoring of changes. Patterns are examined and used to create better forecasts, for example, of the ocean and the atmosphere. Maps are created from imagery, features and anomalies are identified and statistical information is extracted.

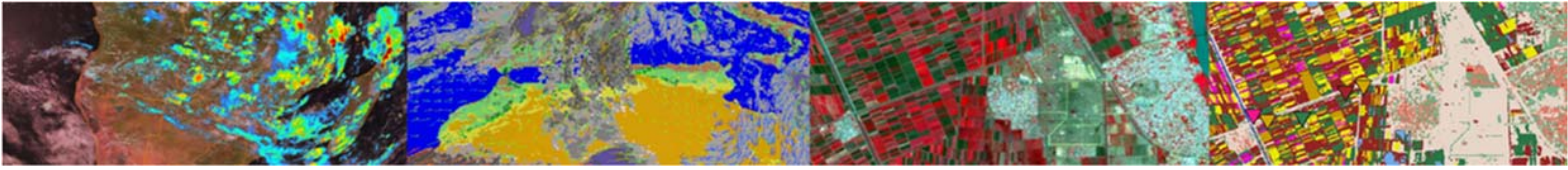
The Sentinel missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring:

- Sentinel-1 is a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services. Sentinel-1A was launched on 3 April 2014 and Sentinel-1B on 25 April 2016. Both were taken into orbit on a Soyuz rocket from Europe's Spaceport in French Guiana.
- Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2 can also deliver information for emergency services. Sentinel-2A was launched on 23 June 2015 and Sentinel-2B followed on 7 March 2017.
- Sentinel-3 is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The mission will support ocean forecasting systems, as well as environmental and climate monitoring. Sentinel-3A was launched on 16 February 2016.
- Sentinel-5 Precursor – also known as Sentinel-5P – is the forerunner of Sentinel-5 to provide timely data on a multitude of trace gases and aerosols affecting air quality and climate. It has been developed to reduce data gaps between the Envisat satellite – in particular the Sciamachy instrument – and the launch of Sentinel-5. Sentinel-5P was taken into orbit on a rocket launcher from the Plesetsk Cosmodrome in northern Russia on 13 October 2017.
- Sentinel-4 is a payload devoted to atmospheric monitoring that will be embarked upon a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit.
- Sentinel-5 is a payload that will monitor the atmosphere from polar orbit aboard a MetOp Second Generation satellite.
- Sentinel-6 carries a radar altimeter to measure global sea-surface height, primarily for operational oceanography and for climate studies.

As part of Copernicus, ESA (https://sentinel.esa.int/) will be responsible for the operation of Sentinels 1, 2 and 3 (land) and EUMETSAT (www.eumetsat.int) will be responsible for the operation of Sentinel-3 (marine), 4 and 5. A precursor satellite mission, Sentinel-5P aims to fill in the data gap and provide data continuity between the retirement of the Envisat satellite and NASA's Aura mission and the launch of Sentinel-5. The mission performs atmospheric monitoring and was launched in October 2017. Level 1B and Level 2 products are available via the Copernicus Open Access Hub.

1.2 OBJECTIVES OF THE TRAINING PACKAGE

EO4SD-WRM project has a capacity building component that is subdivided into continental and regional trainings. The continental trainings target International Financial Institutes (IFI's) and managers in the client states (CSs) and address the wider context of EO applications and services. Whereas the regional trainings aim at supporting the stakeholders in the CSs to use and streamline EO products for the management of water resources.



The main objectives of the EO4SD Capacity Development for the regional trainings are:

- For IFI: Awareness and understanding of EO – capacity data and products for WRM
- For Managers or lead of organizations: Support integration of EO-data and products into daily working practices of organization to improve planning and policy making for WRM
- For Technical staff: Derive EO-based information and products for WRM

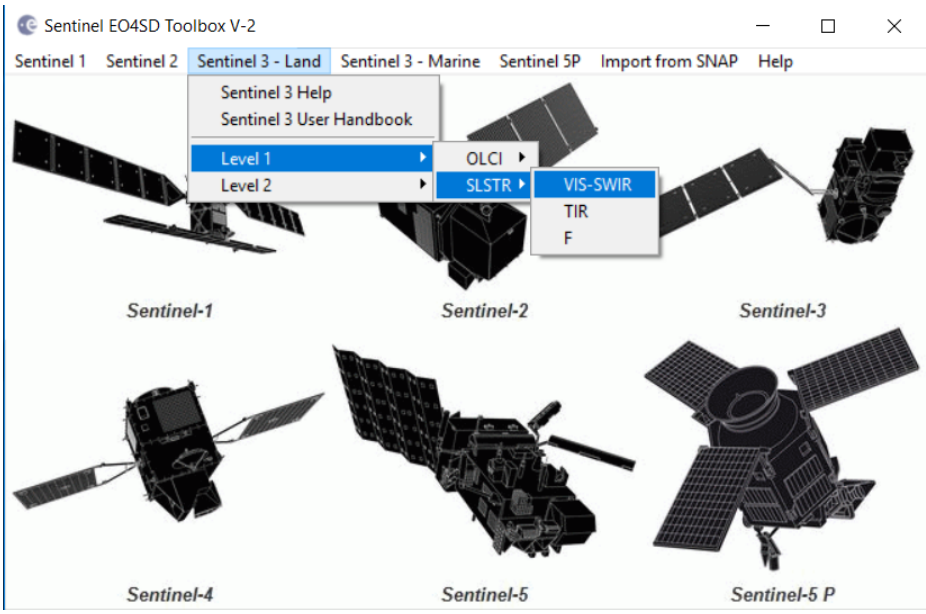
This training package initially mainly supported the technical staff in the utilization of EO based data. As the role of the various Sentinel satellites and associated products is becoming more important, functionality was added, so the tools can also be utilized by people interested in atmospheric research / air quality and therefore within version 2 also a number of level 2 products consisting of a number of atmospheric products with high spatial-temporal resolution can be processed.

1.3 THE SENTINEL EO4SD TOOLBOX

The toolbox developed currently supports the import and pre-processing of Sentinel 1 A/B Level 1C Ground Range Detected Geo-Referenced Products, Sentinel 2 A/B Level 1C Multi Spectral Imager spectral channels and True Colour Image, Sentinel 3 Level 1 Ocean and Land Imager (OLCI) and Sea and Land Surface Temperature Radiometer (SLSTR) spectral channels and Sentinel 3, Level 2 Land and Marine products, like Land Surface Temperature and Sea Surface Temperature. For level 2 Marine products also those provided through the Copernicus Online Data Access portal and EUMETCast (for OLCI and SLSTR) are supported. Data processed using SNAP can be translated as well. Figure 1A is providing the main menu through which the user can make the selection of the satellite product to be ingested.

Within version 2 a number of level 2 products from Sentinel 5P have been added, like Carbon Monoxide (CO), Formaldehyde (HCHO), Methane (CH4), Nitrogen Oxide (NO2) and Sulphur Dioxide (SO2), together with an option to import their quality masks.

Figure 1A: the Sentinel EO4SD Toolbox Opening menu



Once the user has selected a certain option from the main menu a sub menu appears, showing the required information for the final import of the image or product and the visualization / post processing software to be used. In general 4 parameters need to be specified, which can be selected interactively. A progress bar provides an indication of the state of advancement of the import routine. A sample using the Sentinel 2 True Colour Composite (Level 1C) is given below and the resulting visualization using QGIS in combination with Open Street Map, in figure 1C.

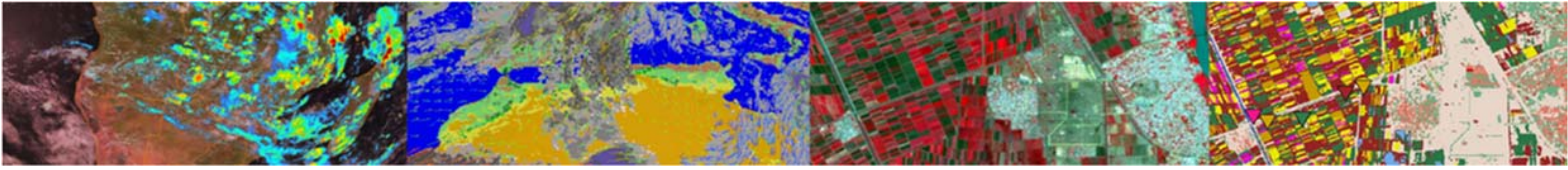


Figure 1B: the Sentinel EO4SD Toolbox sub menu

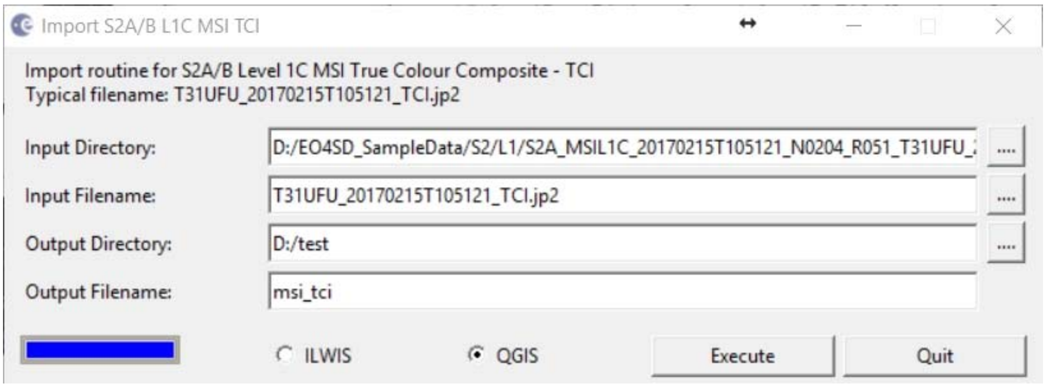
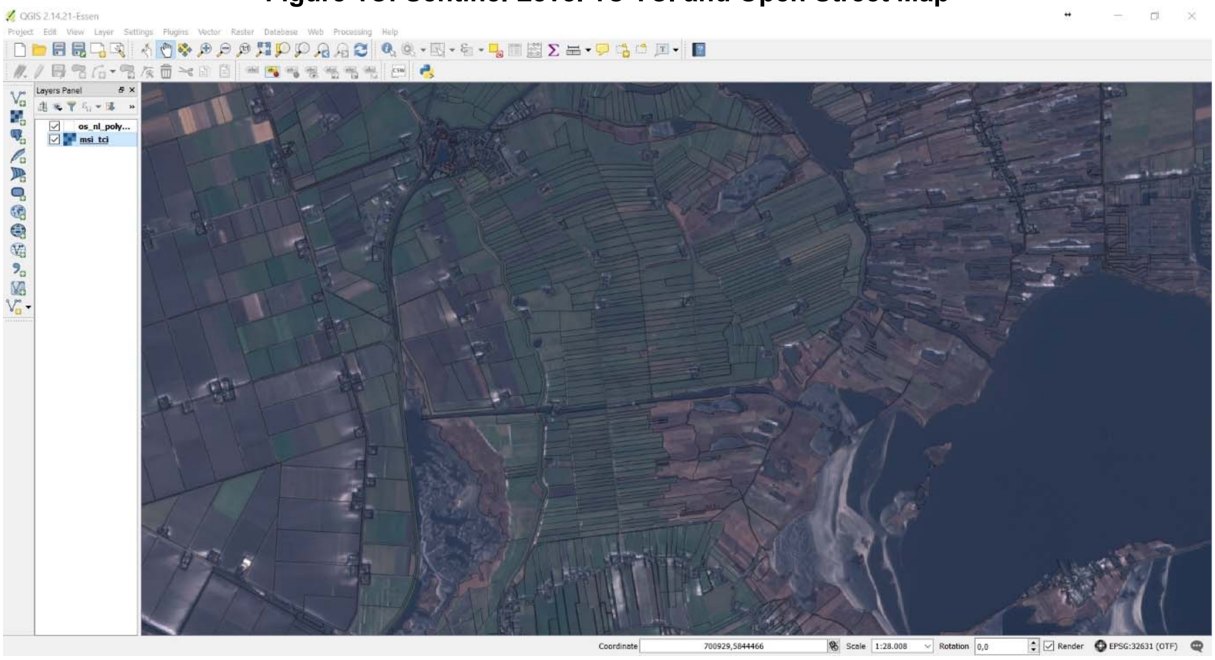
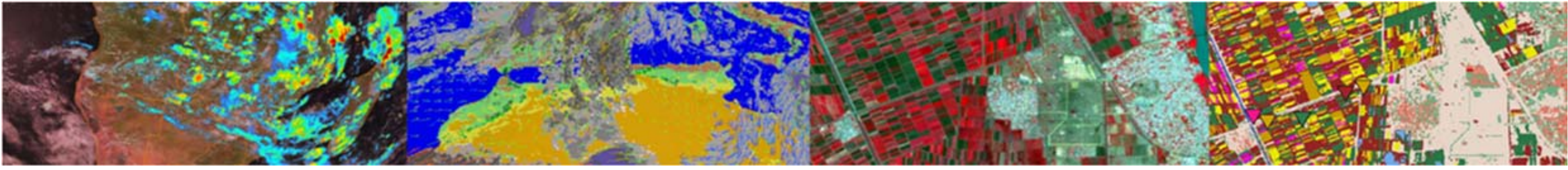


Figure 1C: Sentinel Level 1C TCI and Open Street Map



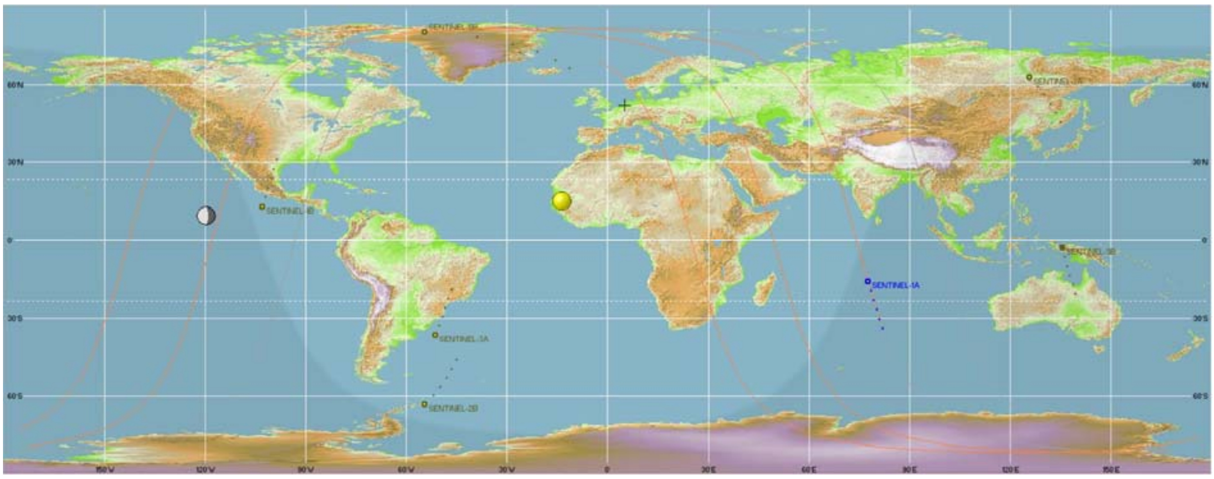


2. WORKING WITH DATA FROM SENTINEL

2.1 THE SENTINEL SUITE OF SATELLITES

As already indicated before, at the moment of writing this document a number of Sentinel satellites have been launched and are operational, like Sentinel 1A and B, 2A and B, 3A and 3B, as well as Sentinel 5P. These satellites, for Sentinel 1, 2 and 3 already two identical satellites in different orbit configuration, have different sensors designed with a specific objective, but all provide global coverage.

Figure 2: Sentinel satellite configuration, 10 August 2020 at 13:00 UTC



Some further background on the satellites is provided below as this is required to work with the data collected by the instruments on board of these satellites. Details presented are retrieved from the 'Sentinel User Handbooks', the full handbooks are also available in the EO4SD Toolbox, see the menu in figure 1. Additional information is provided at: https://earth.esa.int/web/sentinel/sentinel-technical-guides.

2.2 SENTINEL 1

The Sentinel-1 mission includes C-band imaging operating in four exclusive imaging modes with different resolution (down to 5 m) and coverage (up to 400 km). It provides dual polarisation capability, very short revisit times and rapid product delivery. Sentinel-1 potentially operates in four exclusive acquisition modes:

- Strip Map (SM), 80 km swath, 5 x 5 m spatial resolution
- Interferometric Wide swath (IW), 250 km swath, 5 x 20 m spatial resolution
- Extra Wide swath (EW), 400 km swath, 20 x 40 m spatial resolution
- Wave (WV), 20 x 20 km, 5 x 5 m spatial resolution

The Sentinel-1 C-band SAR instrument supports operation in single polarisation (HH or VV) and dual polarisation (HH+HV or VV+VH), implemented through one transmit chain (switchable to H or V) and two parallel receive chains for H and V polarisation.

SM, IW and EW are available in single (HH or VV) or dual polarisation (HH+HV or VV+VH). WV is single polarisation only (HH or VV). The primary conflict-free modes are IW, with VV+VH polarisation over land, and WV, with VV polarisation, over open ocean. EW mode is primarily used for wide area coastal monitoring including ship traffic, oil spill and sea-ice monitoring. SM mode will only be used on request for extraordinary events such as emergency management.

Having the Interferometric Wide swath mode as the one main operational mode satisfies most currently known service requirements, avoids conflicts and preserves revisit performance, simplifies mission planning, decreases operational costs and builds up a consistent long-term archive.

For each mode, it will be possible to produce products at SAR Level-0 (raw), Level-1 SLC (Single Look Complex), Level-1 GRD (Ground Range Detected) and Level-2 OCN (Ocean). Spatial resolutions depend on the acquisition mode and the level of processing, see also table 1.

Figure 3: Sentinel-1 Product Modes

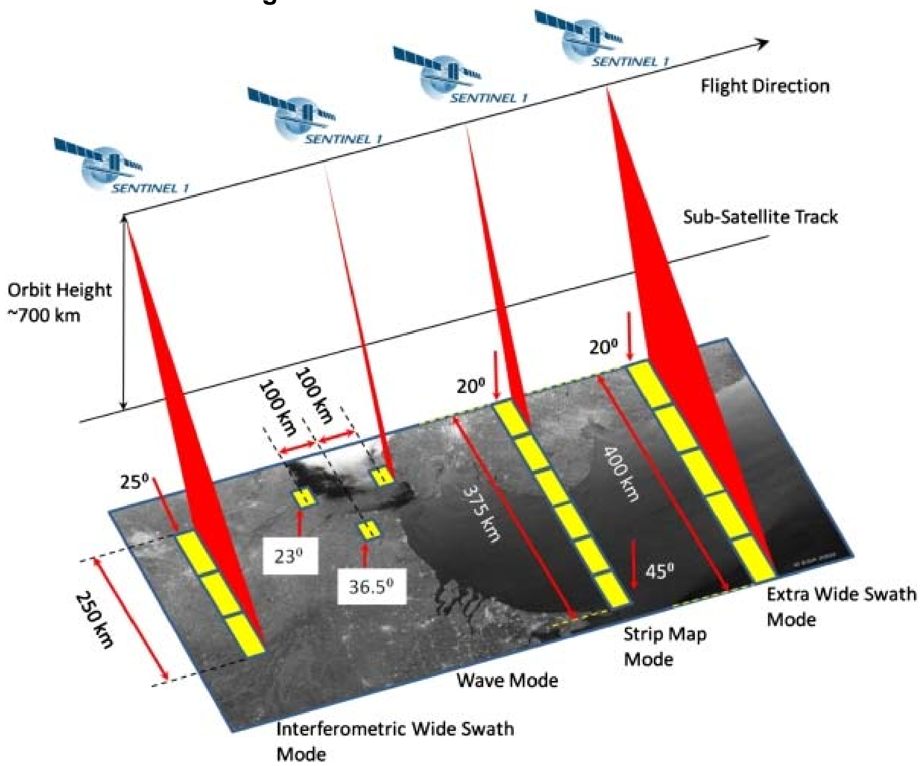


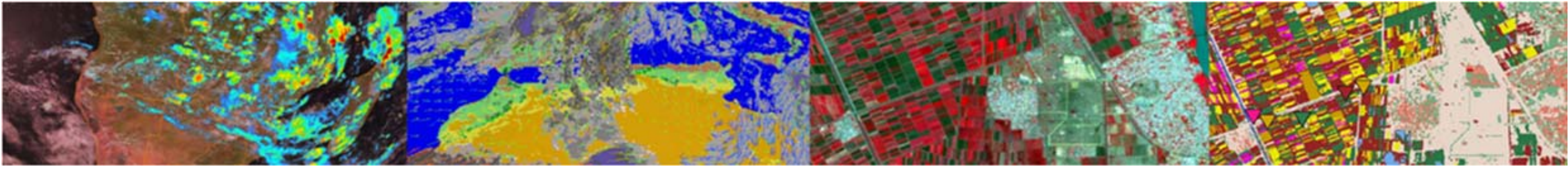
Table 1: Acquisition mode details

Mode	Incidence Angle	Resolution	Swath Width	Polarization (H=horizontal, V=Vertical)
Stripmap	20 – 45	5 x 5 m	80 km	HH+HV, VH+VV, HH, VV
Interferometric Wide swath	29 – 46	5 x 20 m	250 km	HH+HV, VH+VV, HH, VV
Extra Wide Swath	19 – 47	20 x 40 m	400 km	HH+HV, VH+VV, HH, VV
Wave	22 – 35 35 – 38	5 x 5 m	20 x 20 km	HH, VV

Sentinel-1 is in a near-polar, sun-synchronous orbit with a 12 day repeat cycle and 175 orbits per cycle for a single satellite. Both Sentinel-1A and Sentinel-1B share the same orbit plane with a 180° orbital phasing difference. With both satellites operating, the repeat cycle is 6 days.

Level-1 data are the generally available products intended for most data users. Level-1 products are produced as Single Look Complex (SLC) and Ground Range Detected (GRD). Level-1 Single Look Complex (SLC) products consist of focused SAR data geo-referenced using orbit and attitude data from the satellite and provided in zero-Doppler slant-range geometry. The products include a single look in each dimension using the full TX signal bandwidth and consist of complex samples preserving the phase information.

Level-1 Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. Phase information is lost. The resulting product has approximately square resolution pixels and square pixel spacing with reduced speckle at the cost of reduced geometric resolution. GRD products can be in one of three resolutions: Full Resolution (FR), High Resolution (HR) or Medium Resolution (MR). The resolution is dependent



upon the amount of multi-looking performed. Level-1 GRD products are available in MR and HR for IW and EW modes, MR for WV mode and MR, HR and FR for SM mode.

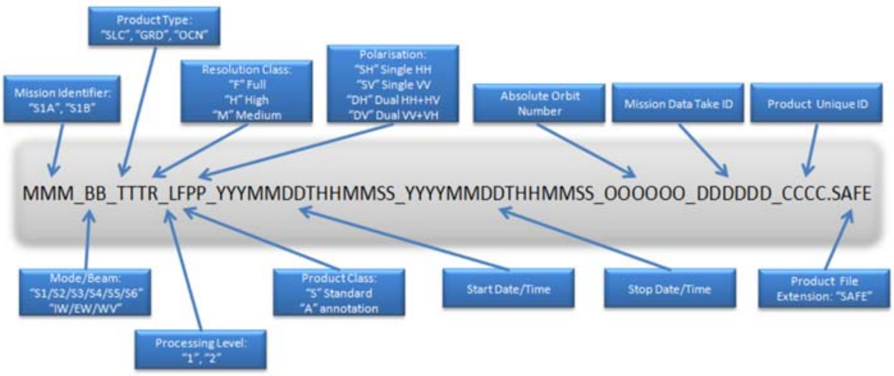
Level-2 OCN products include components for Ocean Swell spectra (OSW) providing continuity with ERS and ASAR WV and two new components: Ocean Wind Fields (OWI) and Surface Radial Velocities (RVL). The OSW is a two-dimensional ocean surface swell spectrum and includes an estimate of the wind speed and direction per swell spectrum. The OSW is generated from Stripmap and Wave modes only. For Stripmap mode, there are multiple spectra derived from internally generated Level-1 SLC images. For Wave mode, there is one spectrum per vignette. The OWI is a ground range gridded estimate of the surface wind speed and direction at 10 m above the surface derived from internally generated Level-1 GRD images of SM, IW or EW modes. The RVL is a ground range gridded difference between the measured Level-2 Doppler grid and the Level-1 calculated geometrical Doppler.

Sentinel-1 can collect several different images from the same series of pulses by using its antenna to receive specific polarisations simultaneously. The Sentinel-1 SAR is a dual polarisation radar. It can transmit a signal and receive in both horizontal (H) and vertical (V) polarisation. Dual polarisation SAR products containing complex value and inter-channel phase information allow for measurement of the polarisation properties of terrain in addition to the backscatter that can be measured from a single polarisation. Targets on the ground have distinctive polarisation signatures reflecting different polarisations with different intensities and converting one polarisation into another. For example, volume scatterers have different polarisation properties than surface scatterers. Polarimetric decompositions allow the separation of different scattering contributions and can be used to extract information about the scattering process, providing improved classification of point targets and distributed target areas.

A SAR signal contains amplitude and phase information. Amplitude is the strength of the radar response and phase is the fraction of one complete sine wave cycle (a single SAR wavelength). The phase of the SAR image is determined primarily by the distance between the satellite antenna and the ground targets. Interferometric SAR (InSAR) exploits the phase difference between two complex radar SAR observations of the same area, taken from slightly different sensor positions, and extracts distance information about the Earth's terrain. By combining the phase of these two images after co-registration, an interferogram can be generated where phase is highly correlated to the terrain topography and deformation patterns can be mapped. If the phase shift related to topography is removed from the interferograms, the difference between the resulting products will show surface deformation patterns occurred between the two acquisition dates.

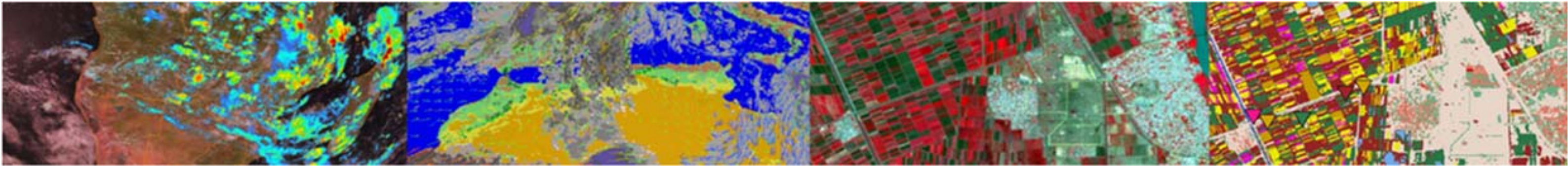
The top-level Sentinel-1 product folder name is composed of upper-case alphanumeric characters separated by an underscore (_).

Figure 4: Product naming conventions



Sentinel data products are distributed using a Sentinel-specific variation of the Standard Archive Format for Europe (SAFE) format specification. The SAFE format has been designed to act as a common format for archiving and conveying data within ESA Earth Observation archiving facilities. The Sentinel-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 product refers to a directory folder that contains a collection of information. It includes:

- a 'manifest.safe' file which holds the general product information in XML;
- subfolders for measurement datasets containing image data in various binary formats;
- a preview folder containing 'quicklooks' in PNG format, Google Earth overlays in KML format and HTML preview files;
- an annotation folder containing the product metadata in XML as well as calibration data;
- a support folder containing the XML schemes describing the product XML.



2.3 SENTINEL 2

The spatial resolution of the Multi Spectral Instrument (MSI) on Sentinel-2 is dependent on the particular spectral band. For the 10 metre resolution also a True Colour Image (TCI) is provided.

Figure 5: S-2 10 m spatial resolution bands: B2 (490 nm), B3 (560 nm), B4 (665 nm) and B8 (842 nm)

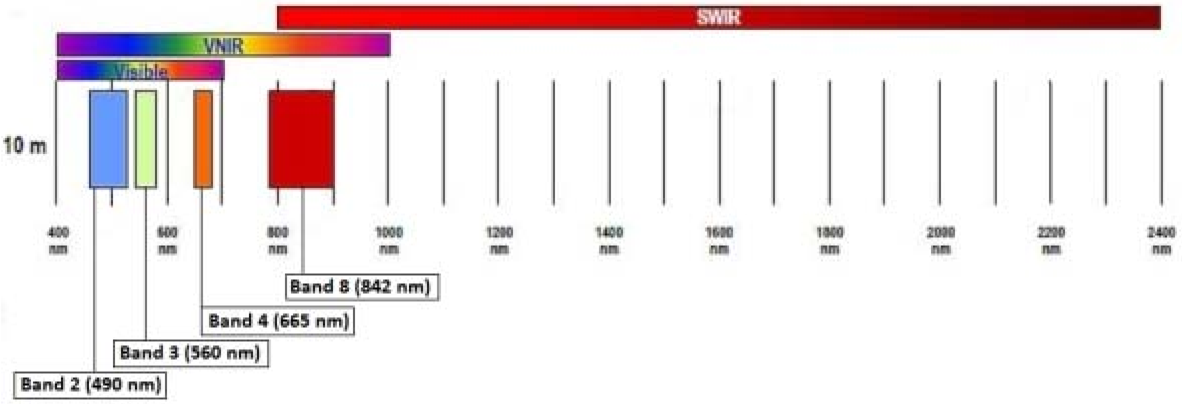


Figure 6: S-2 20 m spatial resolution bands: B5 (705 nm), B6 (740 nm), B7 (783 nm), B8a (865 nm), B11 (1610 nm) and B12 (2190 nm)

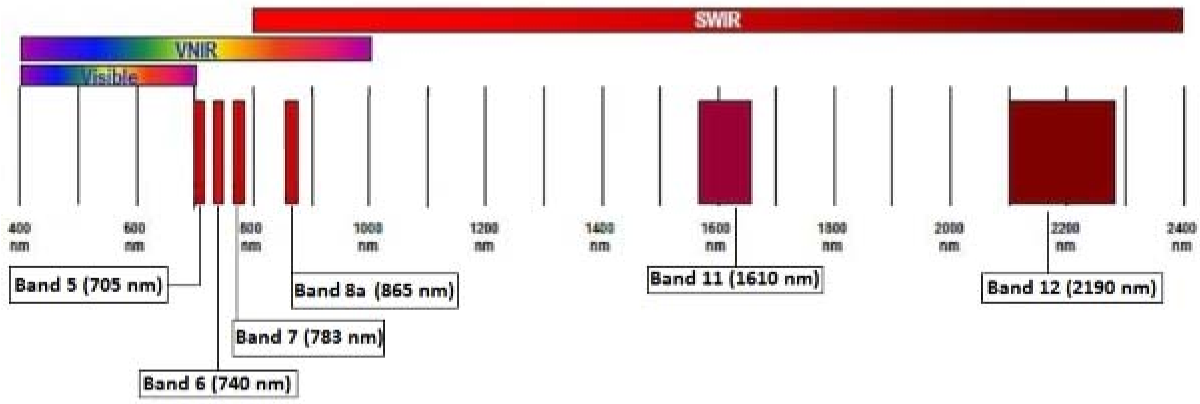
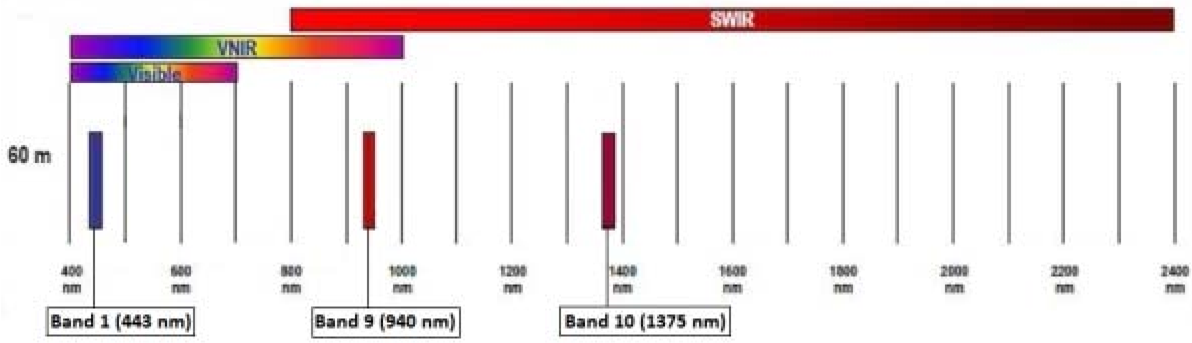


Figure 7: S-2 60 m spatial resolution bands: B1 (443 nm), B9 (940 nm) and B10 (1375 nm)



With its 13 spectral bands, 290 km swath width and high revisit frequency, Sentinel-2's MSI instrument supports a wide range of land studies and programmes. Two identical Sentinel-2 satellites operate simultaneously, phased at 180° to each other, in a sun-synchronous orbit at a mean altitude of 786 km.

The MSI works passively, by collecting sunlight reflected from the Earth. New data is acquired at the instrument as the satellite moves along its orbital path. The incoming light beam is split at a filter and focused onto two separate focal plane assemblies within the instrument; one for Visible and Near-Infra-

Red (VNIR) bands and one for Short Wave Infra- Red (SWIR) bands. The spectral separation of each band into individual wavelengths is accomplished by stripe filters mounted on top of the detectors.

Table 2: Sentinel-2 product types

Name	High-level Description	Production and Distribution	Data Volume
Level-1B	Top-of-atmosphere radiances in sensor geometry	Systematic generation and online distribution	27 MB (each 25*23 km^2)
Level-1C	Top-of-atmosphere reflectances in cartographic geometry	Systematic generation and online distribution	500 MB (each 100*100 km^2)
Level-2A	Bottom-of-atmosphere reflectances in cartographic geometry	Generation on user side	600 MB (each 100*100 km^2)

The Level-1B product is the lowest product level made available to users. Each Level-1B product is composed of an ensemble of granules that are 25 km across track (AC) by 23 km along track (AL). All granules that intersect with a user area of interest (AOI) are delivered. Each granule is approximately 27 MB in size. The Level-1B product provides radiometrically corrected imagery in Top-Of-Atmosphere (ToA) radiance values and in sensor geometry. Additionally, this product includes the refined geometrical model which is used to generate the Level-1C product. Level-1B pixel coordinates refer to the centre of each pixel.

The Level-1C product is composed of 100 km2 tiles (ortho-images in UTM/WGS84 projection). The Level-1C product results from using a Digital Elevation Model (DEM) to project the image in cartographic coordinates. Per-pixel radiometric measurements are provided in Top of Atmosphere (ToA) reflectances with all parameters to transform them into radiances. Level-1C products are resampled with a constant Ground Sampling Distance (GSD) of 10, 20 and 60 m depending on the native resolution of the different spectral bands.

In Level-1C products, pixel coordinates refer to the upper left corner of the pixel. Level-1C products additionally include Land/Water, Cloud Masks and ECMWF data (total column of ozone, total column of water vapour and mean sea level pressure).

The Level-1C Tile consists of:

- Level-1C_Tile_Metadata_File (Tile Metadata): XML main metadata file (DIMAP mandatory file) containing the requested level of information and referring all the product elements describing the tile;
- IMG_DATA: folder containing image data files compressed using the JPEG2000 algorithm, one file per band;
- QI_DATA: folder containing QLQC XML reports of quality checks, mask files and PVI files.
- Inventory_Metadata.xml: inventory metadata file (mandatory);
- manifest.safe: XML SAFE manifest file (Mandatory);
- rep-info: folder containing the XSD schema provided inside a SAFE Level-0 granule

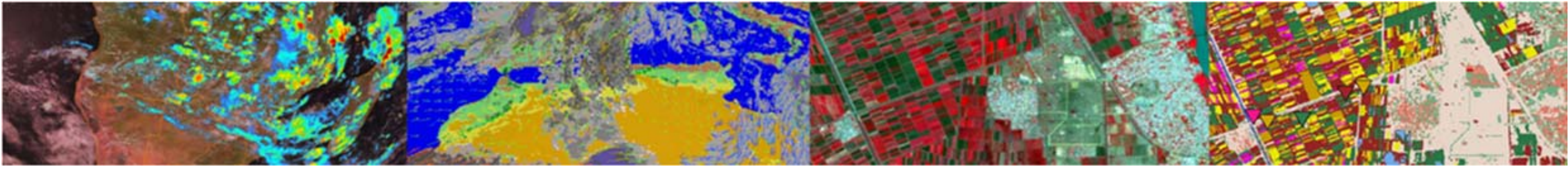
Level-1 Tile Image Data Naming Convention used is as follows:

- S2A_OPER_MSI_L1C_CGS3_20141104T134012_123_15SWC_N11.11

Where:

- S2A is the spacecraft
- OPER is the routine operations
- MSI is the instrument.
- L1C is the product level
- TL is the granule
- CGS3 is the processing centre in which the product is generated.

The Level-2A prototype product is an orthorectified product providing Bottom-of-Atmosphere (BOA) reflectances, and basic pixel classification (including classes for different types of cloud). In the Level-2A, the granules (also called tiles) consist of 100kmx100km squared ortho-images in UTM/WGS84 projection, with one tile per spectral band.



Examples of S2 L2A product main directories are:

- S2A_OPER_PRD_USER2A_047_20140417094512_201404171094728_20140417102538
- S2A_OPER_PRD_USER2A_048_20140417112512_201404171112728_20140417102538

Where:

- S2A is the spacecraft
- OPER is the routine operations
- PRD is the product category
- USER denotes a User-generated product
- 2A is the processing level

Sentinel-2 products are 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. Similarly to Level-1C, Level-2A products are organized in ortho-rectified tiles of 100 km x 100 km in UTM WGS84 projections. The imagery of each band is put in a separate JPEG2000 file. The values are Bottom-Of-Atmosphere (BOA) reflectances. L2A specific bands are also computed:

- AOT: Aerosol Optical Thickness map (at 550nm)
- CLD: Raster mask values range from 0 for high confidence clear sky to 100 for high confidence cloudy
- SCL: Scene Classification. The meaning of the values is indicated in the Category Names of the band.
- SNW: Raster mask values range from 0 for high confidence NO snow/ice to 100 for high confidence snow/ice
- WVP: Scene-average Water Vapour map

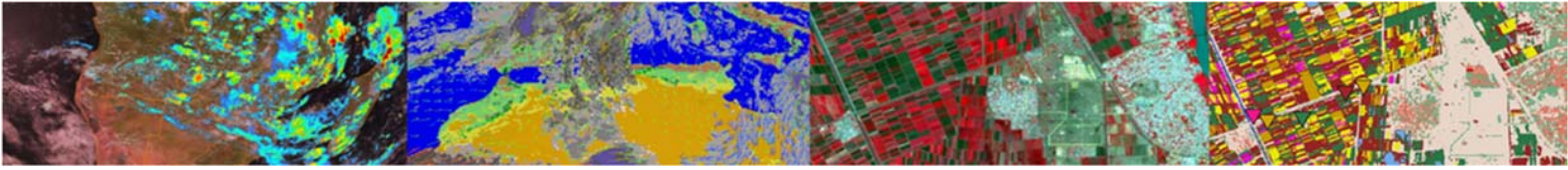
When opening the main metadata .xml file, the driver will typically expose 4 sub-datasets:

- one for the 4 native 10m bands, and L2A specific bands (AOT and WVP)
- one for the 6 native 20m bands, plus the 10m bands, except B8, resampled to 20m, and L2A specific bands (AOT, WVP, SCL, CLD and SNW),
- one for the 3 native 60m bands, plus the 10m&20m bands, except B8, resampled to 60m, and L2A specific bands (AOT, WVP, SCL, CLD and SNW),
- one for a preview of the R,G,B bands at a 320m resolution

All tiles of same resolution and projection are mosaiced together. If a product spans over several UTM zones, they will be exposed as separate subdatasets.

L2A_Scene_Classification_ID (SCL product) uses the following coding system:

0 = sc_nodata
1 = sc_saturated_defective
2 = sc_dark_feature_shadow
3 = sc_cloud_shadow
4 = sc_vegetation
5 = sc_not_vegetated
6 = sc_water
7 = sc_unclassified
8 = sc_cloud_medium_proba
9 = sc_cloud_high_proba
10 = sc_thin_cirrus
11 = sc_snow_ice



2.4 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 and the data is jointly provided by ESA and EUMETSAT to deliver operational land observation and ocean services respectively. The spacecraft carries four main instruments:

- Ocean and Land Colour Instrument (OLCI)
- Ocean and Land Colour Instrument (SLSTR)
- Synthetic Aperture Radar Altimeter (SRAL)
- Microwave Radiometer (MWR)

The two in-orbit Sentinel-3 satellites enable a short revisit time of less than two days for OLCI and less than one day for SLSTR at the equator. The orbit reference altitude is 814.5 km. Sentinel-3B orbit is identical to Sentinel-3A orbit but flown 180° out of phase with Sentinel-3A.

The SLSTR instrument is a conical scanning imaging radiometer employing the along track scanning dual view technique (near-nadir and backward views). The main characteristics of the SLSTR are:

- swath width: dual view scan, 1420 km (nadir) / 750 km (backwards)
- spatial sampling: 500 m (VIS, SWIR), 1 km (MWIR, TIR)
- spectrum: nine bands [0.55-12] µm

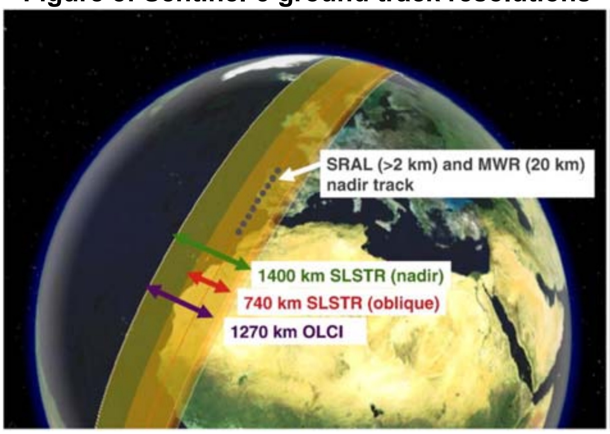
The OLCI push-broom instrument swath is 1270 km. The OLCI swath is not centred at nadir but is tilted 12.6° westwards to mitigate the negative impact of sun-glint contamination. Fully overlapping with SLSTR instrument swath and simultaneous acquisitions facilitates the use of OLCI and SLSTR in synergy. The main characteristics of the OLCI are:

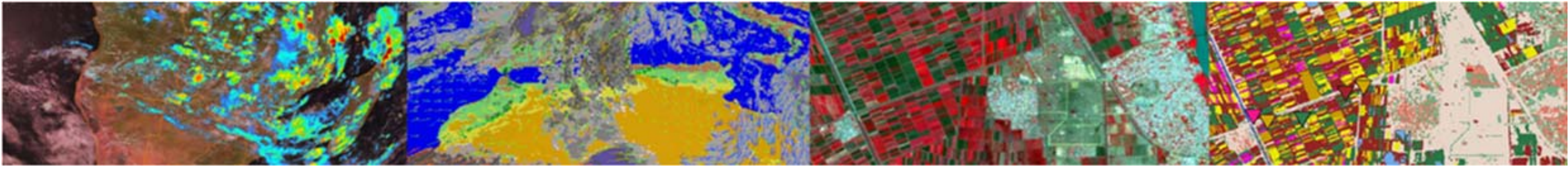
- swath width: 1270 km
- push-broom imaging spectrometer with five cameras, mitigation of sun-glint contamination by tilting cameras in westerly direction
- spatial sampling: 300 m at Sub Satellite Point
- spectrum: 21 bands [0.4-1.02] µm

The altimeter instrument (SRAL) does not have a swath like Sentinel-3 OLCI and SLTSR instruments. Across track, it receives a single measurement of the range (no image) every time a pulse is emitted. The main characteristics of the SRAL (Sentinel-3 Ku/C Radar Altimeter) are:

- radar measurement modes: Low Resolution Mode and SAR (also called High Resolution Mode)
- tracking modes: closed and open-loop
- pulse repetition frequency: 1.9 KHz (LRM), 17.8 KHz (SAR)
- total range error: 3 cm

Figure 8: Sentinel-3 ground track resolutions



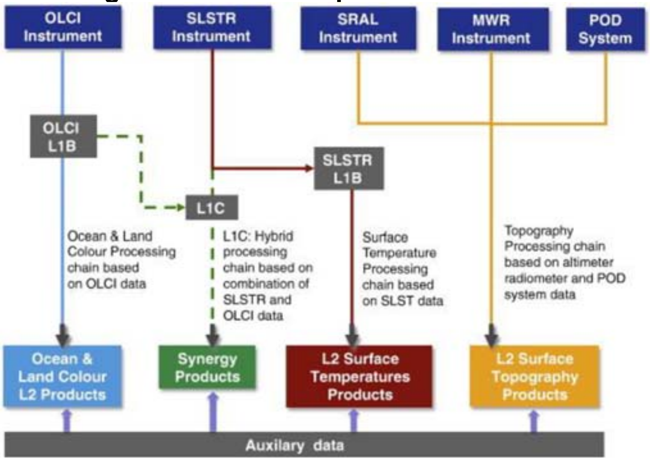


The main characteristics of the MWR (MicroWave Radiometer) are:

- dual frequency, 23.8 / 36.5 GHz
- radiometric accuracy, 3 K absolute (0.6 K relative)

Based on the Sentinel-3 observations a processing chains for generating ocean colour and land reflectance, land and sea temperature and ocean and land topography products has been established as shown in the figure below.

Figure 9: Sentinel-3 products structure



OLCI Level-1 and 2 data products are available to the general public. The OLCI files are collected into a SAFE container. Level-1 and 2 products are provided as netCDF4 product files. There are different data products associated with these levels of processing of OLCI:

- Level-1 includes Top-of-Atmosphere (TOA) radiometric measurements, radiometrically corrected, calibrated and spectrally characterised. It is quality controlled, ortho-geolocated (latitude and longitude coordinates, altitude) and annotated with satellite position and pointing, landmarks and preliminary pixel classification (e.g. land/water/cloud masks). Products are generated in FR (300 m) and in RR (1 km) for the whole globe with the same coverage.
- Level-2 products consist of geophysical quantities derived from the processing of measurement data provided in the Level-1 product. Level-2 products specifically for marine and land application domains are generated separately by ESA (land) and EUMETSAT (ocean). Level-2 atmospheric information relevant for both application domains, such as water vapour, is reported in both data streams.

Level-2 Land products in Full Resolution (FR) or Reduced Resolution (RR) (OL_2_LFR and OL_2_LRR) are:

- surface product as Global Vegetation Index (OGVI) and Terrestrial Chlorophyll Index (OTCI)
- atmosphere by-products as Integrated Water Vapour (IWV) column (this product also contains information for water pixels and is identical to that included in OL_2_WRR and OL_2_WFR)
- error estimates for all products

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

- rectified reflectance for red and MIR channels (RC681 and RC865)
- classification, quality and science flags (LQSF)
- 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.

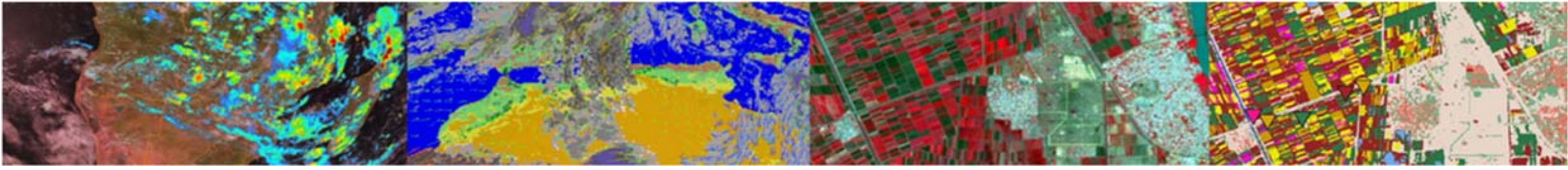


Table 3: OLCI Level-2 land and atmospheric geophysical product

Variables	Description	Units	Input Bands
OGVI	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) in the plant canopy	dimensionless	Oa3, Oa10, Oa17
OTCI	Estimates of the Chlorophyll content in terrestrial vegetation, aims at monitoring vegetation condition and health	dimensionless	-
IWV	Total amount of water vapour integrated over an atmosphere column	$kg.m^{-2}$	Oa18, Oa19
RC681 and RC865	By-products of the OGVI, the so-called red and NIR rectified reflectances, are virtual reflectance largely decontaminated from atmospheric and angular effects, and good proxy to Top of Canopy reflectances.	dimensionless	Oa10, Oa17

Level-2 Water / Ocean products in Full Resolution (FR) or Reduced Resolution (RR) (OL_2_LFR and OL_2_LRR*)* are:

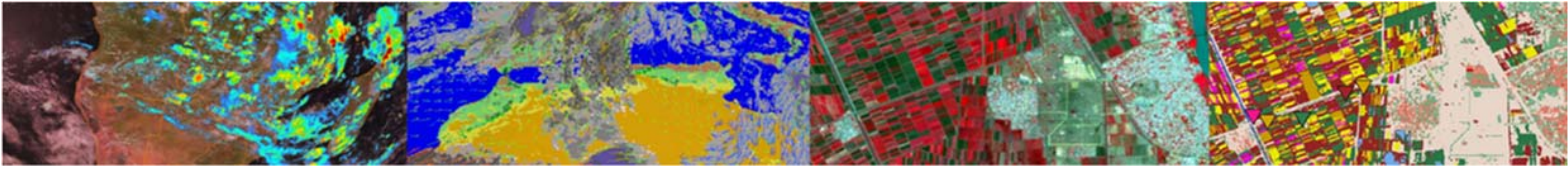
- water-leaving reflectance (Rxxx) for all bands except those dedicated to measurement of atmospheric gas. Two types of reflectance are distinguished: the BAC reflectance for "Baseline Atmospheric Correction algorithm"(MERIS heritage) or AAC reflectance for "Alternative Atmospheric Correction algorithm" (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.
- ocean colour products such as algal pigment (chl_oc4me and chl_nn, in two separated files), Total Suspended Matter (TSM_NN) concentrations and transparency characterisation based on the Diffuse Attenuation coefficient (KD490_M07).
- neural network water-inherent optical properties such as CDM absorption (ADG_443_NN).
- 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.
- 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: OLCI Level-2 water / ocean and atmospheric geophysical product

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.	$\mu Einstein.m^{-2}.s^{-1}$	-
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



SLSTR Level-1 and 2 data products are available to the general public. The SLSTR files are collected into a SAFE container. Level-1 and 2 products are provided as netCDF4 product files. There are different data products associated with these levels of processing of SLSTR:

- Level-1 includes Top-of-Atmosphere (TOA) radiometric measurements, radiometrically corrected, calibrated and spectrally characterised. It is quality controlled, ortho-geolocated (latitude and longitude coordinates, altitude) and annotated with satellite position and pointing, landmarks and preliminary pixel classification (e.g. land/water/cloud masks).
- Level-2 products consist of geophysical quantities derived from the processing of the measurements data provided in the Level-1 product. Level-2 products specifically for marine and land application domains are generated separately by ESA (land) and EUMETSAT (ocean).

Based on the combination of SLSTR and OLCI products, SYN is composed of mainly two Level-2 product types:

- Surface reflectances and aerosol parameters over land projected on OLCI 300 grid for all SLSTR and OLCI channels (except thermal and absorption)
- SPOT continuity products reproducing similar characteristics of the VEGETATION instrument observation. Ensuring the continuity of SPOT VEGETATION missions, its main aim is monitoring land use, its evolution and impact of weather and climate on agricultural activities. SYN is also an essential information source for worldwide food security. It would also be able to add to climate studies by supplying a continuous NDVI time series initiated by AVHRR and VEGETATION.

The SYN Level-2 product is composed of five different packets, all available to the user except the VGK product:

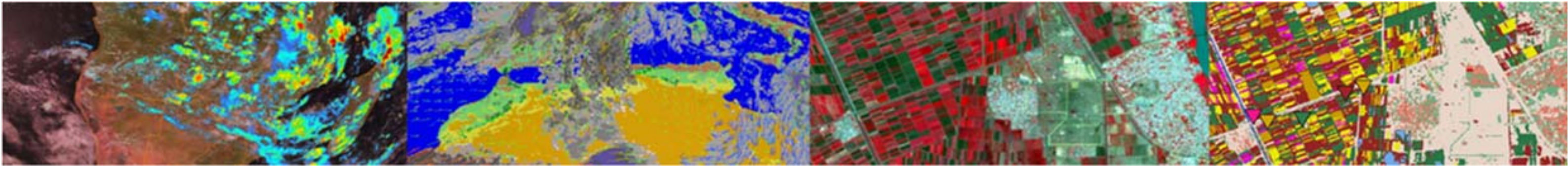
- SY_2_SYN includes surface reflectances and aerosol parameters over land
- SY_2_VGP includes TOA reflectances on 1 km VEGETATION-like product
- SY_2_VGK includes surface reflectances and NDVI for spectral VGT channels
- SY_2_VG1 includes 1 day synthesis surface reflectance and NDVI on 1 km VEGETATION-like product
- SY_2_V10 includes 10 day synthesis surface reflectance and NDVI on 1 km VEGETATION-like product.

For further information consult the Sentinel-3 SYN User Guide, available at https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-3-synergy. The official release of these products to the user community is planned during 2018.

SRAL/MWR Level-2 products, corrected for geophysical effects (including the Level-1 data corrections for instrument effects) are available to the general public. SRAL/MWR files are collected into a SAFE container. Level-1 and 2 products are provided as netCDF4 product files. The main application of the Sentinel-3 topography mission is the study of ocean topography including mean sea level, wave height, wind speed over the surface, sea-ice, ocean currents, Kelvin and Rossby waves, eddies and tides. The geophysical parameters to be measured by the Sentinel-3 topography mission are:

- Sea Surface Height (SSH)
- Significant Wave Height (SWH)
- Wind speed over ocean surface.

The ESA Broadview Radar Altimetry Toolbox (BRAT) can be used to visualise and operate Level-2 products, see also http://www.altimetry.info/toolbox/.

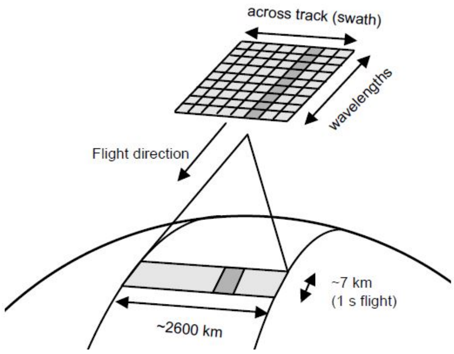


2.5 SENTINEL 5 PRECURSOR

A precursor satellite mission, Sentinel-5P aims to fill in the data gap and provide data continuity between the retirement of the Envisat satellite and NASA's Aura mission. Sentinel-5P was launched in October 2017. The single payload of the S5P mission is TROPOMI and is foreseen to be operated till 2023. The satellite will make daily global observations of key atmospheric constituents, including ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, methane, formaldehyde as well as cloud and aerosol properties. TROPOspheric Monitoring Instrument (TROPOMI), is developed by the Netherlands in cooperation with the European Space Agency (ESA). TROPOMI is a nadir viewing shortwave spectrometer, measuring in the UV-visible wavelength range (270 – 500 nm), the near infrared (710 – 770 nm) and the shortwave infrared (2314 – 2382 nm). S5P uses a high inclination (approximately 98.7°) sun-synchronous orbit with an ascending node equatorial crossing at 13:30 hr Mean Local Solar time. The orbital cycle is 16 days (14 orbits per day, 227 orbits per cycle). The orbit reference altitude is approximately 824 km.

The instrument uses passive remote sensing techniques by measuring at the top of the atmosphere the solar radiation reflected by and radiated from the Earth. The instrument operates in a push-broom configuration with a wide swath. Light from the entire swath is recorded simultaneously and dispersed onto two-dimensional imaging detectors: the position along the swath is projected onto one direction of the detectors, and the spectral information for each position is projected on the other direction. The instrument images a strip of the Earth on a two dimensional detector for a period of approximately 1 second during which the satellite moves by about 7 km. This strip has dimensions of approximately 2600 km in the direction across the track of the satellite and 7km in the along-track direction. After the 1 second measurement a new measurement is started thus the instrument scans the Earth as the satellite moves. The two dimensions of the detector are used to detect the different ground pixels in the across track direction and for the different wavelengths. The measurement principle of TROPOMI is shown in the figure below.

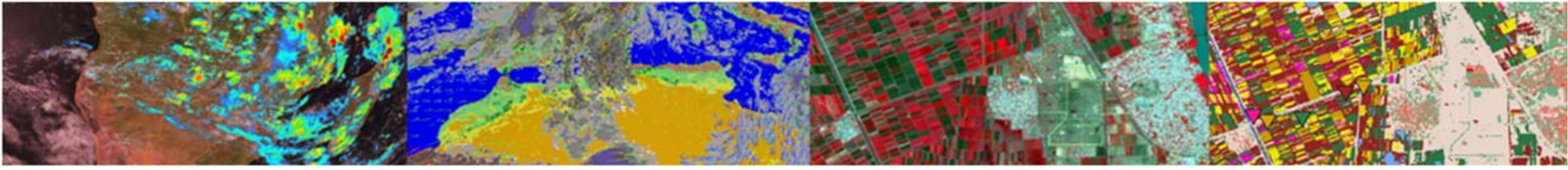
Figure 10: TROPOMI measurement principle



TROPOMI utilizes a single telescope to form an image of the target area onto a rectangular slit that acts as the entrance slit of the spectrometer system. There are four different spectrometers, each with its own optics and detector: medium wave ultraviolet (UV), long wave ultraviolet combined with visual (UVIS), near infrared (NIR), and short wave infrared (SWIR). The spectrometers for UV, UVIS and NIR are jointly referred to as UVN. The table below lists the spectral characteristics of the four TROPOMI spectrometers and the definition of the TROPOMI spectral bands with identifiers 1 to 8. Level 1B-Bands 1-8 Radiance and UVN - S(W)IR Irradiance are available in the Sentinel-5P Pre-Operations Data Hub (https://s5phub.copernicus.eu/).

Table 5: Main spectral characteristics of the four TROPOMI spectrometers and the definition of the spectral bands ID 1 to 8.

Instrument module	UVN						SWIR	
Detector	UV		UVIS		NIR		SWIR	
Band ID	1	2	3	4	5	6	7	8
Spectral range [nm]	270–300	300–320	320–405	405–500	675–725	725–775	2305–2345	2345–2385
Spectral resolution [nm]	0.5	0.5	0.5	0.5	0.5	0.5	0.23	0.23
Spectral sampling [nm/pixel]	0.065	0.065	0.20	0.20	0.124	0.124	0.084	0.097



TROPOMI has a spatial resolution of 7 x 3.5 km at nadir for bands 2 – 6 (UVN), 7 x 7 km at nadir for bands 7 and 8 (SWIR), and 21 x 28 km at nadir for band 1 (deep UV). For the UVN spectrometers about 20 million spectra are observed per day. With that resolution TROPOMI is a major step forward compared to its predecessors OMI (Ozone Monitoring Instrument), SCIAMACHY (SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY) and GOME-2 (Global Ozone Monitoring Experiment-2). The spatial resolution is combined with a wide swath to allow for daily global coverage. The TROPOMI/S5P geophysical (Level 2) operational data products which can be pre-processed using this toolbox are: nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), methane (CH4) and formaldehyde (HCHO).

An example of the file name for a L1b radiance product in netCDF format, containing the radiance measurements of Band 1 (of the UVN module), is:

> “S5P_OFFL_L1B_RA_BD1_20191114T112005_20191114T125934_00140_02_010203_20151204T093045.nc”

The Level 2 product file name convention, using the CO product as example, is:

> “S5P_OFFL_L2__CO_____20190101T000000_20190102T000000_00099_01_000200_20141010T173511.nc”

The components of the file names are given in the table below.

Table 6: File name syntax explanation

Start	End	Length	Meaning
0	3	3	Mission name, always “S5P”
4	8	4	Processing stream, one of “NRTI” (near real-time), “OFFL” (offline) or “RPRO” (reprocessing)
9	19	10	Product identifier
20	35	15	Start of granule in UTC as “YYYYMMDDTHHMMSS”. The “T” is a fixed character.
36	51	15	End of the granulein UTC as “YYYYMMDDTHHMMSS”. The “T” is a fixed character.
52	57	5	Orbit number
58	60	2	Collection number
61	67	6	Processor version number as “MMmmpp”, with “MM” the major version number, “mm” the minor version number, and “pp” the patch level.
68	83	15	The time of processing for this granule in UTC as “YYYYMMDDTHHMMSS”. The “T” is a fixed character.
84	86	2	The file name extension. All Sentinel 5 precursor files are netCDF-4 files and use the extension “nc”

For level 1B, the spectral ranges (nm) for the various bands (1 to 8) used in the import routine are: [(266.8,299.1),(300,320),(320,405),(397.8,498.6),(657,725),(725,775),(2305,2345),(2345,2385)]. These ranges could not be officially confirmed, different ranges are reported!

Using a definition ‘ephoton(wavelength)’ the conversion to radiance is handled as given below:

A	= 6.02214E23 # [mol-1]	Constant of Avogadro
h	= 6.6262E-34 # [J s]	Planck's constant
c	= 299792458 # [m s-1]	Speed of light

Conversion: A*h*c/wavelength # [J] Energy of 1 photon

The (centre) wavelength is derived from the band used and the spectral interval can be specified by the user. For the quality mask the following flag values can be expected: 0 1 2 4 8 16 128. Flags have the following meaning = no_error, solar_eclipse, sun_glint_possible, descending, night, geo_boundary_ crossing and geolocation_error respectively.

2.6 DATA DOWNLOAD FROM COPERNICUS OPEN ACCESS HUB

The 'Copernicus Open Access Hub' is available at https://scihub.copernicus.eu, free registration can be done online. It is assumed that you have registered and have access to the Hub.

The Open Access Hub currently provides complete, free and open access to Sentinel-1, Sentinel-2, Sentinel-3 (Land) user products and Sentinel 5P Pre-Operations Data Hub. The following products are currently available:

- For Sentinel-1 the Level-0 and Level-1 user products for the following acquisition modes are available:
    - Strip Map (SM)
    - Interferometric Wide Swath (IW)
    - Extra Wide Swath (EW)
- For Sentinel-1 the Level-2 user products for the following acquisition modes:
    - Wave (WV)

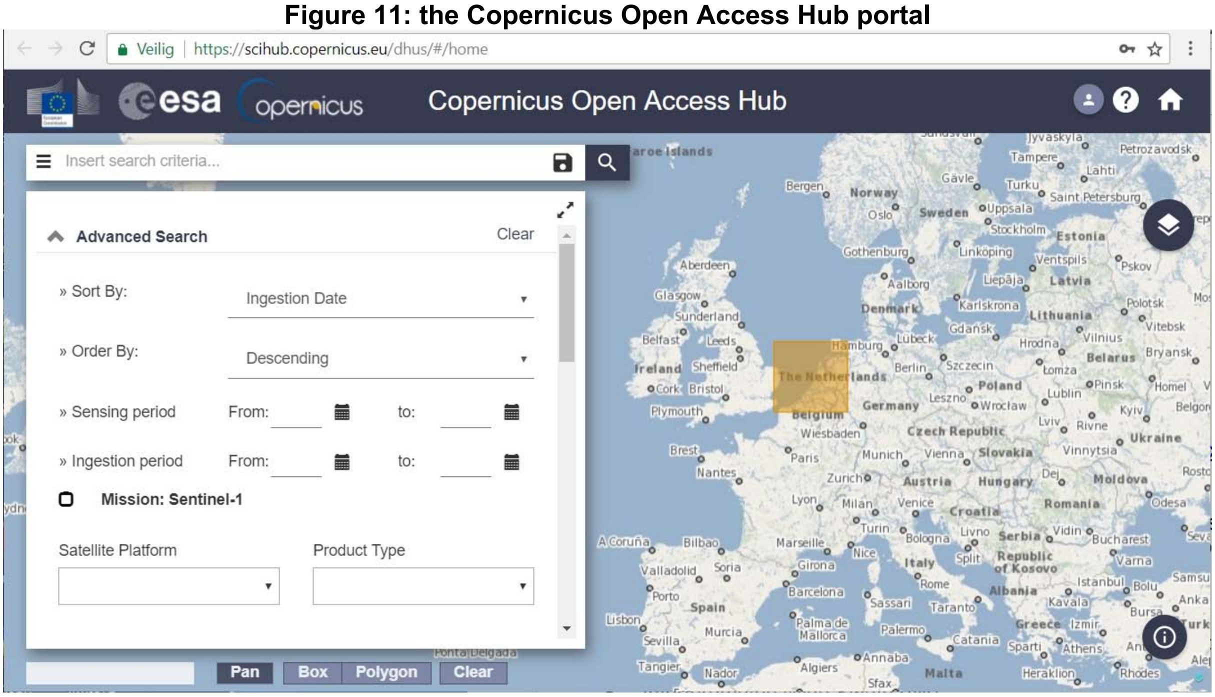
- The Sentinel-2 data provided within the Open Access Hub is consisting of Level-1C and Level-2A user products.

- The Sentinel-3 data in the Open Access Hub consists of Level-1 and Level-2 (Land) user products for the OLCI, SLSTR and SRAL instruments.

- The Sentinel-5 Precursor data in the Pre-Operations Data Hub consists of Level-1b and Level-2 geophysical products derived from the TROPOMI instrument.

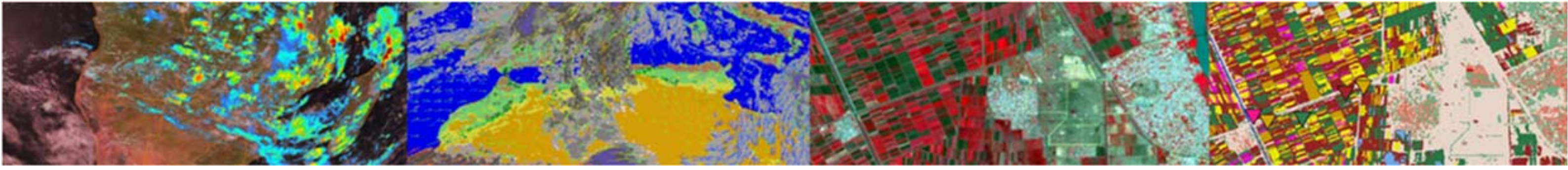
When navigating to the 'Copernicus Open Access Hub' a web-server is shown in your browser, identical to the figure below. Use the "Pan" option to change the geographic location and the "Box" option to select your AoI.

Figure 11: the Copernicus Open Access Hub portal



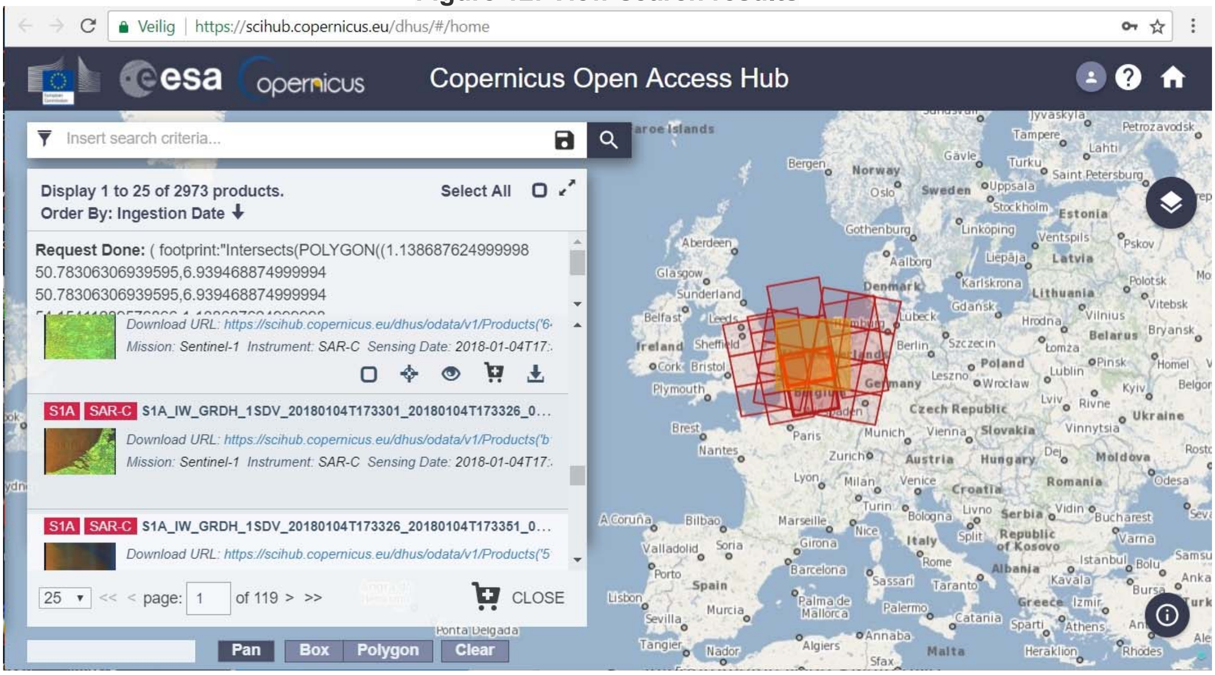
Different search criteria for the different products can be inserted, e.g. here as example the platform selected is Sentinel-1A (S1A_*) and the product type is GRD. The search area covers the Netherlands.

When activating the "Search" icon a search is conducted applying the criteria used. Once the search is completed the results are shown, as indicated in the figure below. By scrolling through the search result list one can select the most suitable image(s). For most of the products, next to the small quick looks



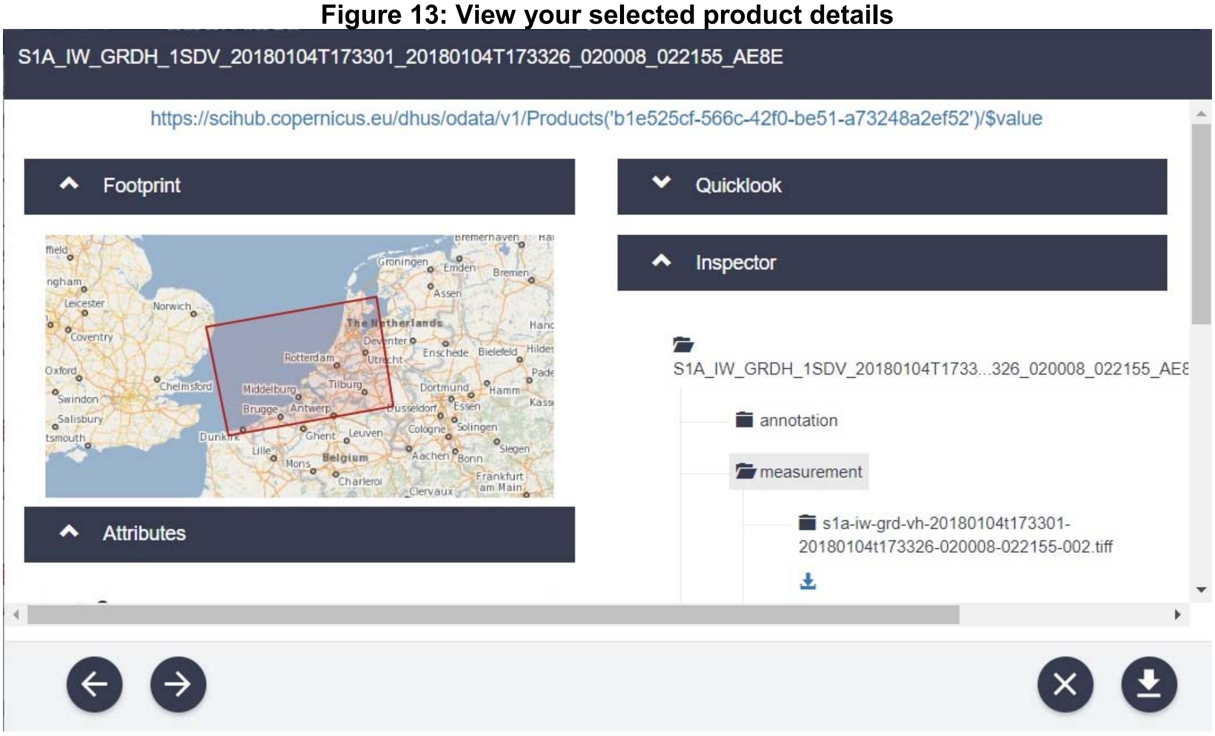
available to get an idea about the image details (e.g. in term of cloud cover – note that this is not applicable for Sentinel-1), other options for a selected product are to zoom to the product in the map window, to view product details, to add the product to the cart and to download the product. Also the direct download URL is provided.

Figure 12: View search results



Using the option “view product details” another window opens, see also the figure below.

Figure 13: View your selected product details



Using the slide bars at the bottom and right hand side of this window allows one to see the complete information provided. It should be noted that additional information is provided when selecting, under “Inspector” the file details. This provides the option do download individual files and not the whole data set. It should be noted that the complete datasets are of considerable file sizes. If only a few channels are required, download of these specific channels only can be helpful especially when working in a low bandwidth environment. For some software tools the full data set is required, like when SNAP is going to be used. When using the EO4SD toolbox the individual images / channels can be processed.

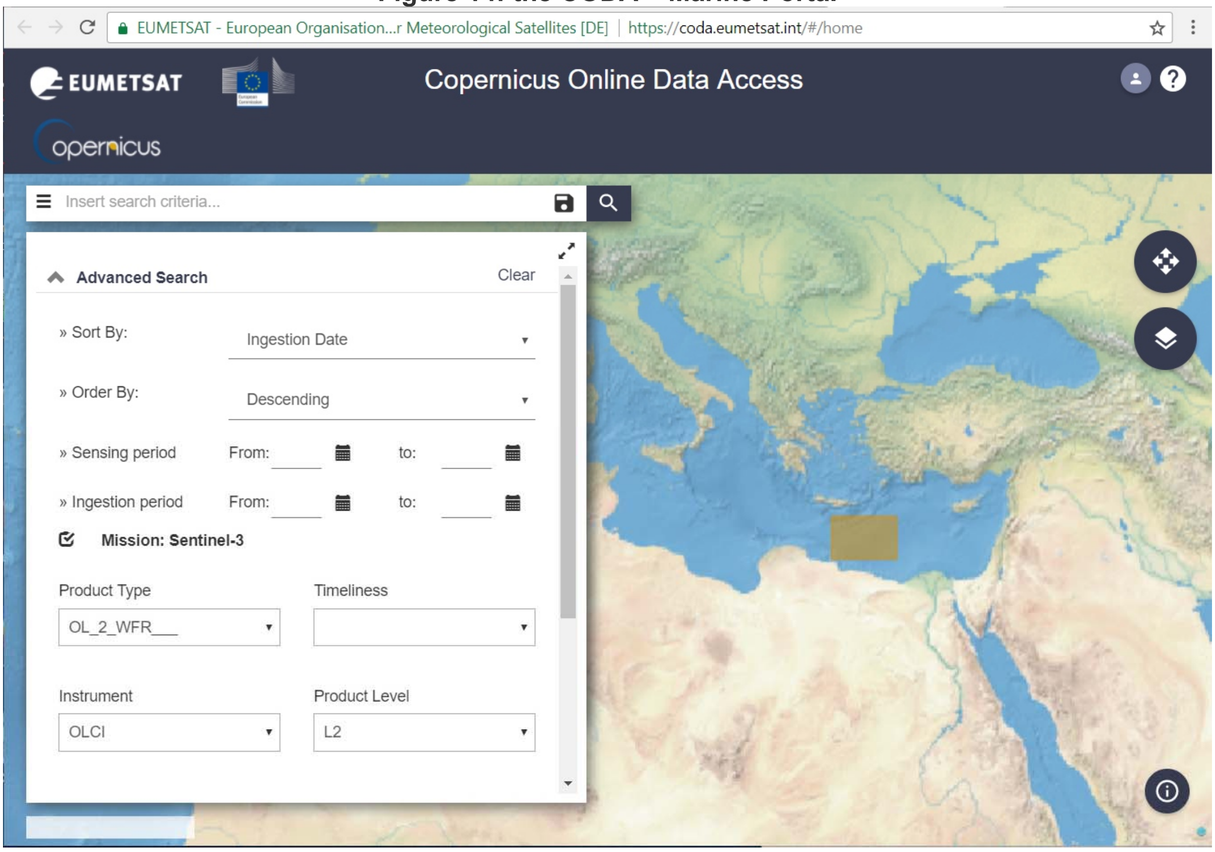
2.7 Data download from Copernicus Online Data Assess Service

The Copernicus Marine Sentinel-3 data is processed at EUMETSAT and the Sentinel Level-1 and Level-2 Marine data is available online through the CODA portal. Download service offers all the recently acquired Sentinel-3 marine and atmospheric products through a rolling archive that (at a maximum) will span 12 months.

If you already have an Earth Observation Portal (EO Portal) account, use your account credentials to log into CODA. Go to https://coda.eumetsat.int (please use Chrome or Firefox). Click 'OK' to be redirected to the EO Portal login screen. Alternatively go to https://eoportal.eumetsat.int/userMgmt/login.faces, create a new account, log in and follow the link 'Copernicus Online Data Access'. Older data (than 12 months including the Copernicus Sentinel-3 marine and atmospheric products) can also be ordered through the EUMETSAT Data Centre, for further information see: https://www.eumetsat.int/website/home/Data/DataDelivery/EUMETSATDataCentre/index.html.

Once logged in the Java web based Data Hub is displayed, see also the figure below. The top right icon allows to draw your region of interest or to navigate on the map. The other features are identical to the Copernicus Open Access Hub, described above.

Figure 14: the CODA – Marine Portal

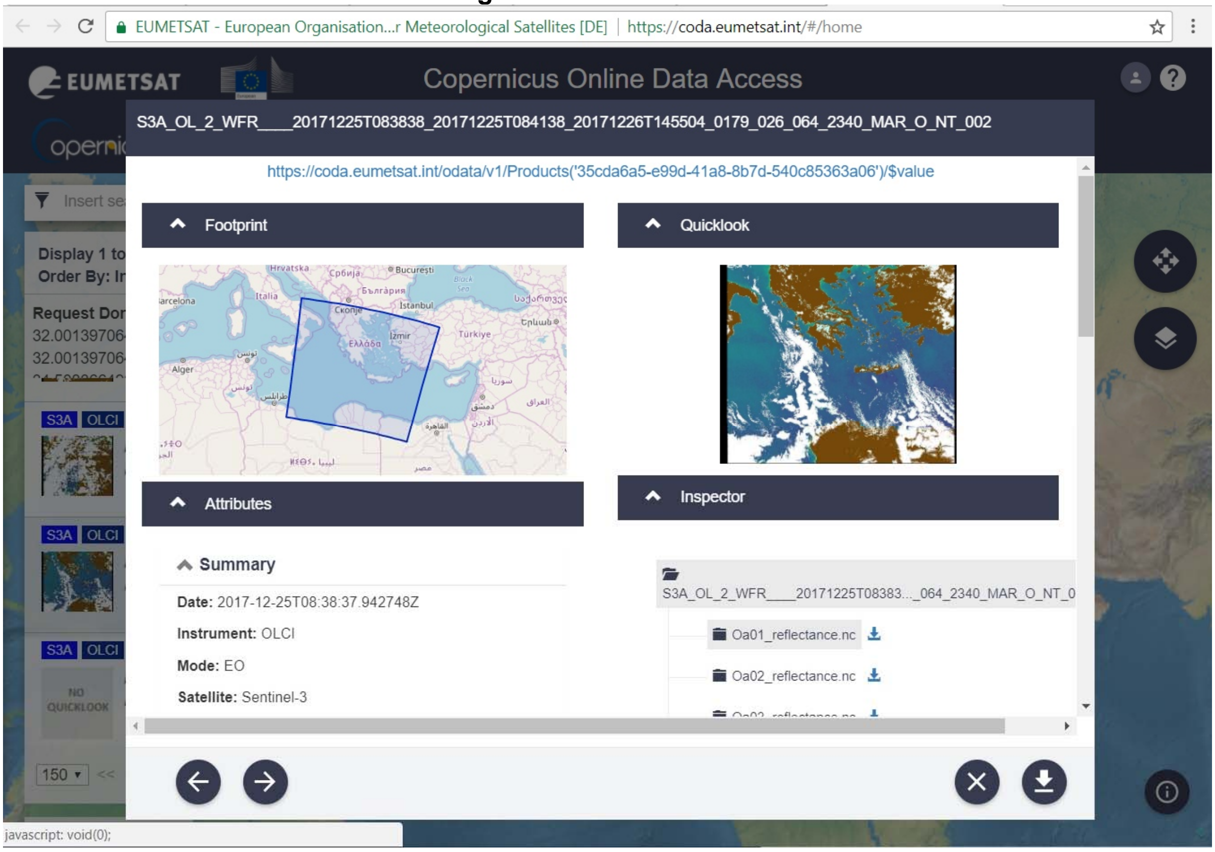


Note the following acronyms for OLCI and SLSTR Level-1 and Level-2 products:

- OL_1_EFR or OL_1_ERR: Full (FR) or Reduced (RR) resolution top of atmosphere radiance
- OL_2_WFR or OL_2_WRR: Full (FR) or Reduced (RR) resolution water and atmosphere geophysical products

- SL_1_RBT: Brightness temperature and radiances.
- SL_2_WST: Level 2P Sea Surface Temperature (GHRSST like)

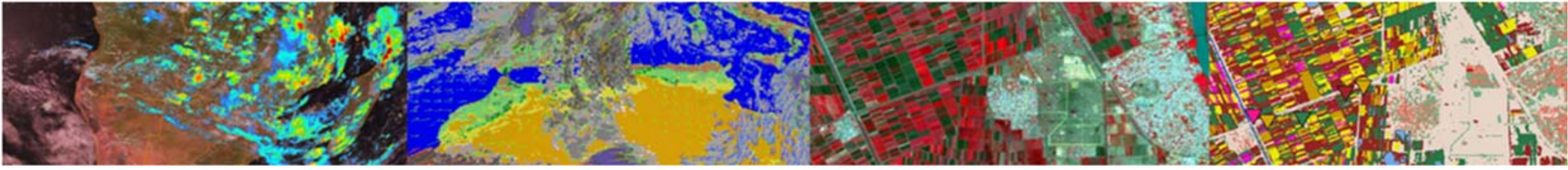
Figure 15: CODA results



For further information on CODA download, see also: https://coda.eumetsat.int/manual/CODA-user-manual.pdf. Note that individual channels can be retrieved, no need to download the full products if there is a bandwidth limitation.

Level-1 (EFR, ERR) and Level-2 OLCI (WRR) Marine products are currently also provided through EUMETCast. The Ocean and Land Colour Instrument (OLCI) Full Resolution (FR) Level L2 data is also provided through the EUMETCast broadcast HVS-2 service as from 2018. The High Data Volume Service (HVS), now disseminates (amongst others):

- Sentinel 3 OLCI level 1 EFR
- Sentinel 3 OLCI level 1 ERR
- Sentinel 3 OLCI level 2 WRR
- Sentinel 3 SR level 2 WAT
- Sentinel 3 Corrected Sea Surface Height
- Sentinel 3 SLSTR level 2 WST



3. DOWNLOAD AND INSTALLATION OF SENTINEL EO4SD TOOLBOX

3.1 INTRODUCTION

The EO4SD-Toolbox is a stand-alone application, developed under Python 36, facilitating the import of images acquired by the Sentinel suite of satellites and transforms the images in a format so it can be ingested in ILWIS and QGIS, free GIS-RS software tools, for further image processing. The toolbox is developed to support education and research in geo-sciences under an ESA sponsored project, called EO4SD. The Toolbox works can currently be operated on a 64 bits Windows Operating System.

3.2 DOWNLOAD ILWIS AND THE SENTINEL EO4SD TOOLBOX

To download the EO4SD toolbox and ILWIS372, navigate to the following link:

https://filetransfer.itc.nl/pub/52n/ILWIS386/Toolbox_plugin/EO4SD_toolbox/Version_2

The ILWIS version found in this link is the version used for the preparation of the exercises, which are available in the toolbox manual. This manual provides step by step exercises to utilize the images and products provided by Sentinel 1, 2, 3 and 5P.

Figure 16: File repository link

Click on the 3 zip files provided to download these, save them in a temporary folder on your system.

To install ILWIS372, unzip the file “ILWIS372.zip”, copy the new folder created “ILWIS372” to the root of your C:\ drive. On your C:\ drive you should have a folder C:\ILWIS372. In this folder, select the file “ILWIS.exe”, right-click with the mouse on the file and from the new menu appearing, select the options “Send to” > “Desktop (create shortcut)”. Double click with the mouse the new shortcut created on your desktop and check if the ILWIS372 installation was successful.

If you are already familiar with ILWIS372 and know how to visualize the data you can also upgrade to ILWIS386. The ‘main touch and feel’ has not changed, apart from how the images are displayed and new display options are provided. The latest official version of the ILWIS (currently version 3.8.6) is freely available at http://52north.org. However, this document focuses on downloading and installing the most recent unofficial version from the following download link, which includes the latest functionality and bug fixes:

https://filetransfer.itc.nl/pub/52n/ILWIS386/Software/

Using the link provided above, download the latest version of ILWIS386. At the time of writing this document this is ‘ILWIS386_20201116.zip’ (version of 16-November-2020). The full installation instructions for ILWIS are given at: https://filetransfer.itc.nl/pub/52n/ILWIS386/Tutorial/ as well as a tutorial and exercise descriptions which are useful if you are not familiar with the software tool. The tutorial is highlighting the main new functionality and once you are familiar with these you can also use this ILWIS version in conjunction with the EO4SD toolbox and the manual provided to conduct the exercises.

To install ILWIS-386, download the file “ILWIS Installation Instructions.pdf” and follow the step by step description to install ILWIS386. In this document it is assumed that the ILWIS installation instructions are strictly followed and the ILWIS software is situated in the folder “C:\ILWIS386_*date*”, were “*date*” is the latest release of ILWIS, at the moment of writing / editing this document: “*20201116*”.

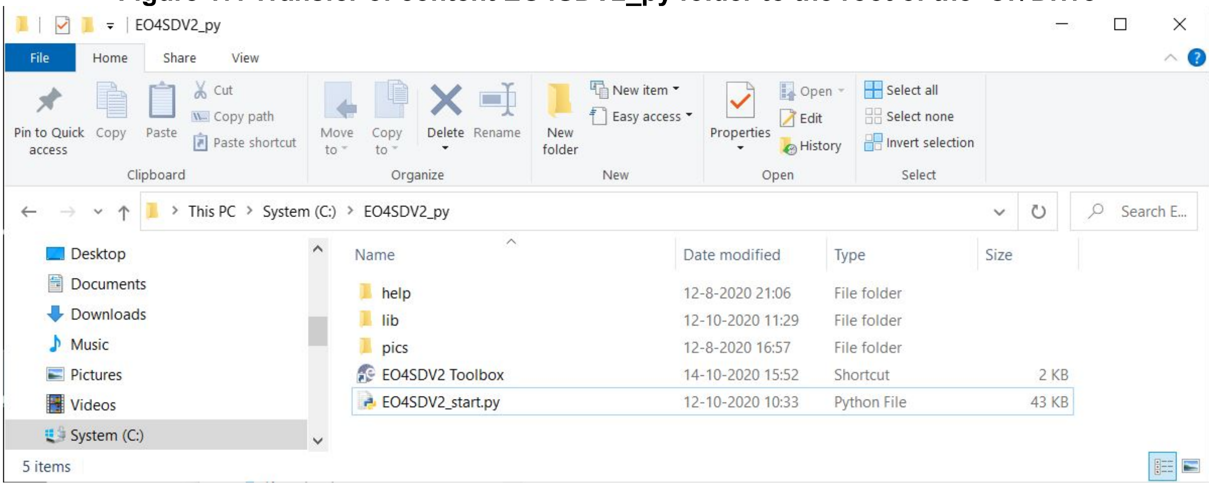
3.3 QUICK INSTALLATION OF THE EO4SD TOOLBOX AND ANCILLARY TOOLS

To install and configure the EO4SD Toolbox, here version 2, follow the steps described below.

Step 1: From the temporary folder / directory:

- Unzip the file ‘EO4SDV2_py.zip’ and copy the new folder created to the root of the C:\ drive. On your C:\ drive you should have a folder C:\EO4SDV2_py

Figure 17: Transfer of content EO4SDV2_py folder to the root of the C:\ Drive



Step 2: From the temporary folder / directory:

- Unzip the file ‘python36.zip’ and copy the new folder created to the root of the C:\ drive. On your C:\ drive you should have a folder C:\Python36. The toolbox expects some site-packages to be available in Python36, like a ‘NetCDF-reader’, ‘ILWISObjects-forPython3.6-64bit.’ and ‘GDAL’. These have already been provided within this Python version, so there is no need to install these yourself.

Note that the Python 36 version and all toolbox side packages used are also available from: http://filetransfer.itc.nl/pub/52n/ILWIS386/Toolbox_plugin/EO4SD_toolbox/Version_2/resources64/.

Note next to Python, the other resources required like the GDAL and NetCDF wheels (Python Side Packages) and ILWISObjects. These can be used if a modified installation is required. This package expects the folder “Python36” on the root of the C:\ drive!

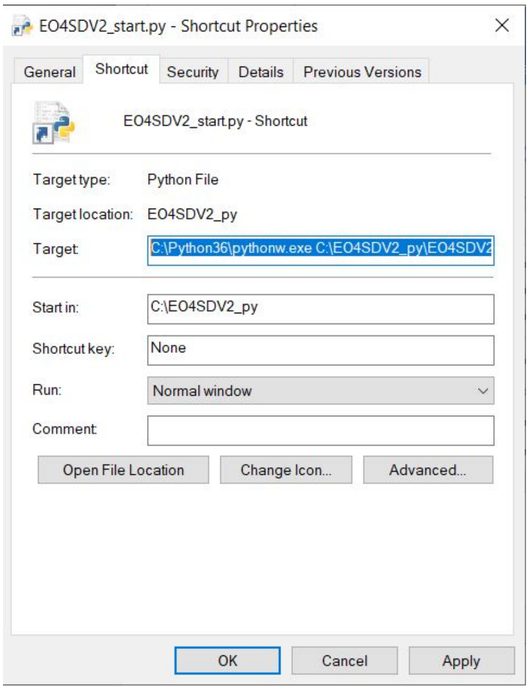
3.4 START THE EO4SD-TOOLBOX

As we have not gone through a full Python installation (only used a copy provided), one of the remaining issues to ensure that the Python executable (here C:\python36\python.exe and C:\python36\pythonw.exe) is recognized by your system using the proper reference to the 'drive:\directory' location of this executable. A simple way to do this is by creating a short-cut with the appropriate 'Target' settings.

- Creating a short-cut:

  From the C:\EO4SD_py directory, right click the file 'EO4SDV2_start.py' and select the option "create shortcut". Right-click the shortcut created, here 'EO4SDV2_start.py - Shortcut', see also the figure below.

Figure 18: Create an EO4SDV2_start.py - Shortcut



Now change the Target to:

C:\Python36\pythonw.exe C:\EO4SDV2_py\EO4SDV2_start.py

Now verify or change for the option 'Start in' to:

C:\EO4SDV2_py

Assuming that you have installed the "EO4SDV2_py" utility on the C:\ drive, else change accordingly. Once done, save the changes by clicking the "Apply" button.

Within the shortcut properties you can also change the name (under the tab "General") and also add another icon, use the option "Change Icon..", see for the icon your directory: C\EO4SDV2_py\pics\esa.ico and click "Apply".

Eventually right-click the shortcut created and use the option 'Send to desktop (create a shortcut)'.

Note that a shortcut “EO4SDV2 Toolbox” is also available in the folder, using the settings provided above. You can also ‘drag and drop’ this shortcut to your desktop.

3.5 WORKING WITH THE EO4SD TOOLBOX

Please take into consideration, straight from the start, the following golden rules when using ILWIS and the EO4SD Sentinel toolbox:

- Don’t use spaces in (sub-) directory or file names, instead use underscores;
- Do not only use numbers as file names, ensure that you start the file name with a character;
- Do not work in multiple output directories;
- Start ILWIS, navigate to your working directory and close ILWIS. Open ILWIS again to ensure that your current working directory is also the actual ILWIS working directory.

Smooth operations are experienced when the ILWIS folder as well as the Python36, EO4SD-toolbox and working directories are situated in the root of your system drive, without spaces in folder names! A known issue is that on new systems some DLL’s required might not be available in the Windows System32 or Syswow64 folders, like msvcr100 and msvcp100 dll’s. You could download and install the Microsoft Visual C++ Redistributable Packages by running the “vc_redist” executable, compatible with your operating system. If having troubles, contact the authors.

Double click the EO4SD toolbox shortcut created. From the menu, select the menu item “Help” > “User Manual”.

Chapters 1 and 2 provide an introduction to Sentinel suite of satellites and how to retrieve the data from open online archives. Chapter 3 can be partially omitted, as the installation has already been done for the toolbox, Python and ILWIS. The exercises also make use of QGIS and SNAP, within chapter 3.6 references are made to these free resources.

Chapter 4 and 5 are exercises. The data required for the exercises can be downloaded from: http://filetransfer.itc.nl/pub/52n/ILWIS386/Data/. Download the file “EO4SD_toolbox_Exercise_Data1.zip” (for Sentinel 1, 2 and 3) and “EO4SD_toolbox_Exercise_Data2.zip” for some of the S5P Level 2 products. S5P Level 1B data has to be downloaded by the user from the S5P repository. Note that these are very large files (more than 7 GB). Create a working directory and get started.

You can download the Sentinel 1, 2,3 and 5P data from the online archive(s) and work with other sample files from https://scihub.copernicus.eu/.

3.6 DOWNLOAD OF OTHER SOFTWARE UTILITIES

A number of software tools are required to work with the data provided by the Sentinel program. The software tools used within this training package are all freely available and can be obtained online. Below the sources to download the software are described. All tools used are for a Windows 64 bit Operating System. Tools have been tested on Windows 7 and Windows 10. Not all tools are required to run the EO4SD toolbox. The use of the toolbox requires Python, two Python extensions (Gdal and netCDF4), ILWIS-Python plugin and ILWIS or QGIS, used for visualization of the Sentinel data imported. SNAP (and Snappy) can be used later on.

QGIS Version 2.14 - QGIS-Essen
Go to: https://www.qgis.org/en/site/, select the option ‘download now’ and select from the Long Term Release repository the version “QGIS Stand Alone Installer 2.14 (32 or 64 bit, which will be used here)”. You can also go to http://download.qgis.org.

To Install QGIS, here Version 2.14 - QGIS-Essen, Activate the installer, here “QGIS-OSGeo4W-2.14.21-1-Setup-x86_64” downloaded and:

- Use default installation settings
- Save eventual work and reboot your system
- Start a QGIS session to check installation

Not all functionality is available in the tools provided, if you look for some advanced tools then the Sentinel Application Platform (SNAP) should be used. Note that to make optimum use of SNAP a complete download of a selected Sentinel data sets is required.

SNAP Version 7

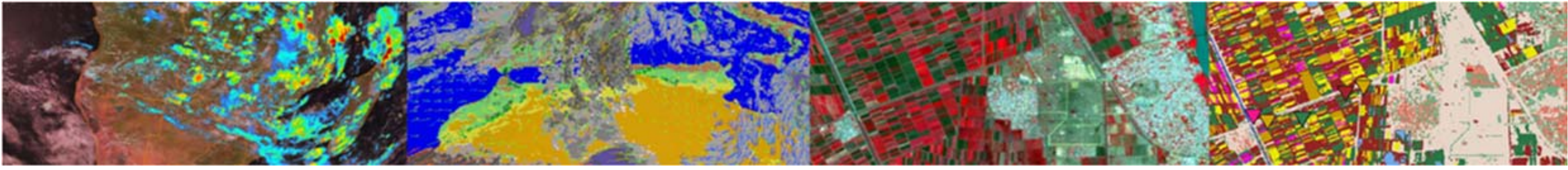
Go to http://step.esa.int/main/toolboxes/snap/. Select the Sentinel toolbox for your operating system, e.g. Windows 32 or 64 bit. Use the ‘download’ link, note that 64-Bit is used here, to ensure compatibility with the other resources. Note that SNAP is using JAVA. Most likely Java is already available on your system, if this is not the case, then navigate to https://java.com/en/download/ and follow the installation instructions.

To Install SNAP, here version 5, run the installer ‘esa-snap_sentinel_windows-x64_7_0.exe’ (install4y.wizard):

- Use default installation settings
- Activate the option: Configure SNAP for Python, navigate to the Python34 directory and select python.exe
- Installation starts, accept the other defaults and press finish to complete installation
- Start SNAP to check if installation is correct

Most likely, once a new session of SNAP is started, a message appears that new updates are available. Accept the message and the updates will be installed and SNAP will be restarted to allow the updates to be activated.

With all these tools installed you are ready to conduct the exercises as provided in the remainder of the document.



4. WORKING WITH THE SENTINEL EO4SD TOOLBOX

4.1 IMPORT SENTINEL DATA AND PRODUCTS IN ILWIS/QGIS

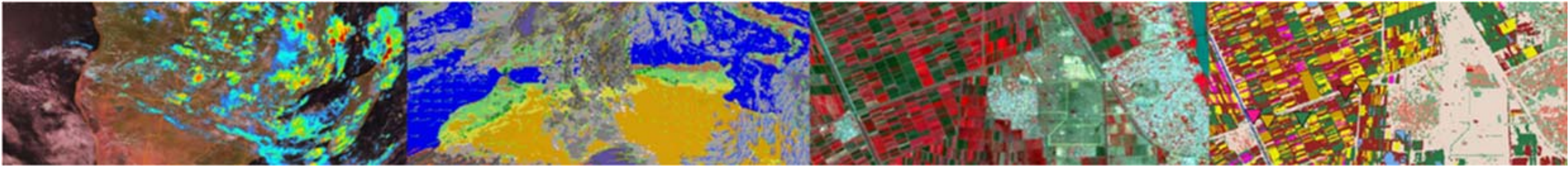
In the table below a summary is provided on the Sentinel data in Full Resolution (FR) which can be processed using the toolbox. The table is providing the naming convention of the SAFE file 'container' and netCDF files (e.g. for S5P) used.

Table 7: Toolbox Sentinel data processing routines

Satellite	Instrument	Level	Channels / Polarizations	Products	File name prefix
S1 A / B	SAR	L1C-GRD	Single and dual polarizations	IW mode	S1A_IW_GRDH_1SDV_
S2 A / B	MSI	L1C	01-21	ToA radiance	S2A_MSIL1C_ *
	MSI	L1C		TCI	S2A_MSIL1C_ *
S2 A / B	MSI	L2	01-21	BoA reflectance	S2B_MSIL2A_*
	MSI	L2		TCI	L2A_T31UFU_ * _TCI_*
S3 A - Land	OLCI	L1	01-21	ToA radiance	S3A_OL_1_EFR_ * _SVL*
	SLSTR	L1	VIS – SWIR: 01-06	ToA radiance	S3A_SL_1_RBT_ * _SVL*
			TIR: 07 - 09	ToA BT	S3A_SL_1_RBT_ * _SVL*
			F: 01 - 02	ToA BT	S3A_SL_1_RBT_ * _SVL*
	OLCI	L2	ogvi	OGVI	S3A_OL_2_LFR_ * _LN1*
			otci	OTCI	S3A_OL_2_LFR_ * _LN1*
	SLSTR	L2		LST	S3A_SL_2_LST_ * _SVL*
S3 A - Ocean	OLCI	L1	01 - 21	ToA radiance	S3A_OL_1_EFR_ * _MAR*
	OLCI	L2	01-12, 16-18, 21	BoA reflectance	S3A_OL_2_WFR_ * _MAR*
			chl_oc4me	Chl-open water	S3A_OL_2_WFR_ * _MAR*
			trsp	KD490-open water	S3A_OL_2_WFR_ * _MAR*
			chl_nn	Chl-complex water	S3A_OL_2_WFR_ * _MAR*
			Iop_nn	ADG443-complex water	S3A_OL_2_WFR_ * _MAR*
			Tsm_nn	TSM-complex water	S3A_OL_2_WFR_ * _MAR*
	SLSTR	L2		SST-skin	S3A_SL_2_WST_ * _MAR*
S5P	Tropomi	L1b	1-8, SIR, UVN	TOA (ir) radiance	S5P_OFFL_L1B_RA_BD4_*
		L2	CO	Carbon Monoxide	S5P_OFFL_L2__CO_____*
			HCHO	Formaldehyde	S5P_OFFL_L2__HCHO___*
			CH4	Methane	S5P_OFFL_L2__CH4____*
			NO2	Nitrogen Dioxide	S5P_OFFL_L2__NO2____*
			SO2	Sulphur Dioxide	S5P_OFFL_L2__SO2____*
Other	Import from SNAP-DIMAP format				*.dim

Within the SAFE file all required data is available. If there is no problem downloading the data then the whole 'SAFE' file can be downloaded onto the local hard disk and the file can be decompressed before use within the toolbox. Also the netCDF files (for S5P) have to be locally available.

On the other hand when download capacity is limited due to small internet band width, individual files required for processing can be selected based on the User needs, see details in figure 13 and figure



15. The table below is showing per Sensor / level and product the type of files required to operate the toolbox. In all cases for Sentinel 1 and 2 the selection of the bands / or polarizations is sufficient. For Sentinel 3 additional files are required as the geocoding is stored as a separate netCDF4 layer. For the S3-OLCI-Land-LST product also the “flags” are required to allow further post-processing, e.g. to remove the impact of clouds. S5P products have a quality mask as a layer in the netCDF file.

Table 8: Individual data layers to be downloaded to operate the toolbox routines

Satellite / Sensor	Resolution / Level	Product	bands	Name input file	Input geolocation file / other ancillary data
S1	IW / L1C	GRD	All polarizations	S1a-iw-grd-**.tiff	none
S2	L1C	MSI bands	01-12	T31UFU_**_B**xx**.jp2	none
		TCI	1	T31UFU_**_TCI.jp2	none
	L2 (at 10, 20 and 60 m)	MSI bands	01-12	L2A_T31UFU_**_B**xx**_10m.jp2	none
		TCI, AOT, SCL, VIS, WVP	1	L2A_T31UFU_**_TCI_10m.jp2 (as example for TCI)	none
S3 - Land					
OLCI	FR / L1	Radiance	01-21	Oa_**xx**_radiance.nc	Geo_coordinates.nc
SLSTR	FR / L1	Radiance (VIS-SWIR)	1-6	S**x**_radiance.nc	Geodetic_an.nc
		FIR	7-9	S**x**_BT_in.nc	Geodetic_in.nc
		F	1,2	F**x**_BT_in.nc	Geodetic_in.nc
OLCI	FR / L2	OGVI	1	Default: ogvi.nc	Geo_coordinates.nc
		OTCI	1	Default: otci.nc	Geo_coordinates.nc
SLSTR	FR / L2	LST	1	Default: lst.nc	Geodetic_in.nc and flags_in.nc
S3-Marine					
OLCI	FR / L1	Radiance	01-21	Oa_**xx**_radiance.nc	Geo_coordinates.nc
	FR / L2	Reflectance	01-12, 16-18, 21	Oa_**xx**_reflectance.nc	Geo_coordinates.nc
		Chl open water	1	Default: chl_oc4me.nc	Geo_coordinates.nc
		KD490-open water	1	Default: trsp.nc	Geo_coordinates.nc
		Chl-complex water	1	Default: chl_nn.nc	Geo_coordinates.nc
		ADG443-complex water	1	Default: iop_nn.nc	Geo_coordinates.nc
		TSM-complex water	1	Default: tsm_nn.nc	Geo_coordinates.nc
		SST-skin	1	**_GHRSST_SSTskin_**	none
S5P					
Tropomi	L1b	(Ir)Radiance	1-8, SIR, UVN	S5P_OFFL_L1B_RA_BD4_*.nc	none
	L2	CO, HCHO, CH4, NO2, SO2	1	S5P_OFFL_L2__**”Product”**____*	none

Where:

xx = band number

** = date and / or orbit number information
Product = selected geophysical product (e.g. CO, HCHO, CH4, NO2, SO2)

Before starting the exercises, ensure that sample data required is locally available and unzipped, eventually download Sentinel data according to your requirements and for Sentinel 3 also the respective geo-coding layers. See chapter 2.6 for further details.

4.2 HANDS-ON EXERCISES USING ILWIS

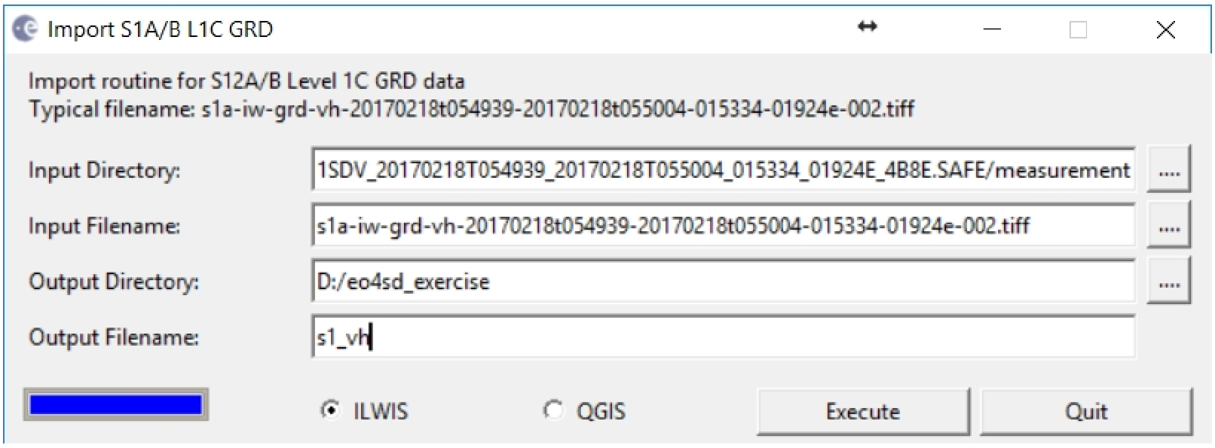
Below a concise description of exercises to be conducted is given, before your start create an output directory, here "d:\eo4sd_exercise" is used.

4.2.1 *Sentinel 1*

Import / visualization of S1A / S1B Radar Level 1C GRD images (IW-GRD-HR-L1):

Open the EO4SD toolbox, select the options "Sentinel 1" > "Sentinel 1A / B L1C GRD", from the sub menu, complete the import settings, both for vv and vh polarization. The sample file is located under /EO4SD_sampledata/S1, for the input directory continue to navigate to the sub directory /measurement. You find the two files with different polarization, a vv polarized and vh cross-polarized image. Import both images, using as output file format ILWIS. After import you can close the Toolbox menus.

Figure 15: Toolbox sub menu to import Sentinel 1 images



Upon completing the import (note the progress bar), open ILWIS 386. Navigate to the output directory defined in the previous step, here d:\EO4SD_exercise. Display the images, using a gray scale Representation and using an appropriate stretch:

- Double click the map "s1_vh", from the left hand menu, use the 'expand' option in front of the map layer name, do the same for the option "Display Tools" > "Portrayal" > "Representation", double click the Representation and select "Gray" as Representation, press "Apply" > "Close".
- Select from the "Display Options" > "Stretch", now type as 'upper stretch', instead of the default value 32767, the value 300, and press OK.
- From the map window menu press the option "Add Map", add the map "s1_vv", also use Gray colour representation and stretch also from 0 to 300.
- Activate the option "Transparency", drag the slide bar from 0 to 100 % and back to compare the difference between the 'vh' and 'vv' polarized images.
- Position the centre of the image at the boundary between water and land, from the map window menu, select "Options", > "No Zoom". From the map window menu press the option "Add Map", from the dropdown button on the right hand of the Filter menu, select instead of "all", the layer "Base maps" > "openstreetmap" and press OK. Note that internet connection is required as the map is obtained online! Open the Display options under "openstreetmap", use different "Transparency" settings, zoom in at different locations on the image and unselect the layer s1_vv (to see the layer below, here "s1_vh"). Check carefully the geometry of the image / map

and the effect of the polarization/ backscatter, also check the image values given in the lower left hand corner of the map display. Try to identify the satellite pass direction, ascending or descending pass direction. Also try to identify different land cover types, using openstreetmap as your ground truth.

Before you continue, create a sub-map. Zoom in to the approximate area as given in the figure below. From the map menu, select the options “File” > “Create” > “Submap”, as raster map specify “s1_vh”, as output raster map specify “s1_vhsub” and press “Define”. Repeat the procedure for the other polarization, call the output map ”s1_vvsub”. Display both images.

You will note that visualization is not optimal, conduct a stretching operation: from the ILWIS main menu, select the options “Operations” > “Image processing” > “Stretch”, as input raster map specify “s1_vvsub”, as output map “s1_vvsubs”, and press “Show”. Repeat the procedure for the map “s1_vhsub” and create as output map “s1_vhsubs”

Conduct Speckle filtering. Given random noise speckle filtering is often required to improve visual interpretation as well as computer assisted classification:

- Apply ‘STD’ filter for the vv and vh polarized images: from the ILWIS main menu, select the options “Operations” > “Image processing” > “Filter”, as input raster map specify “s1_vvsubs”, as filter type select “STD”, apply a 5 rows by 5 columns filter dimension, as output raster specify “s1_vvsubs_std”, as Domain select “Image” and press show. Navigate with your cursor over the image keeping the left mouse button pressed, check the values. Repeat the procedure for the image “s1_vhsubs” and create as output map “s1_vhsubs_std”. Check the values for water, compared to those on land, what is a good threshold to separate water from land?
- Display the results including openstreetmap as transparent layer.
- Display the map “s1_vhsubs_std” once more, from the “Display Options”, select “Interactive Representation”. Use 2 classes, move the slide bar up and down (increasing dark green versus light green and vice versa), and try to determine a good threshold which separates water from land. Repeat the procedure for the map “s1_vhsubs”, can you also define a good threshold or is the backscatter from water mixing with those on land?

A composite RGB (colour) image can also be created, e.g. using the VV channel for red, VH channel for green and the ratio |VV| / |VH| for blue. First the ratio image needs to be calculated. On the ILWIS command line type the following expression:

s1_ratio:=s1_vvsubs_std/ s1_vhsubs_std

As domain select “Value”, keep other settings as their defaults and press OK. As last step also stretch this map. From the ILWIS main menu, select the options “Operations” > “Image processing” > “Stretch”, as input raster map specify “s1_ratio”, as output map “s1_ratios”, and press “Show”.

Now in the ILWIS command line type: mapcolorcomp and in the color composite menu, for Red specify “s1_vvsubs_std”, for Green specify ”s1_vhsubs_std” and for Blue specify “s1_ratio” and as output map “s1_fcc”, press “Show”. Try to determine how many land use / land cover classes can be defined.

Continue with some unsupervised image classification, here we apply the ‘Cluster’ method, based on 7 classes. From the ILWIS main menu, select the options “Operations” > “Image processing” > “Cluster”, use two input maps, as input raster map 1 specify “s1_vvsubs_std”, as input raster map 2 specify “s1_vhsubs”, as number of clusters “7”as output map “cluster7”, as Output Table “”cluster7, and press “Show”.

Once the result is displayed, from the “Display Tools”, select the option ”Portrayal” > “Fixed Colors” > “Multiple Colors” and use the “default” color scheme, for a “7” size color set, click “Apply” and “Close”. Review your results, use also the color composite created “s1_fcc” and “openstreetmap”. Open the table created “cluster7” and check the statistics calculated. The results should resemble those given in the figure below. You have created 7 clusters, try to assign names to the clusters identified! Use openstreetmap as your ground truth.

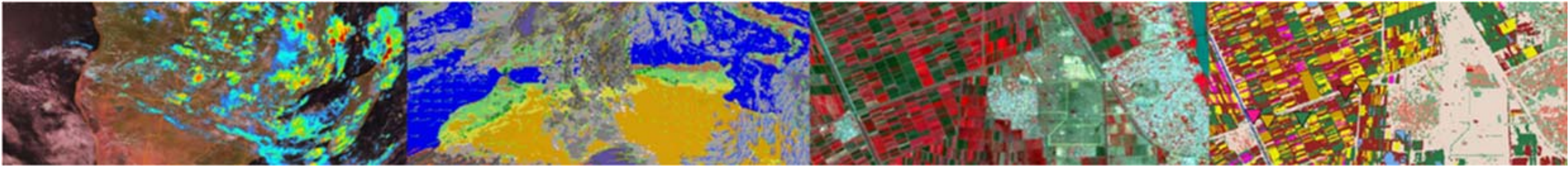
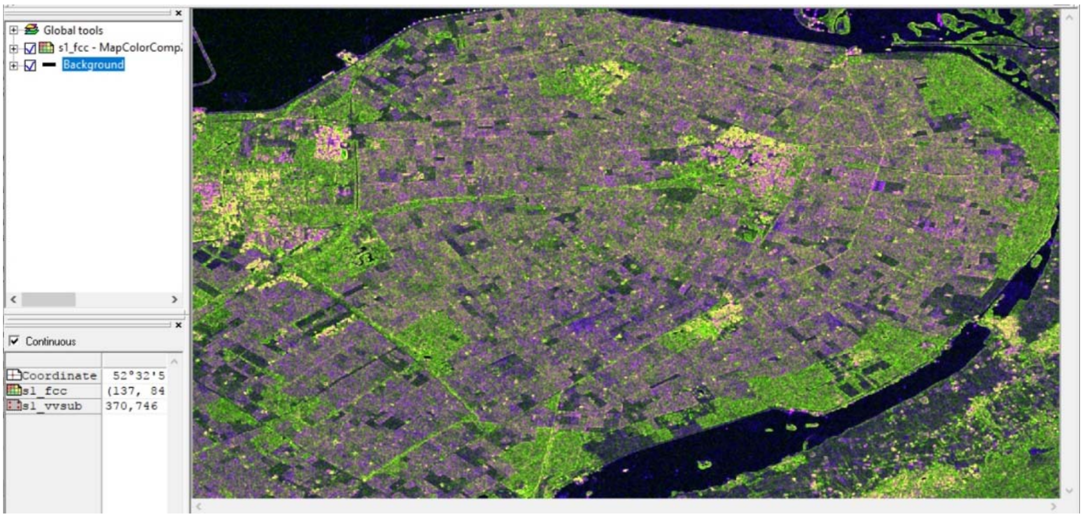


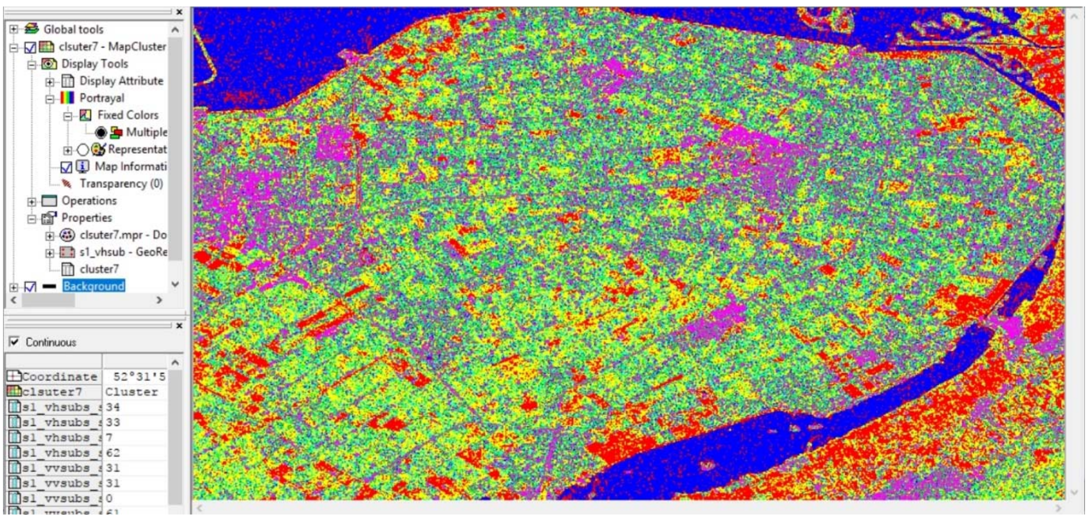
Figure 19: Results of the Sentinel 1 radar image processing

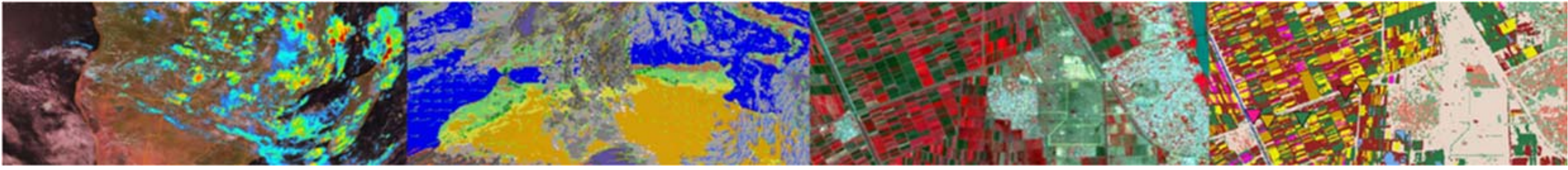
Map 1: Resulting colour composite (r=vv, g=vh, b=ratio vv/vh)



Map 2: Open street map of the area selected

Map 3: Result of the cluster operation, showing 7 classes



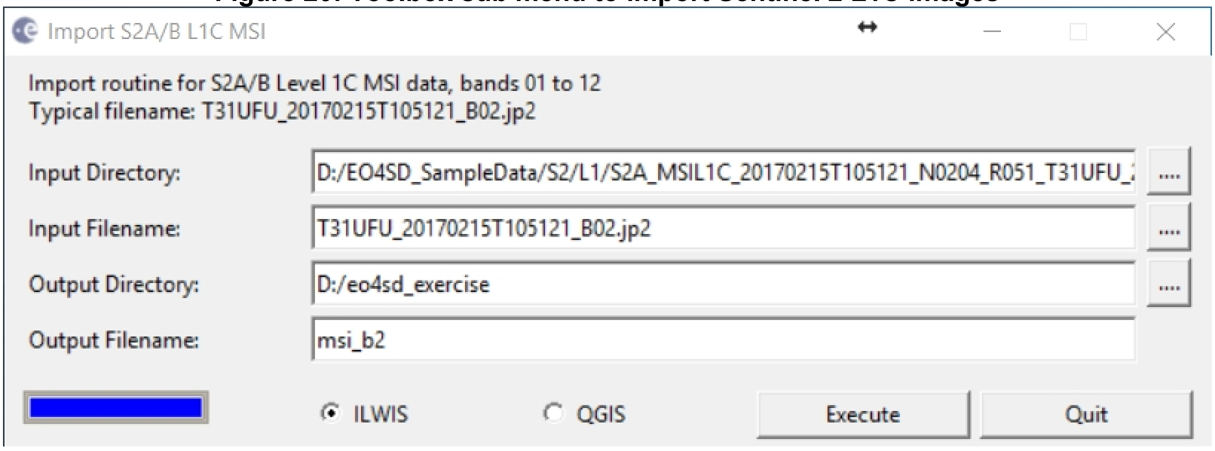


4.2.2 *Sentinel 2*

Now we continue with the import / visualization of Sentinel 2 MSI Level 1C images (S2-MSI-L1C).In the sample data directory the data is available at: D:\EO4SD_SampleData\S2\L1\S2A_MSIL1C_20170215T105121_N0204_R051_T31UFU_20170215T105607.SAFE\GRANULE\L1C_T31UFU_A008628_20170215T105607\IMG_DATA. Note the various bands, also inspect their file sizes. Note the TCI image as well.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 2” > “Level 1” > “Sentinel 2A / B L1C MSI Bands”. Import the 10 meter resolution images from bands 2, 3, 4 and 8 (b,g,r,nir respectively). See also the figure below showing the settings to import band-2.

Figure 20: Toolbox sub menu to import Sentinel 2 L1C images



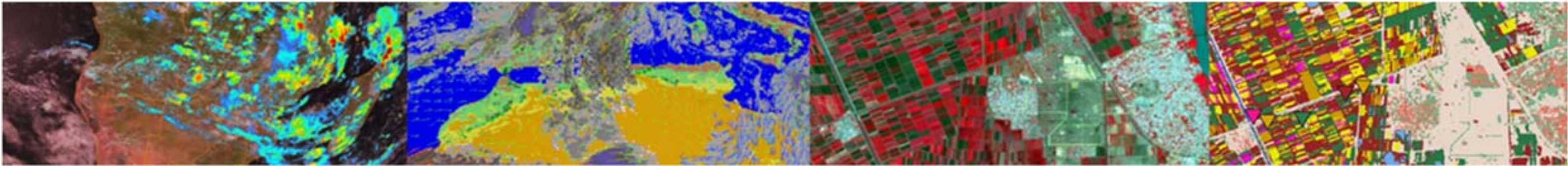
Ensure that the four 10 meter resolution bands have been imported, here as file names msi_b2, msi_b3, msi_b4 and msi_b8 are used. Upon completion close the toolbox and open ILWIS. Navigate to the output directory as specified in the toolbox.

To display msi_b2, right-click with the mouse on the image “msi_b2”, from the context sensitive menu select the options “Statistics” > “Histogram” and press “Define”. Inspect the 1 and 99 % data values and close the histogram. Double click the image “msi_b2”. From the left hand menu, use the ‘expand’ option in front of the map layer name, do the same for the option “Display Tools” > “Portrayal” > “Representation”, double click the Representation and select “Gray” as Representation, press “Apply” > “Close”.

Select from the “Display Options” > “Stretch”, now type as ‘lower stretch’ the value “1095” and as ‘upper stretch’ the value “2301”, and press OK. Check the image, also use openstreetmap as transparent layer. Eventually zoom in to get a better idea about the geometry of the image, check the coordinates at the lower right window, note these are UTM coordinates as well as Lat-Lon coordinates! Also note the image values, these are 16 bits integer values.

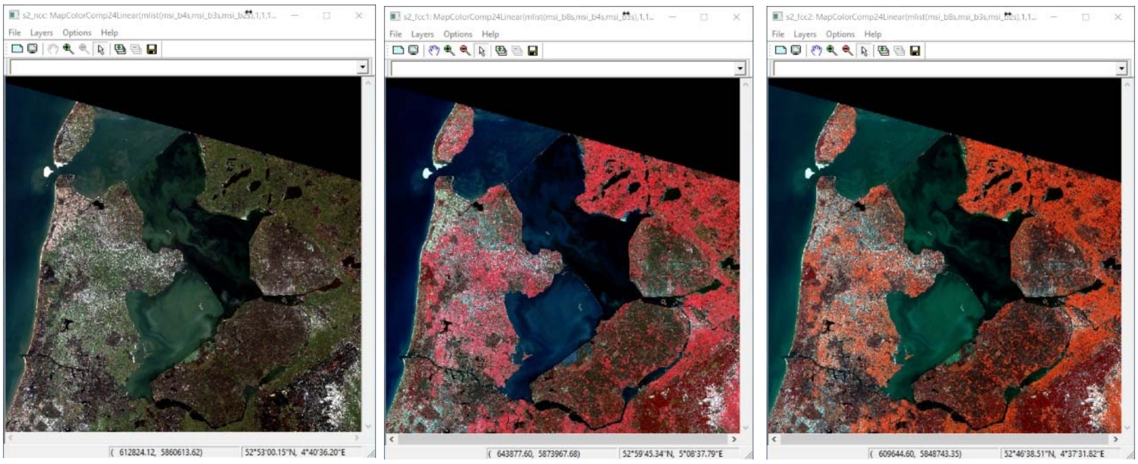
To improve the visualization the imported bands have to be stretched. From the ILWIS main menu, select the options “Operations” > “Image processing” > “Stretch”, as input raster map specify “msi_b2”, as output map “msi_b2s”, and press “Show”.

- Repeat this procedure for the other 3 bands, call them msi_b3s, msi_b4s and msi_b8s respectively
- Create a natural colour composite using the b, g, and r stretched bands. Now in the ILWIS command line type: mapcolorcomp and in the color composite menu, for Red specify “msi_b4s”, for Green specify ”msi_b3s” and for Blue specify “msi_b2s” and as output map “s2_ncc”, press “Show”.
- Create a false colour composite using the g, r, and nir stretched bands. Now in the ILWIS command line type: mapcolorcomp and in the color composite menu, for Red specify “msi_b8s”, for Green specify ”msi_b4s” and for Blue specify “msi_b3s” and as output map “s2_fcc1”, press “Show”.



- Create a false colour composite using the b, g, and nir stretched bands. Now in the ILWIS command line type: mapcolorcomp and in the color composite menu, for Red specify “msi_b8s”, for Green specify ”msi_b3s” and for Blue specify “msi_b2s” and as output map “s2_fcc2”, press “Show”. Your results should resemble those given in the figure below, left image is the ncc, centre image is fcc1 and right image is fcc2.

Figure 21: The 10 meter resolution SMI – Level 1C colour composites created

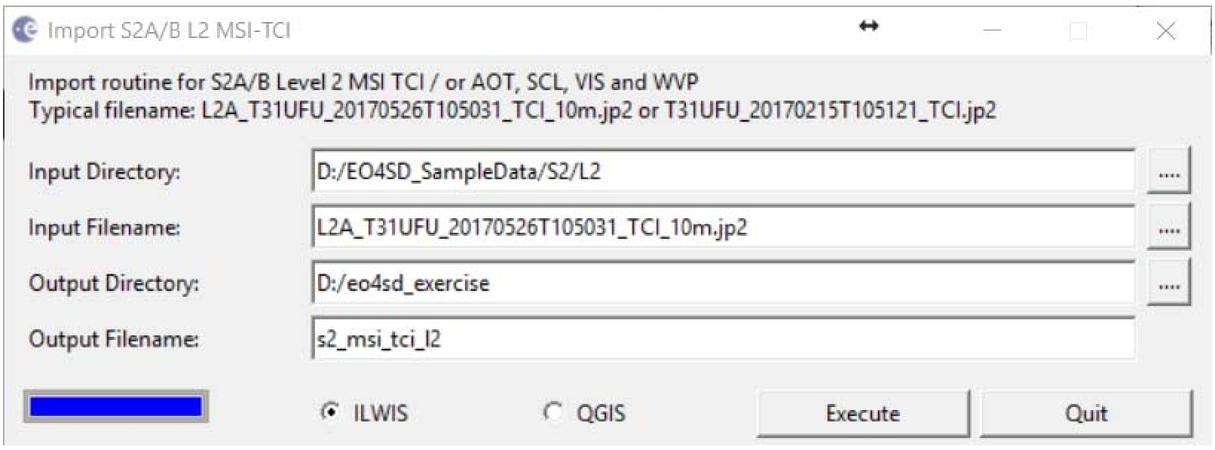


- Explain the differences in colour, use also the information as given in figure 5 and combine it with your knowledge of spectral characteristics over the various parts of the electromagnetic spectrum of different cover types. Use openstreetmap to obtain your ground truth. Why so many different colorations of the water bodies and which composite is showing most information on these water bodies?

To import the 20 meter resolution images select bands 5, 6, 7, 8a, 11 or 12. To import the 60 meter resolution images select bands 1, 9 or 10. The same procedure as described above can be applied, selecting appropriate bands to make the composite! Note also figures 6 and 7.

Continue to import a True Colour Image (TCI) of Level 2. This image was directly downloaded from the Copernicus Science Hub. Use the settings as given in the figure below and wait until progress bar indicates that product is imported, close the sub menu.

Figure 22: S2-MSI – Level 2 TCI import of image 20170526



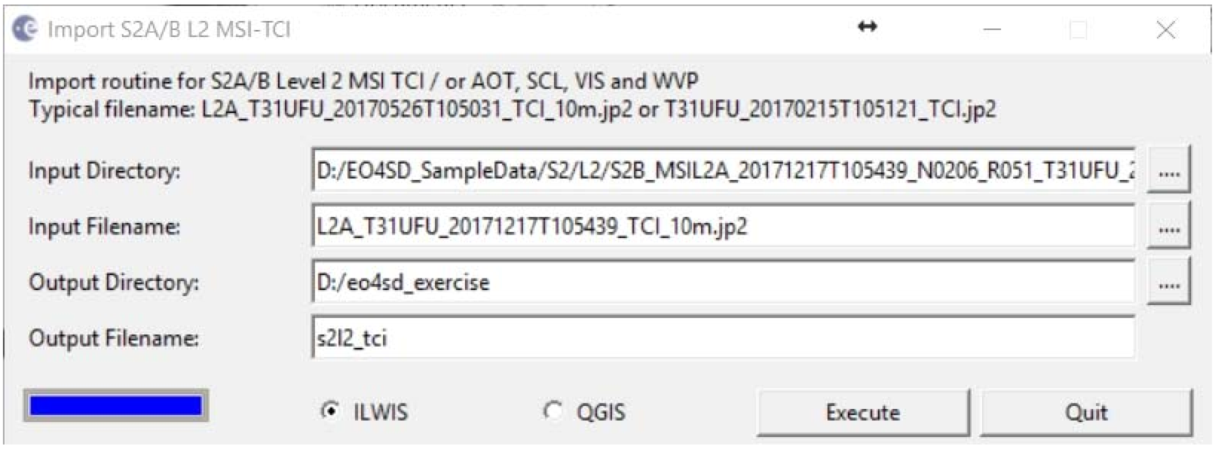
After import calculate for each band the histogram, from the ILWIS main menu, select the options “Operations” > “Image processing” > “Stretch”, as input raster map specify “s2_msi_tci_l2_band_1”, as output map “msi_tci_b1s”, and press “Show”.

- Repeat this procedure for the other 2 bands, call them msi_tci_b2s, msi_tci_b3s respectively.

- Create a natural colour composite using the b, g, and r stretched bands. Now in the ILWIS command line type: mapcolorcomp and in the color composite menu, for Red specify “msi_tci_b1s”, for Green specify ” msi_tci_b2s” and for Blue specify “msi_tci_b3s” and as output map “s2l2_tci_may”, press “Show”.
- Display the colour composite, add the natural colour composite created before, here “s2_ncc”, use for the top layer map in the left hand legend, under “Display Options” the option “Transparency”, zoom in and note the changes.
- Note that the date of the images is for the map ‘s2_ncc’ 20170215, for the map ‘s2l2_tci_may’ the recording date is 20170526.

Finally import another MSI data set. This data has been recorded on 20171217. Open the EO4SD toolbox and from the menu select the options “Sentinel 2” > “Level 1” > “Sentinel 2A / B L1C MSI Bands”. From the sub-menu use the following settings as given in the figure below. Note the full path to the source data is: D:\EO4SD_SampleData\S2\L2\S2B_MSIL2A_20171217T105439_N0206_R051_T31UFU_20171217T125559.SAFE\GRANULE\L2A_T31UFU_A004081_20171217T105433\IMG_DATA\R10m.

Figure 23: S2-MSI – Level 2 TCI import of image 20171217



- After import calculate for each band the histogram, right click using the mouse the file, here “s2l2_tci_band_1”, select the options “Statistics” > “Histogram” and press “Show”. Inspect the histogram values and repeat the procedure for the other two bands.

- From the ILWIS main menu, select the options “Operations” > “Image processing” > “Stretch”, as input raster map specify “s2l2_tci_band_1”, as output map “s2l2_tci_band_1s”, and press “Show”. Repeat the procedure for the other two bands and call them “s2l2_tci_band_2s” and “s2l2_tci_band_3s” respectively

- Create a natural colour composite using the b, g, and r stretched bands. Now in the ILWIS command line type: mapcolorcomp and in the color composite menu, for Red specify “s2l2_tci_band_1s”, for Green specify ” s2l2_tci_band_2s” and for Blue specify “s2l2_tci_band_3s” and as output map “s2l2_tci_dec”, press “Show”.

In the image map window add the maps ‘s2_ncc’ and the map ‘s2l2_tci_may’.Use the “Transparency options” of the two top layers, or uncheck the layer to note the differences between them. Zoom in on the centre southwest (called de Markermeer), just south of the enclosure dam and note the progress in the reclamation of a new island, see also the figure below. Further information can be found at: https://en.wikipedia.org/wiki/Marker_Wadden.

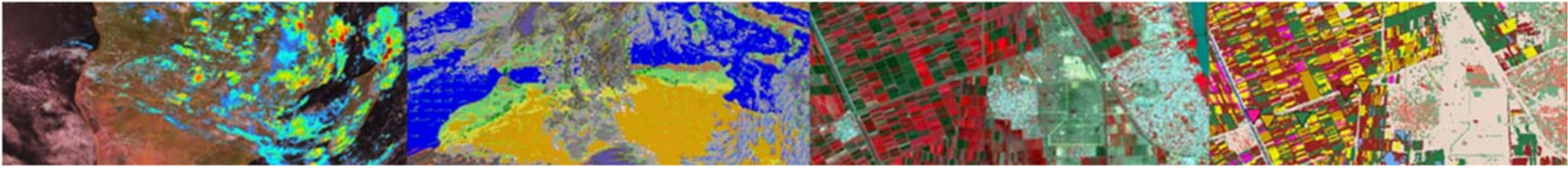
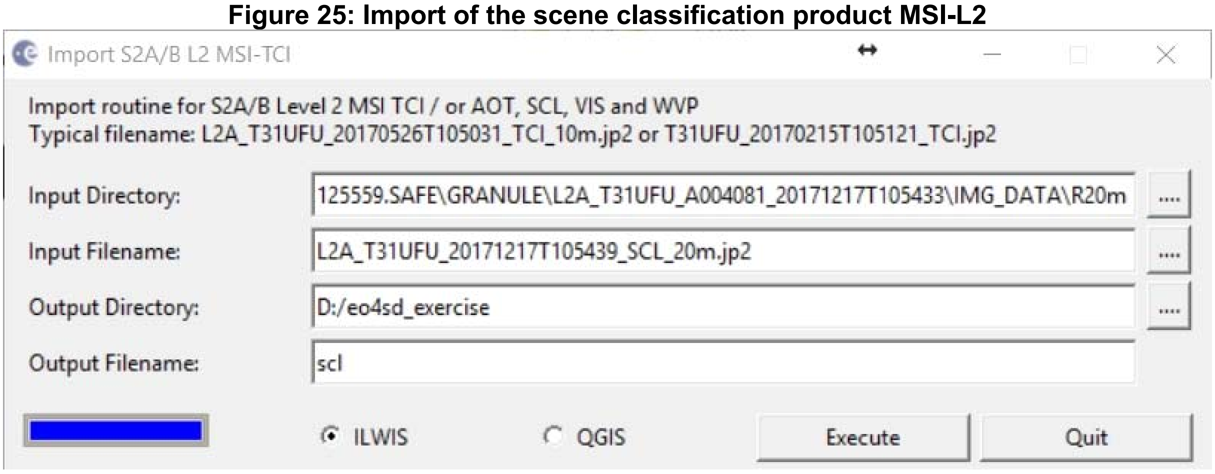


Figure 24: Reclamation progress of the Marker Wadden in 2017

To conclude the exercise using MSI now import from the MSI level-2 20 meter resolution data set the scene classification “SCL” product.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 2” > “Level 2” > “Sentinel 2A / B L2 MSI TCI”. Import from the 20 meter resolution folder the product called “SCL”. Note the folder: D:\EO4SD_SampleData\S2\L2\S2B_MSIL2A_20171217T105439_N0206_R051_T31UFU_20171217T125559.SAFE\GRANULE\L2A_T31UFU_A004081_20171217T105433\IMG_DATA\R20m. Specify the import settings as given in the figure below and wait till the import is completed.

Figure 25: Import of the scene classification product MSI-L2



Open the map “scl” and inspect the map values. Note the legend as given at the end of chapter 2.3. In your sample data directory navigate to the folder ‘\ILWIS_service_objects’ and copy the four files (s2l2_scl.rpr, s2l2_scl.rp#, s2ls_scl.dom and s2l2_scl.dm#) to your working directory (here ‘D:\eo4sd_exercise’).

To transform the map numbers into classes, according to the legend, perform the following operation: from the ILWIS main menu, select the option “Operations” > “Image Processing” > “Slicing”, as input map specify “scl”, as output map “scl_cl” and as domain “s2l2_scl” and press “Show”. Under the display options, as part of the ‘Representation’ the legend can be observed. With the feft mouse button pressed over the map the class information can be obtained. Also display the December colour composite created before and compare the image with the classes differentiated. See also the figure below. Note that a few days before the south east part was affected by snow and still remnants are visible!

You can also compare this classification with the one created based on the cluster procedure for Sentinel 1 for a subset of this window as conducted in the previous exercise.

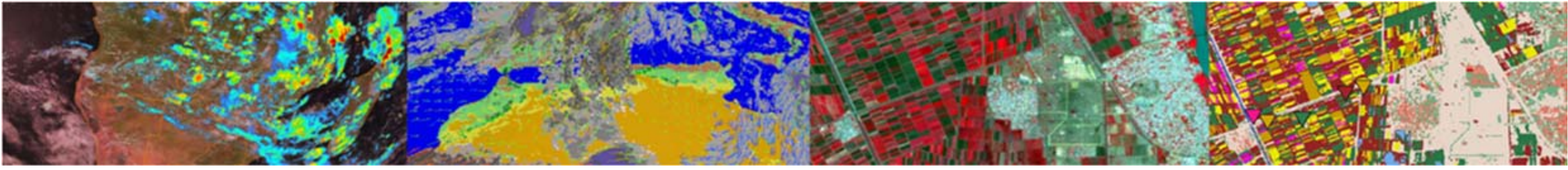
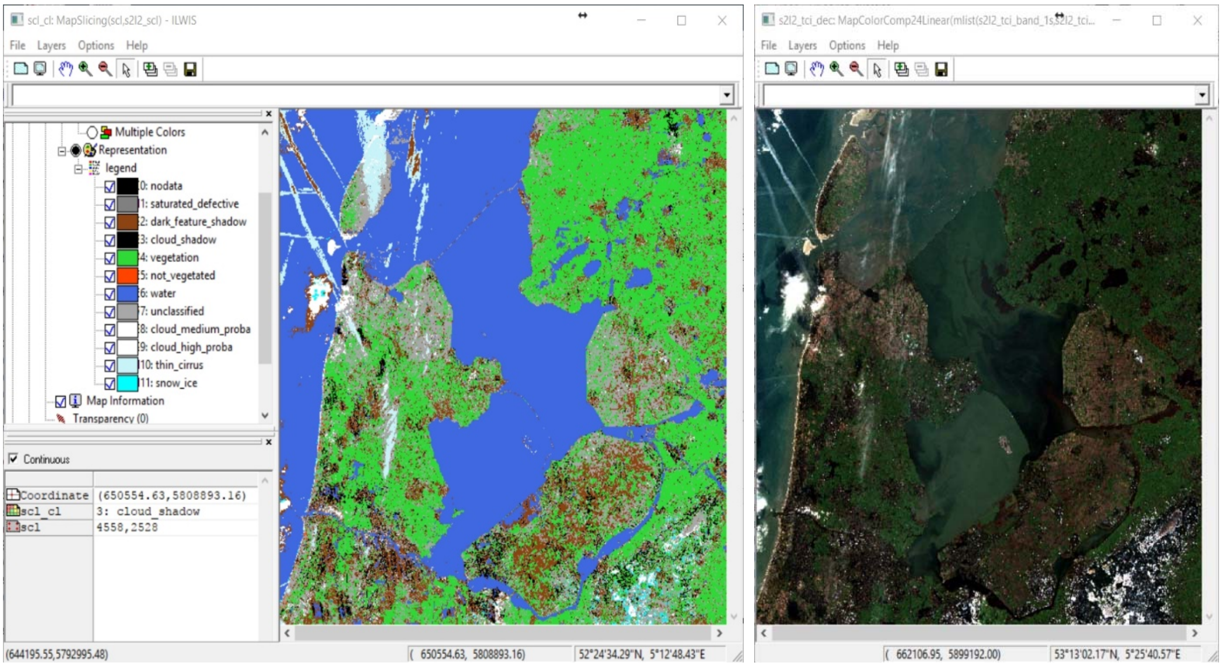


Figure 26: The scene classification and the true colour composite



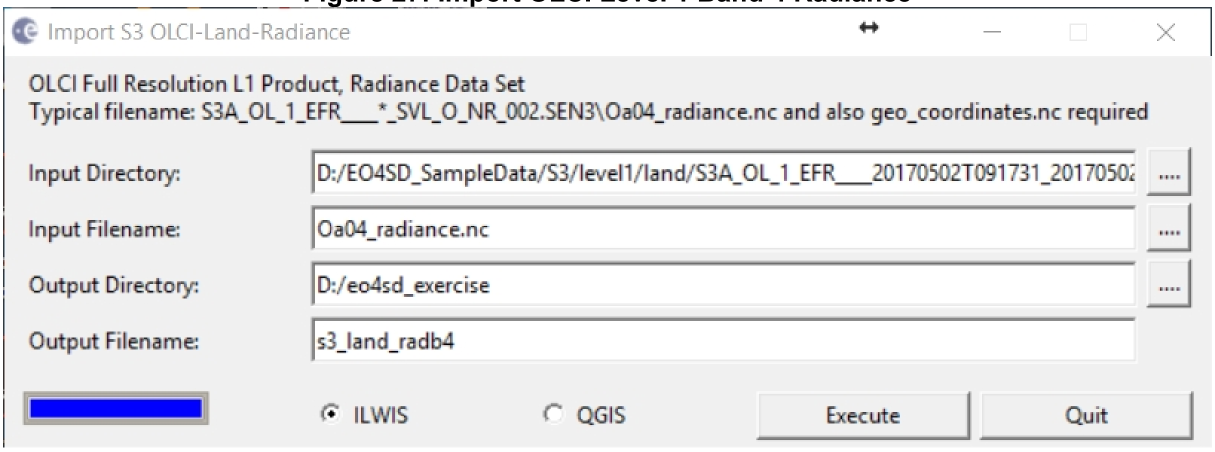
4.2.3 *Sentinel 3 Land*

For Sentinel 3 ESA provides the data over land and EUMETSAT is responsible for the marine data provision derived from the OLCI and SLSTR instruments. It should be noted that for all Sentinel 3 data the coordinate information is stored as a separate layer in the “SAFE” container. It can also be downloaded as a separate file from the data archives. Check once more table 6 before you continue. Also in the sub-menu heading the input files required for data import are given (see ‘Typical Filename’).

In the exercise below an import will be conducted of the OLCI Level 1 Radiance data, note the data is available at: D:\EO4SD_SampleData\S3\level1\land\S3A_OL_1_EFR____20170502T091731_20170502T092031_20170502T111511_0179_017_150_1979_SVL_O_NR_002.SEN3.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 3 - Land” > “Level 1” > “OLCI” > “Radiance 01 - 21”. See also the figure below showing the settings to import band-4 from the sub menu.

Figure 27: Import OLCI Level 1 Band 4 Radiance



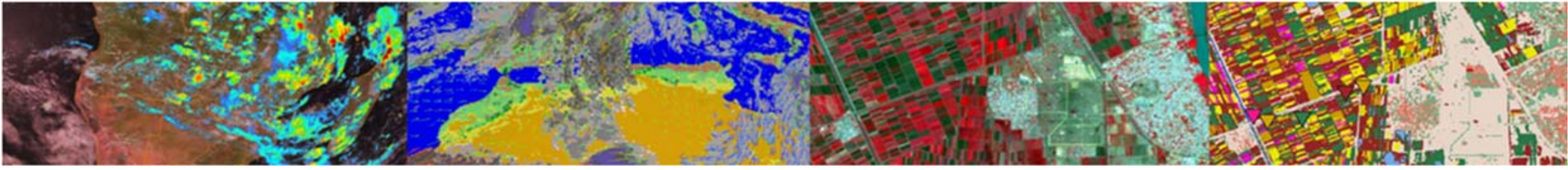
Open ILWIS and display the map “s3_land_radb4”, Open “Display Option”, under “Representation” select “Gray”, under the “Stretch” options, use as upper limit “85”. Check the map values. Eventually add openstreetmap. Note the geometry of the image. At the top of the map display window the syntax is displayed how the image is calculated, note the scaling and offset applied. These are different for the various radiance channels.

Eventually import some of the other channels, like band 6 and band 7 and display the maps, note the scaling coefficient applied. Check which part of the Electro Magnetic spectrum is recorded for each of the channels.

Create a colour composite of a subset of the map (for cloud free area). Copy and paste the syntax presented below, line by line, in the command line of the ILWIS main menu, press enter to execute the expressions. Fist a sub-map is created, then the map is stretched, finally a colour composite is created:

s3_land_rad4_sub.mpr:=MapSubMap(s3_land_radb4,1122,1248,1391,2472)
s3_land_rad6_sub.mpr:=MapSubMap(s3_land_radb6,1122,1248,1391,2472)
s3_land_rad7_sub.mpr:=MapSubMap(s3_land_radb7,1122,1248,1391,2472)

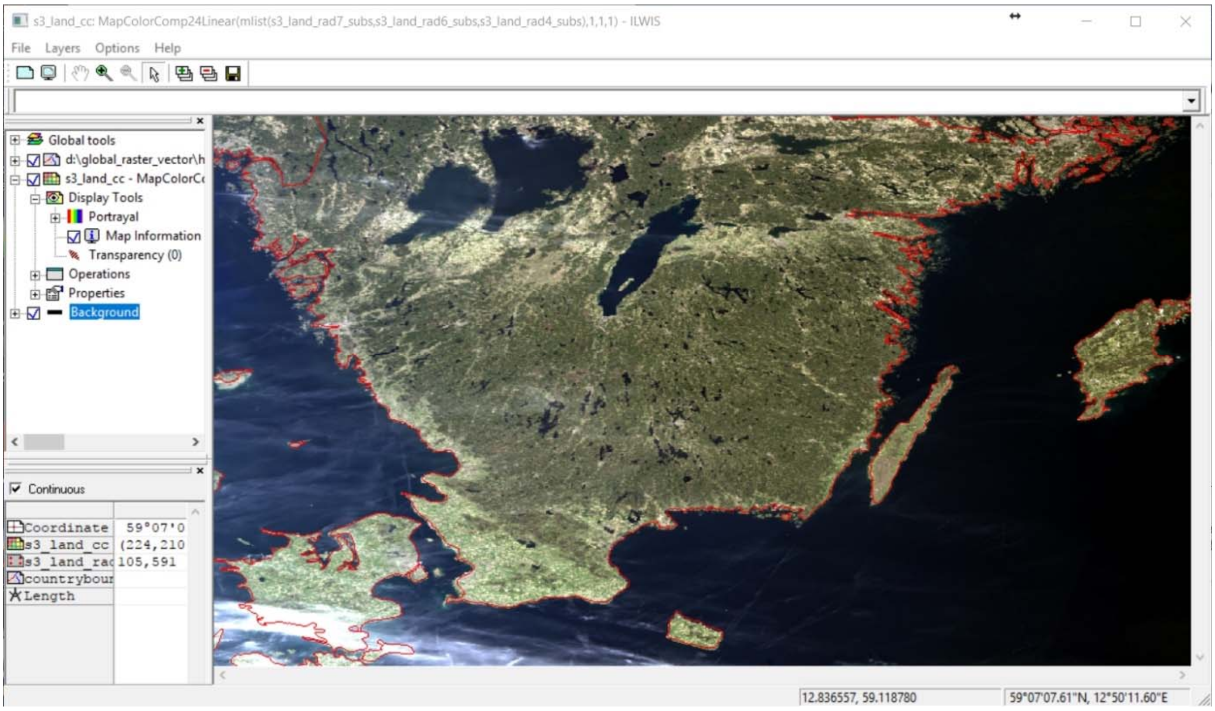
s3_land_rad4_subs.mpr{dom=image.dom;vr=0:255}:=MapStretchLinear(s3_land_rad4_sub,1.000000, image.dom)
s3_land_rad6_subs.mpr{dom=image.dom;vr=0:255}:=MapStretchLinear(s3_land_rad6_sub,1.000000, image.dom)
s3_land_rad7_subs.mpr{dom=image.dom;vr=0:255}:=MapStretchLinear(s3_land_rad7_sub,1.000000, image.dom)



s3_land_cc.mpr=MapColorComp24Linear(mlist(s3_land_rad7_subs,s3_land_rad6_subs,s3_land_rad4_ subs),1.000000,1.000000,1.000000)

The resulting colour composite should resemble the figure given below, note the red coloured segments for the country boundaries are added to show the geometry of the image.

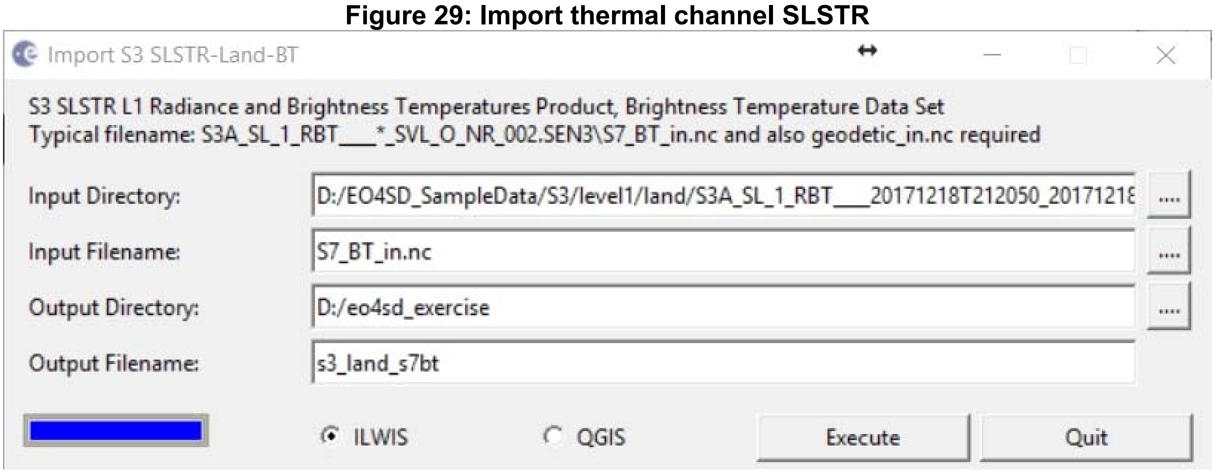
Figure 28: Colour composite of OLCI Level 1 over the Scandinavia



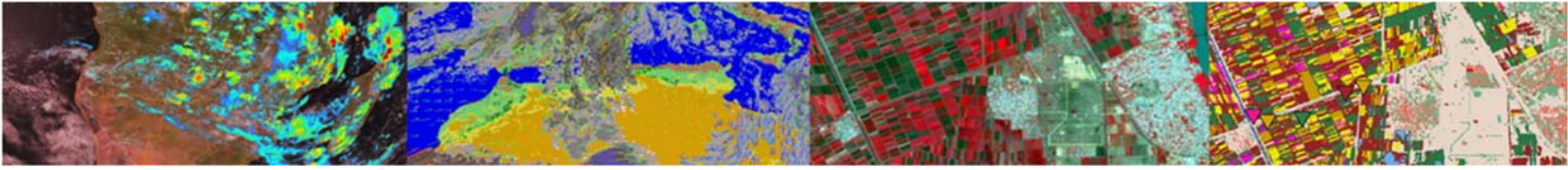
In the exercise below an import will be conducted of the OLCI Level 1 Radiance data, note the data is available at: D:\EO4SD_SampleData\S3\level1\land\S3A_SL_1_RBT____20171218T212050_20171218T212350_20171220T014716_0179_025_357_6779_LN2_O_NT_002.SEN3.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 3 - Land” > “Level 1” > “SLSTR” > “TIR”. See also the figure below showing the settings to import S7 from the sub menu.

Figure 29: Import thermal channel SLSTR



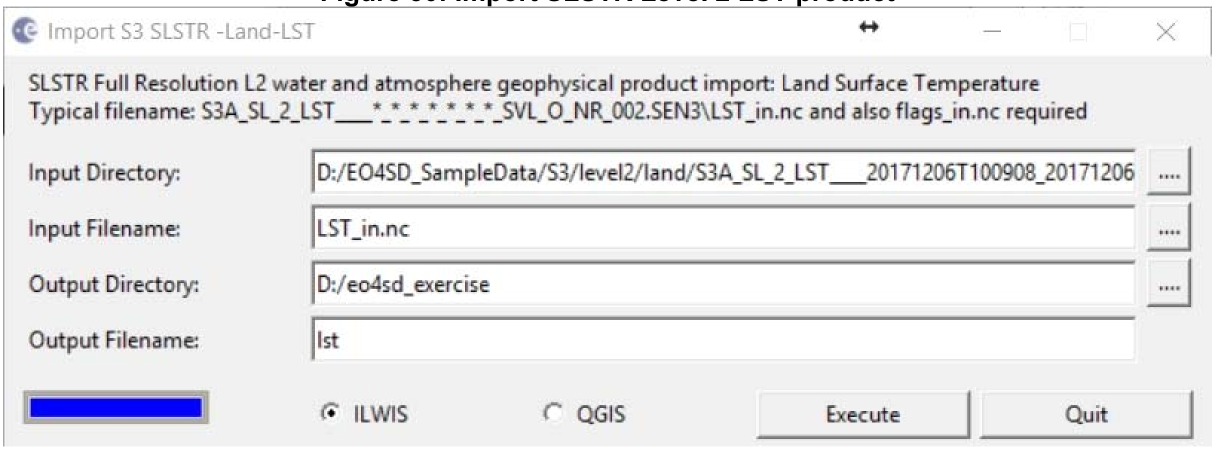
Open the map “s3_land_s7bt”, inspect the map values, note that a Kelvin scale is used! Eventually add “openstreetmap”. Note the temperatures for the different cover types, e.g. land, water, snow, clouds. How to remove the cloud cover from the image?



Open the EO4SD Toolbox, from the main menu select the options “Sentinel 3 - Land” > “Level 2” > “SLSTR” > “LST”. See also the figure below showing the settings to import the LST product from the sub menu, note the default name is already given.

The full path name to the products is: D:\EO4SD_SampleData\S3\level2\land\S3A_SL_2_LST____ 20171206T100908_20171206T101208_20171206T121557_0179_025_179_2160_SVL_O_NR_002.SEN3.

Figure 30: Import SLSTR Level 2 LST product



Display the map “lst”, also note that a map “lst_flags” has been created. Also display this map and note the map values (of both maps).

Apply for the LST product the extracted cloud mask:

- Note that with respect to the flag mask, this layer is imported with same name as the LST image, but is having as suffix ‘_flags’
- To apply flags mask, all cloud flags in the map have a value greater than 1, 1 is the non-clouded area, the area outside the image (note the image is wrapped) is 0. The following map calculation statements can be applied:

  Flag_fin:=iff(lst_flags = 1,255,0)
  Lst_cor_flags:=iff(flag_fin=255,lst,?)

- These operations assign NaN to the cloud contaminated pixels as well as those outside the map. The pixels, having the value of 1, reclassified into 255 (for better visualization if the mask is displayed) will be assigned the LST value in the output map.

Your results should resemble those given in the picture below.

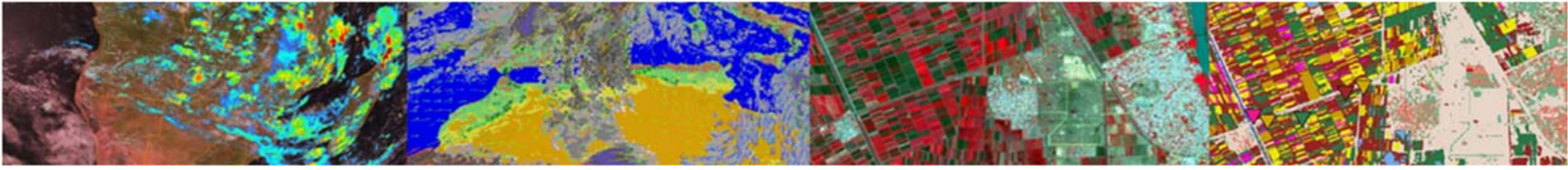
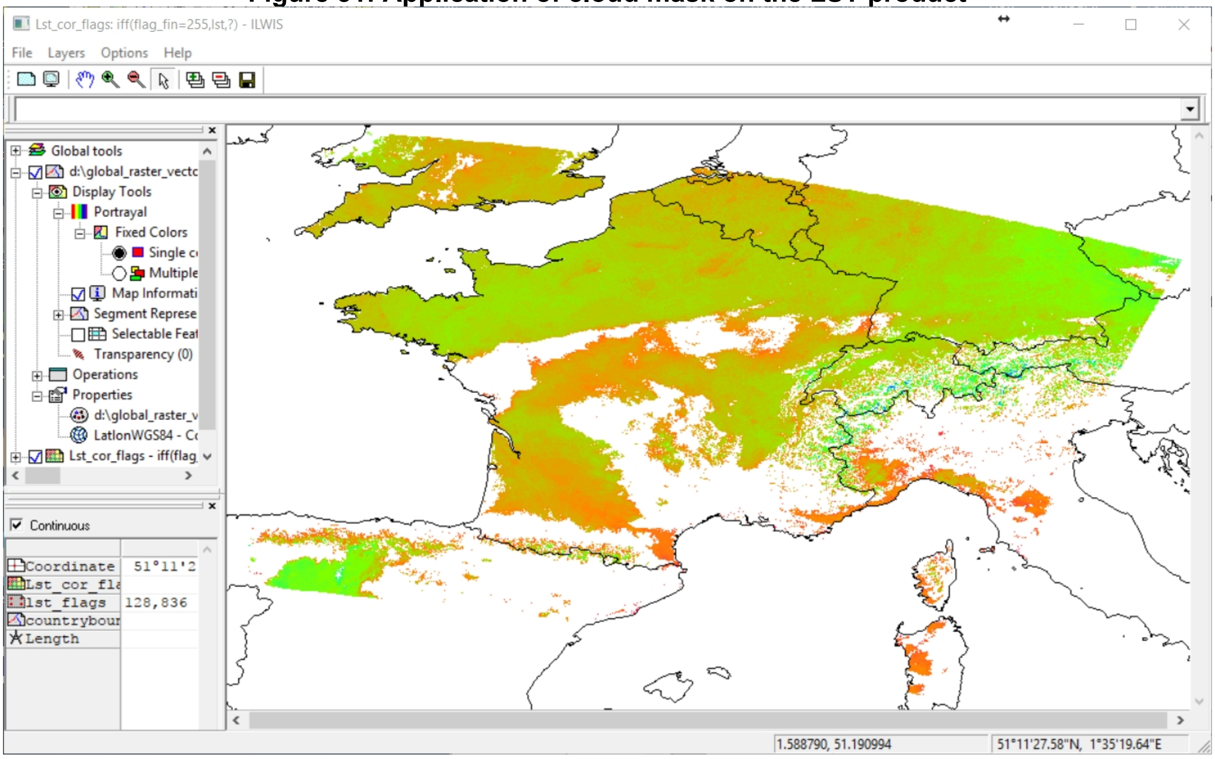


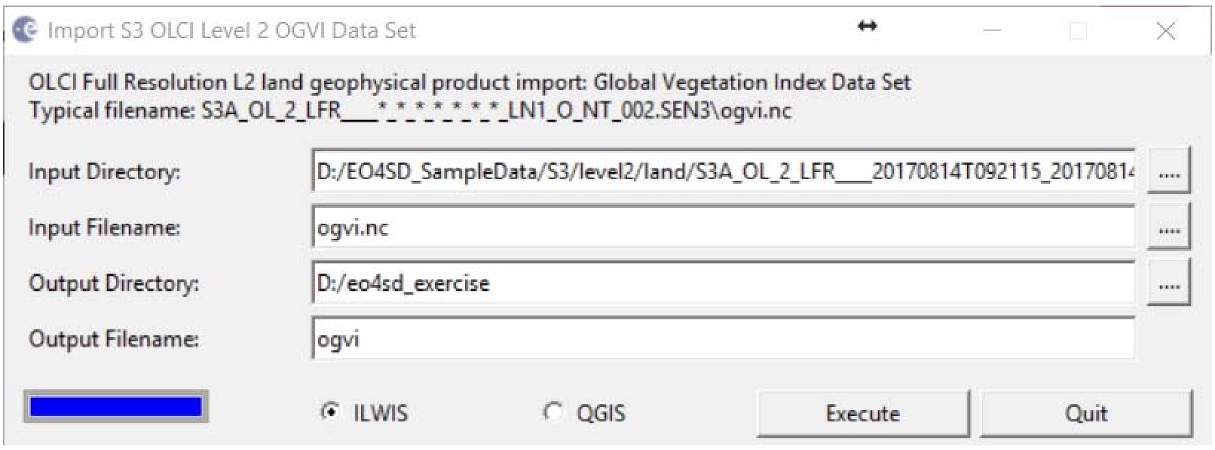
Figure 31: Application of cloud mask on the LST product



Finally we are going to retrieve OLCI Level 2 products, like the OGVI and the OTCI (see table 3). Open the EO4SD Toolbox, from the main menu select the options “Sentinel 3 - Land” > “Level 2” > “OLCI” > “OGVI”. See also the figure below showing the settings to import the OGVI product from the sub menu, note the default name is already given.

The full path name to the products is: D:\EO4SD_SampleData\S3\level2\land\S3A_OL_2_LFR____20170814T092115_20170814T092415_20170815T144543_0179_021_093_1980_LN1_O_NT_002.SEN3.

Figure 32: Import OLCI vegetation product - OGVI



Open ILWIS and display the map “ogvi”, open “Display Options”, under “Representation” select “NDVI1. Check the map values. Eventually add openstreetmap. Note the geometry of the image. At the top of the map display window the syntax is displayed how the image is calculated, note the scaling and offset applied. Repeat the import procedure and now select the ‘otci’ product and display the resulting map “otci”, use as representation “lai”, check the map values and eventually display also openstreetmap. Your results should resemble those of the figure below.

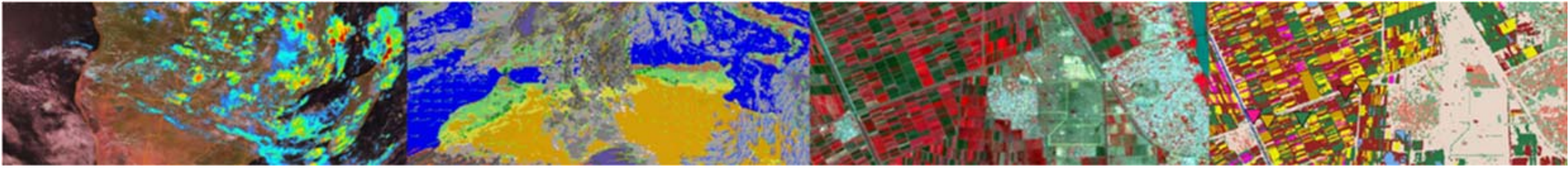
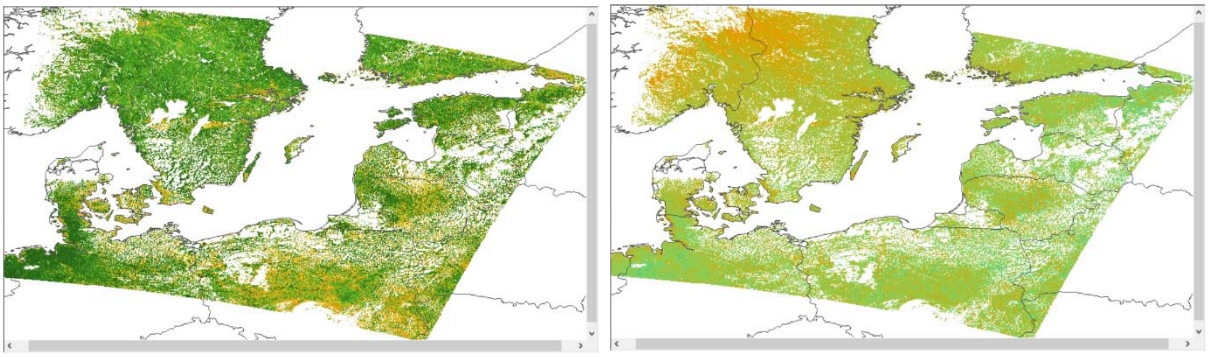


Figure 33: OLCI vegetation products – OGVI (left) and OTCI (right)



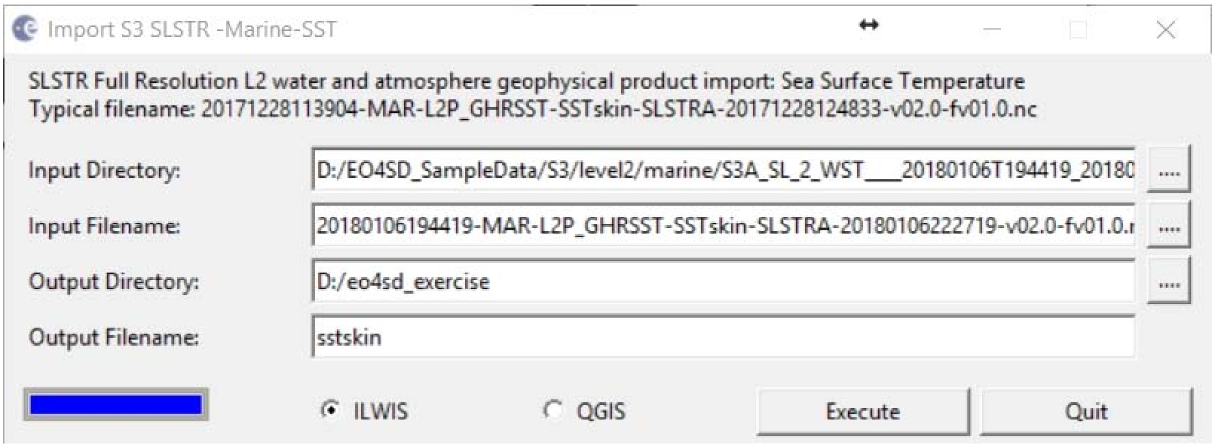
4.2.4 *Sentinel 3 Marine*

For the marine service the data has been retrieved from the Copernicus Online Data Access portal. Also here level 1 and level 2 products are available. The import routine to retrieve the data is identical to those provided in the previous chapter. Here we are going to look at some of the level 2 products, derived from OLCI and SLSTR.

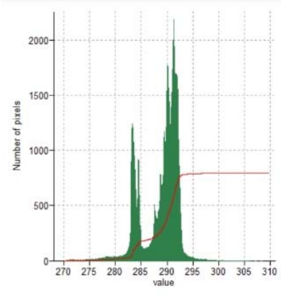
Open the EO4SD Toolbox, from the main menu select the options “Sentinel 3 - Marine” > “Level 2” > “SLSTR – SST Skin”. See also the figure below showing the settings to import the SSTskin from the sub menu.

Note the full path to the data folder is: D:\EO4SD_SampleData\S3\level2\marine\S3A_SL_2_WST____20171228T113904_20171228T114204_20171228T124833_0179_026_108_5759_MAR_O_NR_002.SEN3.

Figure 34: Import SST Skin Temperature



Display the map “sstskin”. Calculate also the histogram and study the histogram visualization in detail (also given here). You will note a bimodal distribution, the left distribution centred around 283 K and the right distribution around 290. The left distribution is representative of the “Black Sea” area and the right one is representing the “Mediterranean Sea”. To get a better idea of the skin temperature of the Mediterranean waters, apply the following equation:



sstkin_med:=iff((sstskin>287) and (sstskin<293),sstskin,?)

Display the map “sstskin_med” using the default representation. Your results should resemble those given in the figure below.

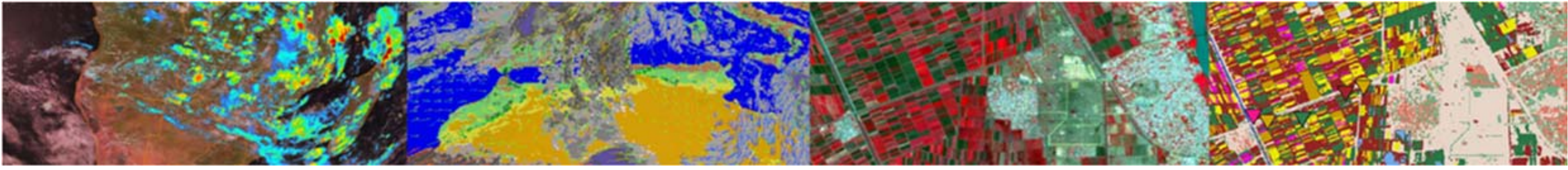
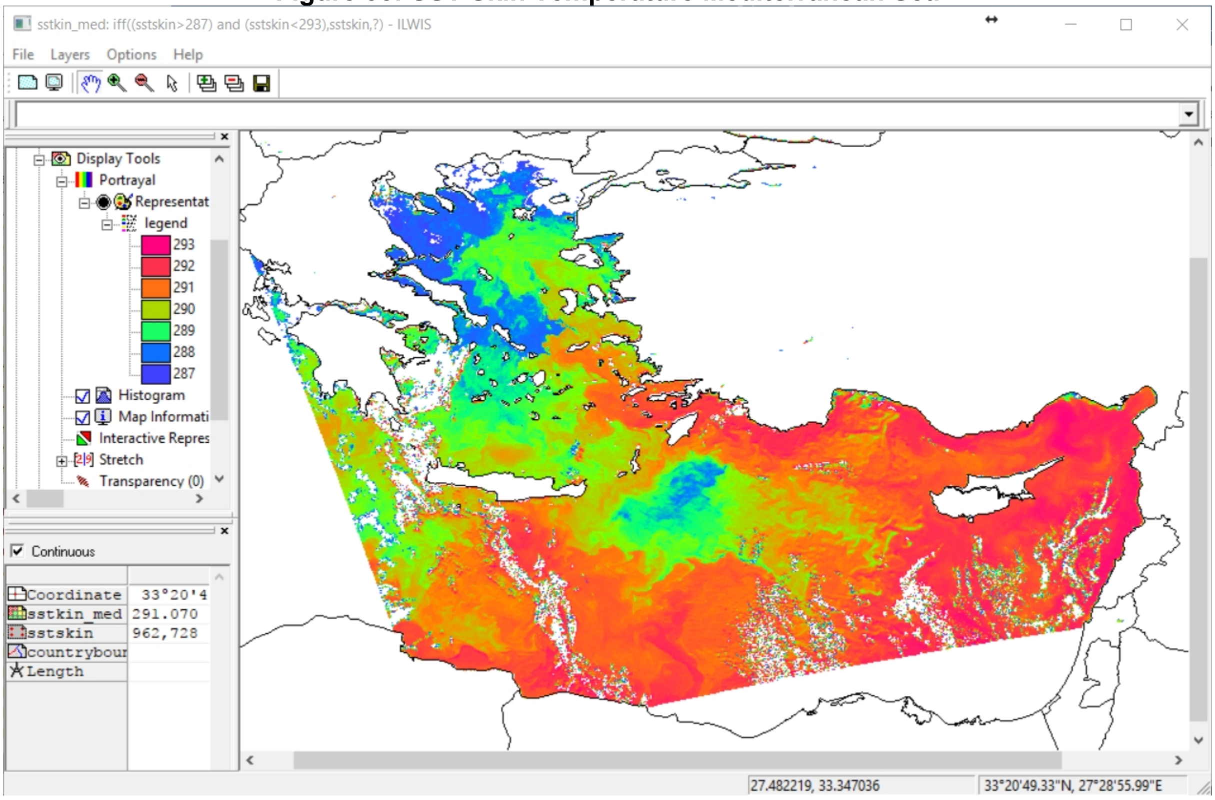


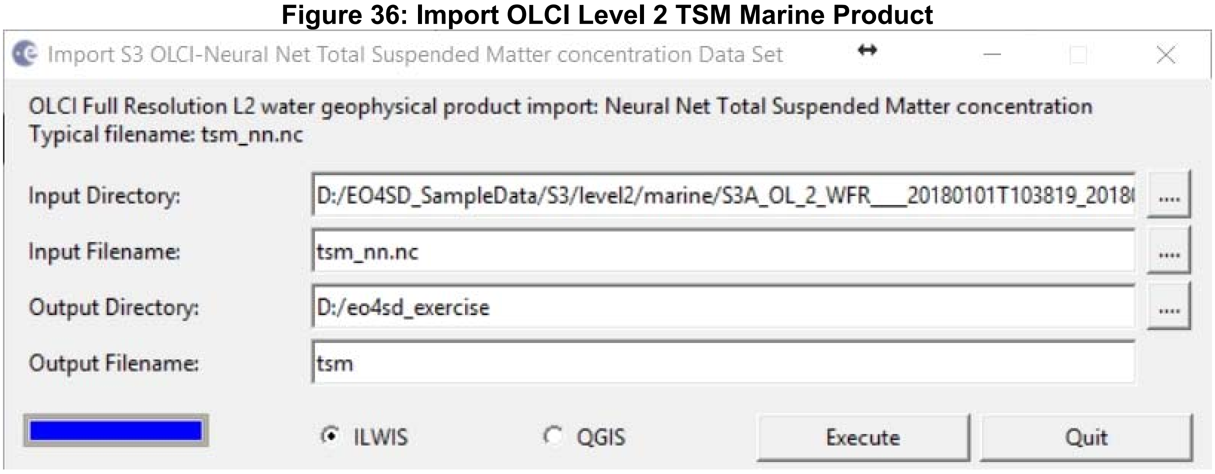
Figure 35: SST Skin Temperature Mediterranean Sea



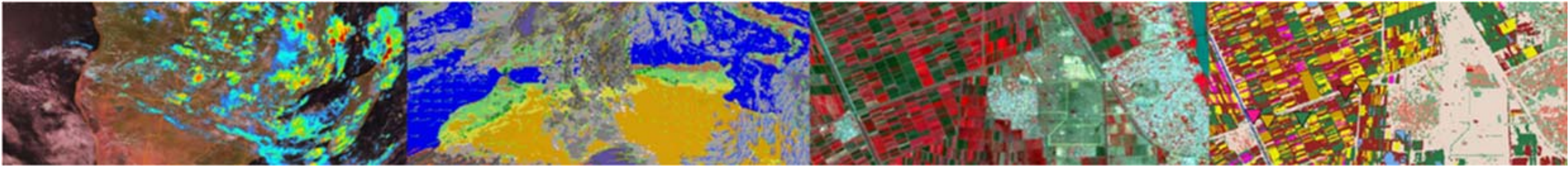
Now continue importing some of the OLCI Level 2 products. The full path name to these products is: D:\EO4SD_SampleData\S3\level2\marine\S3A_OL_2_WFR____20180101T103819_20180101T104119_20180102T171032_0180_026_165_2339_MAR_O_NT_002.SEN3.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 3 - Marine” > “Level 2” > “OLCI – TSM Complex Water”. Use the default product name if this is given in the import sub-menu. The sub menu is given below using as example the “Total Suspended Matter” product.

Figure 36: Import OLCI Level 2 TSM Marine Product



Display the map “tsm”, add openstreetmap and zoom in along the coastal areas and note the patterns of the suspended matter. Eventually import some of the other products, check table 4 for details on the variables. Note the default input filename is already given. Close ILWIS before you continue.

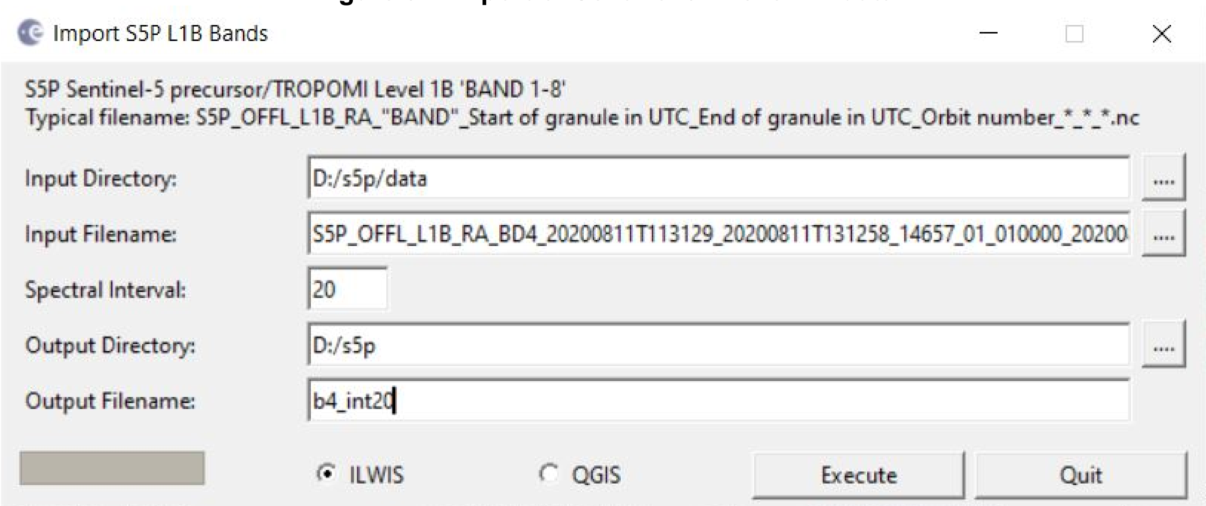


4.2.5 ***Sentinel 5 Precursor***

For the Sentinel 5 Precursor the Level 1B offline data can been retrieved from the Copernicus Online Data Access portal. For this exercise use is made of Band-4 and is containing a full orbit overpass. Note that the spectral range covered by this band is from 397.8 to 498.6 nm with a spectral sampling interval of 0.2 nm resulting in 497 measurements per pixel.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 5P” > “Level 1B” > “Level 1B B 1 – 8 import”. See also the figure below showing the settings to import the L1B data from the sub menu.

Figure 37: Import of Sentinel 5P Level 1B data



An additional option has been included in this user interface, called ‘Spectral Interval’. Each Level 1B band has 497 channels. By specifying an interval of 20, 25 channels are imported, starting from 397,8 nm, with an interval of (20 * 0.2 nm) of 4 nm. By specifying the ‘Spectral Interval’ the user is able to define the detail of the ‘spectral radiance’ curve to be obtained from the spectrometer.

Once the import is completed, open ILWIS and create a new map list of all new maps created corresponding to the spectral interval selected, here 20. Ensure that within the map list the sequence of the channel numbers (here 0 to 480) is in the appropriate sequence, note the position in the map list of layer 20, 40, 60 and 80. Move these to the appropriate position by clicking them using the mouse and dragging these to the appropriate position.

Display one of the imported maps, e.g. “b4_int20_radiance_480_rad” at (397.8 + 20*0,2) 498.8 nm, as Representation use “Spectral Inverse” add the country boundaries. Now from the ILWIS main menu, select: “*Operations*”, “*Statistics*”, “*MapList*” and finally “*MapList Graph*”. Select as “*MapList*” your maplist created during the previous step. Activate the option: “Fix Stretch”, select as minimum “*0”* and as maximum “*0.75”*. Also activate the option “*Always On Top*” but leave the “*Continuous*” option unchecked.

Note that the X-axis of the graph represents the spectral range, here the range from 397.8 to 498.6 nm, having an interval of 0,2 *20 = 4 nm, represented by 1 to 25. Move the mouse cursor over the map and check the corresponding radiance values in the graph once you click with the left mouse on a selected location. Press the left mouse button at a number of locations in the active map window to get the radiance for a given pixel over the whole Band 4 spectral range. Your result should resemble those in the figure below.

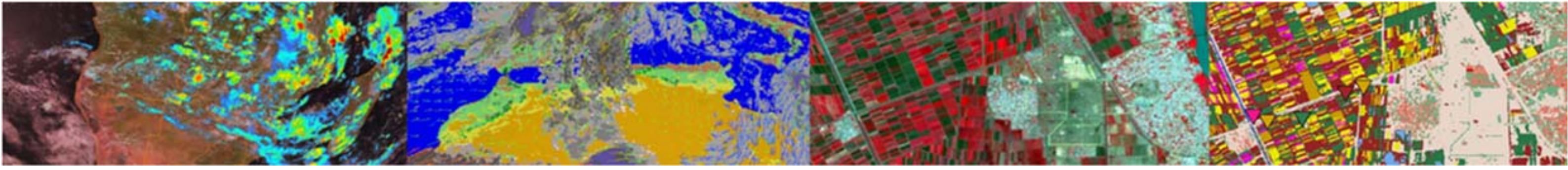
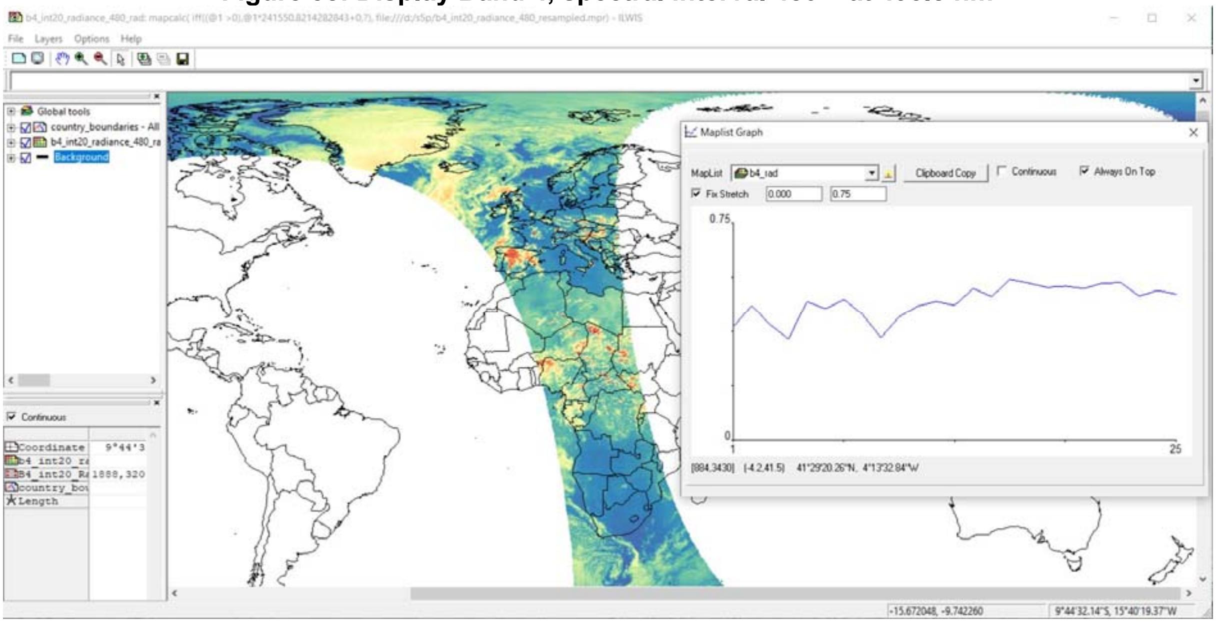


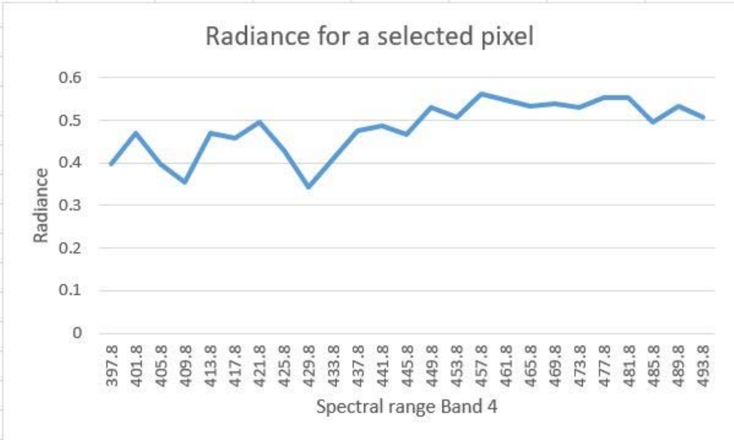
Figure 38: Display Band 4, spectral interval 480 – at 493.8 nm

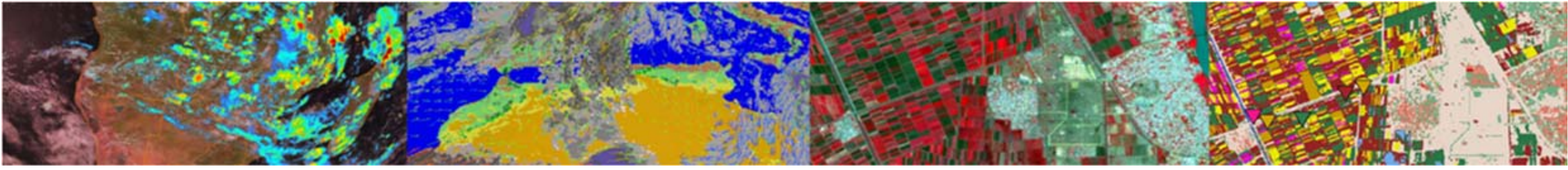


To create an appropriate spectral radiance curve, select a suitable pixel and check the graph, if satisfied press the option "*Clipboard Copy*" and open Excel. Create a new column "selected interval" and specify the intervals created, here "20". Create another column, here "band 4 spectral interval" and use as interval (20*0.2) = 4 nm and add these to the start of the spectral range, here "397.8". Now create a column "Pixel value" and paste the values from the '"*Clipboard Copy*" to the column. Create a line graph, see also the results below.

Figure 39: Radiance curve Band 4, spectral range 397.8 – 493.8 nm using 4 nm interval

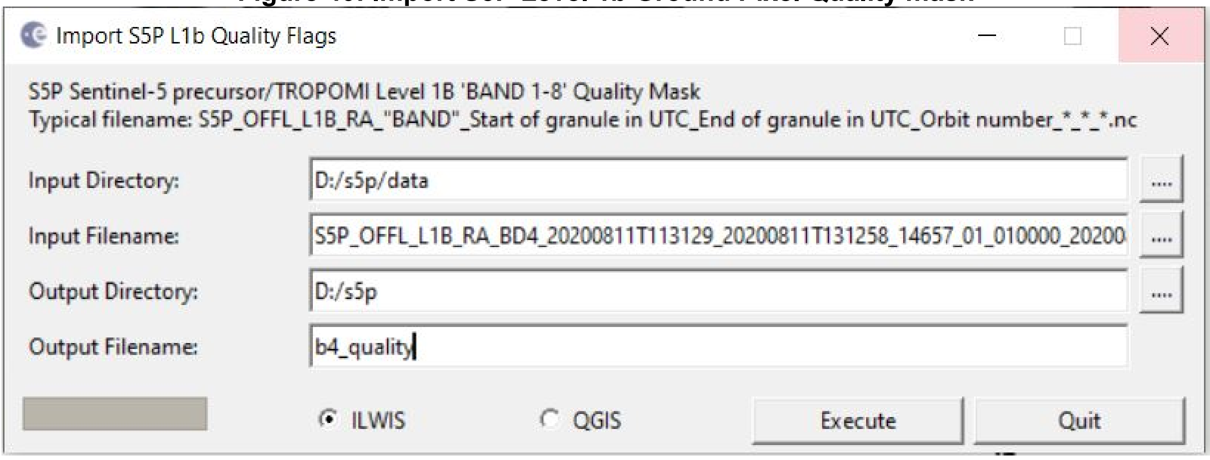
	A	B	C
1	selected	band 4	
2	interval	spectral interval	pixel value
3	0	397.8	0.397
4	20	401.8	0.471
5	40	405.8	0.397
6	60	409.8	0.355
7	80	413.8	0.471
8	100	417.8	0.458
9	120	421.8	0.497
10	140	425.8	0.429
11	160	429.8	0.344
12	180	433.8	0.409
13	200	437.8	0.475
14	220	441.8	0.488
15	240	445.8	0.467
16	260	449.8	0.53
17	280	453.8	0.507
18	300	457.8	0.563
19	320	461.8	0.549
20	340	465.8	0.533
21	360	469.8	0.539
22	380	473.8	0.53
23	400	477.8	0.552
24	420	481.8	0.553
25	440	485.8	0.497
26	460	489.8	0.533
27	480	493.8	0.508





Open the EO4SD Toolbox, from the main menu select the options “Sentinel 5 - Land” > “Level 1B” > “S5P Quality Map for L1b Product”. See also the figure below showing the settings to import the L1B ground pixel quality map from the sub menu.

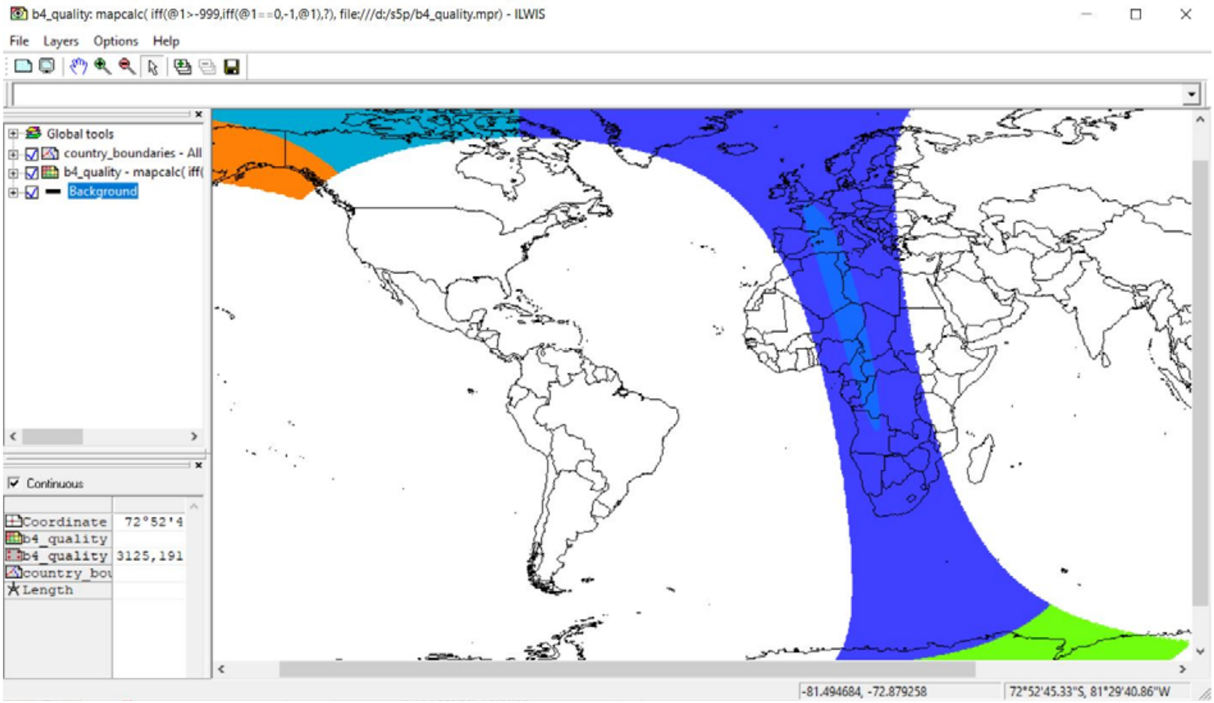
Figure 40: Import S5P Level 1b Ground Pixel Quality mask



Upon completion of the import display the map “b4_quality”. The map has a number of flags: 0= no_ error, 2= sun_glint_possible , 4= descending , and 8= night.

You can move the mouse cursor over the map and inspect the values in the lower left pixel information window. Your results should resemble those in the figure below.

Figure 40: Import of S5P Level 1b Ground Pixel Quality map



Using a map calculation statement like “outputmap:=iff(b4_quality=0,radiancemap,?)”, were the radiance map is for example the map of figure 38, ‘b4_int20_radiance_480_rad’. Using the Function MapList Calculation, this can also be executed over the whole maplist. The flagged result is given in the figure below, note the equation used in the heading of the map window.

Here band 4 is used as example. S5P has 8 bands and all can be imported and (pre-)processed as described above.

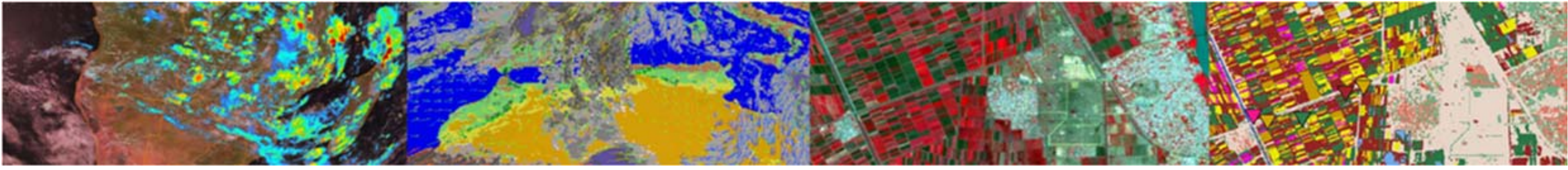
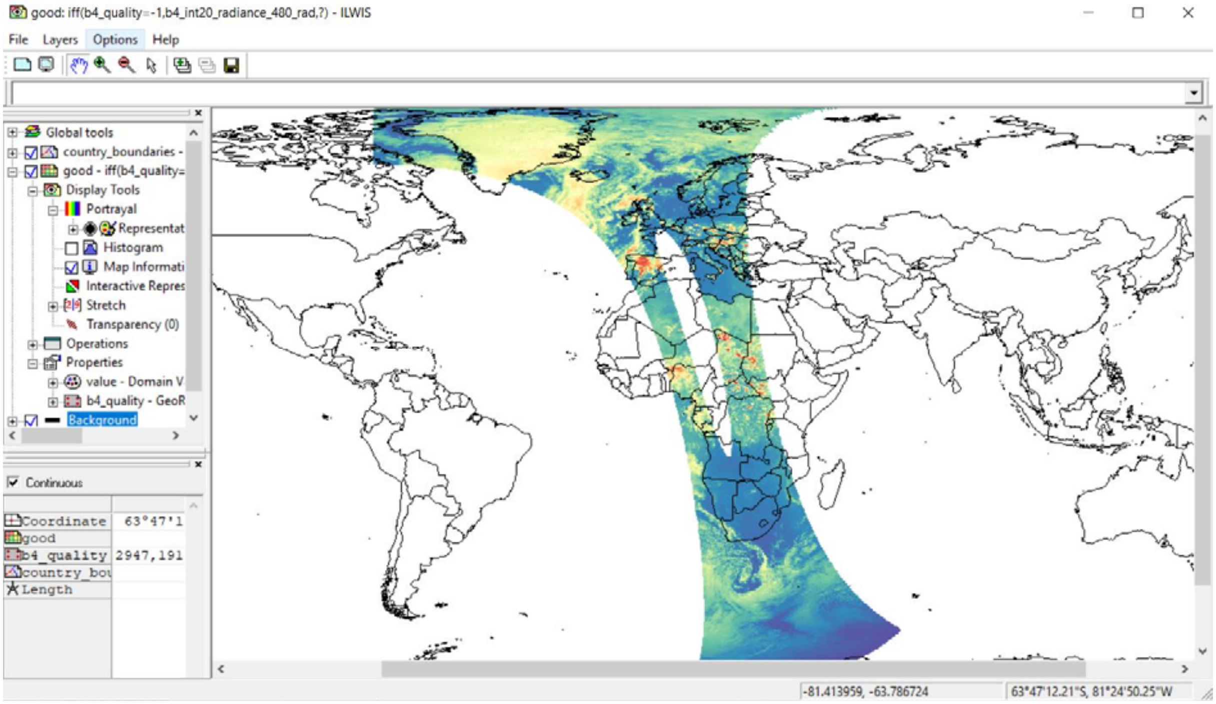


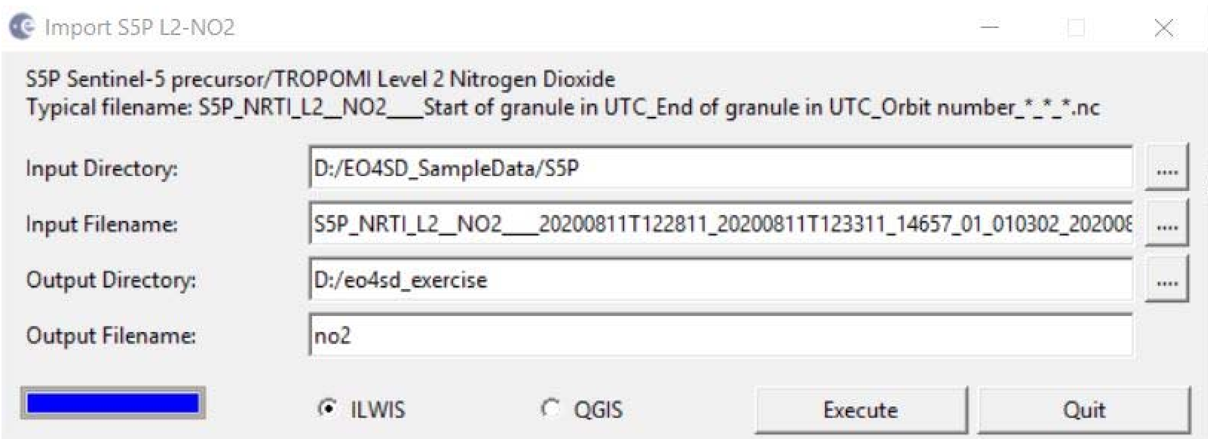
Figure 41: Apply Ground Pixel Quality map using only the no error flags



For the Sentinel 5 Precursor the Level 2 data has been retrieved from the Copernicus Online Data Access portal. The import routine to retrieve the data is identical to those provided in the previous chapter. Here we are going to look at some of the level 2 products, like the NO2 geophysical product.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 5P” > “Level 2” > “Nitrogen Dioxide (NO2)”. See also the figure below showing the settings to import the NO2 product from the sub menu. Note the full path to the data folder is: D:\EO4SD_SampleData\S5P\ and the input file name is S5P_NRTI_L2__NO2____20200811T122811_20200811T123311_14657_01_010302_20200811T131634.nc.

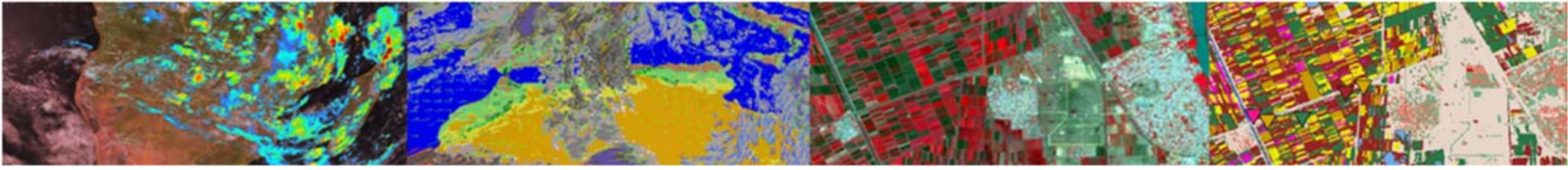
Figure 42: Import S5P Level 2 NO2 Product



Next step is the import of the quality flag. From the main menu select the options “Sentinel 5P” > “Level 2” > “S5P Quality Maps for Level 2 Products”. Use the same input file, now specify as output filename “no2_mask”. Open ILWIS and display the map “no2”. Also display the map “no2_mask” and check the values. To retrieve only the relevant quality NO2 values, use the following calculation expression:

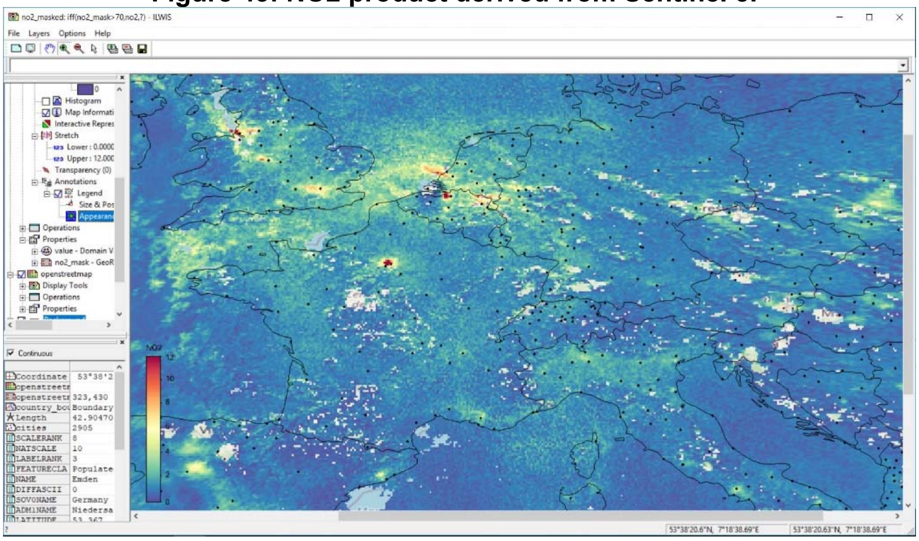
no2_masked:=iff(no2_mask>70,no2,?)

In the Raster Map Definition window, specify for the minimum value (under the Value Range) “0”, others can be kept default and display the new map “no2_masked”. Open “Display Options”, under



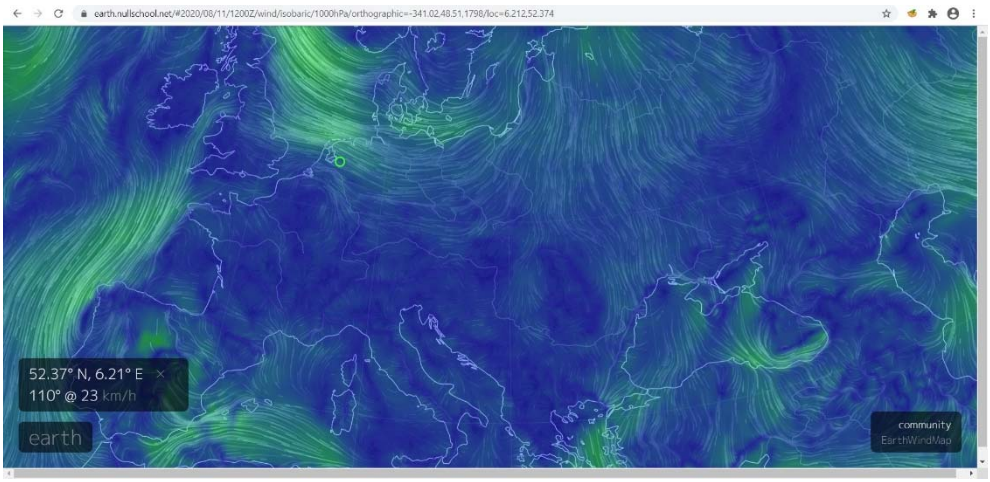
“Representation” select “Spectral_Inv. Check the map values and stretch the map from 0 to 12. Eventually add openstreetmap, the country boundaries and the cities. Assure the appropriate layer sequence (in the left hand legend), eventually use the transparency option. Note the geometry of the image. Your results should resemble those of the figure below.

Figure 43: NO2 product derived from Sentinel 5P

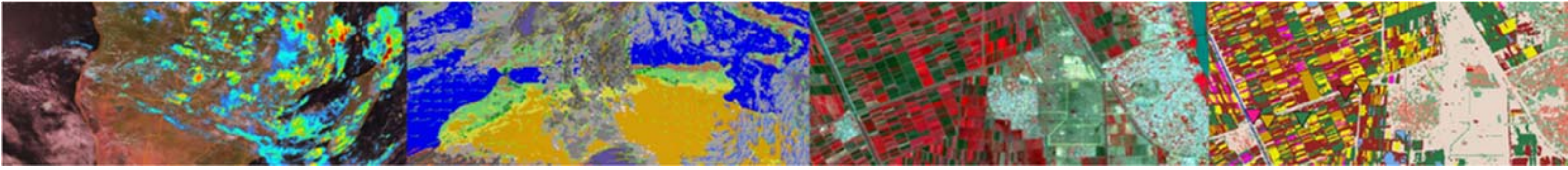


The scaling used here is 46000, to convert from mol/m2 to mg/m2 (46 (g/mol) * 1000 (mg/g) = 46000). As it is an atmospheric product which is very much influenced by the wind direction and wind speed (at various pressure levels) an option has been added in the toolbox to get an impression of the weather situation at the moment of data acquisition. From the toolbox menu, select the options “Sentinel 5P” > “Earth Weather”. Using the “Earth” menu you can select the date and time, as well as the height. An example is provided in the figure below, for the same time step as the Sentinel 5P NO2 product (check the time in the file name). Note the prevailing winds are generally coming from the East over the Netherlands, resulting in NO2 plumes to be dispersed into western direction (as can be seen on the previous figure).

Figure 44: Additional weather information required for interpretation of the S5P products



Eventually import other geophysical products, like SO2, CH4, CO and HCHO available in the SP5 sample data folder. The procedure is identical, also for the quality mask retrieval.

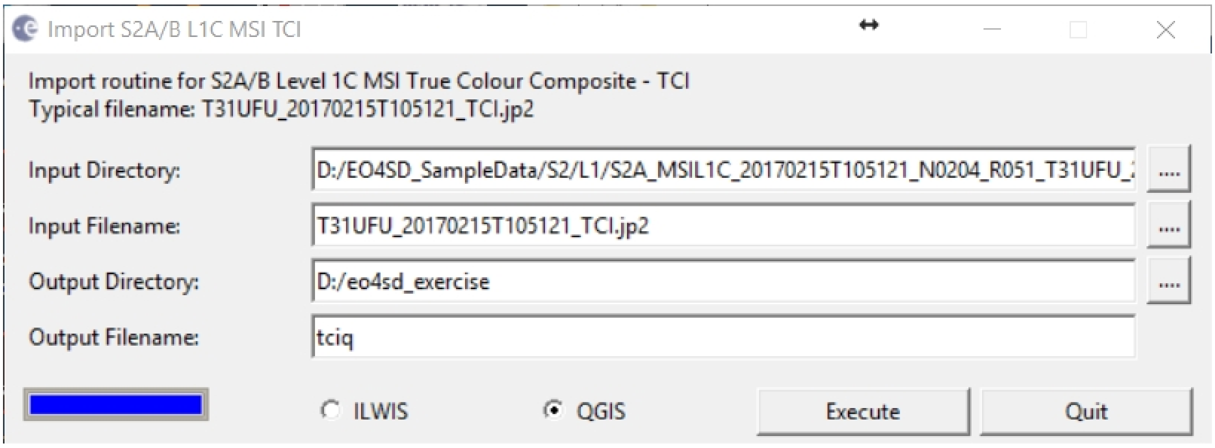


4.3 HANDS-ON EXERCISES USING QGIS

Before already a large number of examples are given how to import the various images and products from the Sentinel family of satellites. Here the focus is on the visualization using QGIS. As you have noticed within the sub-menu as output also QGIS can be selected. An output map is created in a GeoTif format and the data outside the image window is mostly assigned to -999. In the example below a Sentinel2 level 1 MSI TCI is going to be extracted and visualized.

Open the EO4SD Toolbox, from the main menu select the options “Sentinel 2” > “Level 1” > “Sentinel 2A / B L1C MSI TCI”. See also the figure below showing the settings to import the TCI. The full path to the data source is: D:\EO4SD_SampleData\S2\L1\S2A_MSIL1C_20170215T105121_N0204_R051_T31UFU_20170215T105607.SAFE\GRANULE\L1C_T31UFU_A008628_20170215T105607\IMG_DATA

Figure 45: Toolbox sub menu to import Sentinel 2 L1 TCI in QGIS



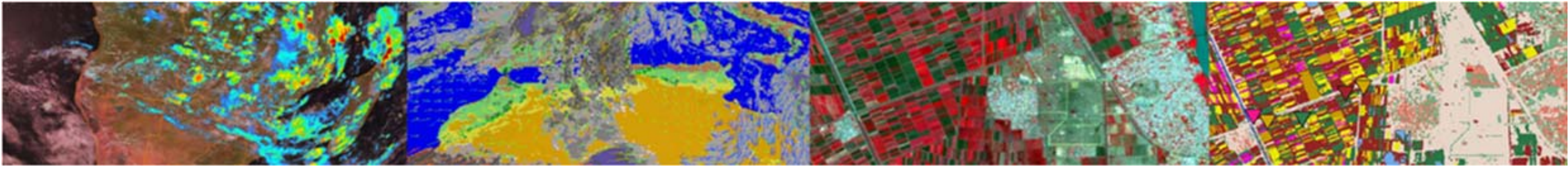
Open QGIS, here version 2.14 (Essen), from the main menu, select the options “Layer” > “Add Layer” > “Add Raster Layer”, select the image “tciq.tif” and press “Open”. Double click on the “tciq.tif” layer in the left hand legend, from the Style properties menu select the option “Transparency” and for “additional no data value” enter “0” and click “Apply”. Now note that the NE part of the image is displayed in transparency mode.

Select the option “Histogram” from the layer properties and press the button “Compute Histogram”, now modify the “Set min/max style for band 1”, use the ‘hand-sign’ marking tool and select a minimum value (here around 33) and a maximum value (here around 170) from the red curve, repeat this procedure for bands 2 and 3 (for the green and blue curves respectively and selection of the appropriate minimum and maximum. Finally press apply. Open the “Style” option, note the minimum and maximum settings for each of the band, see also the figure below, and click “Apply”. Close the “Style Properties” menu and zoom in on the image. Select the area around Schiphol International Airport in the south west corner of the image.

Now from the main menu, select the options “Vector” > “Openstreetmap” > “Download data..” (note that internet connection is required!), activate the option “From Map Canvas”, specify an Output file, navigate to the working directory and specify an output name, here e.g. “D:/eo4sd_exercise/schiphol.osm” and press “OK”. A message will popup when downloading has been conducted successful, press “OK” and “Close” the Download OpenstreetMap Data menu. Be modest and select only a small area!

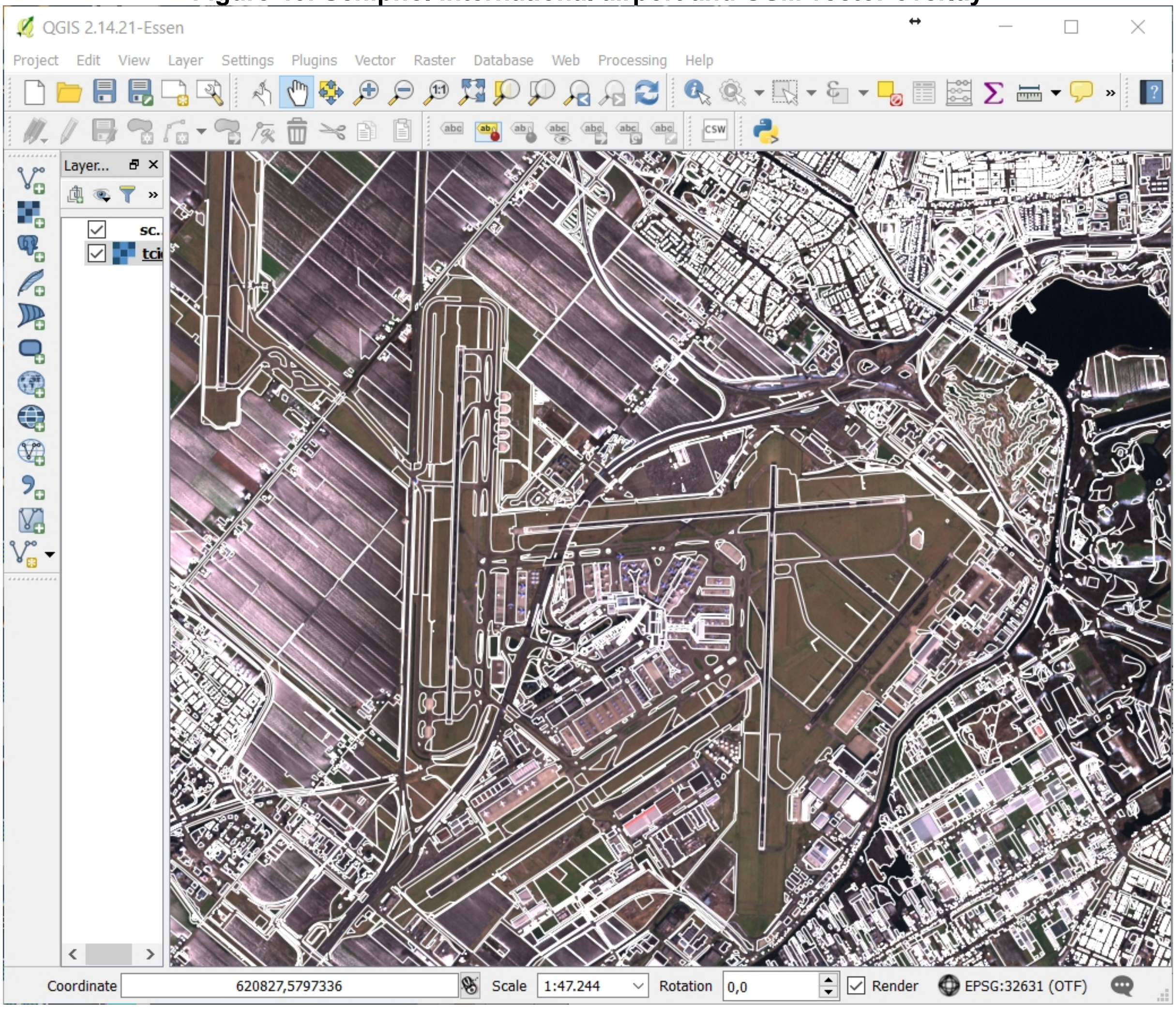
Now from the main menu, select the options “Vector” > “Openstreetmap” > “Import Topology from XML”, specify the input XML, here “Schiphol.osm”, accept the default Output SpatiaLite DB file and press “OK” Accept the message and close the window.

Now from the main menu, select the options “Vector” > “Openstreetmap” > “Export OpenStreetMap Topology to SpatialLite”, select as input DB file: “schiphol.osm.db”, as Export type select the option “Polygons (closed ways)”, use default output name, here “Schiphol_polygons” and under Exported tabs, press the button “Load from DB”, as ‘Tag’ activate the “building” and press “OK”.



The polygons are added to the map display window, double click on the layer “Schiphol_polygons”, activate the option “Style”, as “Fill”, use “Simple Fill”, and from the right hand “Symbol layer type”, under “Colors”, select from the Fill dropdown menu the option “Transparent fill” and as “Border” select the colour “white”, finally press “Apply” and “OK”. Eventually zoom in further to check the accuracy of the overlay of the raster and the vector data. Your results should resemble those presented below.

Figure 46: Schiphol international airport and OSM vector overlay



Note that for the other images or products imported the histogram needs to be adjusted in a similar manner as indicated above, most other products use -999 for “no data”, be sure the histogram is correctly representing your data range.

5. USING THE SENTINEL APPLICATION PLATFORM – SNAP

5.1 PROCESSING OF SENTINEL-1 GRD EXAMPLE FROM ETHIOPIAN HIGHLANDS

Ensure that SNAP is installed and that your system is online. The exercise requires (automatic) download of orbit information and SRTM Elevation data. The sample input file required to conduct this exercise is:

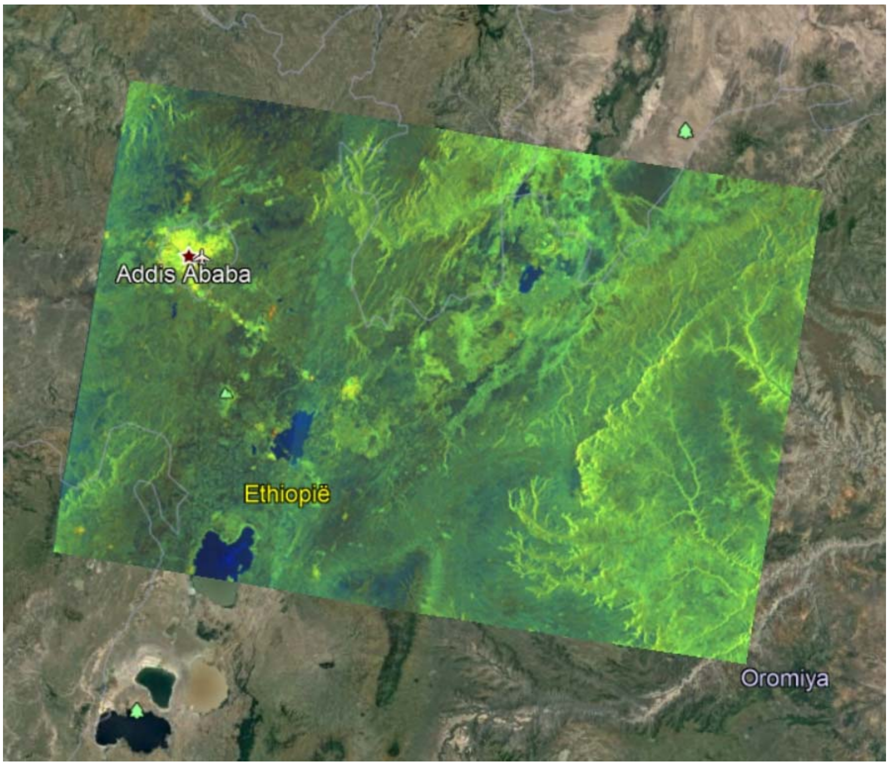
- S1A_IW_GRDH_1SDV_20171206T030912_20171206T030937_019576_0213F2_FFCF.SAFE

Sequence of processing steps to be performed using SNAP:

- Opening a product, reading of the data, using the xml file
- Visualizing the VH and VV polarized data
- Data calibration
- Data filtering – apply ‘Refined Lee’ speckle filter
- Terrain correction Data Geocoding
- Export Dimap format results obtained to be used in other free software tools, like ILWIS

Before you are going to use SNAP, first have a look within the *.SAFE file container. Navigate to the sample data directory SNAP_S1\Ethiopia\S1A_IW_GRDH_1SDV_20171206T030912_20171206T030937_019576_0213F2_FFCF.SAFE\preview. Double click the quick-look.png and also display the file “map-overlay.kml”, which will start a google earth session and displays the quicklook, also see the figure below. Note that the product is ‘ground range detected (GRD)’, the pass direction is descending and the instrument is right looking with respect to the flight direction.

Figure 47: S1A quick-look image of Ethiopia



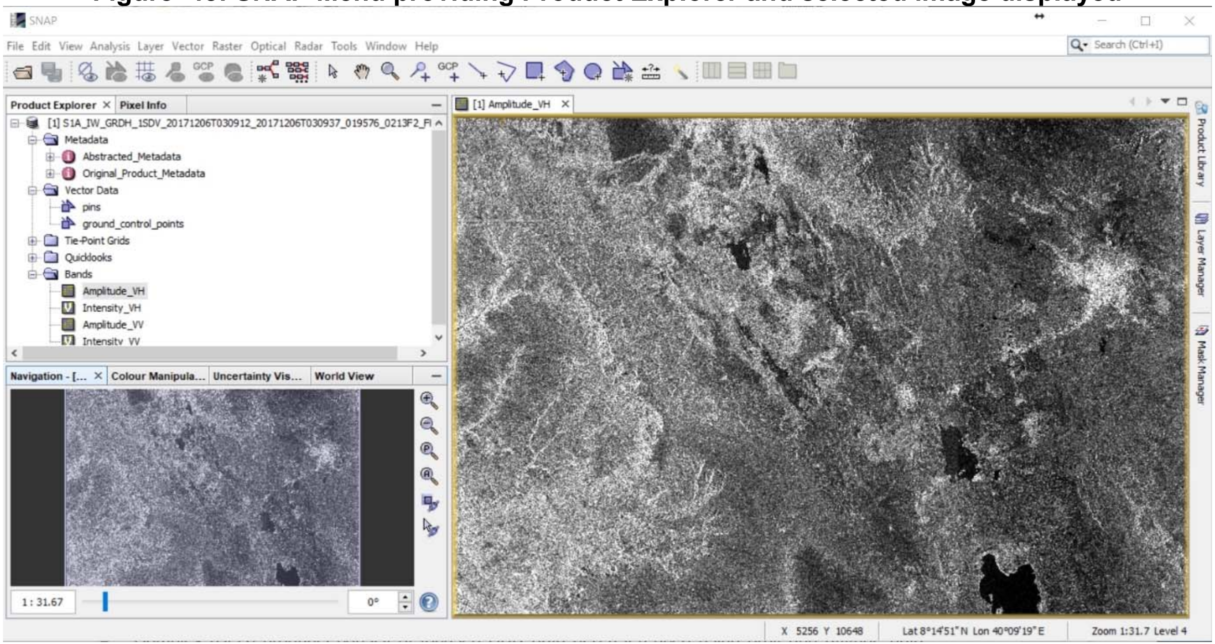
5.2 STARTING A SNAP SESSION AND OPENING A PRODUCT

From the Windows menu, under ESA SNAP, select the option “SNAP Desktop”. From the “Menu” > “Open Product”, navigate to the sample data directory, here ‘D:\EO4SD_SampleData\SNAP_S1\Ethiopia\S1A_IW_GRDH_1SDV_20171206T030912_20171206T030937_019576_0213F2_FFCF.SAFE’ the file ‘manifest.safe’. The data is added to the “Product explorer”. Expand the product by clicking the '+' sign in front to the product name, repeat this for the Meta Data and check the content, especially the Abstracted_Metadata.

Expand the Product 'Bands' layer and double click on the entry "Amplitude_VH", eventually zoom and check the image amplitude of the various cover types. Repeat this procedure for "Amplitude_VV". Display also the virtual Intensity images, e.g. of the VH polarized image. Note the intensity is calculated as: Amplitude_VH * Amplitude_VH. Your result should look like the "amplitude_HV" image displayed in the figure below. Also check the coordinates assigned, provided in the lower right.

Next to the "Product Explorer" Tab also the "Pixel Info" Tab is available, open this Tab and move the cursor over the map and inspect the information provided.

Figure 48: SNAP Menu providing Product Explorer and selected image displayed

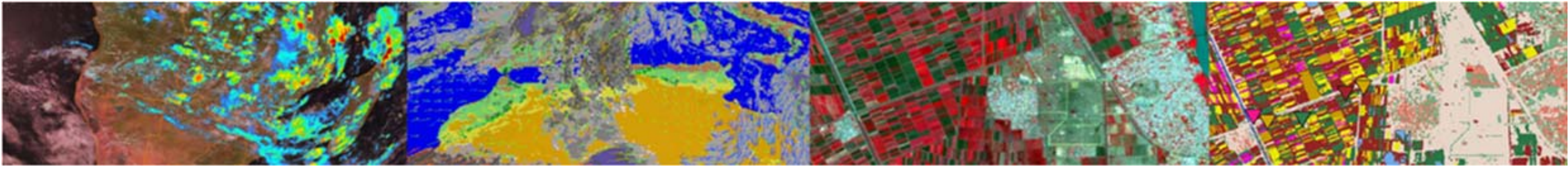


Question: Compare the quick-look image provided in the figure above and the S1A Amplitude_VH image. What can you remark about the geometry and can you explain why? Are you able to differentiate a few main image features, like hills, towns, water bodies, etc? You might need to zoom in to display the full resolution image details.

5.3 Apply Orbit File

The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product. The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated. For Sentinel-1, restituted orbit files and precise orbit files may be applied. Precise orbits are produced a few weeks after acquisition

From the SNAP menu, select the option "Radar" > "Apply Orbit File", define the input and output file names, use the default names and output file format, note that you might want to store it in a different folder. Execute the operation and display the new '*_Orb' product generated using the updated orbit information.



5.4 RADIOMETRIC CALIBRATION

The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. Though uncalibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential to quantitative use of SAR data.

Typical SAR data processing, which produces level 1 images, does not include radiometric corrections and significant radiometric bias remains. Therefore, it is necessary to apply the radiometric correction to SAR images so that the pixel values of the SAR images truly represent the radar backscatter of the reflecting surface. The radiometric correction is also necessary for the comparison of SAR images acquired with different sensors, or acquired from the same sensor but at different times, in different modes, or processed by different processors. Although only a single image is used here, radiometric calibration of the image will be conducted.

From the SNAP menu, select the option “Radar” > “Radiometric” > “Calibrate”, define the input (the image file obtained during the previous step, indicated as layer [2]) and output file names, use the default output name and output file format. Also check the “Processing Parameters” Tab. Execute the operation and display the new ‘*_Cal’ product generated.

5.5 SPECKLE FILTERING

SAR images have inherent salt and pepper like texturing called speckles which degrade the quality of the image and make interpretation of features more difficult. Speckles are caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell. Speckle noise reduction can be applied either by spatial filtering or multilook processing.

SNAP supports a few different filter types. From the SNAP menu, select the option “Radar” > “Speckle Filtering” > “Single Product Speckle Filter”, define the input (the image file obtained during the previous step, indicated as layer [3]) and output file names, use the default output name and output file format. Open the Tab “Processing Parameters” and as “Filter” selected “Refined Lee”. Execute the operation and display the new ‘*_Spk’ product generated.

5.6 TERRAIN CORRECTION

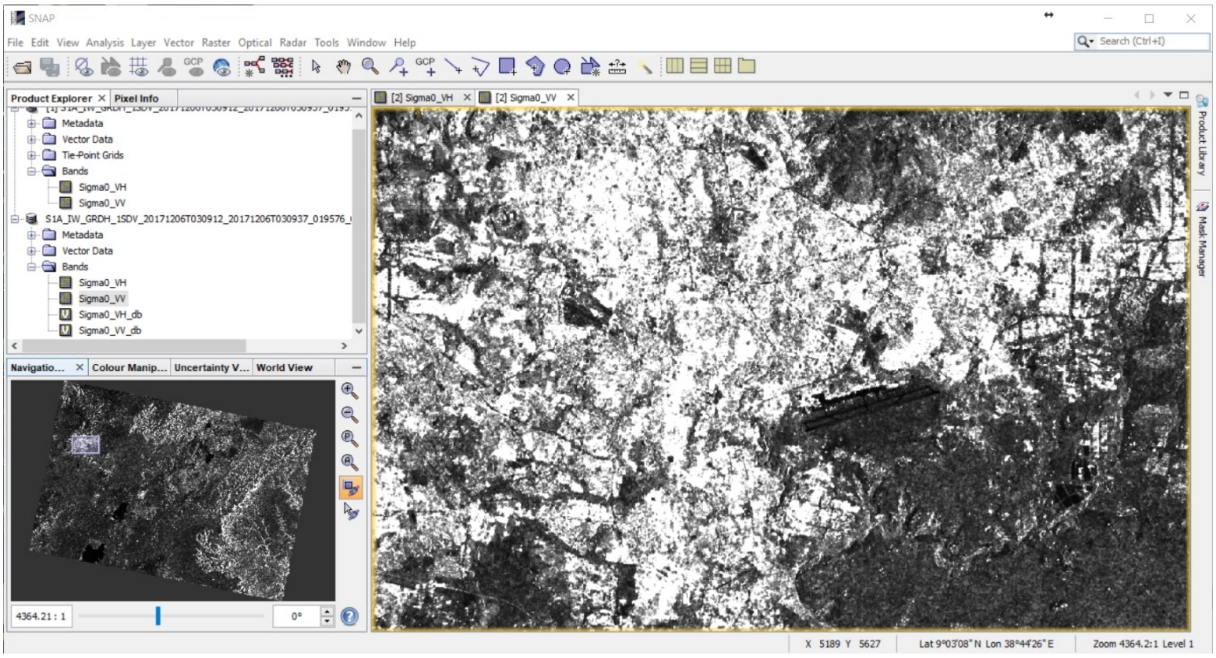
The image is still in ground range detected geometry, note that still ‘Eastings’ is flipped. Next to this the image requires elevation information for appropriate geometric (ortho) rectification. Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Image data not directly at the sensor’s Nadir location will have some distortion. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world.

The Range Doppler Terrain Correction Operator implements an orthorectification method for geocoding SAR images from single 2D raster radar geometry. It uses available orbit state vector information in the metadata, the radar timing annotations, the slant to ground range conversion parameters together with the reference DEM data to derive the precise geolocation information. The STRM v.4 (3” tiles) from the Joint Research Center FTP (xftp.jrc.it) is automatically downloaded in tiles for the area covered by the image to be orthorectified. The tiles will be downloaded to the folder .snap\AuxData\DEMs\SRTM_DEM\tiff. The .snap folder is located in your user folder.

If you are working offline or with low bandwidth connection, copy the SRTM DEM tiles required from the sample data folder \EO4SD_SampleData\SNAP_S1\Ethiopia\srtm4_dem to C:\Users\’yourname’\ .snap\auxdata\dem\SRTM 3Sec.

From the SNAP menu, select the option “Radar” > “Geometric” > “Terrain Correction” > “Range-Doppler Terrain Correction”, define the input (the image file obtained during the previous step, indicated as layer [3]) and output file names, use the default output name and output file format. Open the Tab “Processing Parameters” and note the DEM selected as well as the resampling method. Execute the operation and display the new '*_TC' product generated and note the effects on the geometry of the image! See also the figure below.

Figure 49: Terrain corrected VV polarized image displayed showing Addis Ababa and Int'l Airport



Note that the file has become very large. To continue working a subset will be created. From the main menu select "Raster" > "Subset", note that you will create a spatial subset, Enter the following scene subset details: scene start X: 4608, scene start Y: 5184, scene end X: 9216 and scene end Y: 8832, press OK. Display the subset of the two polarizations.

To view the image in decibel scaling, right-click on the terrain corrected Sigma0_VH band and select Linear to/from dB and confirm to convert the data using a new virtual band. Display the new virtual band created ("Sigma0_VH_db"). Repeat the procedure for the VV polarized product as well. Right click the layer "Sigma0_VH_db" and select the option "Band Maths…" and specify as name "Intensity_VH_db", uncheck the option "Virtual" and press OK. Note that now a real layer has been created. Display the layer and repeat the procedure for the and create a real layer for the VV polarized image, assign as file name "Intensity_VV_db"

Save the subset created, including the two 'intensity' images. Select from the main menu the options "File" > "Save Product As" and save it under a new filename, e.g. "Ethiopia_sub", the output file format is "Dim", and press "Save". After the product has been saved use your windows navigator and check the content of the new file created (in the directory D:\snap_result, note the file "ethiopia_sub.dim" and the sub-directory "ethiopia_sub.data", containing the four data layers. You can close SNAP.

5.7 USING SNAP RESULTS IN OTHER SOFTWARE

As example here the *.dim data will be exported to ILWIS *.mpr format using the "Import from SNAP" routine within the Sentinel EO4SD Toolbox. Before you continue create an new directory, e.g. "d:\snap2ILWIS"

Within the EO4SD_py directory, right click the file "EO4SD_start.py" and open the file with IDLE. Press F5 and the Python Shell and toolbox menu appear. From the toolbox menu select the option "Import from SNAP" > "Generic SNAP – DIMAP Import". In the Python shell specify the input file, here "Intensity_VH_db", press <enter>, use the same name as output file name, press <enter>, as SNAP Data Directory, press <enter>, finally select the sub-directory where you have stored your 'intensity' file, here "D:\snap_result\ethiopia_sub.data" and finally enter your Working Directory, here "d:\snap2ILWIS" and press <enter> once more to execute the operation. Repeat the procedure for “Intensity_VV_db” image.

After the import is completed open ILWIS385 and navigate to the folder “d:\snap2ILWIS”. Display the two layers, change under the “Display Tools” > “Portrayal” > “Representation” to “Gray”. Open the option “Stretch” and move the slide bar to enhance the visualization. Close the map display.

Right click in the catalog the image “Intensity_VV_db”, select the options “Image Processing” > “Stretch” and specify as Output map name “red” and press “Show”. Wait till the processing is completed, the computation of the histogram can take some time. Check the image values once the map is displayed, note that the data is now in byte format.

Repeat the procedure for the image “Intensity_VH_db”, select the options “Image Processing” > “Stretch” and specify as Output map name “green” and press “Show”.

Now compute the ratio image, defined as |VV|/|VH|. To do so type the following expression in the command line:

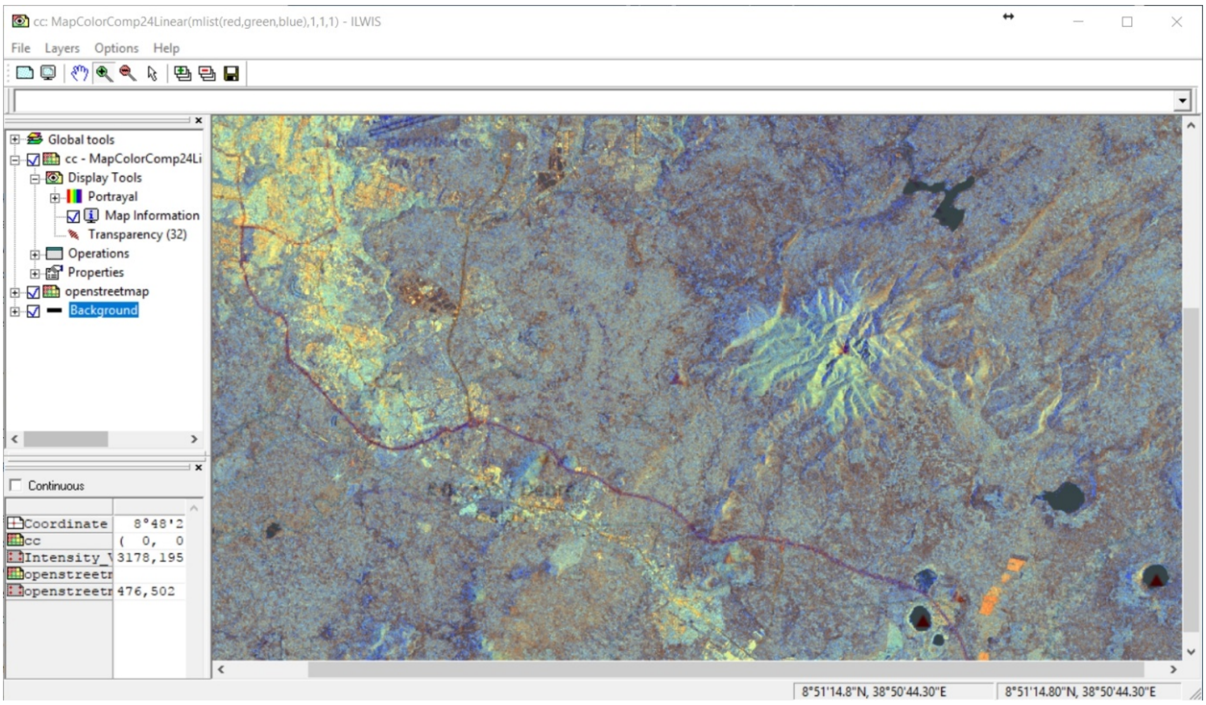
    blue_ratio:=green/red

Use the default settings and press OK. Also stretch the image “blue_ratio”, select the options “Image Processing” > “Stretch” and specify as Output map name “blue” and press “Show”.

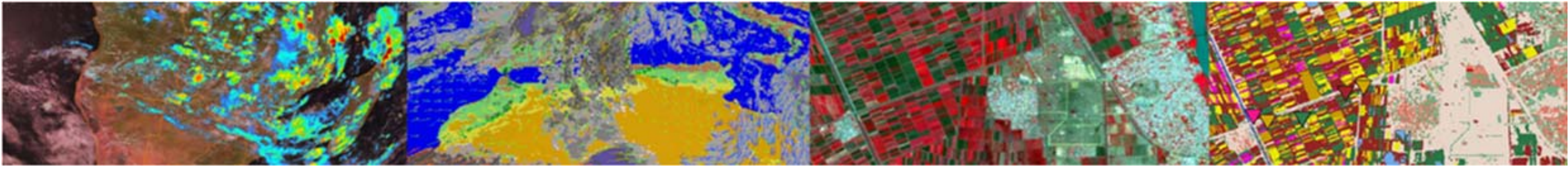
The composite RGB (colour) image to be created is using the VV channel for red, VH channel for green and the ratio |VV| / |VH| for blue. Press the Tab “Finder” from the left hand menu, select the operation “Color Composite” and use “Red” for the red band, “Green” for the green band and “blue” for the blue band. As output map specify “cc”. Display the resulting map “cc”.

From the map window select the option “Add Data Layer”, from drop down button at the filter option, select “Basemaps” > “OpenStreetmap” and press OK. Drag the openstreetmap layer in the legend below the cc-colour composite. Open the Display Tools properties of the map “cc”, which is now the top layer. Activate the option “Transparency” and move the slidebar. Eventually zoom into the image. Check the results of the terrain correction, these should resemble the figure below.

Figure 50: Terrain corrected Sentinel-1 composite RGB (colour) image



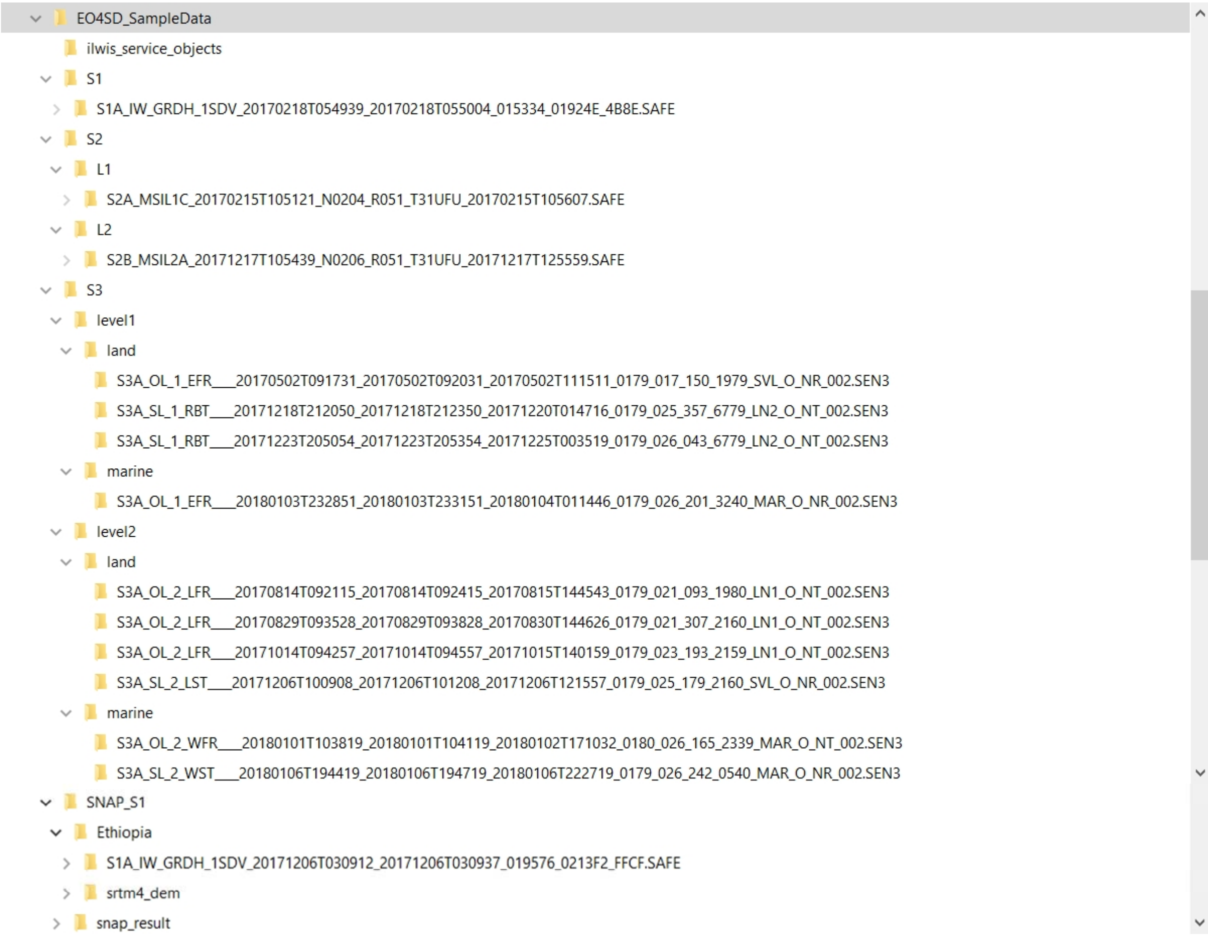
Close all open programs, like ILWIS, the Sentinel EO4SD Toolbox and eventually QGIS or SNAP, if not closed already. Check your working directory as you have created a large number of files which consume considerable storage resources. Eventually delete obsolete files.



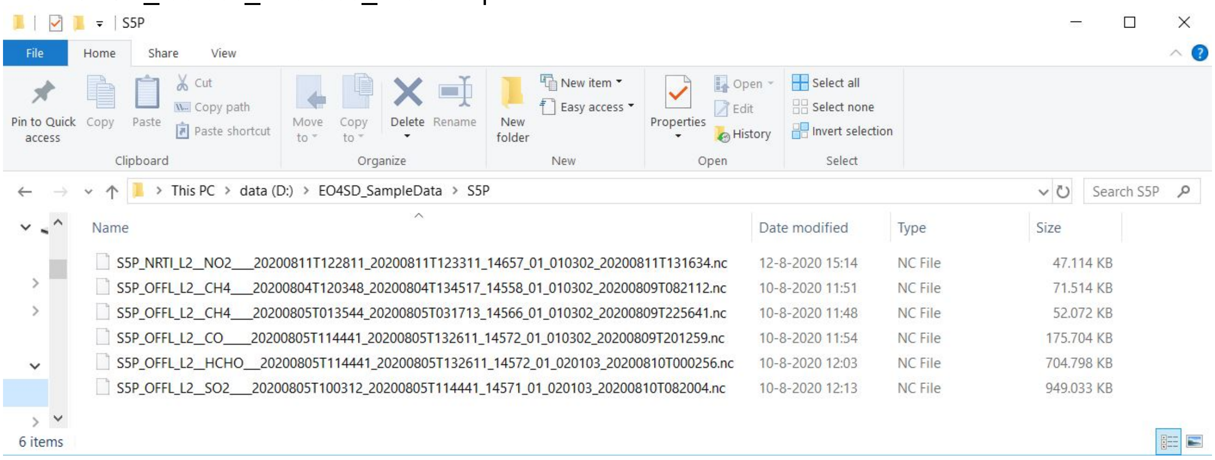
6. APPENDICES

Sample data at http://filetransfer.itc.nl/pub/52n/ILWIS386/Data/. Directory structure is given below.

File: EO4SD_toolbox_Exercise_ Data1.zip



File EO4SD_toolbox_Exercise_ Data2.zip



Sentinel 5P L1B offline (*_OFFL_*) data can be downloaded from the Sentinel-5P Pre-Operations Data Hub at https://s5phub.copernicus.eu/dhus/#/home with the username and password provided. Note the file sizes, several GB!