COPERNICUS AUSTRALASIA REGIONAL DATA HUB

Workshop Training Material

FrontierSI has prepared this training material on behalf of the Copernicus Australasia Regional Data Hub Steering Committee.

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Australian Government

Copernicus Europe's eyes on Earth

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1 Table of Acronyms

AARNet	Australia's Academic and Research Network
API	Application Programming Interface
ARD	Analysis Ready Data
BOA	Bottom-Of-Atmosphere
C-SAR	C-band Synthetic Aperture RADAR
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEA	Digital Earth Australia
DES	Department of Environment and Science (Qld)
DIAS	Data and Information Access Service
EDS	Early Detection System
EO	Earth observation
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EW	Extra Wide Swath
FR	Full Resolution
GA	Geoscience Australia
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
GRD	Ground Range Detected
GUI	Graphical User Interface
IW	Interferometric Wide Swath
MSI	Multispectral Instrument
NCI	National Computational Infrastructure
OCN	Ocean
ODC	Open Data Cube
OEH	Office of Environment and Heritage (NSW)
OLCI	Ocean and Land Colour Instrument
RAW	Raw
RR	Reduced Resolution
S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3
SAR	Synthetic Aperture RADAR
SARA	Sentinel Australasia Regional Access
SLATS	Statewide Landcover and Trees Study
SLC	Single Look Complex
SLSTR	Sea and Land Surface Temperature Radiometer
SM	Strip Map

SRAL	SAR RADAR Altimeter
SYNERGY or SYN	OLCI + SLSTR combined product
TOA	Top-Of-Atmosphere
WV	Wave

2 Aim

The aim of this training material is to help increase awareness and improve uptake of the Copernicus Australasia Regional Data Hub (the Hub). The training material is intended to be delivered via single day (6 hour) workshops to users with some existing knowledge of Earth observation (EO) and at an Earth Observation Australia webinar. The material may also be made available online. It is primarily focussed on data access, i.e. how to download data from the Hub (sub-section 7), with a secondary focus on tools available to use the data and applications as case studies.

The document is broken into four Sections and an Appendix as follows:

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SECTION A – COPERNICUS AUSTRALASIA REGIONAL DATA HUB

3 Introduction to the Hub

3.1 Mission

To be *the* regional data repository providing **fast, free**, **open**, **trusted** and **reliable** access to Sentinel satellite data for users in Australasia, South-East Asia, the South Pacific and Australia's Antarctic Territory.

3.2 Vision

To be the **first port of call** by 2021 for **bulk government and scientific research users** to access a **targeted** set of Sentinel products at **various processing levels**, covering Australasia, South-East Asia, the South Pacific and the Australian Territory of Antarctica and **expand its user base**.

Our **values** are to:

- be reliable (to build confidence);
- be open and transparent (to build trust); and
- offer good value (to build loyalty).

To be *reliable*:

- our systems must be available most of the time and report when they are not;
- new data must be available as soon as it is captured;
- the archive must be complete; and
- the data must be trustworthy and defensible.

To be *open and transparent*:

- the system must be easy to find, learn and use;
- we must provide good support structures and respond quickly to problems;
- we must report performance to the public; and
- we must be open to new partners.

To *offer good value*:

- the Hub partners and the Hub user community must receive a unique and efficient service;
- the service must enable their business with minimal overheads; and
- must result in a reasonable return on money and/or time invested.

3.3 Position in the Market

3.3.1 Positioning Statement

Accessing **big data** from Europe is challenging for users in Australasia, South-East Asia, the South Pacific and Australia's Antarctic Territory due to bandwidth; users cannot download data at the rate it is collected. Through negotiated agreement with the European Union (EU), the Hub syncs data over **high bandwidth** to provide a **timely**, **systematically acquired**, **local** and **targeted** source of Sentinel products at **various processing levels** which are **free**, **open** and **easy** to access quickly. This is essential for **bulk users** of the data and those with existing processing and value-add workflows. As data is stored on the National Computational Infrastructure (NCI) it is uniquely collocated with other nationally and internationally significant datasets as well as petascale computing facilities.

3.3.2 Position in the Landscape

The Hub is comparable to the other national mirrors, pulling data from the official EU data hubs and services that are made available to Copernicus partners and Collaborative Ground Segment members. These provide local sources, often with reduced geographic coverage, which allow faster access to the data than the European Space Agency (ESA) Copernicus Open Access Hubs. The Hub differs from the other access types outlined below through a focus on being reliable and replicating a geographical subset of Sentinel data from Europe defined by our geographic region. It is the single point of truth for Sentinel data primarily for bulk government and research users in Australasia, South-East Asia, the South Pacific and Australia's Antarctic Territory. It provides a large range of Sentinel products including the recently released Sentinel-2 L2A (considered analysis ready data (ARD)) via the Sentinel Australasia Regional Access (SARA) portal to view quick looks and select products for single and/or bulk download. It does not provide tools to process the data, nor portals to view data in depth. It is a syncing facility to improve data access.

The Hub is sponsored by the Digital Earth Australia (DEA) program and other State government equivalent programs reliant on EO data (more detail in Section 3.5). The definitive Sentinel data sourced from the Hub supports these programs.

There are many other sources to access Sentinel data (refer to Appendix A.4). For instance, there are at least 11 other official data hubs and national mirrors by Copernicus partners and Collaborative Ground Segment members, e.g. the ESA Copernicus Open Access Hub and the United Kingdom National Mirror, plus eight partial mirrors which integrate specific Sentinel data into existing search and discovery platforms, e.g. Centre for Environmental Data Analysis (S1, S2) and EUMETSAT CODA (S3 Marine Products). There are also eight Copernicus Data and Information Access Service (DIAS) cloud environments and cloud providers that host Sentinel data and allow users to bring their own code to process it without the need to download the data, e.g. CREODIAS and Amazon Web Services. There are 11 other tools specific to Sentinel data search and download, e.g. sentinelsat and awsdownload, and 15 viewers and portals specific to Sentinel data e.g. Sinergise "Sentinel Playground". There are also at least 16 tools for processing Sentinel data to ARD, e.g. SNAP (Sentinel Application Platform) and ARCSI.

Table 1 The Hubs Position in the Landscape

	Copernicus Australasia Regional Data Hub	Open Data Cubes	National Map	European Hub	National Mirrors	Partial Mirrors	DIAS	Cloud Providers
Comprehensive replica subset of Sentinel Data from European hubs	✓	X	X	✓	✓	✓	✓	X
Raw Data Access	✓	X	X	✓	✓	✓	✓	✓
Local & Fast (to AU region)	✓	X	X	X	X	X	X	X
Free & Open Data/Service	✓	✓	✓	✓	✓	✓	✓ X	X
ARD	✓	✓	✓	✓	✓	✓ X	✓	✓
Other Satellite Data (not Copernicus)	X	✓	✓	X	X	✓	✓	✓X
Other Spatial Data	X	X	✓	X	X	✓	✓	X
Data Viewing	✓	✓	✓	✓	✓ X	✓ X	✓	X
Data Processing (by user)	X	✓	X	X	X	X	✓	✓

✓ = Yes, ✓ = Partially (i.e. quick look only), X = No, ✓X = Some platforms Yes and some No

3.4 What It Is

The Hub is *the* regional data repository providing fast, free, open, trusted and reliable access to Sentinel satellite data for users in Australasia, South-East Asia, the South Pacific and Australia's Antarctic Territory.

Sentinel satellite data comes from the European Union's Copernicus Programme, which delivers global, near-real-time satellite and in situ observations with the aim of achieving better understanding of the planet, sustainably managing the environment, understanding and mitigating the effects of climate change and ensuring civil security (https://www.copernicus.eu/en/about-copernicus). The Copernicus Programme is developing a family of six missions called Sentinels. Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements, as well as dozens of third-party satellites known as 'contributing space missions'. These missions carry a range of technologies, such as RADAR and multispectral imaging instruments for land, ocean and atmospheric monitoring. The Hub supports Europe's ambitious and multifaceted Copernicus EO program by streamlining access to Sentinel data in our region (see Figure 1).

For users in Australasia, South-East Asia, the South Pacific and Australia's Antarctic Territory, accessing big data directly from Europe is challenging due to bandwidth. Similarly, syncing high volumes of data to Australia is extremely difficult for a single agency to achieve. Hence, a consortium of Australian and New Zealand organisations collaborated to bring a consolidated approach and singular voice to negotiating with the EU, ESA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The resulting agreement allows the Hub to sync large volumes of Sentinel satellite data over high bandwidth across the globe cost-effectively and in a timely fashion. The existing Australia Academic and Research Network (AARNeT) and NCI provides the physical infrastructure to implement and operate the data repository, providing syncing, storage and access.

The Hub is a local and complete source of systematically acquired and managed Sentinel products that is fast and easy to access. There are multiple ways to access data within the Hub for different types of users, including an intuitive map-based data search and download portal called SARA and a Python API (Application Programming Interface) for advanced users (refer to sub-section 7 for information on how to download data) and the NCI THREDDS server.

The Hub syncs and distributes data over the region shown in Figure 1 for Sentinel-1 (S1) and Sentinel-2 (S2) and globally for Sentinel-3 (S3) and soon Sentinel-5P. It includes imagery acquired since the beginning of each Sentinel mission. The Hub Sentinel data offer consists of (also described in Table 2:

- Sentinel-1, 2014 to present - providing all-weather, day and night RADAR imagery for land and marine services
    - Level-0 and Level-1 user products for the following acquisition modes
        - Strip Map (SM)
        - Interferometric Wide Swath (IW)
        - Extra Wide Swath (EW)
    - Level-2 user products for the following acquisition modes
        - SM

- IW (limited products available)
- EW
- Wave (WV)

- Sentinel-2, 2015 to present - providing high-resolution multispectral imagery for land and marine services
  – Level-1C user products Top-of-Atmosphere (TOA) Reflectance
  – Level-2A user products Bottom-of-Atmosphere (BOA) Reflectance
- Sentinel-3, 2016 to present - providing high-accuracy optical, RADAR and altimetry data for land and marine services
  – Level-1 and Level-2 user products for the OLCI, SLSTR and SRAL instruments (refer to sub-section 4.4)
- Sentinel-5P, soon to be added - a precursor to provide dedicated atmospheric composition monitoring

Table 2 Matrix overview of data synced by the Hub

Data Processing Level	Sentinel-1	Sentinel-2	Sentinel-3				Sentinel-5P
			OLCI	SLSTR	SYNERGY	Altimetry	
Level 2	Ocean data (SM, IW, EW, WV)	BOA Reflectance data	Ocean & Atmosphere + Land & Atmosphere data	Sea Surface Temperature, Land Surface Temperature	Synergy VGT-P like product, VGT-S like product	Marine data, Land data	Atmospheric data
Level 1	SLC & GRD data (SM, IW, EW)	TOA Reflectance data	TOA Radiance data	Brightness temperatures, TOA Radiances	-	-	-
Level 0	Raw data (SM, IW, EW)	-	-	-	-	-	-

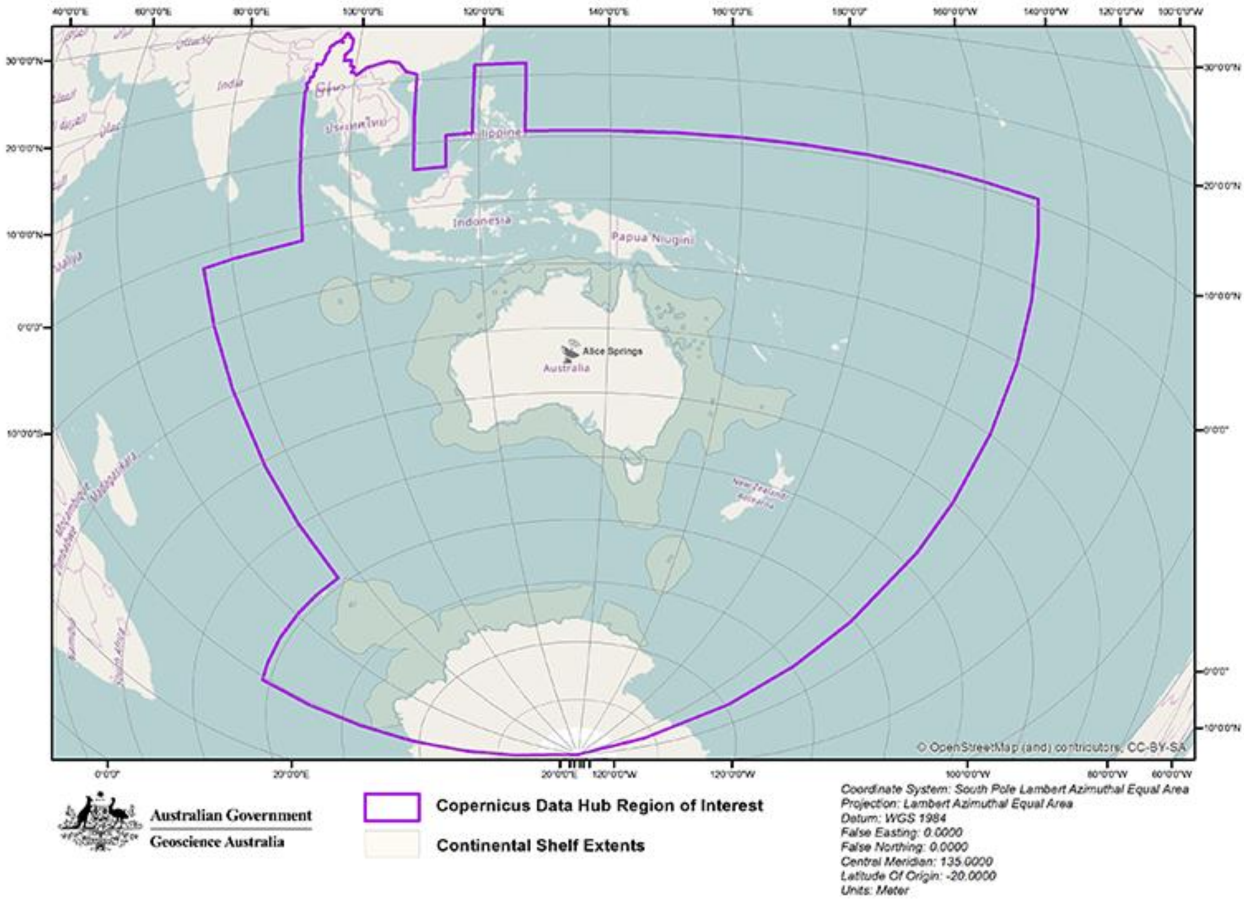


Figure 1 The Hub Region of Interest

(Copernicus Australasia Regional Data Hub, http://www.copernicus.gov.au/about-us)

As of June 2019, the Hub stored 2.5 petabytes of data with an average user download volume of about 120 terabytes per month across all products. These numbers continue to increase daily.

3.5 Why It Exists

Europe's Copernicus Programme and its constellation of Sentinel satellites is a critical source of EO data for Australasia. The objective of the Hub is to increase the use and impact of Sentinel satellite data in the Australasian region by providing fast, easy and free access to data from Sentinel missions 1, 2, 3 and soon 5P. The Hub supports the business requirements of the partner agencies, forms a consolidated approach to enhance access to EO data for research, industry and civil society and fulfils a commitment to give back to the international satellite EO community. Sponsored by Australian and New Zealand government organisations, the Hub supports programs which are reliant on EO satellite imagery, including:

- Geoscience Australia’s Digital Earth Australia program;
- New South Wales and Queensland land management and landcover programs;
- Western Australia’s Land Monitor and FireWatch programs; and
- Commonwealth Scientific and Industrial Research Organisation (CSIRO) research programs.

3.6 Partners and Users

The Hub is established under a series of partnership agreements including the Consortium partners that manage and operate the Hub; delivery partners who sync and distribute the data across the globe; and supporting partners who provide access to the data.

The Consortium partners are Geoscience Australia (GA), the Queensland Department of Environment and Science (DES), the New South Wales Office of Environment and Heritage (OEH), the Western Australian Land Information Authority represented by Landgate, the CSIRO and New Zealand's XERRA Earth Observation Institute.

The delivery partners are the National Computational Infrastructure (NCI) which is contracted to implement and operate the data repository and AARNet and GÉANT (pan-European data network for the research and education community) to get the data physically across the globe.

The supporting partners are the European Commission, ESA, the European Environment Agency and EUMETSAT.

The primary users of the Hub are the partner agencies, large government organisations and the scientific research community. That is, users accessing data in bulk and applying their own processing and value-add workflows. The Hub is looking to expand its user base in the future to include industry, academia and non-government sectors across the region. In New Zealand, commercial companies already make up 20 per cent of the user base.

3.7 Data Management Statement

The Hub replicates a subset of Europe’s repository, covering the geographic region defined in Figure 1.

The Hub has three access methods to its repository:

1. Graphical User Interface (GUI) or API access through the SARA website for registered users (https://copernicus.nci.org.au/sara.client/#/home).
2. Open access through NCI’s THREDDS server for all users.
3. Direct file system access through Virtual Desktop Infrastructure (VDI) and Raijin for users registered at NCI.

The Hub checks for new data every hour for the products as per **Error! Reference source not found.** and attempts to download these within <u>one hour</u> of being available from the European hubs, i.e. ESA and EUMETSAT.

Table 3 Hub Product Management

Mission - status	Product	Region of capture and management regime
Sentinel-1A & 1B - operational	RAW GRD – Full Resolution GRD – High resolution GRD – Medium Resolution SLC OCN	Sync products over Hub Region only
Sentinel-2A & 2B - operational	L1C TOA L2A BOA	Sync products over Hub Region only
Sentinel-3A & 3B - operational	OLCI L1B TOA OLCI L2 – Marine and Land SLSTR L1B TOA SLSTR L2 – Marine and Land SRAL L1+L2 SYNERGY	Sync globally, remove any 'time critical' products that have been superseded, then maintain Hub Regional only data after 60 days post 1 July 2019.
Sentinel-5P - commissioning	L2	Sync global products

The Hub aims to make 90 per cent of the data available in Australia within 24 hours of it appearing in the European hubs (and achieves this). Successful data replication, completeness as well as consistency with the European hubs is checked routinely and cleaned monthly. Any issues with products downloaded from the Hub should be reported to earth.observation@ga.gov.au. Problems due to access via SARA, THREDDS or VDI should be reported to help@nci.org.au.

New products are added to the Hub based on the needs of its users, currently comprising government partners who finance its operations, and future users including industry, academia, and non-government sectors across our Region. If users have a particular need for Sentinel products not listed in Table 3 that fall within our Region of Interest, please contact earth.observation@ga.gov.au.

SECTION B – ABOUT THE COPERNICUS PROGRAMME

4 Missions & Data Available

4.1 Missions Overview

Copernicus is the new name for the Global Monitoring for Environment and Security (GMES) programme. ESA is developing a new family of next-generation Earth observation missions called Sentinels, specifically for the operational needs of the Copernicus Programme. The goal is to replace older Earth observation missions that have reached retirement or are nearing the end of their operational life span. This will ensure a continuity of data so that there are no gaps in ongoing studies.

The missions carry a range of technologies, such as RADAR and multispectral imaging instruments and focus on different aspects of Earth observation: Atmospheric, Marine, and Land monitoring, making the data useful in many applications. Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements. At present, three complete two-satellite constellations are in orbit plus an additional single satellite, Sentinel-5P.

The Sentinel-1 mission provides all-weather, day and night RADAR images from satellites Sentinel-1A and -1B, launched respectively in April 2014 and April 2016. Sentinel-2 is designed to deliver high-resolution multispectral images for land services with satellite Sentinel-2A launched on 23 June 2015 and Sentinel-2B on 7 March 2017. The two Sentinel-3 satellites, Sentinel-3A and -3B launched on 16 February 2016 and 25 April 2018, provide data for services relevant to the ocean and land. The Sentinel-5 Precursor mission has been developed to reduce data gaps between Envisat and the launch of Sentinel-5. Sentinel-5P, the first Copernicus mission in orbit dedicated to monitoring the atmosphere, was launched on 13 October 2017.

4.2 Sentinel-1

Sentinel-1 is an imaging Synthetic Aperture RADAR (SAR) mission. SAR has the advantage of operating at wavelengths in the microwave range that can penetrate cloud cover and are not impeded by a lack of illumination, meaning it can acquire continuous all-weather, day-and-night imagery. Sentinel-1 comprises single instrument platforms carrying C-band SAR (C-SAR). The mission is currently composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B, sharing the same orbital plane. The Sentinel-1 constellation provides high reliability, short revisit time (6 days), geographical coverage, dual polarisation capability and rapid data dissemination to support operational applications in the priority areas of marine monitoring, land monitoring and emergency services.

Sentinel-1 C-band imaging operates in four exclusive imaging modes with different resolution (down to 5m) and coverage (up to 400km). The main operational mode, Interferometric Wide Swath, features a wide swath (250 km) with medium geometric (typically 20 m Level-1 product resolution) and radiometric resolutions, suitable for most applications. For each observation, precise measurements of spacecraft position and attitude are available.

The four **acquisition modes** (Figure 2) and polarisations available for Sentinel-1 include:

1. Stripmap (SM)
    a. A standard SAR stripmap imaging mode where the ground swath is illuminated with a continuous sequence of pulses, while the antenna beam is pointing to a fixed azimuth and elevation angle.
    b. SM mode is used on request mainly for emergency management.
    c. Data products are available in dual polarisation (VV+VH or HH+HV) or single polarisation (HH or VV).
2. Interferometric Wide Swath (IW)
    a. Data is acquired in three swaths using the Terrain Observation with Progressive Scanning SAR (TOPSAR) imaging technique. In IW mode, bursts are synchronised from pass to pass to ensure the alignment of interferometric pairs.
    b. IW is Sentinel-1's primary operational mode over land.
    c. Data products are available in dual polarisation (VV+VH or HH+HV) or single polarisation (HH or VV).
3. Extra Wide Swath (EW)
    a. Data is acquired in five swaths using the TOPSAR imaging technique. EW mode provides very large swath coverage at the expense of spatial resolution.
    b. EW mode will be used mainly for sea-ice monitoring services and maritime surveillance, with the capability to cover 400 km wide area at each datatake.
    c. Data products are available in dual polarisation (VV+VH or HH+HV) or single polarisation (HH or VV).
4. Wave (WV)
    a. Data is acquired in small stripmap scenes called "vignettes", situated at regular intervals of 100 km along track. The vignettes are acquired by alternating, acquiring one vignette at a near range incidence angle while the next vignette is acquired at a far range incidence angle.
    b. WV is Sentinel-1's operational mode over open ocean.
    c. Data products are available in single polarisation (VV or HH).

Polarisation refers to whether the RADAR signal is being measured in the horizontal or vertical plane. Polarisation is a property of transverse waves (waves oscillating perpendicular to the direction of energy transfer) that specifies the geometrical orientation (horizontal or vertical for RADAR) of the oscillations. An example is vibrations traveling along a taut string like a guitar string. Depending on how the string is plucked, the vibrations can be in a vertical or horizontal direction (or at any angle perpendicular to a string). For further explanation of polarisation see the RADAR Polarimetry chapter of the Fundamentals of Remote Sensing tutorial from the Canadian Centre for Remote Sensing (CCRS; https://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309). As a general principle, the Sentinel-1 RADAR polarisation scheme uses the following logic:

- HH+HV or HH polarisation for the monitoring of polar environments and sea-ice zones
- VV+VH or VV polarisation for all other observation zones, including land outside of the poles

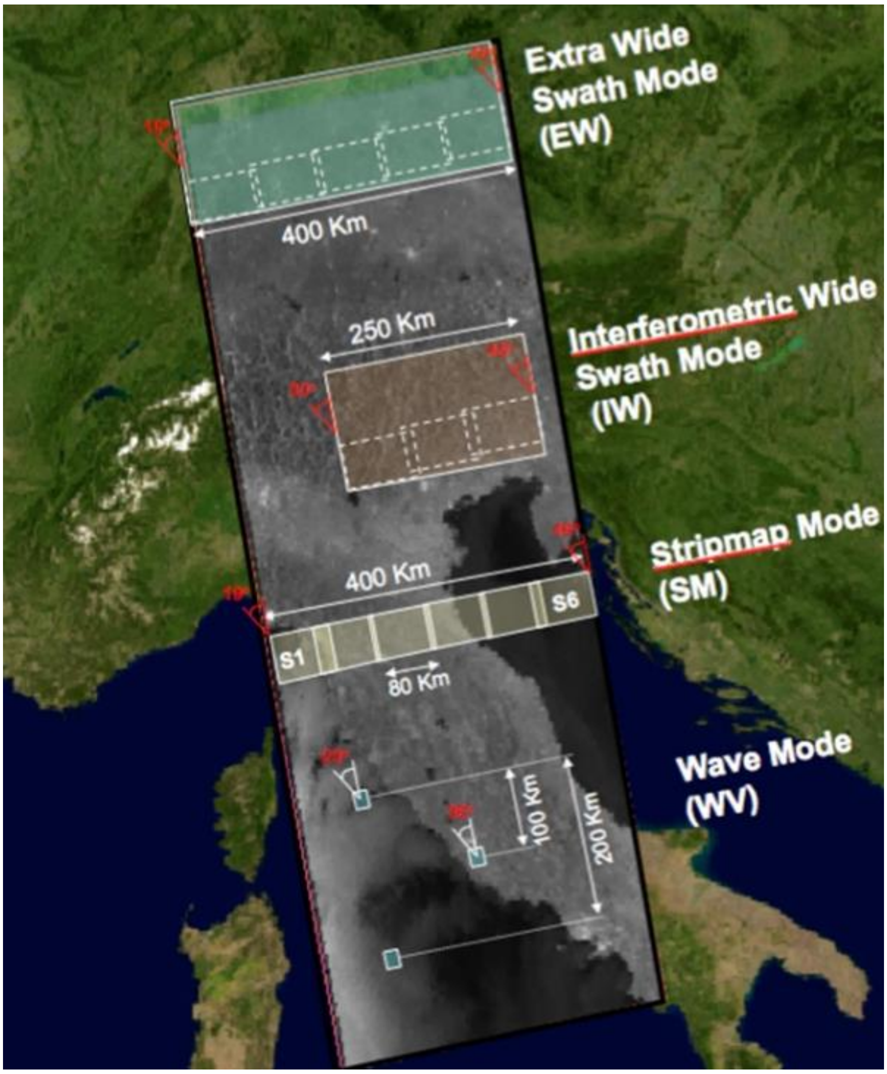


Figure 2 Sentinel-1 swath coverage and acquisition modes

(ESA, https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/revisit-and-coverage)

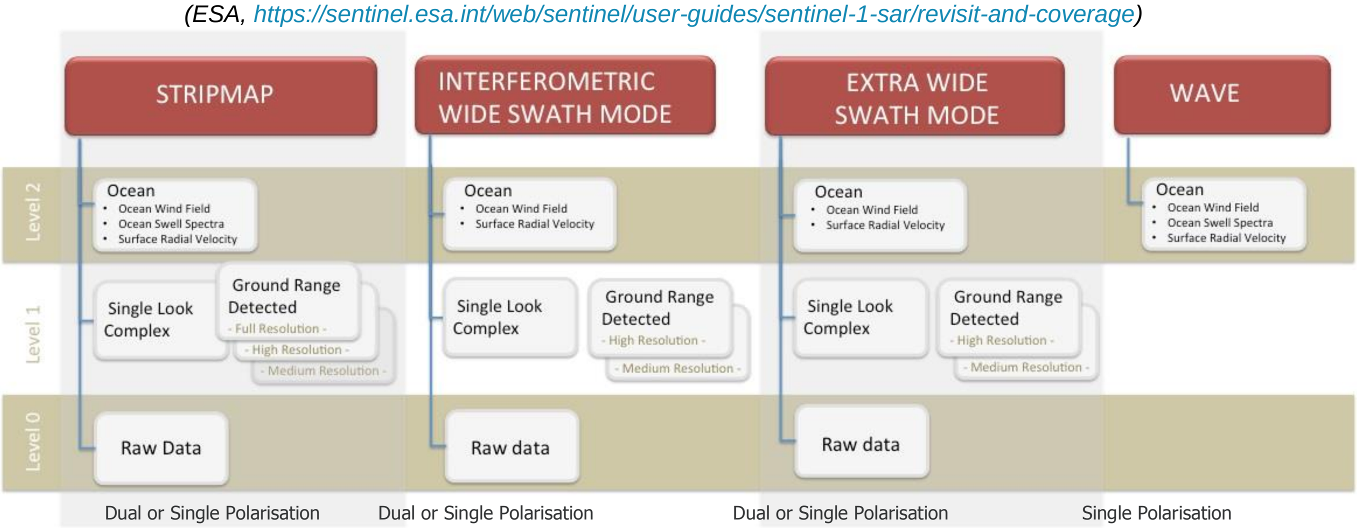


Figure 3 Sentinel-1 products (distributed by the Hub)

(ESA, https://sentinel.esa.int/web/sentinel/missions/sentinel-1/data-products)

The Sentinel-1 **data products** that are synced by the Hub (as shown in Figure 3) include:

- Level-0
  - Compressed unfocused raw data. Level-0 products are the basis from which all other high-level products are produced. For the data to be usable, it needs to be decompressed and processed.
- Level-1
  - Level-1 data are the products intended for most data users and form a baseline product from which Level-2 products are derived. Products are:
    - Single Look Complex (SLC) data comprising complex imagery with intensity and phase information.
    - Ground Range Detected (GRD) data with multi-looked intensity only. Phase information is discarded, and the resulting product has spatial resolution represented by approximate square pixels and their spacing. The reduced speckle is a result of the spatial resolution. GRD products are provided in one of three resolutions:
      - Full Resolution (FR) for SM mode
      - High Resolution (HR) for SM, IW and EW modes
      - Medium Resolution (MR) for SM, IW, EW and WV modes
- Level-2
  - Processed Ocean (OCN) data for retrieved geophysical parameters of the ocean. Products for wind, wave and currents applications include components for Ocean Swell spectra (OSW), Ocean Wind Fields (OWI) and Surface Radial Velocities (RVL). Products are:
    - 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.
    - 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.
    - RVL is a ground range gridded difference between the measured Level-2 Doppler grid and the Level-1 calculated geometrical Doppler.

Each of the four acquisition modes can potentially produce products at Level-0, Level-1 SLC, Level-1 GRD and Level-2 OCN.

Sentinel-1 data products are distributed in the Sentinel Standard Archive Format for Europe (SAFE) format (https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar/data-formats/safe-specification). Further information on the SAR format is available at https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar/data-formats/sar-formats.

4.3 Sentinel-2

Sentinel-2 is a wide-swath, high-resolution, multispectral optical imaging mission. It comprises single instrument platforms carrying Multispectral Instruments (MSI). The mission is composed of twin satellites, Sentinel-2A and Sentinel-2B, flying in the same orbit but separated by 180°. This design gives a high revisit frequency of five days with the two satellites under cloud-free conditions, which results in 2-3 days at mid-latitudes. Sentinel-2 provides redundancy in case of failure for SPOT and LANDSAT-type image data in a spectral sense (however not in terms of spatial resolution). The mission coverage and high revisit frequency provides for the generation of geoinformation at local, regional, national and international scales. The data is designed to be modified and adapted by users interested in applications such as land management, agriculture and forestry, disaster control, humanitarian relief operations, risk mapping and security concerns.

The Sentinel-2 MSI captures 13 spectral bands: four bands at 10m, six bands at 20m and three bands at 60m spatial resolution. The orbital swath width is 290km. The maximum continuous acquisition of an image from one Sentinel-2 satellite is 15 000 km. The continuous acquisition is called a "datatake". If a datatake is acquired by two separate receiving stations, the datatake may be sub-divided into datastrips. The elementary level of Sentinel-2 MSI products are granules of a fixed size, dependent on the product level. For the orthorectified Level-1C and Level-2A products, the image is divided into 100 km tiles in UTM/WGS84 projection (Figure 4). All products contain granules/tiles from a single datatake. A datatake is presented inside a product as a set of one or more datastrips (corresponding to acquisition segments downlinked to different ground stations).

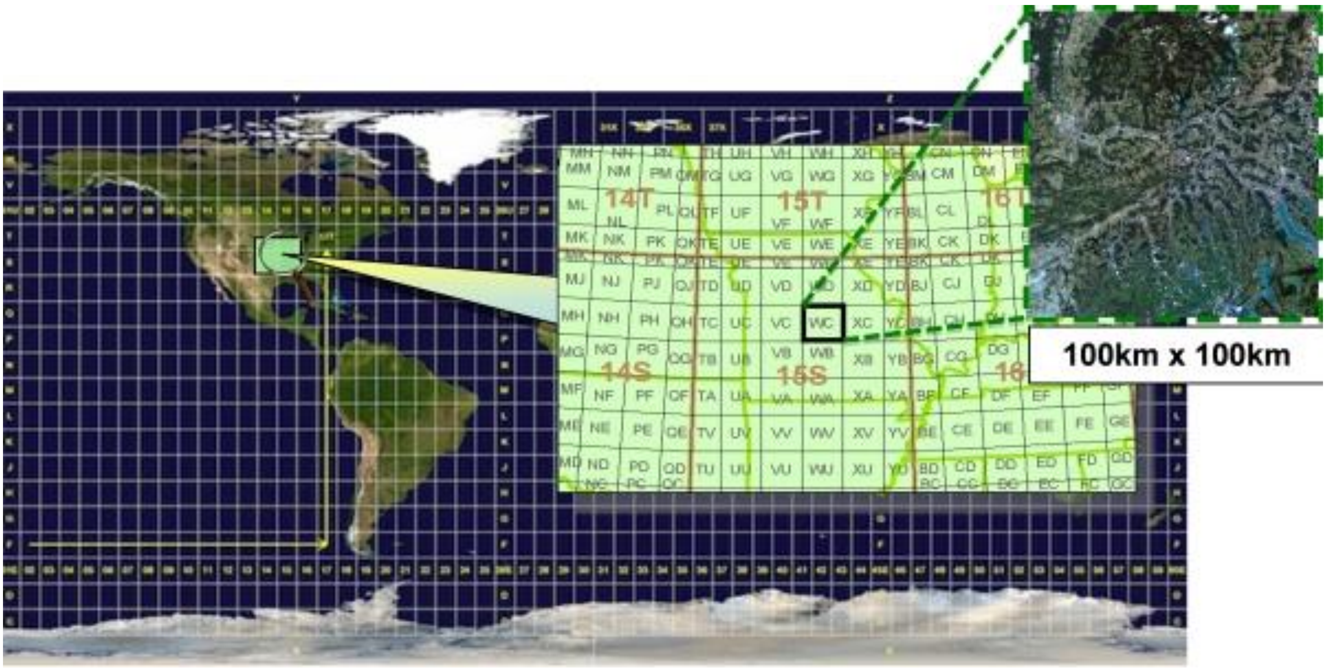


Figure 4 Sentinel-2 Level-1C and 2A product tiling

(ESA, https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/product-types)

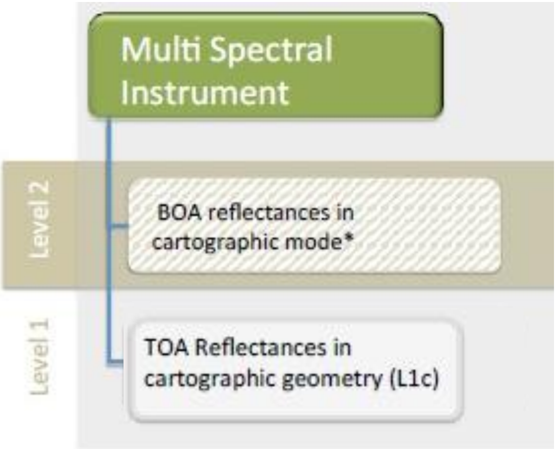


Figure 5 Sentinel-2 products (distributed by the Hub)

(ESA, https://sentinel.esa.int/web/sentinel/missions/sentinel-2/data-products)

The Sentinel-2 **data products** that are synced by the Hub (as show in Figure 5) include:

Level-1C

- Data processing includes radiometric and geometric corrections including ortho-rectification and spatial registration on a global reference system with sub-pixel accuracy. This produces Top-Of-Atmosphere (TOA) reflectances in cartographic geometry.
- Composed of 100x100 km2 tiles (ortho-images in UTM/WGS84 projection) resulting from using a Digital Elevation Model (DEM) to project the image in cartographic geometry.
- Per-pixel radiometric measurements are provided in TOA reflectances along with the parameters to transform them into radiances.
- Resampled with a constant Ground Sampling Distance (GSD) of 10, 20 or 60 m depending on the native resolution of the different spectral bands.
- Additionally include Cloud Masks and ECMWF data (total column of ozone, total column of water vapour and mean sea level pressure).

Level-2A

- Level-2A products are ARD generated either by the Payload Data Ground Segment using the Sen2Cor processor, or on the User side through the Sentinel-2 Toolbox.
- Data processing includes a scene classification and an atmospheric correction applied to TOA Level-1C orthoimage products. The Level-2A main output is an orthoimage BOA corrected reflectance product.
- Each BOA reflectance image is composed of 100x100 km2 tiles in cartographic geometry (UTM/WGS84 projection).
- Level-2A products have been systematically generated at the ground segment over Europe since March 2018, and the production was extended to global in December 2018.

Sentinel-2 data products are distributed in the SAFE format (https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/data-formats).

4.4 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 with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. Sentinel-3 satellites carry four main instruments: Ocean and Land Colour Instrument (OLCI), Sea and Land Surface Temperature Radiometer (SLSTR), Synthetic Aperture RADAR Altimeter (SRAL) and Microwave Radiometer (MWR). The mission is composed of a constellation of two satellites, Sentinel-3A and Sentinel-3B, flying in the same orbit but separated by +/-140°. The two satellites enable a short revisit time of less than two days for OLCI and less than one day for SLSTR at the equator.

The Sentinel-3 user products are disseminated in Product Dissemination Units (PDU), to ease online dissemination and data handling for users. The PDU is a portion of data and is defined per product type. Three kinds of PDU are defined: "frame", "stripe" and "tile" (see Figure 6 and Figure 7).

- A frame is identified by a fixed reference system. The along-track coordinate identifies the product frame start point with respect to a fixed orbit position. Each frame is stepped by a constant time interval along the orbit track. The along-orbit cycle coordinate identifies the relative orbit number within the orbit cycle.
- A stripe coincides either with the acquisition dump or with a defined acquisition time segment whose length may differ according to the instrument type (for example full orbit pole to pole, half orbit etc.). A special case of stripe is provided by the Vegetation-like product (called VGT-P) where the stripe is mapped on a Plate Carrée geographical projection.
- Tiles are defined only for Vegetation-like 1- or 10-day synthesis products, VGT-S1 and VGT-S10, provided on a Plate Carrée map projection. A tile corresponds to a geographical subset of the synthesis image as shown in Figure 7.

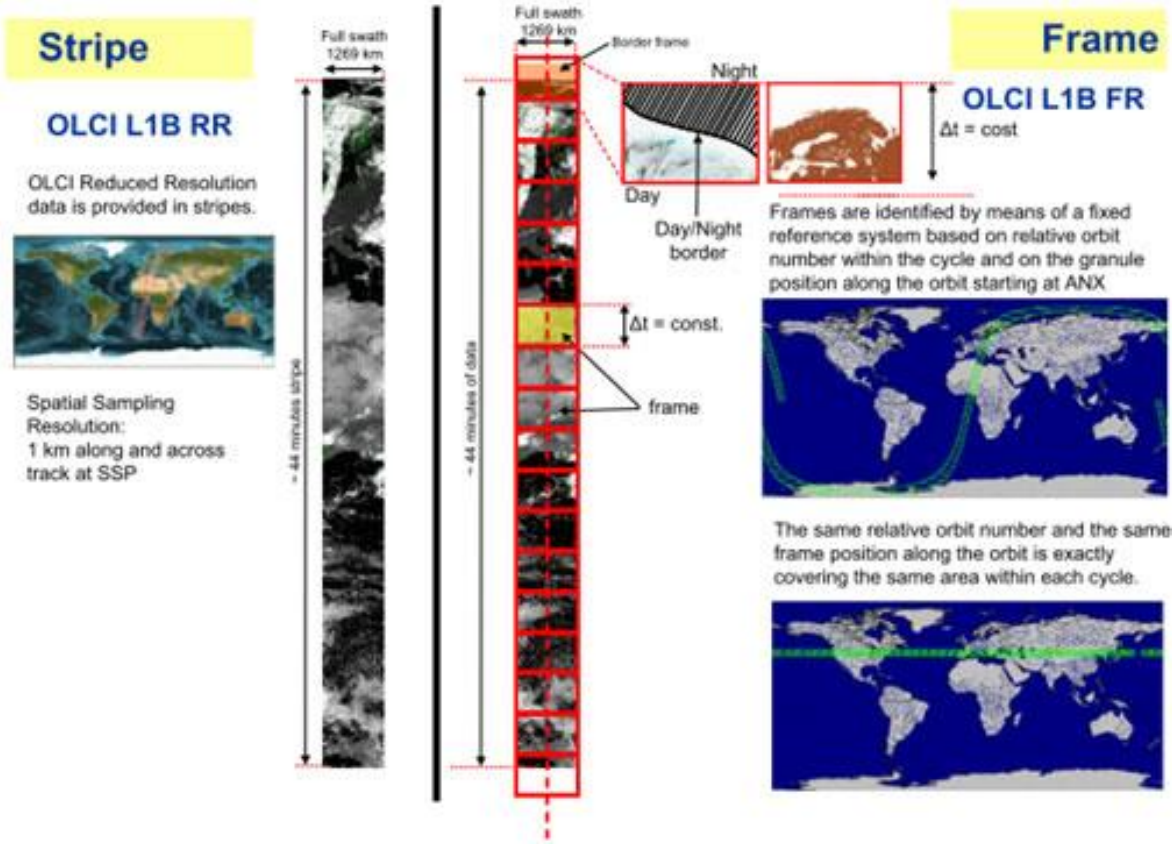


Figure 6 Example of PDUs for Sentinel-3 OLCI L1B products: stripe and frame concept

(ESA, https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/data-products/user-dissemination-concept)

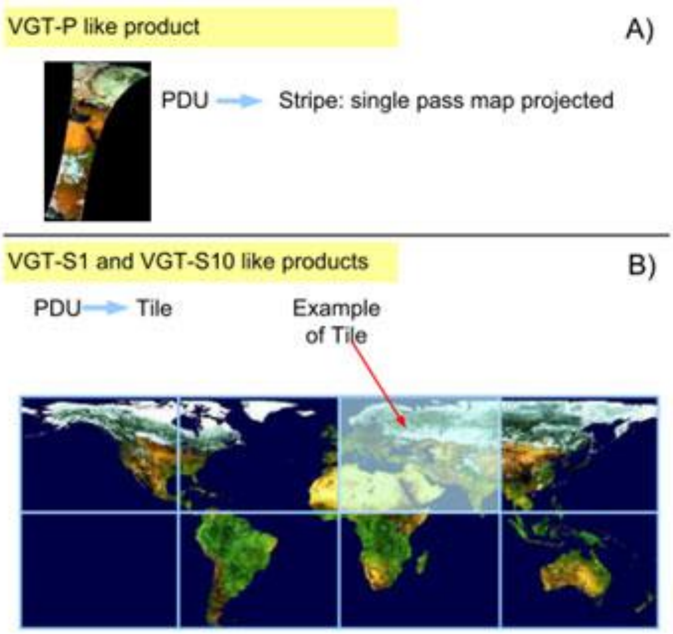


Figure 7 Sentinel-3 example of PDUs for Vegetation-like products

(ESA https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/data-products/user-dissemination-concept)

The Sentinel-3 instruments and combined products are

1. OLCI
   a. An optical instrument used to provide data continuity for ENVISAT's MERIS instrument. It is a push-broom imaging spectrometer that measures solar radiation reflected by the Earth. The primary objective of OLCI products is to screen the ocean and land surface to harvest information related to biology. OLCI also provides information on the atmosphere and contributes to climate study.
2. SLSTR
   a. A dual scan temperature radiometer. The principal objective of SLSTR products is to provide global and regional Sea Surface Temperature and Land Surface Temperature (SST, LST) to a very high level of accuracy for both climatological and meteorological applications.
3. Altimetry (SRAL/MWR)
   a. SRAL/MWR is a topography mission whose main application 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.
4. SYNERGY (OLCI + SLSTR = SYN)
   a. OLCI in conjunction with SLSTR, delivers the SYN products, providing continuity with SPOT VEGETATION. The primary objective of SYN products is the monitoring of land use. SYN also provides information relating to worldwide food security and contributes to the study of climate.

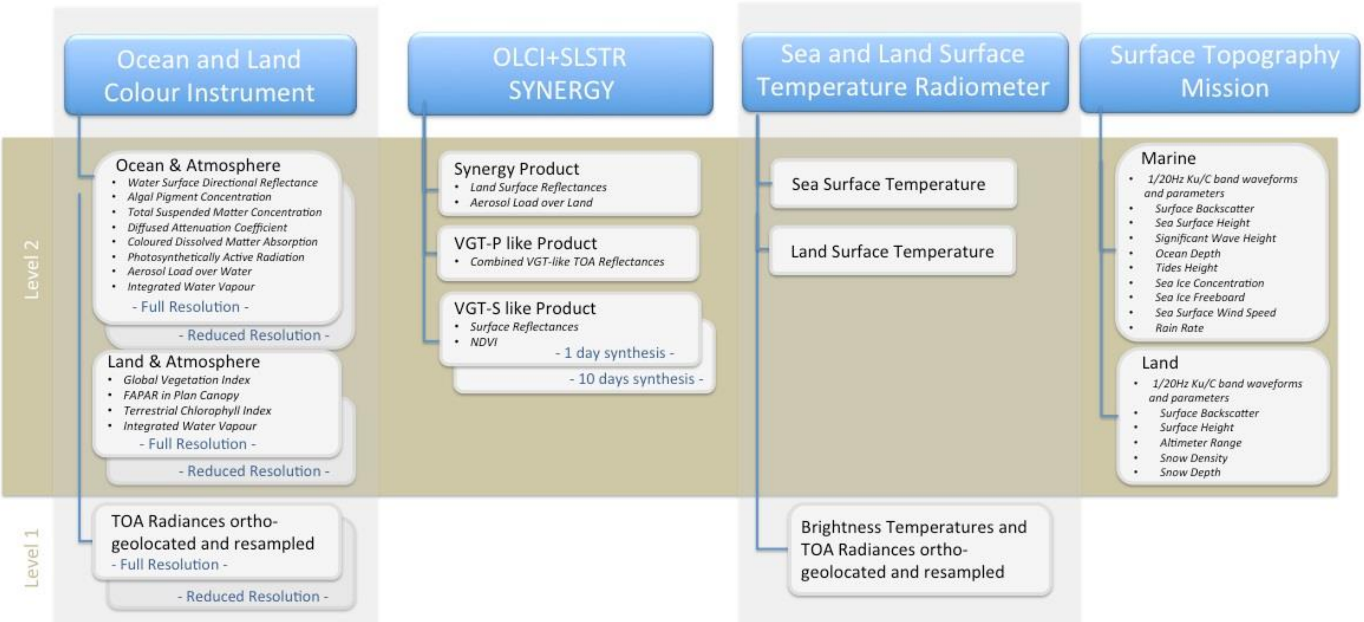


Figure 8 Sentinel-3 products (distributed by the Hub)

(ESA, https://sentinel.esa.int/web/sentinel/missions/sentinel-3/data-products)

The Sentinel-3 **OLCI data products** synced by the Hub (as shown in Figure 8) include:

- Level-1B
  - 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 for the whole globe with the same coverage in:
    - Full Resolution (FR) of 300 m
    - Reduced Resolution (RR) of 1.2 km
- Level-2 Land
  - Product consist of land and atmospheric geophysical parameters derived from the processing of measurement data provided in the Level-1 product computed for:
    - FR
    - RR
- Level-2 Water
  - Product consist of water and atmospheric geophysical parameters derived from the processing of measurement data provided in the Level-1 product computed for:
    - FR
    - RR

The Sentinel-3 **SLSTR data products** synced by the Hub (as show in Figure 8) include:

- Level-1B
  - The Level-1 product provides radiances and brightness temperatures for each pixel in a regular image grid, each view and each SLSTR channel, plus annotations data associated with SLSTR pixels.
- Level-2 Land
  - Products consist of land surface temperature derived from the processing of the measurement data provided in the Level-1 product.
- Level-2 Water
  - Products consist of sea surface temperature derived from the processing of the measurement data provided in the Level-1 product.

The Sentinel-3 Altimetry **SRAL/MWR data products** synced by the Hub (as shown in Figure 8):

- Level-1A
  - The Level-0 data corrected for instrumental effects providing geo-located bursts of echoes with all calibrations applied.

- Level-1B
  - The Level-0 data corrected for instrumental effects providing geo-located and fully calibrated multi-looked High Resolution power echoes.
- Level-1BS
  - The Level-0 data corrected for instrumental effects providing fully SAR-processed and calibrated High Resolution complex echoes arranged in stacks after slant range correction and prior to echo multi-look (multi-look processing reduces noise by averaging of adjacent pixels, and thereby reduces the standard deviation of the noise level).
- Level-2 Land
  - The Level-1 data corrected for geophysical effects providing land products generated by the Land Centre.
- Level-2 Water
  - The Level-1 data corrected for geophysical effects providing water products generated by the Marine Centre.

In addition, the SRAL/MWR data consists of different product types depending on delivery time to users and the available consolidated auxiliary or ancillary data. The selection of a product type in terms of delivery time is a trade-off between real-time needs and the final accuracy needed. The delivery time product types are

- **Near Real-Time (NRT)**: delivered less than 3 hours after data acquisition and mainly used for marine meteorology and ocean-atmosphere gas transfer studies (and possibly for operational oceanography depending on orbit accuracy). Data products are 10 minutes in length.
- **Short Time Critical (STC)**: delivered within 48 hours after data acquisition, due mainly to the consolidation of some auxiliary or ancillary data (e.g. preliminary resituated orbit data) and the data are mainly used for geophysical studies and operational oceanography. Data products correspond to half-orbit information (pole-to-pole).
- **Non-Time Critical (NTC)**: typically delivered within 1 month after data acquisition. This additional delay allows consolidation of some auxiliary or ancillary data (e.g. precise orbit data) and the data are mainly used for geophysical studies and operational oceanography. Data products correspond to half-orbit information (pole-to-pole).

The OLCI, SLSTR and SRAL/MWR files are collected into SAFE containers. Level-1 and 2 products are encapsulated in free-standing netCDF 4 product files. More information on the formats can be found at the below links and their child pages.

- OLCI: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-olci/data-formats
- SLSTR: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/data-formats
- SRAL/MWR: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/data-formats

The Sentinel-3 **SYNERGY** data are all synced by the Hub. These include a synergy of OLCI (OL_1_EFR) and SLSTR (SL_1_RBT) products (refer to sub-section 7.1.4.4) as shown in Figure 8:

- Level-2
  - Processing aims to combine information from the OLCI and SLSTR instruments to provide improved data for land surface analysis. There are five products available to users:
    - SYN Surface Reflectance and Aerosol parameters over Land
    - VGP 1 km VEGETATION-Like product TOA Reflectance
    - VGK Surface reflectance over Land
    - VG1 1 km VEGETATION-Like product one day synthesis surface reflectance and NDVI
    - V10 1 km VEGETATION-Like product 10 day synthesis surface reflectance and NDVI

As for all Sentinel-3 products, SYNERGY packages are composed of one information package map, also called a manifest, and several measurement and annotation data files. The manifest file is written in XML format and gathers general information concerning the product and processing. The measurement and annotation data files are written in netCDF4 format and include dimensions, variables and associated attributes. More information can be found at https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-synergy/sentinel-safe.

4.5 Sentinel-5P

The Sentinel-5 Precursor mission is the first Sentinel mission dedicated to monitoring the atmosphere. The mission consists of one satellite carrying the TROPOspheric Monitoring Instrument (TROPOMI). The main objective of the Sentinel-5P mission is to perform atmospheric measurements with high spatio-temporal resolution, to be used for air quality, ozone and ultraviolet radiation, and climate monitoring and forecasting. Data is not yet available from the Hub but is coming soon. Level 2 data products will be synced by the Hub as described in Table 4. Further information can be found at https://sentinel.esa.int/web/sentinel/missions/sentinel-5p.

Table 4 The Sentinel-5P Level 2 data to be synced to the Hub

Product Prefix	Product	Source Document
L2__O3____	Ozone (O_3) total column	IODD-UPAS
L2__O3_TCL	Ozone (O_3) tropospheric column	IODD-UPAS
L2__O3__PR	Ozone (O_3) profile	IODD-NL
L2__O3_TPR	Ozone (O_3) tropospheric profile	IODD-NL
L2__NO2___	Nitrogen Dioxide (NO_2), total and tropospheric columns	IODD-NL
L2__SO2___	Sulfur Dioxide (SO_2) total column	IODD-UPAS
L2__CO____	Carbon Monoxide (CO) total column	IODD-NL
L2__CH4___	Methane (CH_4) total column	IODD-NL
L2__HCHO__	Formaldehyde (HCHO) total column	IODD-UPAS
L2__CLOUD_	Cloud fraction, albedo, top pressure	IODD-UPAS
L2__AER_AI	UV Aerosol Index	IODD-NL
L2__AER_LH	Aerosol Layer Height (mid-level pressure)	IODD-NL

SECTION C – APPLICATION EXAMPLES

5 Applications & Benefits

The applications and benefits of each Sentinel mission are described in the following sub-sections. More specifically, data from the Hub is being used within the local region to support programs of work delivered by the Hub partners, including:

- near real-time and long-term monitoring of native vegetation changes and woody vegetation extent in support of legislative and regulatory requirements
- improving the quantification of ground cover information for monitoring wind and water erosion and agricultural land management and productivity
- modelling water quality and land condition of Great Barrier Reef catchments and receiving waters
- mapping of coal seam gas physical infrastructures to support regulatory and activity monitoring
- development of methodologies to monitor ground deformation and subsidence
- measurement of natural water flows and monitor water quality both coastal and inland
- development of "near-real-time" burnt area mapping and feed into fire-simulation tools to model fire behaviour and improve greenhouse emissions programs
- mapping fire scars and fuel loading
- development of methodologies for monitoring broad crop types
- development of vegetation biomass and net primary productivity products to inform emerging market-based instruments for carbon and other greenhouse gas trading schemes
- responding to, and recovering from disasters
- monitoring, detecting and characterising land, water and infrastructure changes across Australia
- climate impact research and studies

5.1 Sentinel-1

Sentinel-1 supports applications in priority areas of maritime and land monitoring, and emergency management. The mission's ability to provide observations in all-weather day and/or night, makes it ideal for maritime and Arctic monitoring. Its rapid data dissemination and short revisit cycles together with its interferometric capabilities also benefits emergency response users in situations such as floods, earthquakes, volcanic eruptions and landslides. The mission will benefit numerous services particularly related to applications exploiting SAR's polarimetric and interferometric (InSAR) properties, such as measuring deformation and subsidence.

Applications of backscatter products (using the amplitude/intensity images for either or both polarisations) include:

- Agriculture - crop type identification, crop condition monitoring and soil moisture measurement

- Forestry - biomass estimation, species identification and fire scar mapping
- Hydrology - monitoring wetlands and snow cover
- Oceanography - sea ice identification, coastal wind field measurement and oil spill detection
- Security - ship detection and classification
- Deformation – mapping large ground deformations

Applications of InSAR products (using the interferometric products such as interferograms and interferometric coherence) include:

- Geophysical monitoring of natural hazards - earthquakes, volcanoes and landslides
- Time-series analysis of ground surface deformation - subsidence and structural stability
- Glacier motion analysis (if the speed of ice movement is slow i.e. sub centimetre between images)
- Digital elevation mapping (although this is not what the mission was designed for)

5.2 Sentinel-2

Sentinel-2 supports applications in areas of land monitoring, emergency management and security. With its twin-satellite capability, it ensures frequent and systematic coverage to support the mapping of land cover, classification and change maps, and accurate assessment of geophysical parameters. Sentinel-2 observations also support rapid mapping in response to emergency events. The mission will benefit services in application areas such as

- Land monitoring
  - spatial planning
  - agro-environmental monitoring
  - water monitoring
  - forest and vegetation monitoring - Leaf Area Index, Fractional Vegetation Cover etc.
  - land carbon, natural resource monitoring
  - global crop monitoring
- Emergency management
  - natural disasters - floods, fires, landslides, storms, earthquakes etc.
  - technological accidents
  - humanitarian crises - for instance after a period of severe drought, famine etc.
  - civil crises
- Security domains

- maritime surveillance – boat detection, sea borders, illegal immigration and trafficking surveillance, safety
- infrastructure surveillance - land border, critical infrastructure e.g. pipelines
- peace-keeping - population monitoring, resources e.g. water
- intelligence and early warning
- crisis management operations

5.3 Sentinel-3

Sentinel-3 supports ocean, land, atmospheric, emergency, security and cryospheric applications. Its main objectives are to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The specific applications of the instruments and products are:

- OLCI - screens the ocean and land surface to harvest information related to biology plus provides information on the atmosphere and contributes to climate study.
- SLSTR - provides global and regional Sea and Land Surface Temperature to a very high level of accuracy for both climatological and meteorological applications.
- SRAL - provides ocean topography including mean sea level, wave height, wind speed over the surface, sea-ice, ocean currents, Kelvin and Rossby waves, eddies and tides.
- SYNERGY - provides continuity with SPOT VEGETATION, the primary objective being the monitoring of land use, as well as information relating to worldwide food security and the study of climate.

There are many benefits of Sentinel-3; for example, more accurate forecasting of atmospheric and oceanic conditions helps protect people from the impacts of extreme weather events such as hurricane winds, storm surges and flooding. It monitors ocean conditions for security and safety such as pollution (due to shipping accidents), passenger vessel safety and potential terrorist actions. By observing the status and characteristics of coastal zone waters it supports environmental monitoring of water quality and phenomena such as harmful algal blooms for habitat assessment and management (aquaculture, sea-defences and tourism). It also supports international negotiations and agreements (i.e. the United Nations Kyoto Protocol, the Framework Climate Convention, the Biodiversity Convention) by providing marine, coastal and land environmental data. Sentinel-3 provide the accurate, stable, long term and consistent quality data required to monitor and study the regulating effect that ocean processes exert on climate.

5.4 Sentinel-5P

Sentinel-5P performs atmospheric measurements with high spatio-temporal resolution, relating to air quality, climate forcing, ozone and UV radiation. The environmental themes it covers are Air Quality, Stratospheric Ozone Layer, Climate Change Monitoring and Forecasting. Its applications and services include

- Provision of services to operational weather forecast centres
- Monitoring volcanic eruption activities

- Determination of sources and sinks of atmospheric pollutants
- Issuing alerts in support of health services in case of poor air quality forecasts

At the Earth's surface, aerosols, ozone and other reactive gases such as nitrogen dioxide determine the quality of the air around us, affecting human health and life expectancy, the health of ecosystems and the fabric of the built environment. Ozone distribution in the stratosphere influence the amount of ultraviolet radiation reaching the surface. Dust, sand, smoke and volcanic aerosols affect the safe operation of transport systems and the availability of power from solar generation, the formation of clouds and rainfall, and the remote sensing by satellite of land, ocean and atmosphere. Sentinel-5P is a key data contributor to address these environmental concerns.

6 Examples

The following section provides six case study examples using Sentinel data from the Hub. Each of the Hub partners have provided a case study based on their application of the data.

6.1 CASE STUDY 1 – A New Approach to Estimating Pasture Biomass

Bringing new levels of understanding in pasture productivity and land condition to Australian farms, at the paddock scale using Sentinel-2 imagery.

Cibo Labs Pty Ltd (www.cibolabs.com.au) is an agricultural data analytics company based in Queensland and servicing farms nationally. Cibo Labs uses pre-processed Earth observation imagery provided by Digital Earth Australia (www.ga.gov.au/dea), together with on-ground data and its own machine learning techniques to bring new levels of understanding in pasture productivity and land condition to every farm, paddock or field in Australia.

In this specific case study Sentinel-2 imagery from the Copernicus Programme has provided DEA a powerful data stream with more frequent glimpses and information about what is happening on the farm. With improved three to five days revisit capability, depending on location, and improved spatial resolution of 10 meters.

6.1.1 Challenge

During 2018, Cibo Labs began using the Sentinel-2 Surface Reflectance product produced by DEA as a primary data source for the development of its land information products including: a comprehensive suite of pasture biomass estimation, land condition monitoring and land management tools for the livestock industry.

In 2016-17, Australia's red meat and livestock industry contributed $18.4 billion to Gross Domestic Product (GDP) – or 1.6% of Australia's key industry GDP – and generated $13.3 billion in export revenue through the supply of products to more than 100 global markets. In the same year, the industry created (direct and indirect) employment for approximately 438,100 people.

Cibo Labs Managing Director, Phil Tickle, notes that by preparing satellite data for Australian conditions and making it freely available, DEA is reducing up-front costs for businesses and enabling them to concentrate on innovation and value-adding for their clients. "DEA is letting us focus on product development, rather than the raw imagery analysis that we used to have to deal with in the past," said Mr Tickle.

6.1.2 Solution

Being able to access pre-processed Sentinel-2 Surface Reflectance products in near-real-time has enabled Cibo Labs to focus on development of value-added products for its clients rather than financially and temporally costly data processing.

Cibo Labs is developing a comprehensive suite of pasture biomass estimation, land condition monitoring and land management tools for the livestock industry by combining ARD EO imagery with on-ground data and machine learning techniques (Figure 9 and Figure 10). The tools Cibo Labs are developing will enable producers to increase productivity through improved understanding of their land condition and pasture health.

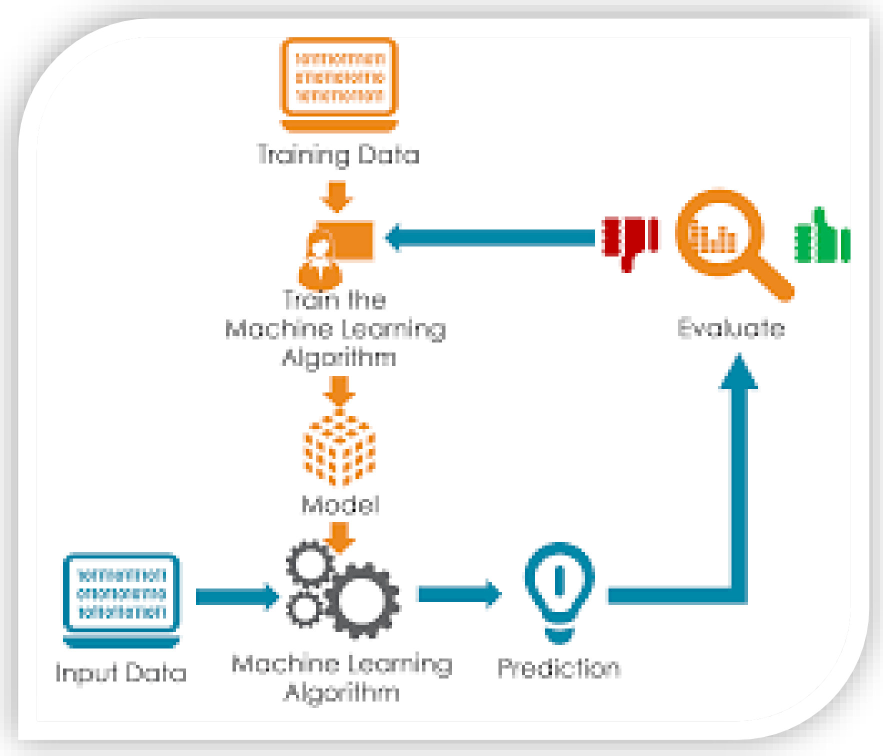


Figure 9 Cibo Labs machine learning technique (Image supplied by Cibo Labs)

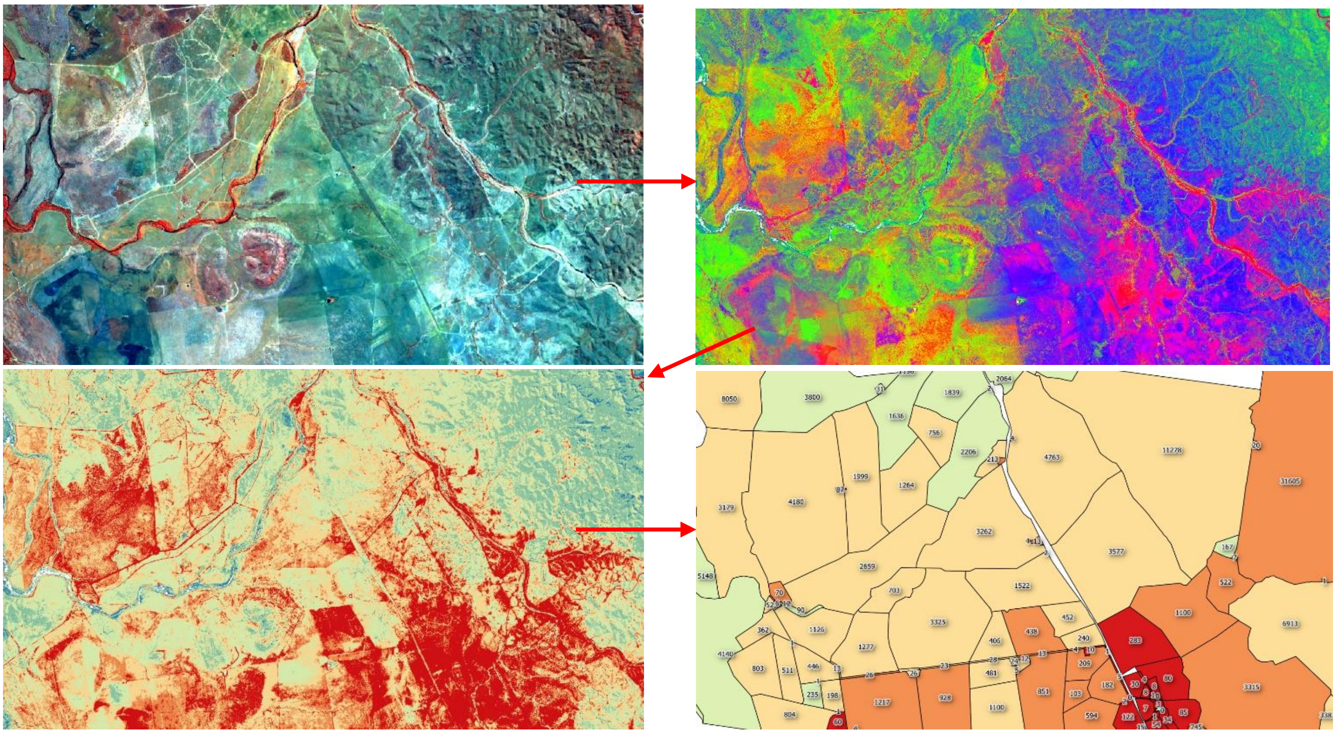


Figure 10 Cibo Labs pasture biomass: 5 daily fully calibrated 10m imagery (top left) to Fractional Cover (top right) to Total Standing Dry Matter (TSDM) in kg/ha (bottom left) to TSDM per paddock (bottom right) (Images supplied by Cibo Labs)

6.1.3 Impact

Greater utilisation of satellite imagery from the Copernicus Programme in our Region is a consequence of building and operating the Copernicus Australasia Regional Data Hub that was facilitated by the important relationship developed between Australia and the European Union. Supporting Cibo Labs to deliver information and tools to enhance the productivity of one of Australia's most successful and important industry sectors is both an exciting opportunity and an important proving ground for the potential impact and benefits of satellite data.

"As a small company trying to build confidence with new clients (who could never appreciate what it takes to keep large scale operational systems running), we really appreciate DEA's commitment to best practice science, and efforts to support industry." – Phil Tickle, Managing Director, Cibo Labs.

Free and open access to satellite imagery from the Copernicus Programme has provided the perfect environment and opportunity for industries and companies like Cibo to develop their unique solutions and services that previously would not have been possible.

6.2 CASE STUDY 2 - Queensland Early Detection System

The Queensland Department of Natural Resources, Mines and Energy (DNRME) assesses land clearing and monitors landholder compliance with vegetation management laws using a range of measures. One of these is the Early Detection System (EDS) which provides a framework for proactive compliance for vegetation clearing using Earth observation technology. The project is collaboratively managed by the Department of Environment and Science (DES) and the DNRME.

6.2.1 Challenge

The challenge was to develop an early detection system, complementary to existing systems, enabling more frequent and expedient detection of recent clearing events across Queensland.

Queensland is climatically diverse and encompasses a wide variety of landscapes. Effective management of the state's woody vegetation is critical for balancing environmental protection and sustainable growth of industry. The *Vegetation Management Act 1999* identifies regulated vegetation and their conservation value status and is underpinned by a vegetation management compliance framework. Regulated vegetation covers approximately 80 per cent of the State, relating to over 90 per cent of properties in Queensland.

Systematically acquired satellite imagery, such as Sentinel-2 data from the Copernicus Australasia Regional Data Hub, lends itself well to state-wide monitoring programs. Historically, comprehensive vegetation clearing has been mapped annually, using satellite imagery, in the Statewide Landcover and Trees Study (SLATS). While SLATS provides a comprehensive picture of anthropogenic clearing across the State, the annual data supply limits effective and timely compliance responses and has meant that compliance responses are often reactive.

In recent years, the focus has been on developing proactive and targeted compliance approaches that support early engagement with landholders. The challenge was to develop an early detection system, complementary to SLATS monitoring and mapping, enabling more frequent and expedient detection of recent clearing events across the State: a challenge that data from the Hub was expected to help solve.

6.2.2 Solution

The Copernicus Australasia Regional Data Hub was chosen as the method of data access for the EDS due to its high level of reliability and guaranteed large scale and timely data access. Images accessed via the Hub are processed by the DES Remote Sensing Centre. Processing considers radiometric and atmospheric corrections, as well as cloud, topographic shadow and water masks to enable comparison between pairs of Sentinel-2 images of the same location from different times. A woody vegetation clearing index, representing high likelihood of clearing, is calculated to detect areas of change between a pre-clearing image and a post-clearing image. The detection is then inspected by remote sensing scientists to confirm the automated outputs and ensure only true detections are reported (e.g. the black outline in Figure 11). EDS information is then cross-referenced with data about exemptions, current notifications and clearing approvals to help identify unexplained clearing of native vegetation.

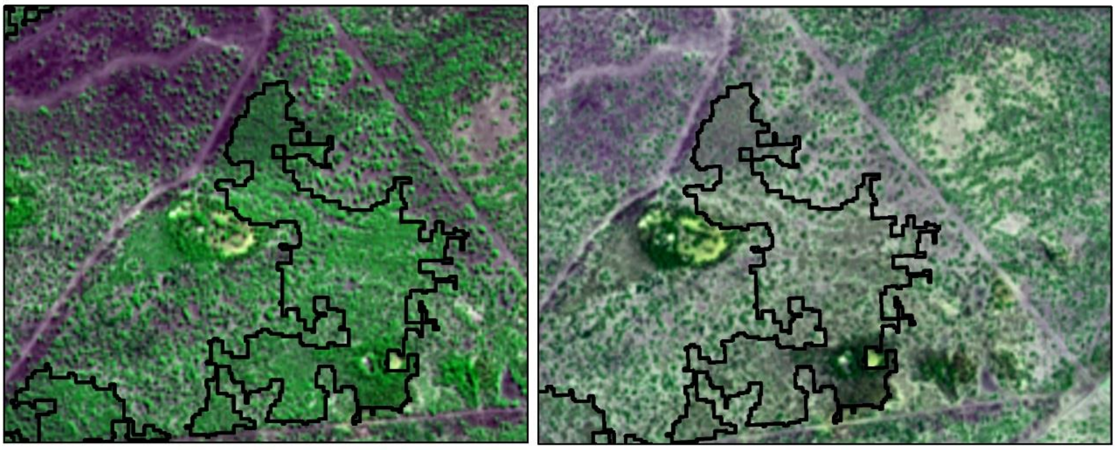


Figure 11 Sentinel-2 pre-clearing image (left) and post-clearing image (right).

Images produced from ESA remote sensing data and processed by Department of Environment and Science. (Images supplied by DES).

6.2.3 Impact

The EDS uses Sentinel-2 imagery to continually identify changes in regulated woody vegetation. The immediate benefit of using Sentinel-2 imagery from the Hub in the EDS is that the five day temporal frequency of localised imagery provides multiple opportunities for cloud-free images within a reporting period, maximising the quality of the input data used to detect clearing.

The Hub has facilitated reliable access to timely Sentinel-2 data enabling clearing detections to be reported fortnightly (rather than annually) to guide decision making on compliance responses. The guaranteed data availability through the Hub permits early detection and proactive engagement with landholders, often minimising further clearing activities. In some cases, it also minimises the need for high-end compliance actions such as prosecution.

6.3 CASE STUDY 3 – NSW Fire Extent and Severity Mapping

The NSW Rural Fire Service (RFS) are responsible for fire protection within 95 per cent of the land area of NSW. The Office of Environment and Heritage (OEH) and the RFS are collaboratively developing a consistent state-wide approach to mapping fire extent and severity.

6.3.1 Challenge

The challenge was to develop a consistent approach to mapping fire extent and severity across NSW.

Fire behaviour modelling, fuel assessment, hazard-reduction burn planning and ecological and climate change research all rely on accurate fire extent maps. At present, fire management agencies map the extent of the fire during an incident with the primary objective of supporting fire-fighting efforts. This data is currently the best record of fire extent history available in NSW but its usefulness is limited because of the highly-variable nature of mapping accuracy between fire incidents.

Fire severity is the amount of plant biomass (grasses, shrubs and trees) consumed by fire. Fire severity varies greatly between fires and within a single fire, because of the varying climate, weather conditions, topography, and vegetation community types present. Fire severity has been mapped for a few notable fires, but the methods used were inconsistent.

The OEH and the RFS are developing a consistent, state-wide approach to mapping fire extent and severity. The approach uses satellite imagery because the large extent and remoteness of many wildfires prevent routine field assessment of severity. The OEH has an established partnership with the Copernicus Australasia Regional Data Hub, which provides routine access to Sentinel-2 products. This facilitated the development of a semi-automated approach for high-accuracy mapping of fire severity and extent that would otherwise not be possible at the state-wide scale. The severity and extent data can be used for applications such as developing more sophisticated models of fire behaviour, when preparing hazard reduction plans and to support ecological research.

6.3.2 Solution

During a 12-month research and development project, a comprehensive literature review revealed current best-practice and emerging advancements in machine learning applications for remote sensing-based fire mapping. There are well known limitations of commonly used reflectance-based fire severity indices, such as the normalised burn ratio. For example, the inherent difficulty of using reflectance data to quantify change in vegetation cover (a remote sensing surrogate for biomass) in comparable units to field measures. Innovative solutions were developed and tested to overcome these limitations. For example, several additional fire severity indices were developed based on spectral un-mixing models of sub-pixel fractions of photosynthetic and non-photosynthetic vegetation as well as bare soil cover, using a calibrated relationship with high quality, quantitative field data.

Image differencing of pre- and post-fire Sentinel 2-derived surface reflectance and fractional cover-based indices provided the input data used to train and test machine learning algorithms for supervised classification of the Sentinel-2 imagery. High resolution aerial photograph interpretation and clearly defined classification rules were used to hand digitise samples of five distinct severity classes based on varying levels of vegetation scorch and consumption of canopy and understorey layers. The classes have been used to distinguish different degrees of post-fire loss of biomass in Australian forests, woodlands and shrublands with strong correlations to field-based measures of fire severity. Random sampling points were generated within the aerial photograph interpretation severity polygons with corresponding pixel values extracted for each Sentinel-2 derived input index. This provided the training and testing data for a random forest machine learning algorithm to generate and validate severity maps for the case study fires (Figure 12). Cross-validation assessments were also undertaken to quantify the predictive capacity for mapping novel fires, not used to train the models.

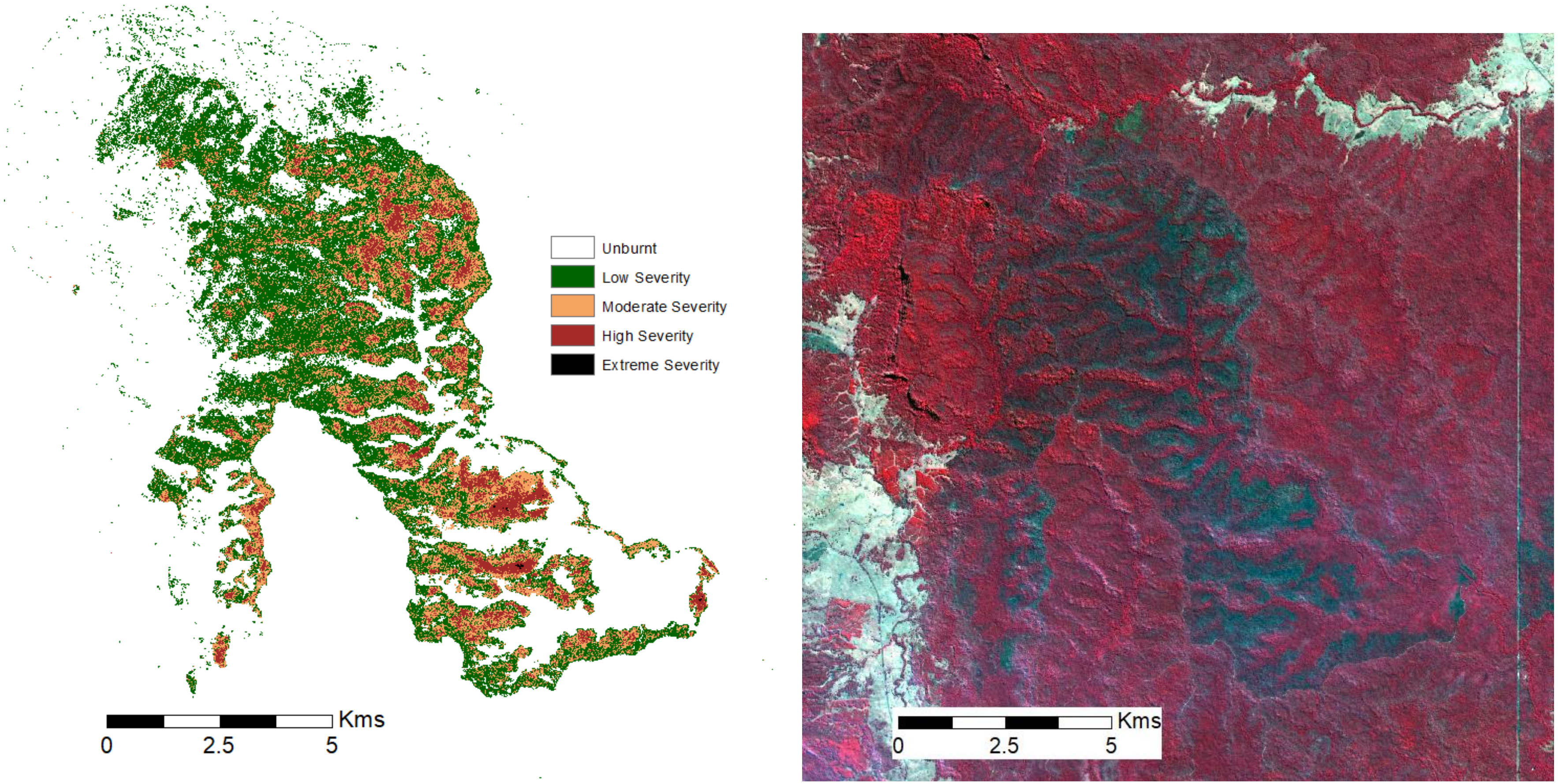


Figure 12 A Fire Severity Map (left) created from Sentinel-2 satellite imagery (right) of the Mt Marsh bushfire in Richmond Valley, northern NSW in August 2018. (Images supplied by OEH).

6.3.3 Impact

Extensive visual interpretation of the fire severity maps against high resolution aerial photography indicated consistent, strong adherence to the aerial photograph interpretation classification rules. Independent validation data indicated an average accuracy of all severity classes greater than 80 per cent, including greater than 95 per cent accuracy for the unburnt and extreme severity classes. There was generally low variability in the balanced accuracy statistic between different fires within each severity class, which demonstrates the consistency in modelled severity classes between fires across the landscape.

Cloud contamination in satellite imagery is historically one of the greatest limitations in reliance on remote sensing products for near-real time operations. However, the high frequency (about five-day site revisit) of Sentinel-2 imagery and the streamlined provision of imagery through the Copernicus Australasia Regional Data Hub greatly enhanced the capacity of this project to achieve an outcome suitable for NSW RFS operations. This was a key decision point in selecting products from the Copernicus Australasia Regional Data Hub for this project, which facilitated the success and rapid delivery of the research and development project.

The new extent maps will readily be adopted into existing operations. Warwick Hehir (Team Leader Spatial Support, NSW RFS) said;

"The NSW RFS regard the fire extent and severity analysis, and contribution of Sentinel-2 Copernicus imagery, as part of its arsenal of information to detect the effects of fire in the landscape. We have further plans to expand on its use, with analysed imagery (fire severity maps) as an input into fire behaviour analysis."

A significant reduction in manual labour is expected, which currently occurs in validating extent maps to be incorporated into the fire history database. The new severity mapping will facilitate National Parks and Wildlife Service rapid post-fire response operations, as well as post-fire field assessments for staff in OEH Regional Operations and Saving our Species programs. Institutions such as the Centre for Environmental Risk Management of Bushfires at the University of Wollongong also have a great interest in using severity mapping for research into fire regimes. Other fire managers and researchers interested in fire regimes are also expected to greatly benefit from the improved consistency and accuracy of state-wide fire extent and severity mapping.

6.3.4 Future

The RFS is continuing a collaboration with the OEH Remote Sensing & Analysis Team to develop semi-automated systems for data sharing and processing fire extent and severity maps for future fires. Continual improvements are planned with ongoing refinements and reviews of the processing systems and accuracy of the fire extent and severity maps. A greater diversity of fires across vegetation types and climates are intended be included in updated versions of the training data used in the machine learning algorithms. Further field validation is required across a greater number of fires in different vegetation types to assess the severity maps against the classification rules. Collaborative partnerships are expected to facilitate the field validation campaign. Volunteers are encouraged to contact the OEH Remote Sensing & Analysis Team if interested in becoming involved in field validation of fire severity maps.

Improving the accuracy of the severity mapping for low severity class (burnt understory with an unburnt canopy) may be challenging in dense canopy forests, due to the limitations of the remote sensing approach. This is particularly pertinent for mapping hazard reduction burns, which are typically low severity with unburnt patches. Higher resolution options may be investigated, which could be used in conjunction with the Sentinel-2 severity models. However, quantifying the density of canopy where accuracy in the Sentinel-2 based severity maps becomes unreliable, is required. Further research is also planned to enable the fire severity maps to be appropriately adopted into routine operational fire management. For example, assessment of fuel loads alongside severity maps in different ecosystems will inform predictive modelling and fuel hazard assessments.

6.4 CASE STUDY 4 – Mapping Surface Deformation Caused by the Lake Muir Earthquake using Sentinel-1 InSAR

6.4.1 Challenge

Geoscience Australia monitors, analyses and reports on the occurrence of significant earthquakes within Australia and its territories. This is principally achieved using a national network of roughly 100 seismometers operated by Geoscience Australia. Although seismology can provide very rapid information on the size (magnitude) and location (epicentre and depth) of an earthquake, the uncertainties on the location are typically quite large (up to ten kilometres or more) by virtue of the sparsity of the seismic monitoring network.

On 16th September 2018, an earthquake of local magnitude 5.7 occurred in the Lake Muir region of Western Australia, approximately 120 km north-west of Albany. Seismic data indicated that the rupture was a shallow focus reverse faulting earthquake, which may have produced surface deformation. In addition, Geoscience Australia received many felt reports in the region of the epicentre. However, relying only on the seismic evidence (with large location uncertainty), it was difficult to locate where (or even if) surface deformation had occurred. Furthermore, the determination of optimum locations for deploying temporary aftershock monitoring instruments was hampered by the large location uncertainties in the immediate aftermath of the earthquake.

6.4.2 Solution

It is possible to map spatial patterns of ground surface movement that have occurred in the time between the acquisition of two Synthetic Aperture RADAR (SAR) images by applying interferometric processing techniques (InSAR). The InSAR method is particularly effective in mapping surface deformation caused by shallow-focus earthquakes, where centimetres to metres of surface displacement can be distributed over wide regions.

Following the earthquake at Lake Muir, Geoscience Australia made use of two Sentinel-1 images from the Copernicus Australasia Regional Data Hub, captured in the epicentral region on 14th and 26th September 2018. The post-earthquake image was captured 10 days following the earthquake. The resulting interferogram (Figure 13) depicts a coloured fringe pattern close to the seismologically-determined epicentre (grey star). Each coloured fringe (colour cycle from blue to red) represents 2.8 centimetres of surface motion in the line of sight of the satellite. Approximately 10 colour fringes are seen on the eastern side of a ~ 5 km long north-trending linear discontinuity (dotted black line), and 2 fringes on the western side. This amounts to ~28 cm and ~6 cm of line of sight surface displacement on the eastern and western sides of the discontinuity, respectively. A continuous field of surface displacement in the satellite's field of view (line of sight) can be derived by 'unwrapping' the interferometric fringe pattern.

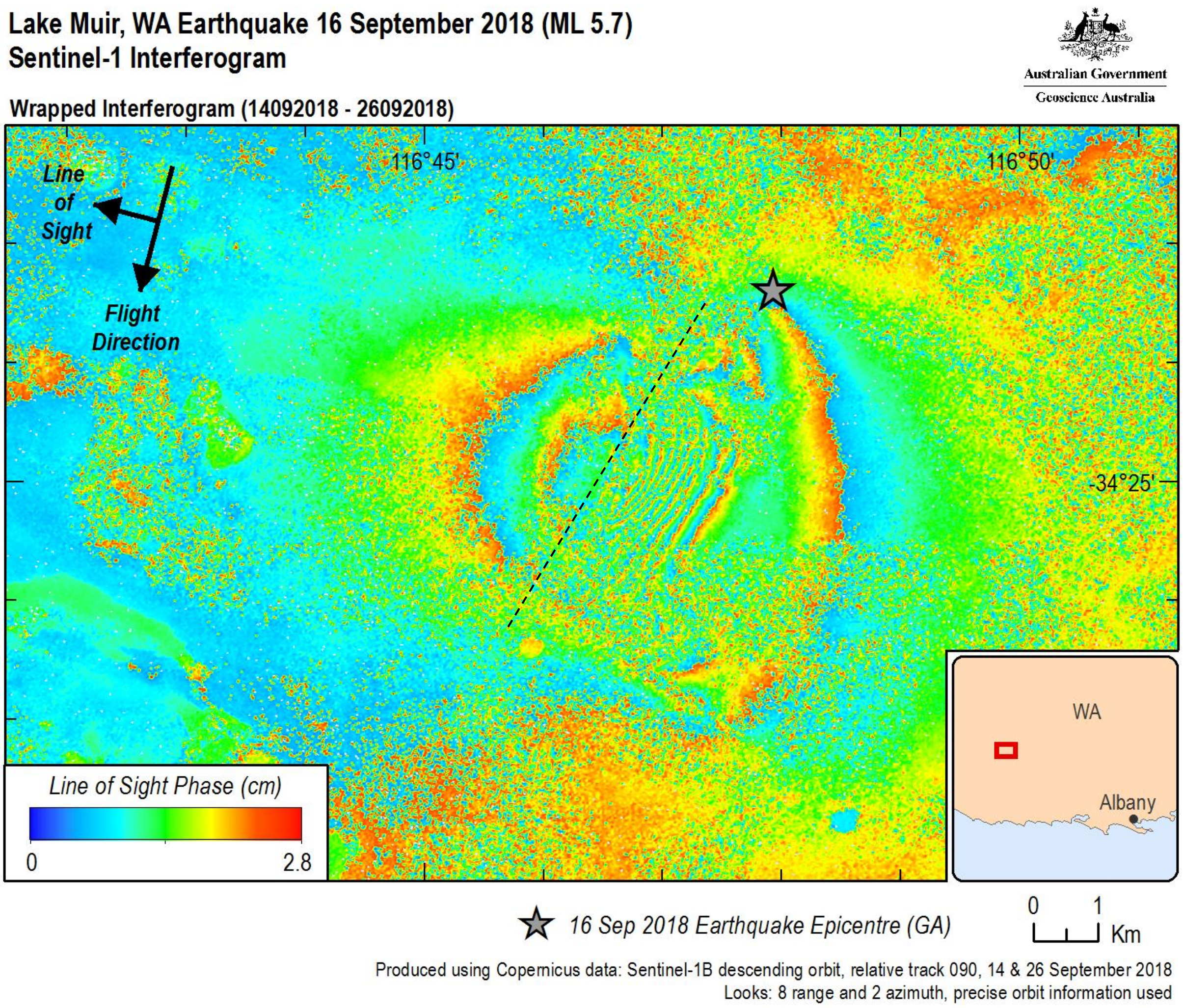


Figure 13 Sentinel-1 interferogram of the Lake Muir earthquake, that occurred on 16 September 2018 (Image supplied by GA).

6.4.3 Impact

Following the production of the interferogram (Figure 13), field teams travelled to the epicentral region to map and measure surface deformation and macroseismic effects. Using the InSAR-derived surface deformation field, they were able to target the 5 km-long linear discontinuity and identify it as a discrete surface rupture. It was also possible to map other more subtle features (e.g. warps, fissures, isolated scarp segments) quickly and efficiently using the surface deformation field imaged with Sentinel-1 InSAR data. The field team also acquired a new digital elevation model over the epicentral region using drone technology to precisely capture the vertical component of surface displacement of the rupture. The InSAR data was key in demonstrating that discrete and mappable surface deformation had occurred as a result of the earthquake, in guiding the field teams to fundamental elements of the surface rupture, and in defining the spatial extent of the surface deformation field in a level of detail not possible using ground mapping. This made possible a more comprehensive understanding of the earthquake rupture.

6.4.4 Future

Sentinel-1 is a game-changing mission in the application of InSAR to earthquake monitoring. Before Sentinel-1, it was rare that a SAR image existed in an epicentral region prior to an earthquake occurrence. When a SAR image did exist, it was usually so old that the resulting interferogram generated with the pre- and post-earthquake SAR images was very noisy and was therefore hard to interpret.

Since October 2016, the entire Australian continent is imaged every 12 days by the Sentinel-1 satellites. This means there is always a pre-earthquake image available and that the time gap between images is never more than 12 days. This ensures that high-quality interferograms can be generated for every earthquake, thus improving the chance of detecting surface deformation caused by even small earthquakes.

Geoscience Australia is currently working towards operational production of Sentinel-1 interferograms, with the goal that an interferogram is available rapidly after the data has been ingested in to the Copernicus Australasia Regional Data Hub. This will benefit the rapid response operations following earthquakes, such as mapping damage and surface deformation, deploying aftershock monitoring instruments, and improving seismic hazard assessment. Sentinel-1 InSAR data produced in this way can also have application in monitoring surface movements more broadly. For instance, capturing subtle mass-movements that may occur before landslides or dam failures, or measuring subsidence caused by sub-surface mining or groundwater extraction.

6.5 CASE STUDY 5 - Agricultural Change Detection and Biomass Estimation in New Zealand

The use of atmospherically corrected Sentinel-2 data to estimate paddock level biomass and changes associated with farming practices in New Zealand.

Sentinel-2 is a unique resource providing a snapshot of agricultural activities over New Zealand every five days. These snapshots allow land managers to prepare their weekly strategies, and over time to better manage resources. New Zealand has a variety of agricultural users from dairy farms with high density grazing and regular grazing rotations, to less densely stocked high country stations. The dry matter estimation and temporal analysis product discussed in the case study is being developed for the Agricultural industry. In addition to grazing, the biomass estimates are used to estimate potential yields and identify problems in orchards. The regular, New Zealand wide coverage of Sentinel-2, makes Sentinel-2 derived products ideal for understanding factors that impact yield.

6.5.1 Challenge

Agricultural production relies on estimates of yield, for example, grass yield in pastures used for managing livestock, or fruit in vineyards and orchards. Without access to remote sensing capabilities, these yields are typically measured by in situ sampling. In situ sampling suffers from various issues including that measurement is time consuming, it samples a limited area (for example a single path around the farm or selected rows in an orchard) and it can suffer from inconsistency in measurement technique from person to person or at different times. Regular observation from space provides an opportunity to measure larger areas in more detail and more often than is practical with in situ sampling. In addition, it allows the creation of repeatable workflows.

Automated workflows estimating biomass from remotely sensed data rely on the availability of regular space-based observation, and the ability to receive and process these observations soon after they are sensed (i.e. a data hub). Prior to the existence of the Copernicus Australasia Regional Data Hub, access to regular nationwide satellite observations was more challenging, limiting the ability to deliver this type of automated solution in the New Zealand Agricultural industry.

The expected outcome of working with the Copernicus Australasia Regional Data Hub was to have a stable API that would allow discovery and ingestion of the new imagery as soon as possible after it was sensed. A well-documented and stable API is essential to allow new data to be ingested into the automatic processing workflows. In addition, the Copernicus Australasia Regional Data Hub makes it easy to host workflows on Australia's NCI collocated with the data to minimise any delay associated with data transfer. It is critical that remote sensing observations are provided with indication of factors that negatively impact the quality of observation, for example environmental factors including cloud. This was found to be another benefit of the Copernicus Australasia Regional Data Hub as atmospherically corrected data was supplied with quality masks.

6.5.2 Solution

The challenge was to provide regular reports to many agricultural users across New Zealand (Figure 14) and for these reports to be used for analysis over time. Based on the remote sensing and geospatial analysis experience of the team it was known that this required regular atmospherically corrected nation-wide imagery with estimates of quality. This remote sensing data had to be combined with polygons representing the regions for which biomass would be estimated. In addition, it required feedback to ensure estimates could be related to in situ measurements. This relationship to in situ measurements is found to be critical to allow the shift from familiar techniques, to reliance and trust of automated remote sensing-based estimation.

The solution involves specifying a region and time of interest along with boundaries for the appropriate agricultural unit (e.g. paddocks or a row). This triggers a query that returns the URLs for each of the relevant Sentinel-2 images. Once the images are retrieved, they are passed through automated task-based workflows that can be run in parallel, transforming the images from reflectance to mean biomass. Results are rendered and presented in images and charts and automatically published in reports. This solution was deployed on Australia's NCI because of the ability to run many jobs in parallel and stable environments, including the availability of a robust Python environment.

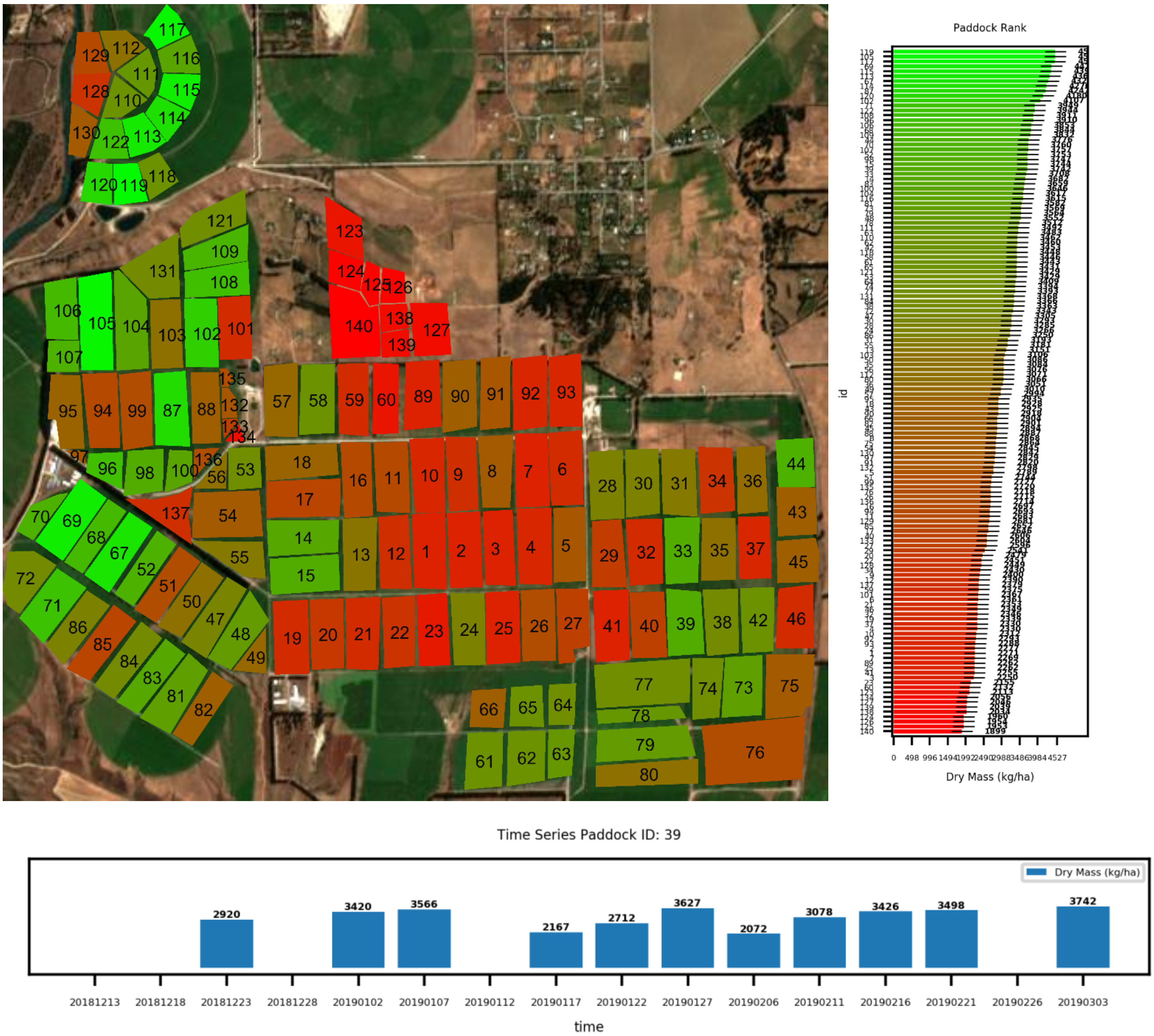


Figure 14 Estimation of dry matter from atmospherically corrected Sentinel-2 imagery. Farm paddocks coloured by rank in dry matter estimate (left), paddocks ranked as a feed wedge based on dry matter (right) and temporal variation for a paddock with missing data caused by cloud coverage (bottom). (Images supplied by XERRA).

6.5.3 Impact

This product has generated interest with agricultural land users and service providers in New Zealand. It is seen by end users as a way to reduce the amount of time needed for manual measurements of yield. In addition, it is seen as a path to better information driving better decisions, including decisions such as the amount and location of irrigation, fertilisation and treatment for disease.

Regular reports generated from the five-day overpass of Sentinel-2 are providing new insights into farming practices including time of harvest, maximum leaf cover and grazing rotations, as well as environmental factors such as proximity of grazing to waterways. This project has proven to New Zealand customers that it is possible to efficiently process satellite data at scale, nation-wide and with good temporal frequency. The primary metric of success with this product will be adoption of remote sensing techniques by regional councils and other customers as a supplement and replacement for existing in situ measurements.

6.5.4 Future

New Zealand is known as the land of the Long White Cloud. This is an accurate description of the fact that large parts of New Zealand are regularly covered by cloud, limiting optical remote sensing from space. For this reason, the development of workflows that allow agricultural change detection using Sentinel-1 SAR are being pursued. These are showing promise for supplementing optical observations.

SECTION D – WORKING WITH THE HUB

7 Download the Data

There are multiple ways to access data from the Hub: the Sentinel Australasia Regional Access (SARA) map-based interface, the SARA Python API for advanced users, the NCI's THREDDS server and directly through the NCI's file system for registered NCI users. The SARA map interface and API are the recommended access paths. Both require users to register before they can download data.

7.1 SARA Map Interface

SARA provides users an easy to use map-based data search and download GUI. The SARA map interface is not well supported by Internet Explorer. It is recommended that users use Chrome or Firefox. To download data using the SARA interface, follow the instructions below. The instructions assume a basic level of computer literacy.

7.1.1 SARA Home Page

To access the home page for SARA go to https://copernicus.nci.org.au/sara.client/#/home (Figure 17).

Alternatively, from the Copernicus Australasia Regional Data Hub website home page (http://www.copernicus.gov.au/ - Figure 15) click **Regional Data Access,** then as shown in Figure 16 click the **Sentinel Australasia Regional Access (SARA) interface** link to open the SARA home page (Figure 17).

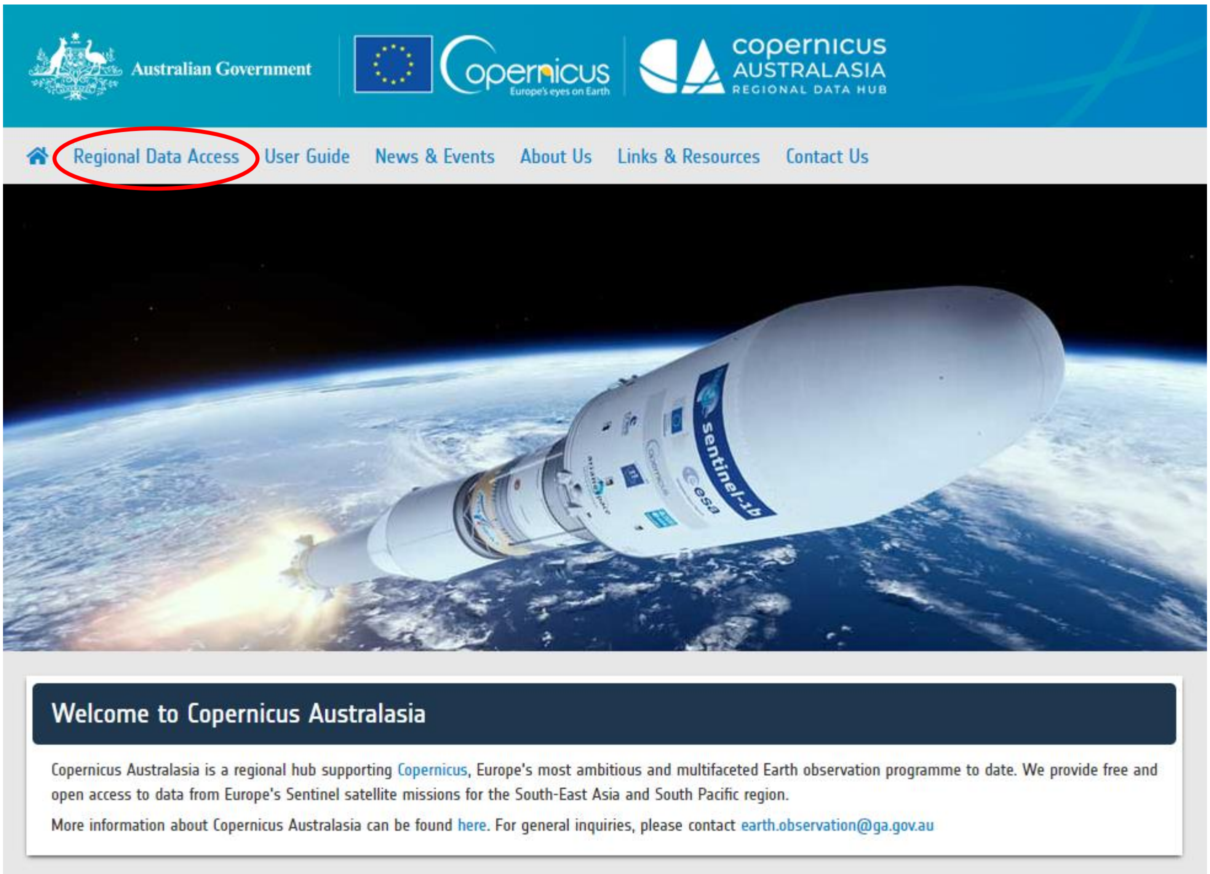


Figure 15 Copernicus Australasia Regional Data Hub home page

Figure 16 Copernicus Australasia;s SARA access

7.1.2 Register

Anyone can explore data on SARA however users must register with SARA to download data. Registration is free, and helps the Hub understand the number and variety of users within the Hub. Please see https://www.ga.gov.au/privacy for the relevant privacy policy. Click the **Register** button shown in Figure 17.

NOTE. When registering, use a simple password without any special characters (e.g. !, $, %). This will ensure that the SARA Python API bulk download method works smoothly.

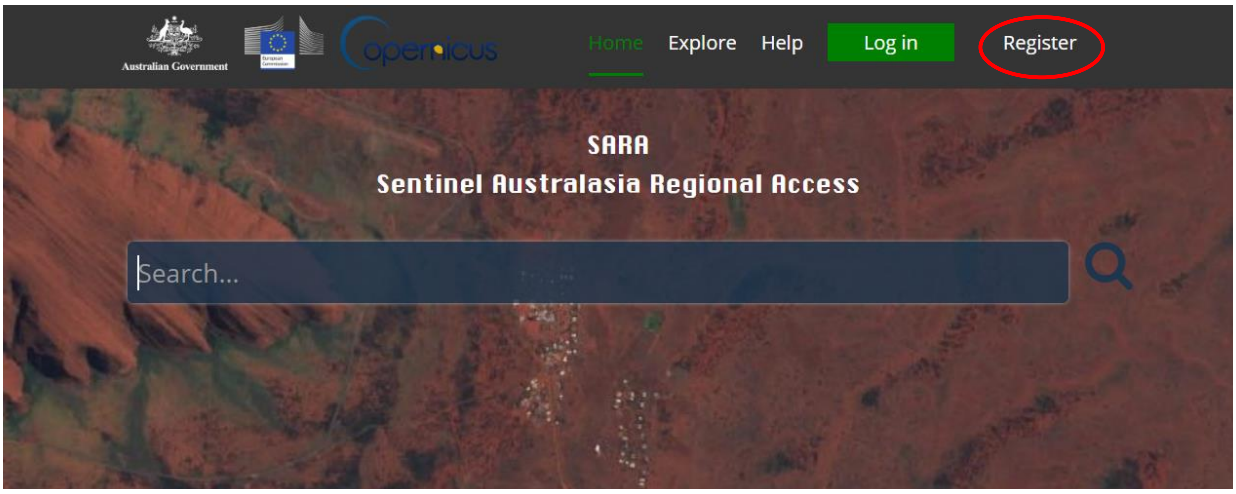


Figure 17 SARA home page

Complete the registration details as shown in Figure 18 and click **Register** (the button will become active when registration details are provided).

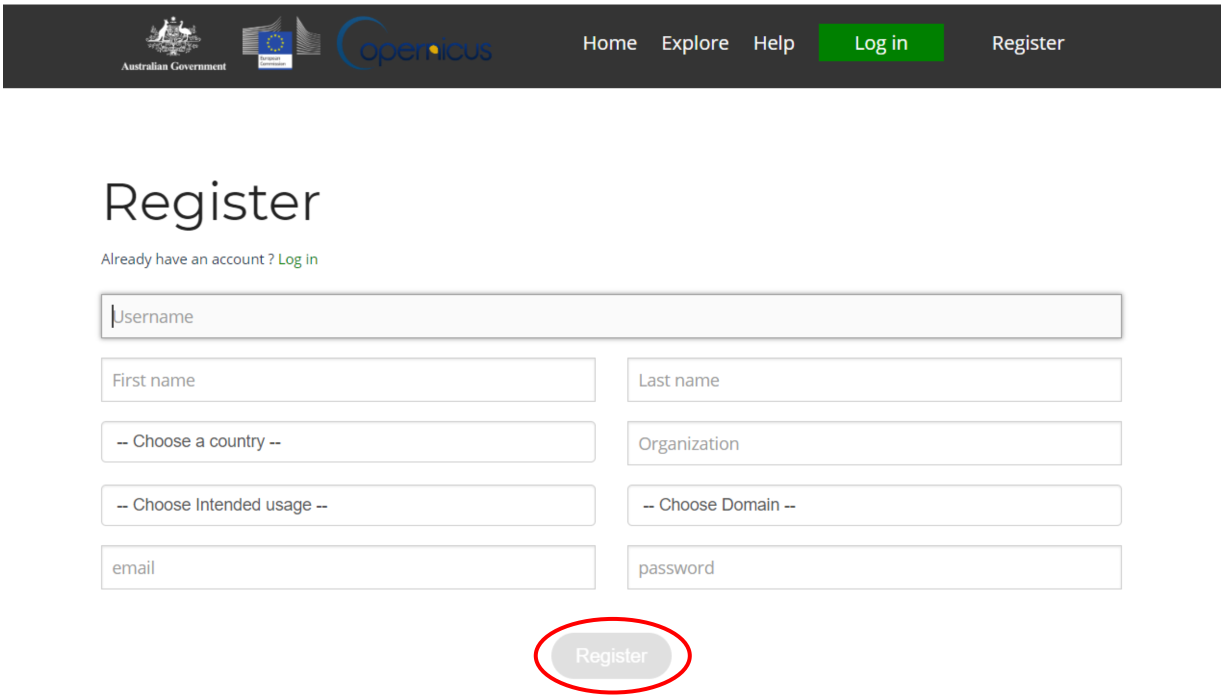


Figure 18 Register for SARA

An email from the NCI titled “[sara] Activation code” will be sent to the email address provided. Click the link in the email to validate the SARA account which will open the Log in page as shown in Figure 19.

7.1.3 Log in

The email link will open the SARA Log in page (Figure 19). Enter the email address and password used to register for SARA and click **Sign in** (the button will become active when login details are provided). The Home page will open, which will now display My cart and Profile buttons instead of Log in and Register at the top right (see Figure 20).

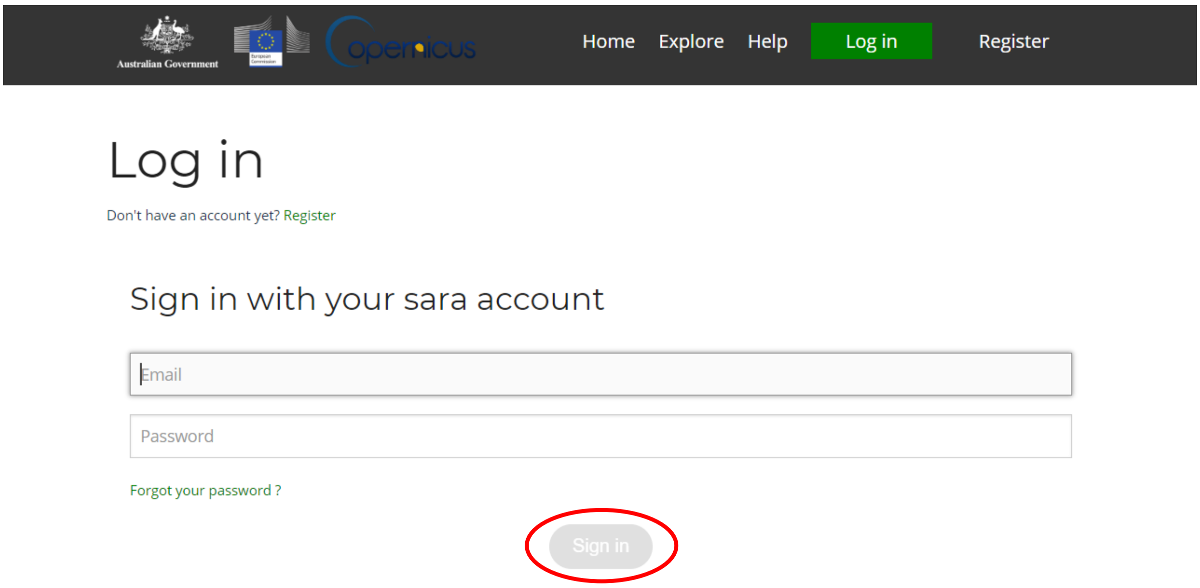


Figure 19 SARA log in page

7.1.4 Explore Data

Although the SARA home page provides a search bar, it is not the best place from which to search. It is useful for semantic search over relatively small places, for example entering "Canberra April 2019 Sentinel-2" will return https://copernicus.nci.org.au/sara.client/#/explore?q=Canberra%20April%202019%20Sentinel-2. For a better search experience, click the **Explore** button (Figure 20) to see the Explore page as shown in Figure 21. Here, detailed search criteria can be provided to narrow the search.

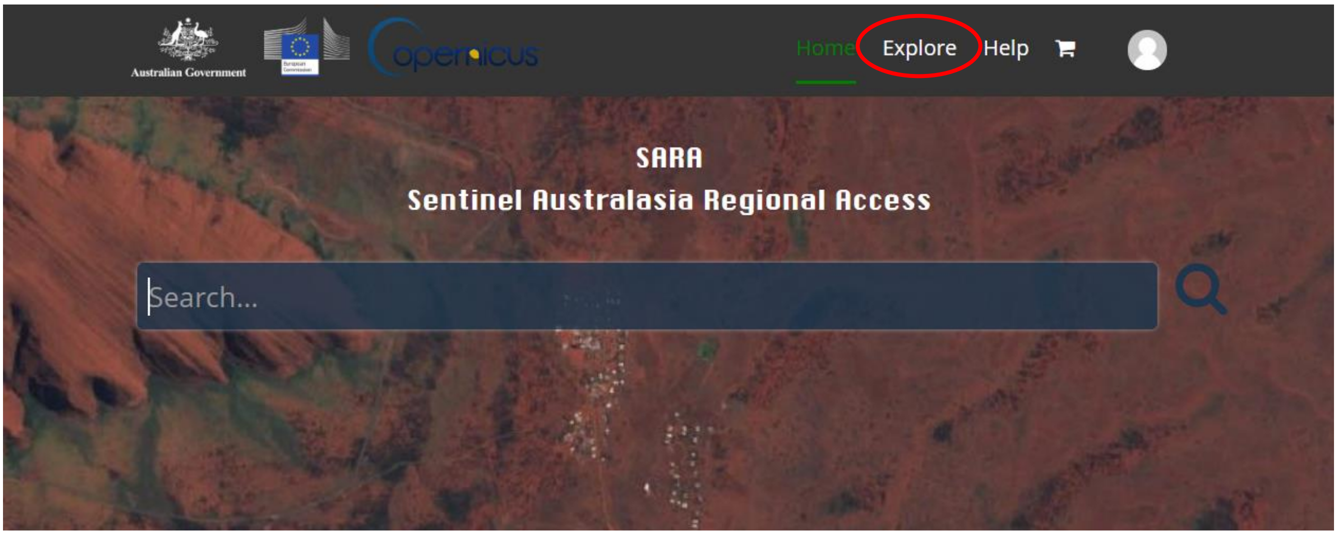


Figure 20 SARA home page when logged in

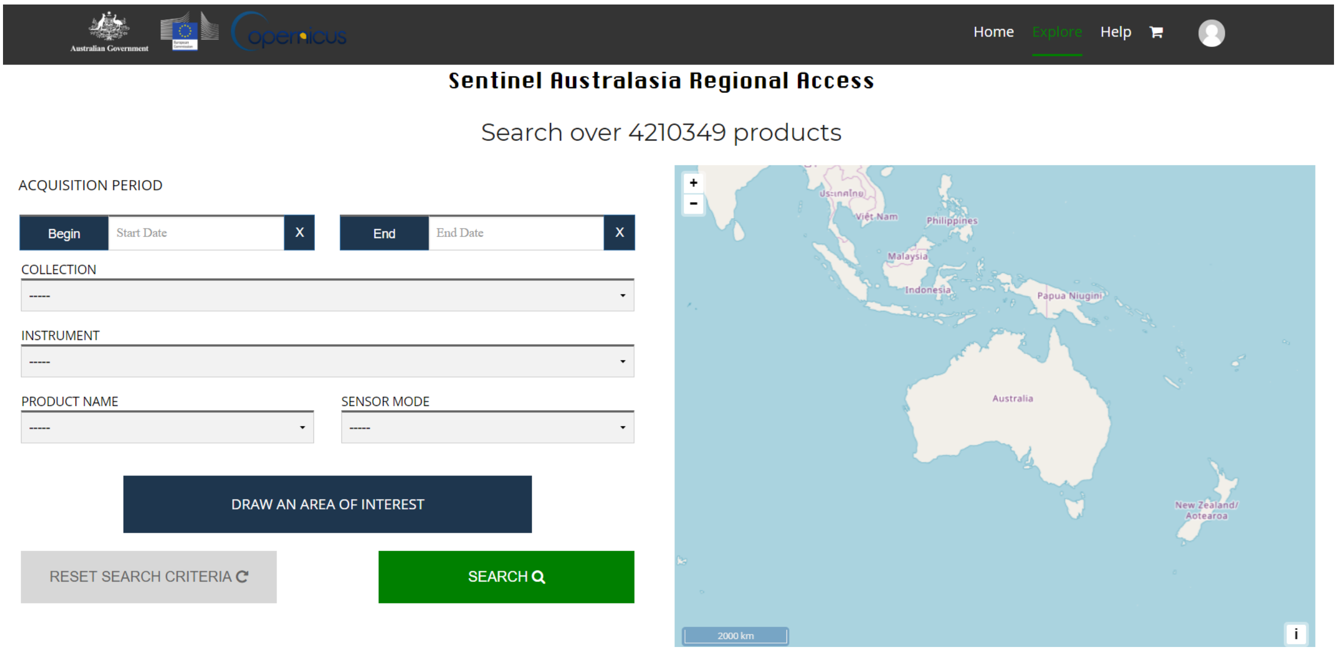


Figure 21 SARA explore page

It is very useful at this point to know a bit about the data to be downloaded (based on application). The user can search on any combination of criteria (or no criteria). The more criteria provided, the more targeted the results will be to requirements. The search criteria applicable to each mission are summarised in Table 5 and include:

- the acquisition period of interest;
- the Sentinel mission (collection);
- the instrument type (especially if interested in Sentinel-3 which has multiple instruments);
- the product name;
- the sensor mode (applicable to Sentinel-1);
- the orbit direction (applicable to Sentinel -1);
- the polarisation (applicable to Sentinel -1);
- the maximum cloud cover percentage allowable (applicable to Sentinel -2); and
- area of interest.

Table 5 Summary matrix of search criteria applicable to missions

	Sentinel-1	Sentinel-2	Sentinel-3
Acquisition Period	2014 – present	2015 – present	2016 - present
Sentinel Mission	S1	S2	S3
Instrument Type	✓	✓	✓
Product Name	✓	✓	✓
Sensor Mode	✓	X	X
Orbit Direction	✓	X	X
Polarisation	✓	X	X
Cloud Cover	X	✓	X
Area of Interest	✓	✓	✓

7.1.4.1 Acquisition Period

To limit the acquisition period (Figure 22), select a Begin date by clicking in the **Start Date** box and selecting a date from the calendar. Then select an End date by clicking in the **End Date** box and selecting a date from the calendar. Please refer to sub-section 4.1 for the year each mission began. To clear a selected date, click the **X** to the right of the relevant box.

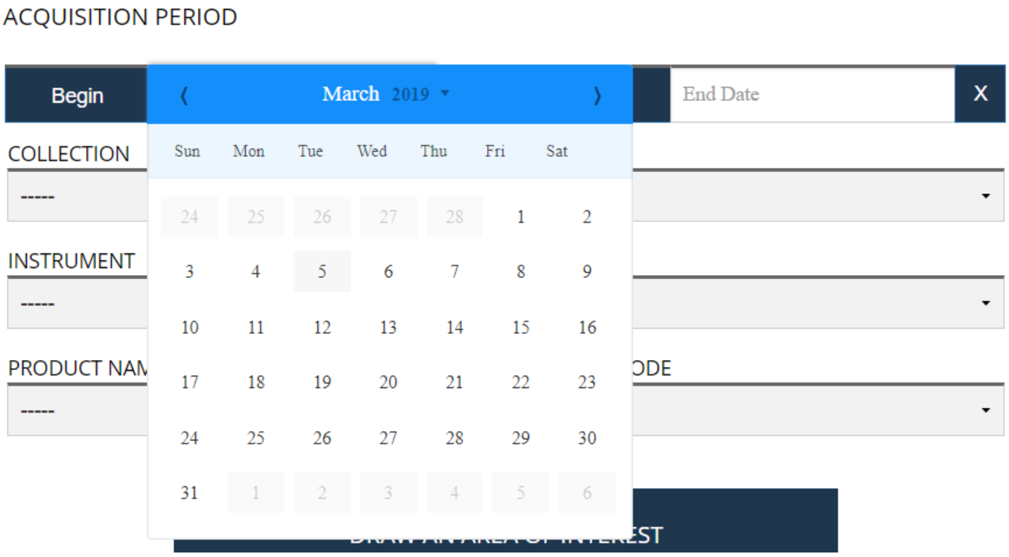


Figure 22 Acquisition period selection

7.1.4.2 Collection

To specify the Sentinel mission of interest, use the **Collection** drop down box (Figure 23) to select either:

S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3

Refer to sub-section 4, for explanation of the Sentinel missions and data.

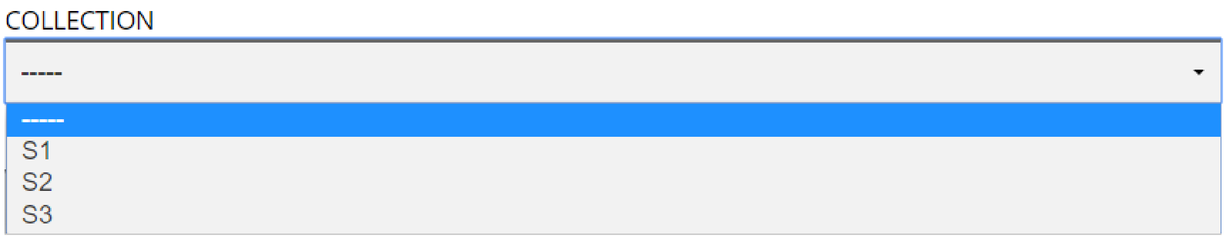


Figure 23 Sentinel collection selection

7.1.4.3 Instrument

To specify the Sentinel instrument of interest, use the **Instrument** drop down box (Figure 24) to select either:

C-SAR	Sentinel-1 C-band Synthetic Aperture RADAR (C-SAR) Instrument
MSI	Sentinel-2 Multispectral Instrument
OLCI	Sentinel-3 Ocean and Land Colour Instrument
SLSTR	Sentinel-3 Sea and Land Surface Temperature Instrument
SRAL	Sentinel-3 SAR RADAR Altimeter Instrument
SYNERGY	Sentinel-3 OLCI + SLSTR Instruments

NOTE. If a collection (as in 7.1.4.2) has been selected, the instruments available in the list (Figure 24) will be reduced to those applicable to that collection.

Refer to sub-section 4, for brief overview of the Sentinel instruments, as well as the instrument sections of the ESA Technical Guides for detail on the instruments e.g. https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-1-sar/sar-instrument.

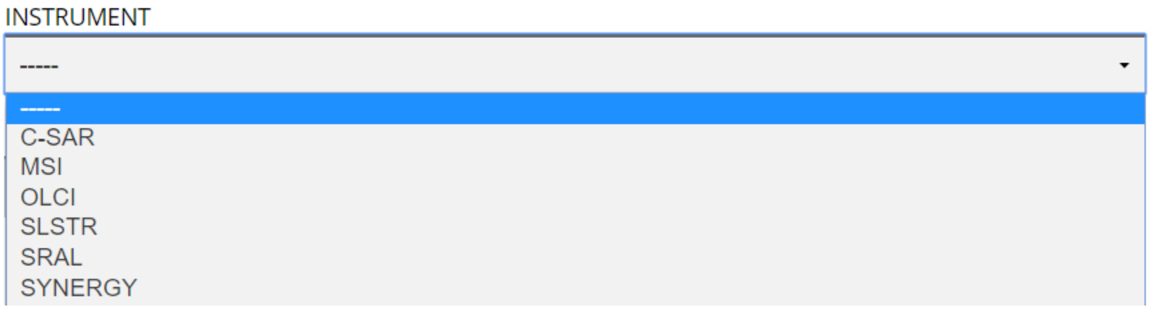


Figure 24 Sentinel instrument selection

7.1.4.4 Product Name

To specify the Sentinel product, use the **Product Name** drop down box (Figure 25) to select either:

GRD	S1 C-SAR Level-1 Ground Range Detected
OCN	S1 C-SAR Level-2 Ocean
RAW	S1 C-SAR Level-0 Raw data
SLC	S1 C-SAR Level-1 Single Look Complex (SLC)
S2MSIL1C	S2 MSI Level-1C Top-Of-Atmosphere reflectance
S2MSIL2A	S2 MSI Level-2A Bottom-Of-Atmosphere reflectance
OL_1_EFR__	S3 OLCI Level-1 Earth Observation Full Resolution
OL_1_ERR__	S3 OLCI Level-1 Earth Observation Reduced Resolution
OL_2_LFR__	S3 OLCI Level-2 Land and atmosphere geophysical products in Full Resolution
OL_2_LRR__	S3 OLCI Level-2 Land and atmosphere geophysical products in Reduced Resolution
OL_2_WFR__	S3 OLCI Level-2 Water and atmosphere geophysical products in Full Resolution
OL_2_WRR__	S3 OLCI Level-2 Water and atmosphere geophysical products in Reduced Resolution
SL_1_RBT__	S3 SLSTR Level-1 Radiances and Brightness Temperatures
SL_2_LST__	S3 SLSTR Level-2 Land Surface Temperature
SL_2_WST__	S3 SLSTR Level-2P Sea Surface Temperature
SR_1_SRA__	S3 SRAL/MWR Level-1 SAR RADAR Altimeter
SR_1_SRA_A_	S3 SRAL/MWR Level-1A SAR RADAR Altimeter
SR_1_SRA_BS	S3 SRAL/MWR Level-1BS SAR RADAR Altimeter
SR_2_LAN__	S3 SRAL Level-2 Land products generated by the Land Centres
SR_2_WAT__	S3 SRAL Level-2 Water products generated by the Marine Centre
SY_2_SYN__	S3 SYNERGY Level-2 Surface Reflectance and Aerosol parameters over Land
SY_2_V10__	S3 SYNERGY Level-2 1km VEGETATION-Like product, 10 day synthesis surface reflectance and NDVI

SY_2_VG1__	S3 SYNERGY Level-2 1km VEGETATION-like product, 1 day synthesis surface reflectance and NDVI
SY_2_VGP__	S3 SYNERGY Level-2 1km VEGETATION-like product, Top-Of-Atmosphere reflectance

NOTE. If a collection (as in 7.1.4.2) has been selected, the products available in the list (Figure 25) will be reduced to those applicable to that collection. If not, they will appear in alphabetical order, not grouped by collection as above.

Refer to sub-section 4, for explanation of the Sentinel products.

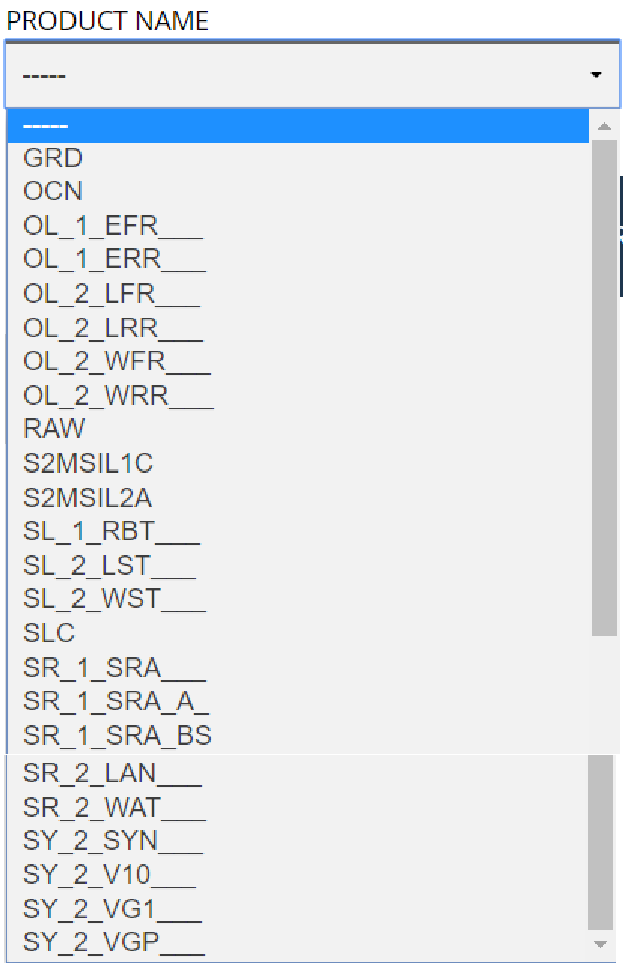


Figure 25 Sentinel product name selection

7.1.4.5 Sensor Mode

Sensor mode is only applicable to Sentinel-1. To specify the sensor mode of interest, use the **Sensor Mode** drop down box (Figure 26) to select either:

EW	Extra-wide swath
IW	Interferometric Wide Swath
SM	Stripmap
WV	Wave

NOTE. If S2 or S3 have been selected as the collection (as in 7.1.4.2), sensor mode is not applicable so there will be no modes available in the list (Figure 26).

Refer to sub-section 4, for explanation of S1 sensor modes.

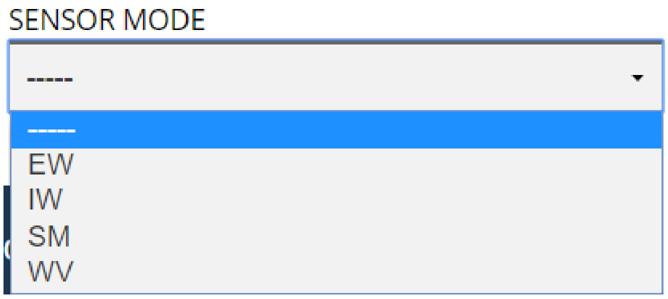


Figure 26 Sentinel-1 sensor mode selection

7.1.4.6 Orbit Direction

Orbit direction is only applicable to Sentinel-1. To specify the orbit direction of interest, use the **Orbit Direction** drop down box (Figure 27) to select either:

Ascending	The pass of the satellite going from south to north
Descending	The pass of the satellite going from north to south

NOTE. If S2 or S3 have been selected as the collection (as in 7.1.4.2), orbit direction is not applicable and will not appear.

Refer to sub-section 4, for brief overview of S1 orbit direction, as well as https://sentinel.esa.int/web/sentinel/missions/sentinel-1/satellite-description/orbit for orbit detail.

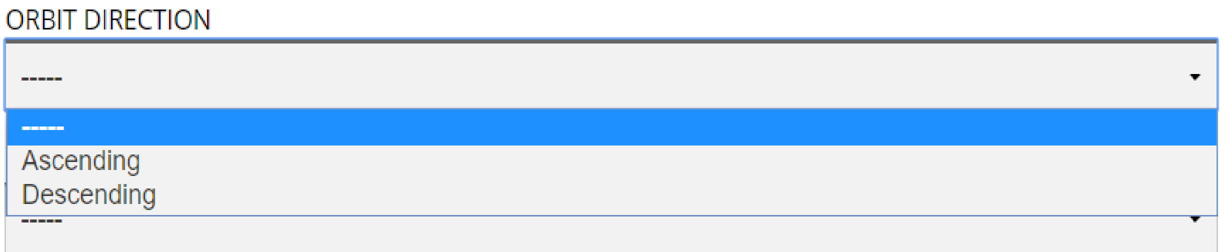


Figure 27 Sentinel-1 orbit direction selection

7.1.4.7 Polarisation

Polarisation is only applicable to Sentinel-1. To specify the polarisation of interest, use the **Polarisation** drop down box (Figure 28) to select either:

HH	Single polarisation for horizontal transmit and horizontal receive
HH+HV	*Dual polarisation for horizontal transmit and horizontal receive plus horizontal transmit and vertical receive
HV	Single polarisation for horizontal transmit and vertical receive
VH	Single polarisation for vertical transmit and horizontal receive
VV	Single polarisation for vertical transmit and vertical receive
VH+VV	*Dual polarisation for vertical transmit and vertical receive plus vertical transmit and horizontal receive

NOTE. If S2 or S3 have been selected as the collection (as in 7.1.4.2), polarisation is not applicable and will not appear.

**NOTE BUG.* There is currently (as at July 2019) a bug with the dual polarisation options in the SARA GUI due to a metadata issue. If searching with a dual polarisation option set, SARA may return a 'no result' warning when results do exist. Please leave the polarisation option blank to work around this issue or use the SARA Python API.

Refer to sub-section 4, for brief overview of S1 polarisation, as well as https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-overview/polarimetry and https://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9275 for details on polarisation.

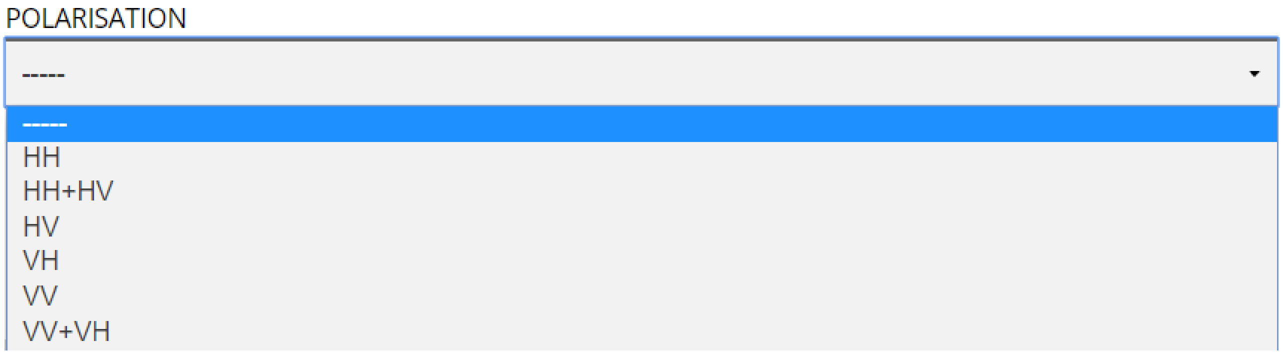


Figure 28 Sentinel-1 polarisation selection

7.1.4.8 Cloud Cover

Cloud cover is only applicable to Sentinel-2. To specify the maximum cloud cover percentage allowable for the data, use the **Cloud Cover** scroll text box (Figure 29) to select or type a whole number between 0 and 100.

0	No cloud cover allowed
100	Total cloud cover allowed

NOTE. If S1 or S3 have been selected as the collection (as in 7.1.4.2), cloud cover is not applicable and will not appear.

Refer to the ESA Sentinel-2 Technical Guide for detail on cloud masks: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-1c/cloud-masks.

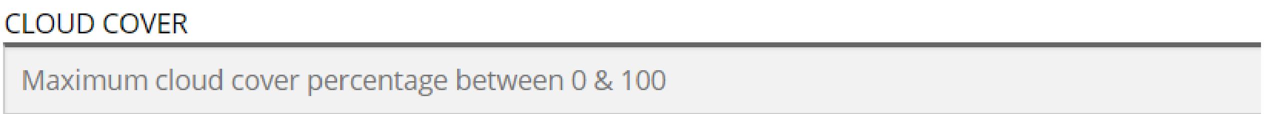


Figure 29 Sentinel-2 cloud cover selection

7.1.4.9 Area of Interest

To specify the area of interest, click the **Draw An Area Of Interest** button so that it changes to read Cancel draw. A blue circle will now appear when the cursor hovers over the map. Zoom (using the + and – buttons at the top left of the map) to the area of interest and click on the map to draw a rough boundary of the area of interest. Each click creates a new vertex (corner). When ready to complete the area, double click to join the first and last points, completing the boundary. The selected area will fill in with a pink shading to indicate the area of interest has been defined (see Figure 30).

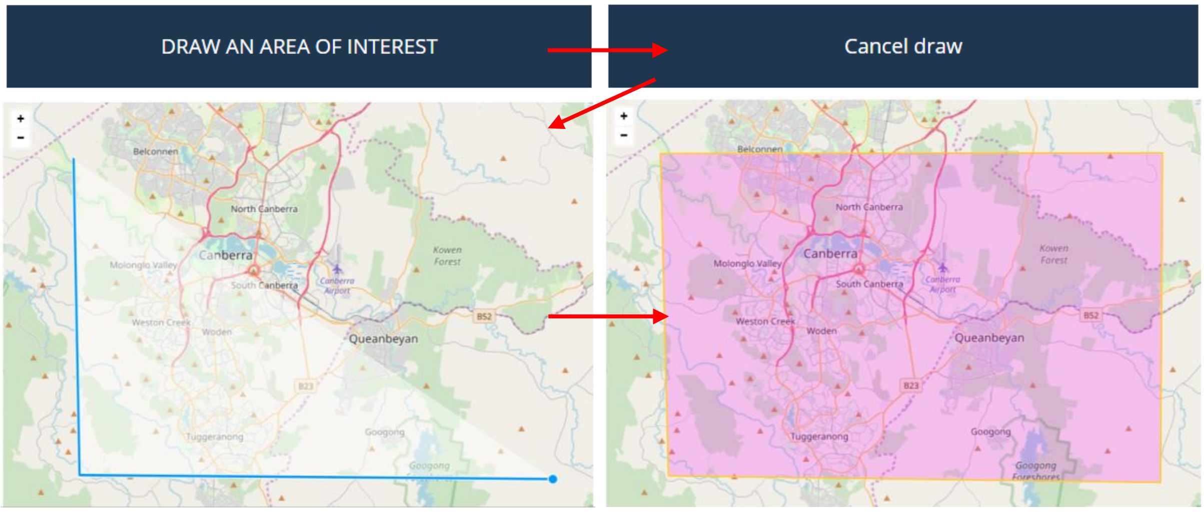


Figure 30 Drawing an area of interest

7.1.4.10 Search

When all desired criteria have been provided, click **Search** (Figure 31). If no results exist, the red warning as in Figure 31 will appear at the top of the screen. If results exist, the map view will display these spatially and scrolling down will reveal a list of datasets matching the search criteria (Figure 32). Click on the **Details >** button for any result to see further details and properties of that dataset (Figure 33).

Figure 31 Search button and no result error message

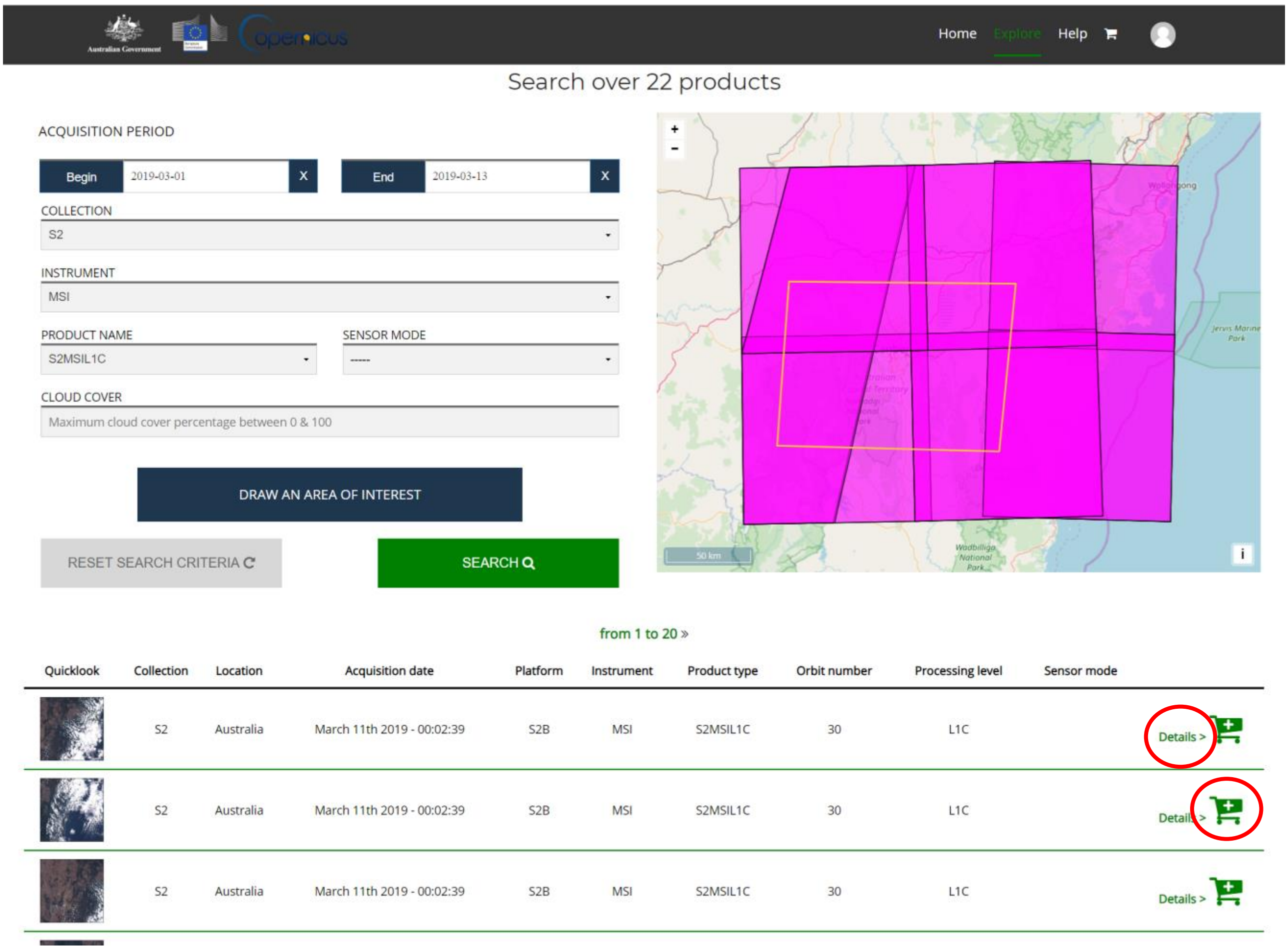


Figure 32 Example of SARA search results

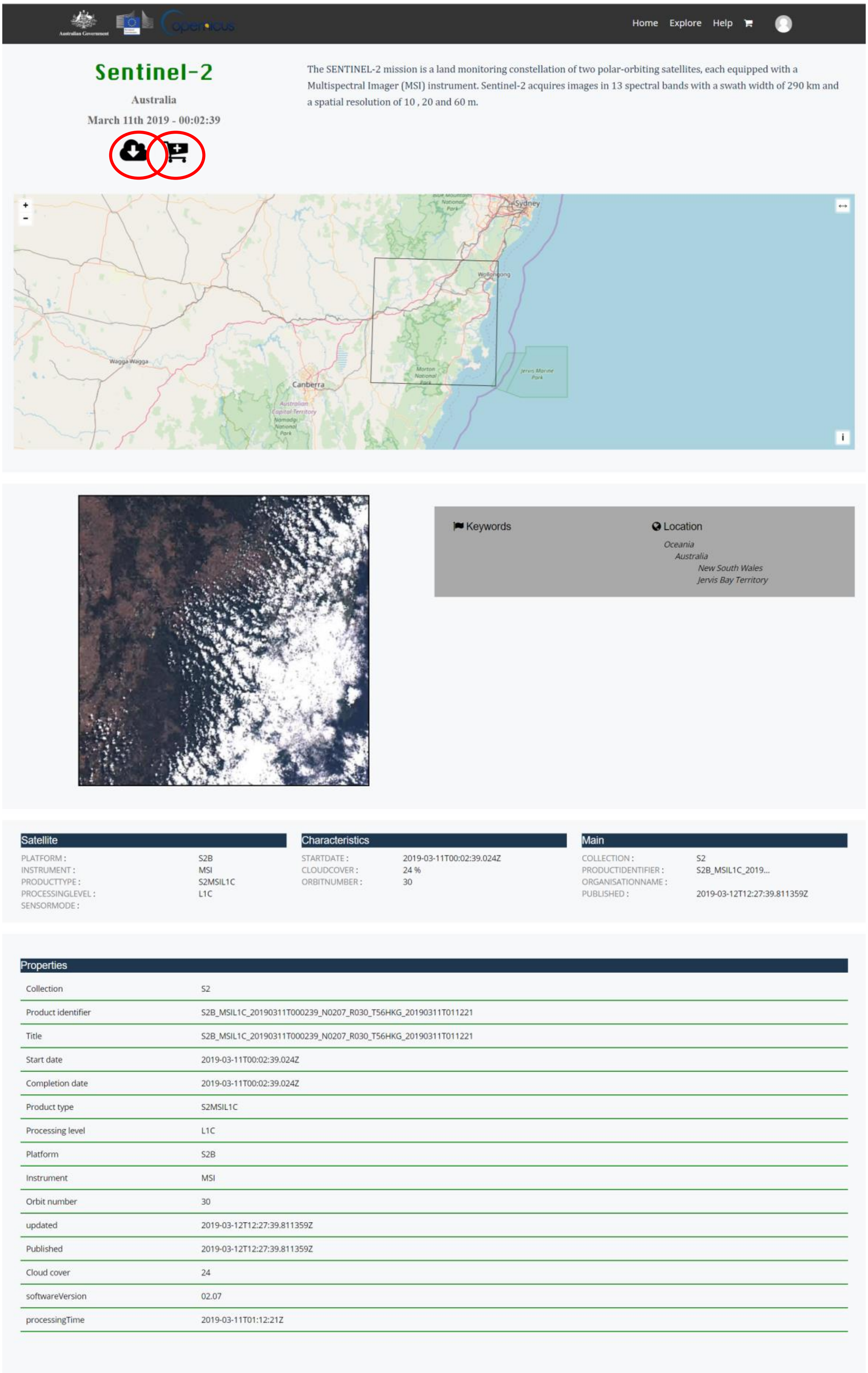


Figure 33 Search result dataset details

7.1.5 Download Individual Datasets

To easily download one (or a small number) of search results, click the **Download** icon on the dataset details page of each individual result (see 7.1.4.10 and Figure 33). Choose where to save the zip file.

> *Congratulations on successfully downloading Sentinel data using the SARA map interface! The data will now need to be unpacked and processed to ARD for use in applications, which will all occur externally to the Hub. Some examples are provided in sub-sections 8 and 5.*

7.1.6 Download Data in Bulk

NOTE. Downloading data in bulk as follows is slightly more complicated than downloading individual datasets and requires use of the command line to install an application. Instructions are provided for Windows. If you are a Mac user, it is highly recommended that you use the SARA Python API for bulk download as described in sub-section 7.2. Hence, no instructions are provided for GUI bulk download if using Mac.

To download the search results in bulk, add each item to the cart. To do so, click the **Add to Cart** icon on the results page (Figure 32) or the details page (Figure 33) of each result.

Figure 34 shows the following three steps. When all items have been added to the cart, review them by clicking the **My Cart** icon at the top right of the webpage. To remove an item, click the **Delete** icon . To download the cart content, click the **Checkout** button and choose where to save the file.

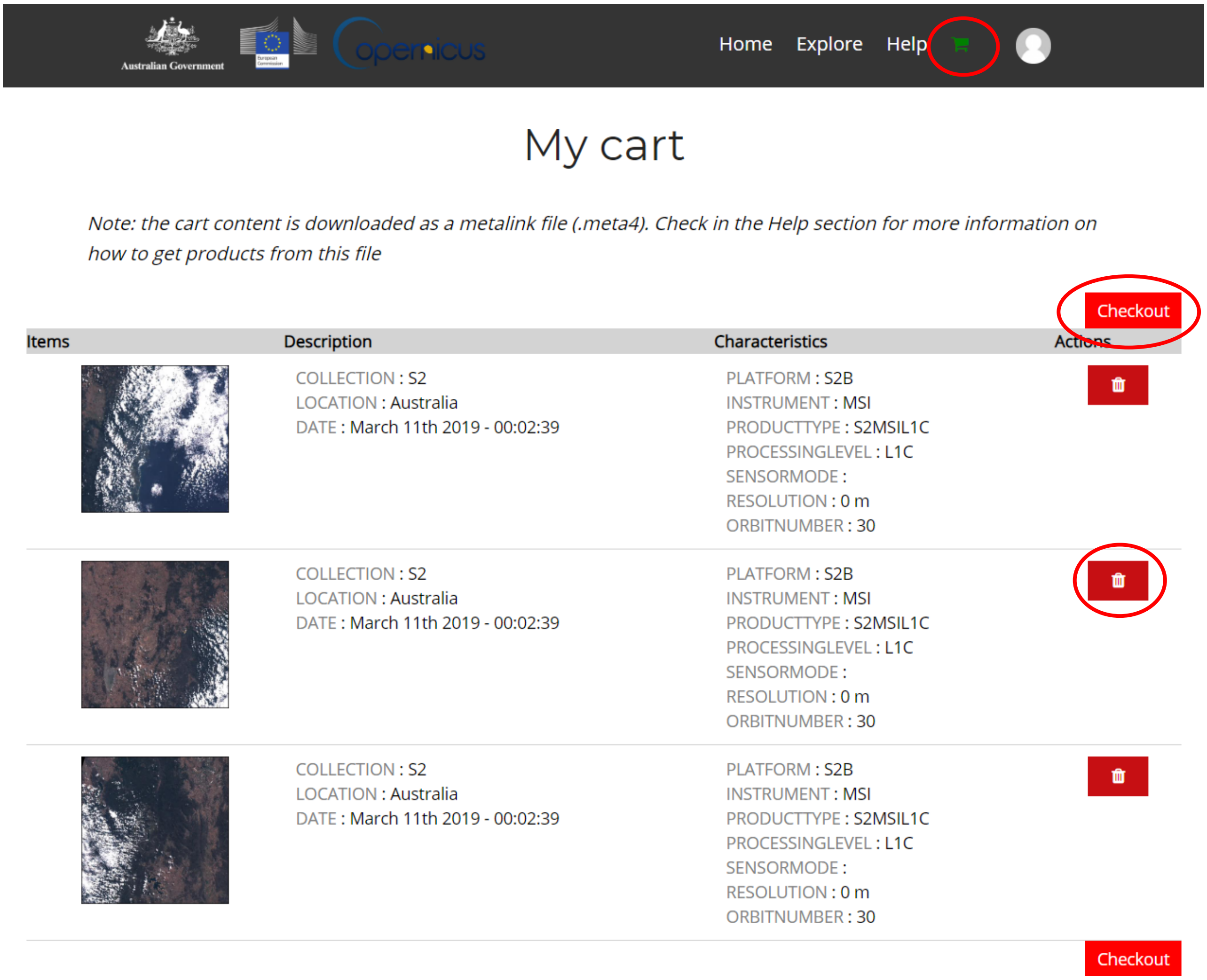


Figure 34 Review the items in My cart

Cart content is downloaded as a metalink file (.meta4). A metalink file is a simple XML file containing resource urls (references to the data) and checksums (to detect download errors). To access the data from this metalink file, use a download manager such as DownThemAll! (Firefox addon https://www.downthemall.net/) or the aria2 (https://aria2.github.io/) command line utility and its webui-aria2 user interface (https://github.com/ziahamza/webui-aria2). The following sub-sections describe how to use aria2 and webui-aria2.

7.1.6.1 Download and Start aria2

For Windows, download the latest stable release of aria2 by clicking the **download version x.x.x** link under the Download section at the top of https://aria2.github.io/. On the page that opens, scroll down to Assets at the bottom and click on the zip file for the appropriate Windows build (32bit or 64bit) to download e.g. 'aria2-1.34.0-win-64bit-build1.zip'. Choose where to save the file (if applicable). Unzip the zip file using an unzip program (e.g. 7zip or similar). The unzipped folder will contain the files shown in Figure 35.

If you are a Mac user, it is highly recommended that you use the SARA Python API for bulk download as described in sub-section 7.2. Hence, no instructions are provided for GUI bulk download if using Mac.

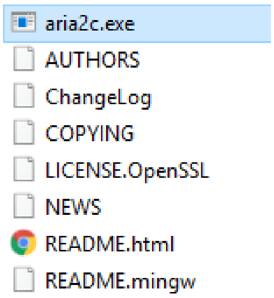


Figure 35 aria2 unzipped files

Throughout this section, the example folder path used is:

Windows path:

```
C:\Users\User Name\Documents\aria2\ aria2-1.34.0-win-64bit-build1
```

For Windows, the executable of interest is ‘aria2c.exe’, which should be run via the command prompt. Open the preferred terminal program (e.g. type “cmd” into the windows search tool and open the Command Prompt), navigate to the unzipped folder (e.g. ‘aria2-1.34.0-win-64bit-build1’) using the change directory command and start aria2. The commands required to do this are shown below (see Figure 36 for an example).

Windows commands:

```
cd C:\Users\User Name\Documents\aria2\ aria2-1.34.0-win-64bit-build1
aria2c.exe --enable-rpc --rpc-listen-all
```

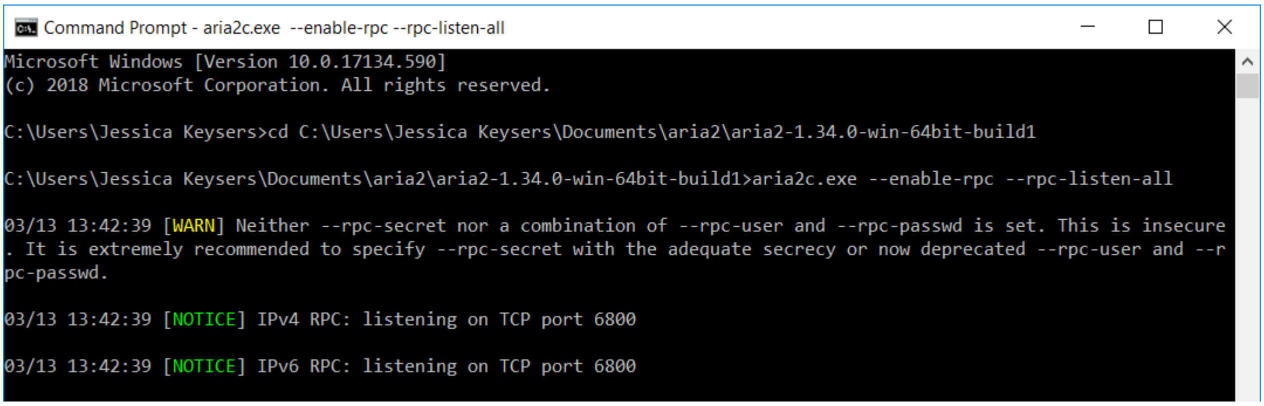


Figure 36 Navigating to and starting aria2 in the command line

The executable is a standalone program and won’t install anything. Leave the terminal program running and move to the next step.

7.1.6.2 Download and Run webui-aria2

Download webui-aria2 from this link https://github.com/ziahamza/webui-aria2/archive/master.zip and choose where to save the file (if applicable). Unzip the file using an unzip program (e.g. 7zip or similar). The unzipped folder will contain the files shown in Figure 35. Open the ‘docs’ folder and then double-click the ‘index.html’ file to open it in a web browser (Chrome or Firefox recommended), which should appear as in Figure 38.

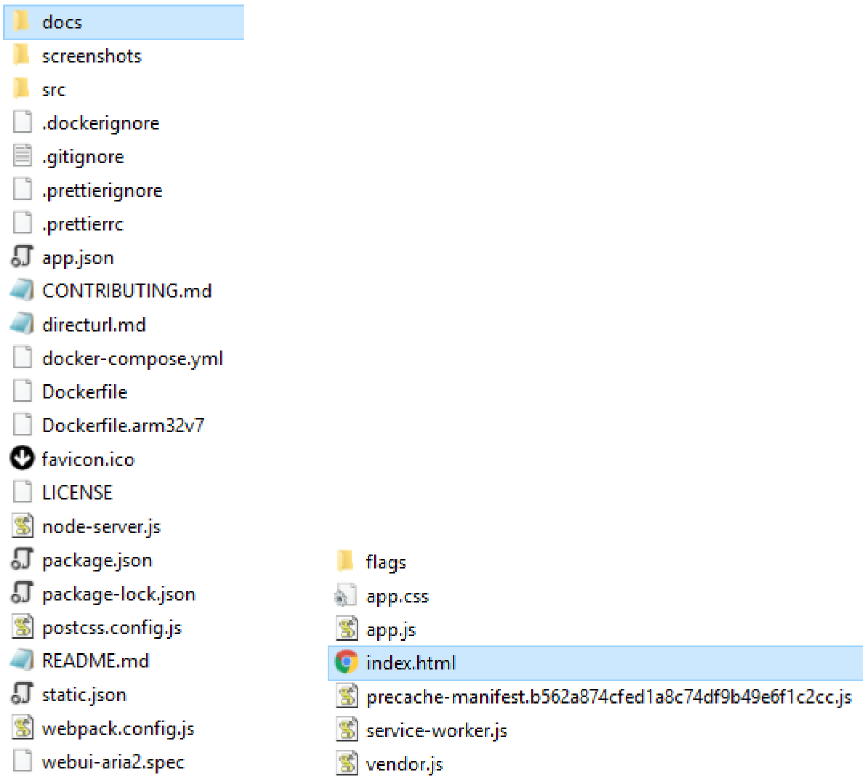


Figure 37 webui-aria2 unzipped files

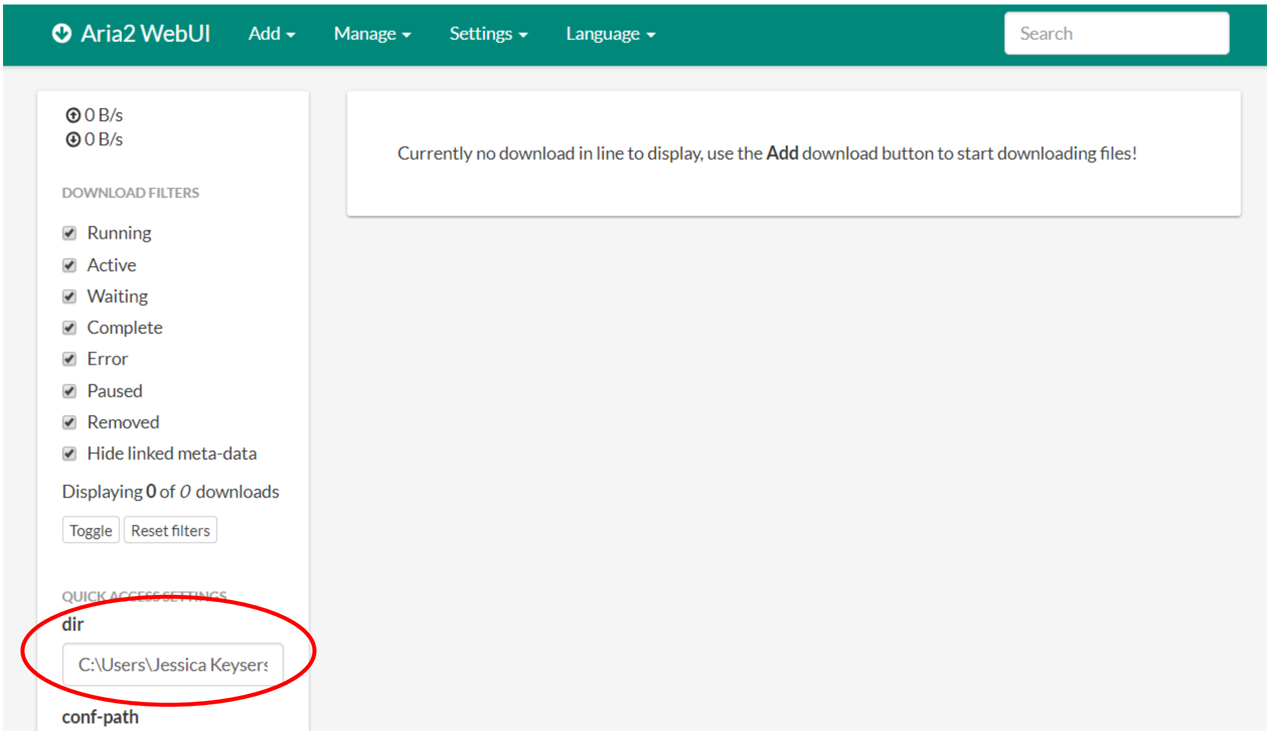


Figure 38 webui-aria2 web interface

Set the download directory for the data using the **dir** text box (Figure 38). From the **Add** menu select **By Metalinks** then click **Choose file** and locate the '.meta4' file checked out and saved earlier from SARA (Figure 39). Click **Start** and the download process should start as shown in Figure 40.

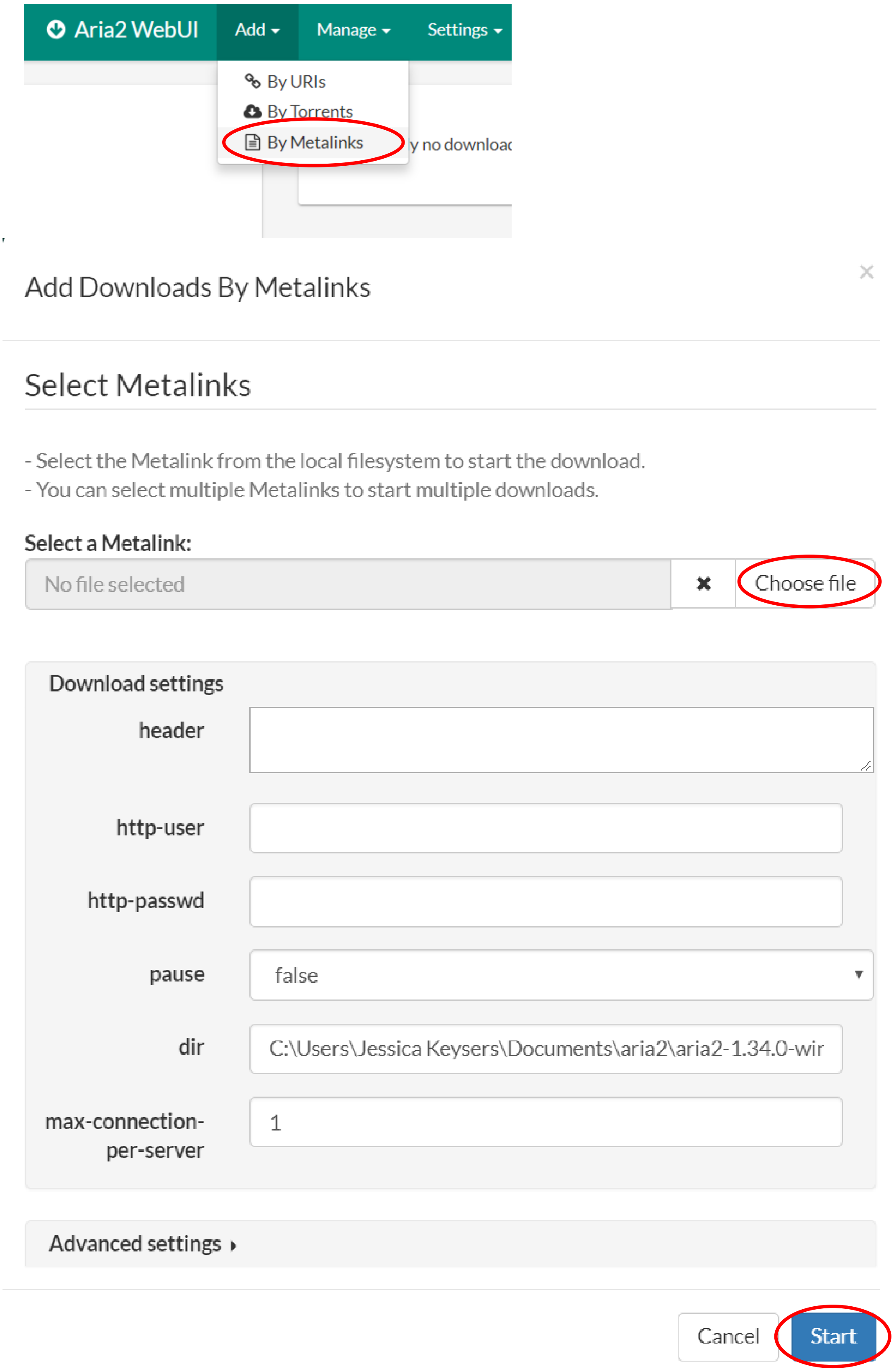


Figure 39 Add data By Metalinks

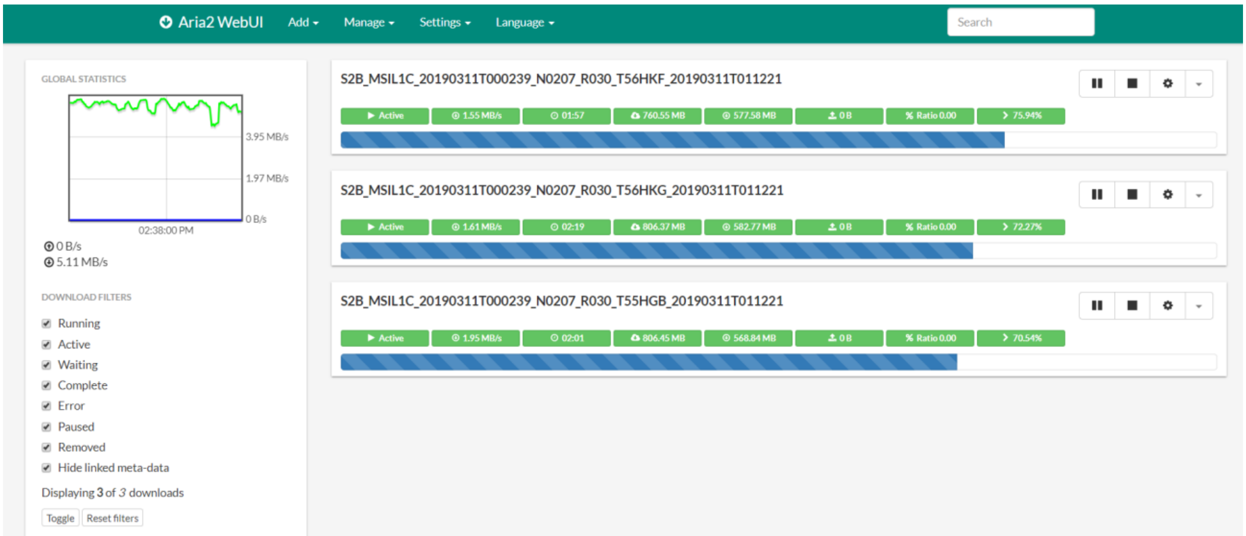


Figure 40 webui-aria2 data download

When the blue progress bars turn green and the downloads say ‘Complete’ (not ‘Active’), navigate to the output directory to retrieve the data.

Congratulations on successfully downloading Sentinel data in bulk using the SARA map interface and aria2! The data will now need to be unpacked and processed to ARD for use in applications, which will all occur external to the Hub. Some examples are provided in sub-sections 8 and 5.

NOTE. For another example of querying SARA using the map interface and downloading results in bulk using aria2 and webui-aria2 see https://docs.google.com/document/d/1nfxWJe2YdXrcdko595DOwlsfPlj83WuGpdPvDPwYrwo/edit.

7.2 SARA Python API

The SARA Python Application Programming Interface (API) enables programmatic search and retrieval of data from SARA. To download data using the SARA API, follow the instructions below. Instructions are provided for both Windows and Mac.

NOTE. To use the SARA Python API a basic understanding of Python and how to run Python from the computer’s terminal application (e.g. Windows Command Prompt or Mac Terminal) is required. If uncomfortable with this, use of the SARA Map Interface as described in sub-section 7.1 is recommended.

7.2.1 SARA Home Page

To access the home page for SARA go to https://copernicus.nci.org.au/sara.client/#/home (Figure 43).

Alternatively, from the Copernicus Australasia website home page (http://www.copernicus.gov.au/ - Figure 41) click **Regional Data Access**, then as shown in Figure 42 click the **Sentinel Australasia Regional Access (SARA) interface** link to open the SARA home page (Figure 43).

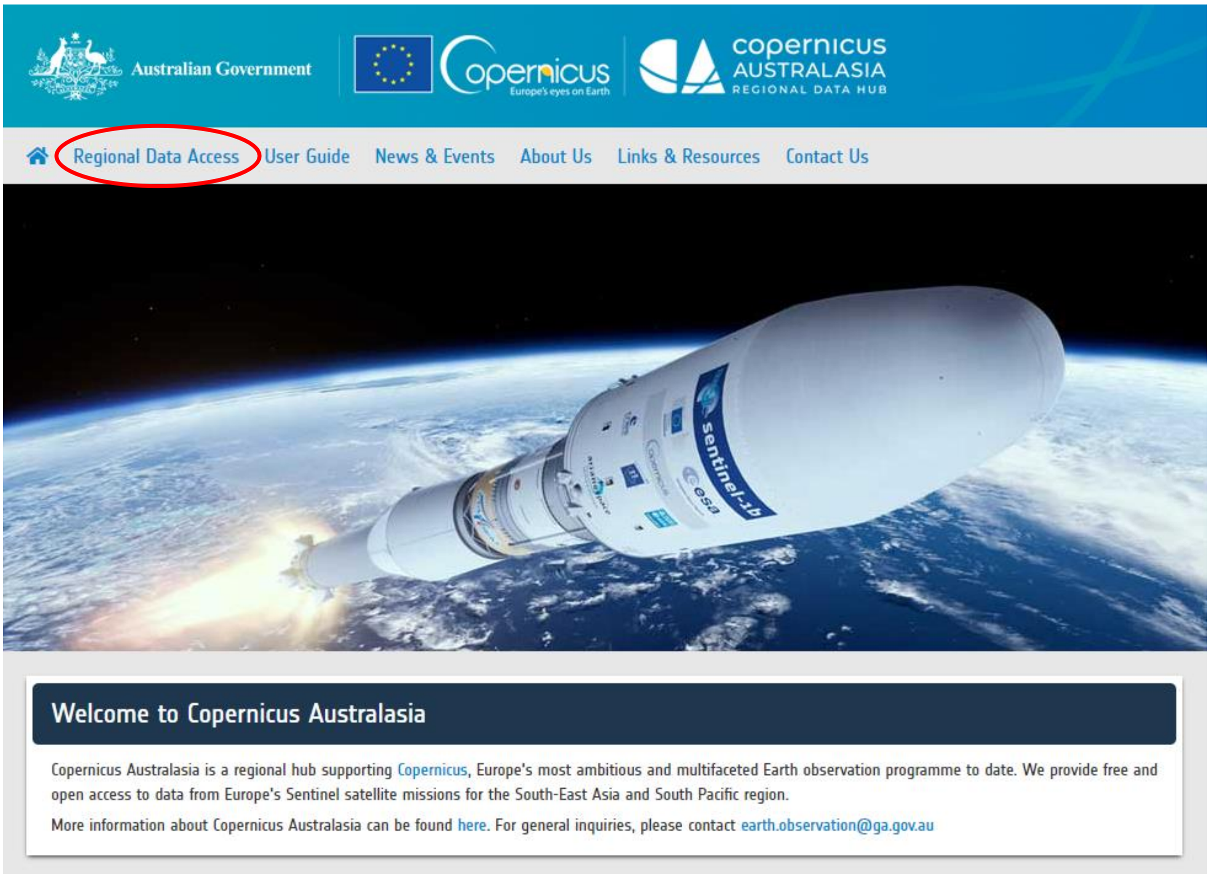


Figure 41 Copernicus Australasia home page

Figure 42 Copernicus Australasia regional data access

7.2.2 Register

Anyone can explore data on SARA however users must register with SARA to download data. Registration is free. Click the **Register** button shown in Figure 43.

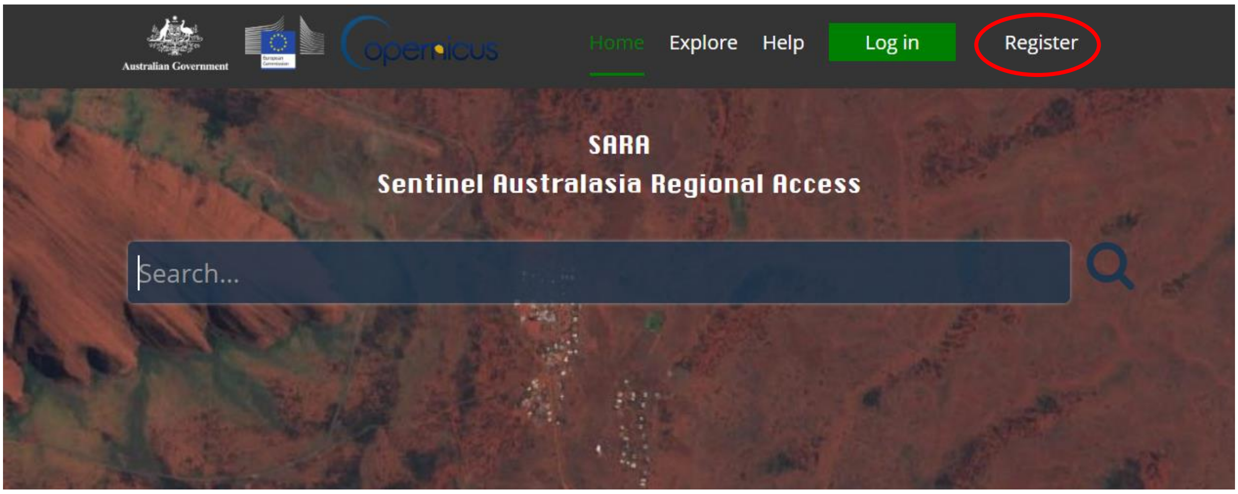


Figure 43 SARA home page

Complete the registration details shown in Figure 44 and click **Register** (the button will become active when registration details are provided).

WARNING. As the password selected must be explicitly used in the Python code to log in and access SARA through the API, it will not be entirely secure. Hence, *please choose a new password that is not used for any other account*.

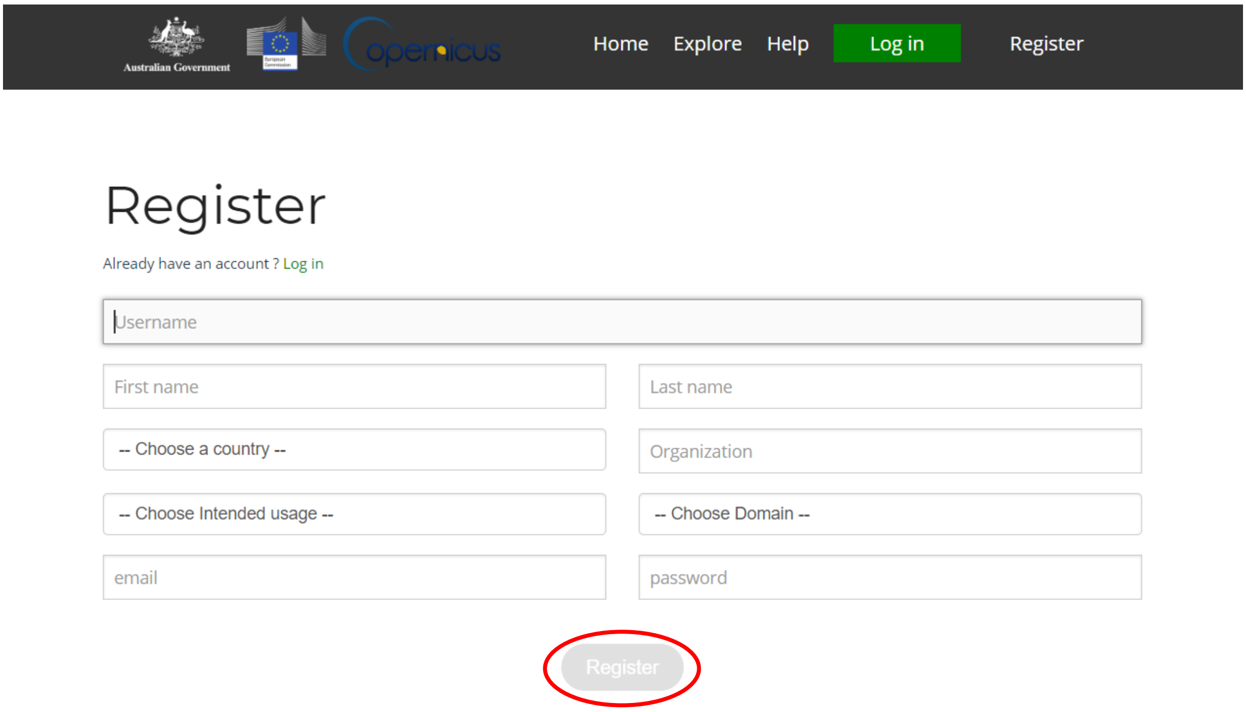


Figure 44 Register for SARA

An email from the NCI titled “[sara] Activation code” will be sent to the email address provided. Click the link in the email to validate the SARA account which will open the Log in page. However, there is no need to log in at this point as this will be done via Python.

7.2.3 Download and Install the Python Scripts

Before getting started, please note that this process will require:

- executing multiple steps in the computer's terminal application (e.g. Windows Command Prompt or Mac/Linux Terminal)
- an installation of Python
  - If Python is not installed, download Python 3 through Anaconda from https://www.anaconda.com/distribution/#download-section
- an installation of the GDAL Python package
  - For Windows follow the install instructions at https://pythongisandstuff.wordpress.com/2016/04/13/installing-gdal-ogr-for-python-on-windows/
  - For Mac, after installing Python through Anaconda, run "conda install gdal" from your terminal
- 7zip to unzip files https://www.7-zip.org/download.html

7.2.3.1 Download Scripts

To download the scripts for searching and downloading files through the SARA API go to the Copernicus Australasia Regional Data Hub BitBucket at https://bitbucket.org/chchrsc/auscophub. This will show the Overview page. Navigate to **Downloads** by clicking the button as shown in Figure 45.

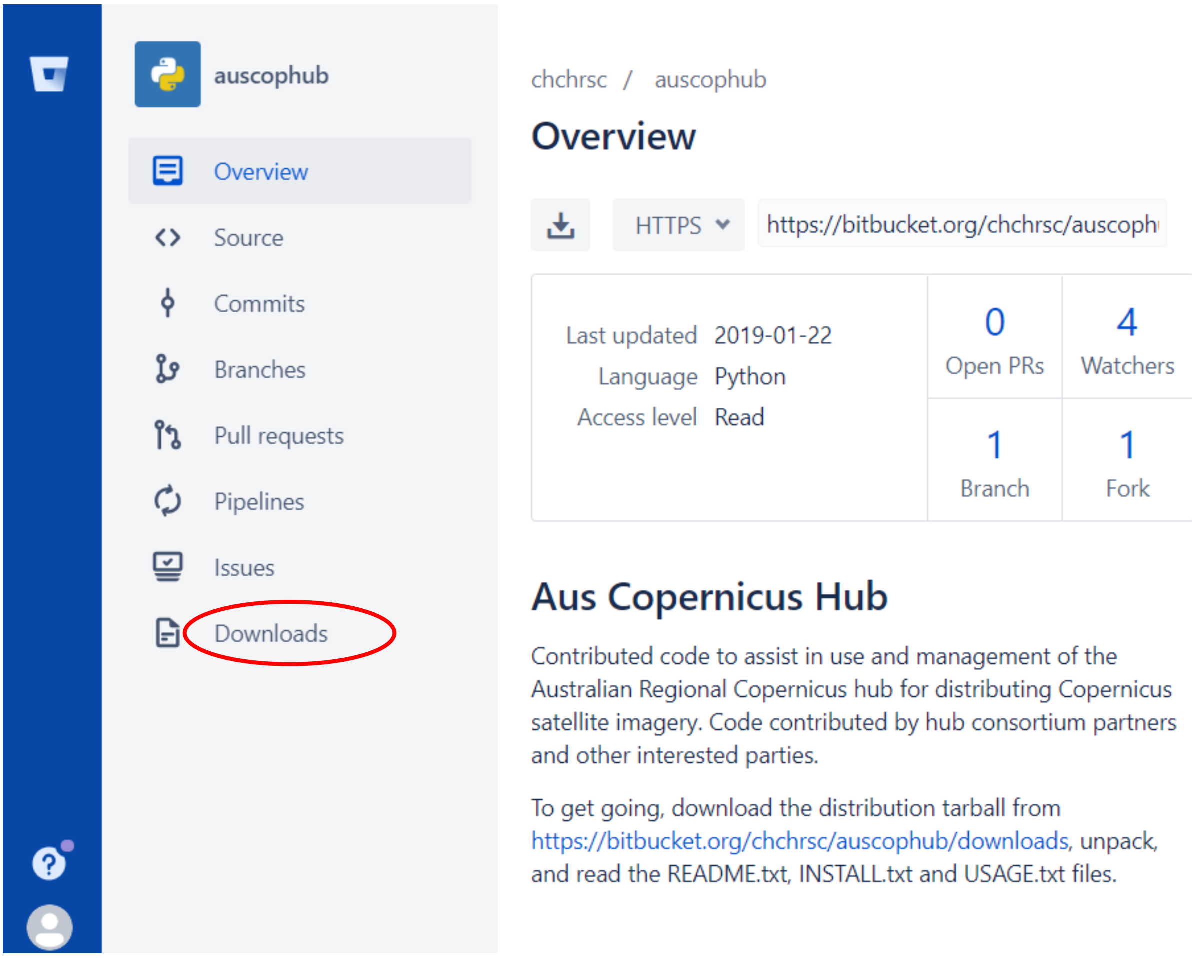


Figure 45 Copernicus Australasia Regional Data Hub BitBucket overview page

Once on the Downloads page, click the most recent '.tar.gz' file (example highlighted in Figure 46) to download it. Save the file to the location where you wish to keep these python scripts, or if the file automatically saves to the 'Downloads' folder, please move it to the location where you wish to keep these python scripts. The chosen folder will be used to access SARA using the scripts. Throughout this section, the example folder paths below will be used (where *User Name* is your user name):

Mac path:

```
~/Documents/AusCopHub/
```

Windows path:

```
C:\Users\User Name\Documents\AusCopHub\
```

chchrsc / auscophub

Downloads

Downloads Tags Branches

Name	Size	Uploaded by	Downloads	Date
Download repository	331.0 KB			
auscophub-1.1.8.tar.gz	49.2 KB	neilflood	14	2019-01-22
auscophub-1.1.7.tar.gz	53.4 KB	neilflood	41	2018-04-30

Figure 46 Copernicus Australasia Regional Data Hub BitBucket downloads page

7.2.3.2 Unzip and Install Scripts

The '.tar.gz' has two levels of compression which need to be unzipped. Unzip both levels of the '.tar.gz' file using an unzip program (e.g. 7zip). Unzipping the file will create a new folder with the same name, containing the necessary files (see Figure 47).

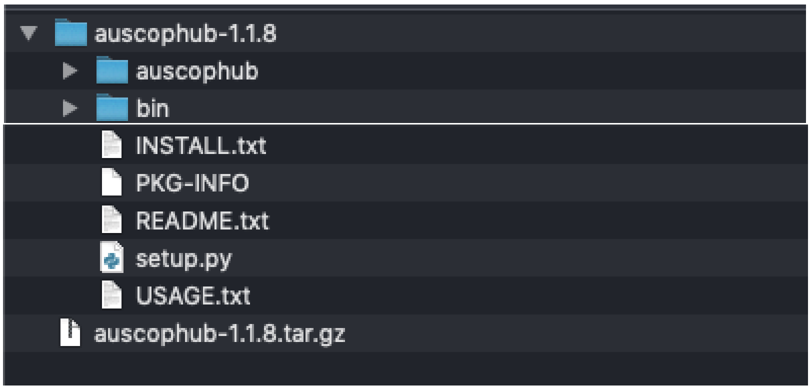


Figure 47 Newly created auscophub-1.1.8 folder and files after unzipping the downloaded tar.gz file

Open the preferred terminal program, navigate to the unzipped folder (e.g. 'auscophub-1.1.8') and install the Python scripts using the two commands below (see Figure 48 for an example).

NOTE. If Python is not recognised by your terminal program, try opening the Anaconda Prompt terminal and running everything from there. This should be accessible if you installed Python from Anaconda.

Mac commands:

```
cd ~/Documents/AusCopHub/asucophub-1.1.8/
python setup.py install
```

Windows commands:

```
cd C:\Users\User Name\Documents\AusCopHub\auscophub-1.1.8
python setup.py install
```

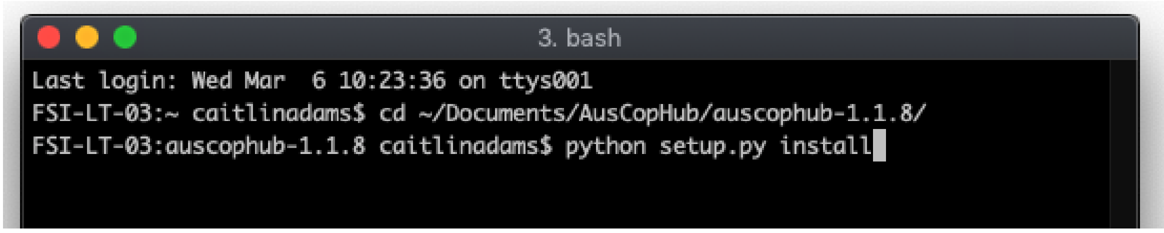


Figure 48 Navigating to and installing the Python scripts in the terminal environment

Installing the Python scripts creates a new ‘build’ directory, which contains the scripts directory. This will be labelled ‘scripts-x.y’, where ‘x.y’ will be your Python version, e.g. ‘2.7’ or ‘3.7’ (see Figure 49).

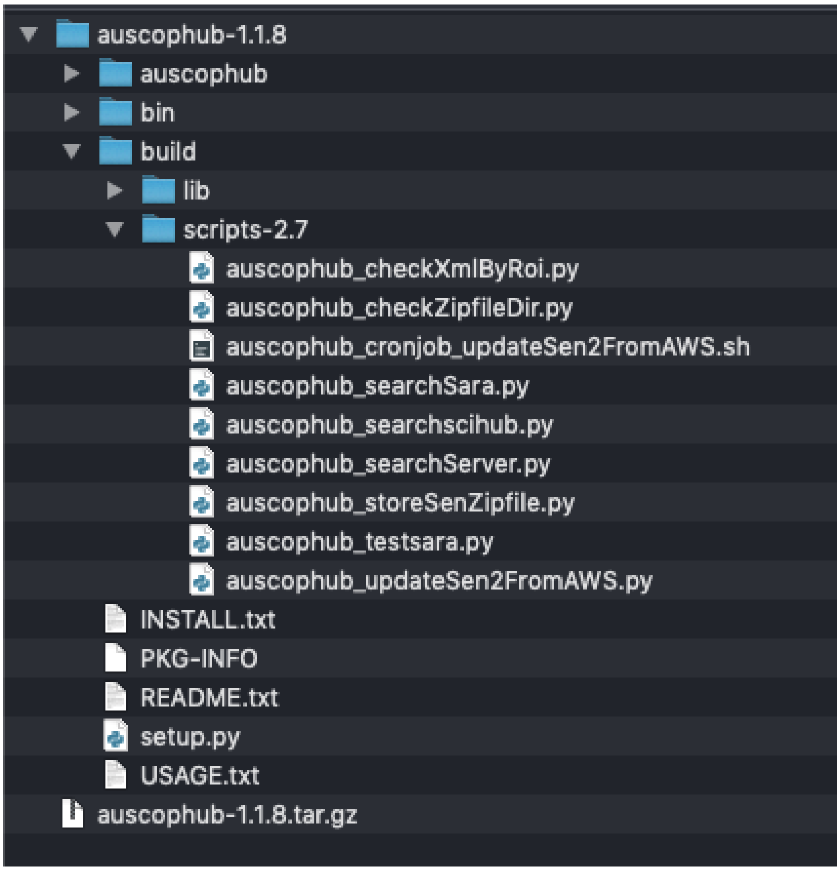


Figure 49 Directory structure after installing the Python scripts

The functionality to search for and download data is contained within the ‘auscophub_searchSara.py’ script. To use this script, copy it from the command line or from your file explorer to the folder that you want to work in. In this example it will be copied to the path:

Mac path:

```
~/Documents/AusCopHub/
```

Windows path:

```
C:\Users\User Name\Documents\AusCopHub\
```

It is now time to interface with the SARA API, which is covered in the next section.

7.2.4 Interface with SARA API through Python

This section will use the example script ‘auscophub_searchSara.py’, executed with command line arguments. To learn more about the command line arguments, navigate to the folder where you copied the script (in this example ‘AusCopHub’) in your terminal program and run ‘python auscophub_searchSara.py --help’.

Mac commands:

```
cd ~/Documents/AusCopHub
python auscophub_searchSara.py --help
```

Windows commands:

```
cd C:\Users\User Name\Documents\AusCopHub
python auscophub_searchSara.py --help
```

There are several command line inputs, listed in Table 6. Capital lettered terms indicate the expectation of an input from the user.

Table 6 List of command line arguments for ‘auscophub_searchSara.py’

Command	Usage
--help	Show this help message and exit.
--sentinel {1,2,3}	Number of Sentinel satellite family to search on (default will search over all Sentinels).
--proxy “PROXY”	URL of proxy server. Default uses no proxy, assuming direct connection to the internet.
--excludelist “EXCLUDELIST”	File listing zipfile names to exclude from search results. Useful for excluding files already obtained, or ones with known problems. Each line should contain one zipfile name, with no path or URL details.
-q “QUERYPARAM”	A SARA query parameter, given as a single string 'name=value'. This will be passed straight through to the SARA API as part of the query URL. Can be given multiple times, each extra parameter further restricts the search. The SARA API does not provide a mechanism to combine multiple terms with OR, only AND. Please see the SARA API documentation for allowable query parameters at https://copernicus.nci.org.au/sara.server/1.0/api/collections/describe.xml.
--polygonfile “POLYGONFILE”	Vector file of a polygon AOI to search within. The polygon can be any vector format readable using GDAL/OGR. It should contain a single polygon layer, with one or more polygons. Highly complex polygons will only slow down searching, so keep it simple.
--urllist “URLLIST”	Output file of zipfile URLs, one per line. Default does not write this out.
--curlscript “CURLSCRIPT”	Name of bash script of curl commands for downloading zipfiles. Default does not write this.
--curloptions “CURLOPTIONS”	Command line options to add to the curl commands generated for --curlscript. Give this as a single quoted string. Default='--silent --show-error'. (Note that --proxy will automatically add a -x option for curl, so not required here).
--jsonfeaturesfile “JSONFEATURESFILE”	Filename to save the JSON for all the features found, constructed from paged returns from the SARA server. This is a compliant GeoJSON file and can be read by software like QGIS. Default does not write this.
--simplejsonfile “SIMPLEJSONFILE”	Filename to save the simple JSON for all the zipfiles found. The JSON for each feature is the very simple dictionary constructed internally. Default does not write this.

The command line arguments can be broken into two types: those related to the construction of the query, and those related to the outputs, described below.

7.2.4.1 Constructing the Query

Query parameters are passed to the script via the '-q' option. This is typically done in the form '-q "name=value"', where 'name' is the parameter to query on, and 'value' is the constraint to pass to. A full list of query parameters is at https://copernicus.nci.org.au/sara.server/1.0/api/collections/describe.xml. The most important options are covered in Table 7.

Table 7 List of query arguments for 'auscophub_searchSara.py'

Name	Example Command	Description
geometry	-q "geometry=POLYGON((149.03 -35.18,149.23 -35.18,149.23 -35.38,149.03 -35.38,149.03 -35.18))"	Region of Interest defined in Well Known Text standard (WKT) with coordinates in decimal degrees (EPSG:4326).
box	-q "box=148.0,-36.0,150.0,-35.0"	Region of Interest defined by 'west, south, east, north' coordinates of longitude, latitude, in decimal degrees (EPSG:4326).
name	-q "name=Paris, France"	Location string.
lon	-q "lon= 149.12807"	Longitude expressed in decimal degrees (EPSG:4326). Should be used with lat (see next).
lat	-q "lat= -35.28346"	Latitude expressed in decimal degrees (EPSG:4326). Should be used with lon (see above).
radius	-q "radius=1000"	Radius around lat,lon point to consider, expressed in metres. Should be used with lon and lat (see above).
startDate	-q "startDate=2018-08-20"	Beginning of the time slice of the search query. Format should follow RFC-3339.
completionDate	-q "completionDate=2018-08-26"	End of the time slice of the search query. Format should follow RFC-3339.
instrument	-q "instrument=C-SAR"	Instrument to search on. Refer to sub-section 7.1.4.3 Instrument for possible values. Nature of query means only one instrument may be specified.
productType	-q "productType=RAW"	Product type to search on. Refer to sub-section 7.1.4.4 Product Name for possible values. Nature of query means only one product type may be specified.
sensorMode	-q "sensorMode=EW"	Sensor mode to search on. Refer to sub-section 7.1.4.5 Sensor Mode for possible values. Nature of query means only one sensor mode may be specified.
polarisation	-q "polarisation=HH,HV"	Polarisation to search on. Refer to sub-section 7.1.4.7 Polarisation for possible values. Nature of query means only one polarisation may be specified.

There are four possible ways to store the results from the query. The below query example is built from the argument examples in Table 7. The minimum information required is the location and date range to search over. The example below does this with the geometry, startDate and completionDate commands, meaning the query commands will take the form '-q "geometry=POLYGON((149.03 -

35.18,149.23 -35.18,149.23 -35.38,149.03 -35.38,149.03 -35.18))" -q "startDate=2018-08-20" -q "completionDate=2018-08-26"'. Here, the 'POLYGON' marks out an area around Canberra. To query a generic location, use the name parameter rather than the geometry parameter, e.g. '-q "name=Canberra". Note that each query parameter is proceeded by the command for query '-q' and the query itself is encased in double quotation marks.

NOTE. Before running any of the commands below, please navigate to the folder where 'auscophub_searchSara.py' is located. In this document that is '~/Documents/AusCopHub' on Mac and 'C:\Users*User Name*\Documents\AusCopHub' on Windows.

The next section, **Error! Not a valid bookmark self-reference.**, automates the download process. The remaining output options covered are secondary.

7.2.4.2 Bulk Download with Curl

To automate the download process, the API will generate a script that utilises 'curl' to download the files stored in the URLs returned by the query. Curl is used to automate downloading from the command line (see https://curl.haxx.se/). The script is generated using the '--curlscript "CURLSCRIPT"' and '--curloptions "CURLOPTIONS"' command line options when calling the 'auscophub_searchSara.py' script. 'CURLSCRIPT' is the name of the file where the curl script will be stored.

To download with this option, the email and password used to sign up to SARA (see sub-section 7.2.2) are required. This allows the script to download the files as a user. These can be passed to the 'auscophub_searchSara.py' script via the command line option '--curloptions "-u email:password"', where 'email' is the email used to sign up and 'password' is the password used to sign up.

NOTE. A consequence of using this option is that login information for SARA will be displayed in the resulting curl script. It is recommended to delete these scripts after use to protect login information.

It is necessary to provide a name for the curl script, for example 'Canberra_20180820_20180826_CURL.sh' for Mac and 'Canberra_20180820_20180826_CURL.bat' for Windows, where the file extension indicates an executable script.

The complete Python command for Mac is:

```
python auscophub_searchSara.py -q "geometry=POLYGON((149.03 -35.18,149.23 -35.18,149.23 -35.38,149.03 -
35.38,149.03 -35.18))" -q "startDate=2018-08-20" -q "completionDate=2018-08-26" --curlscript
"Canberra_20180820_20180826_CURL.sh" --curloptions "-u email:password"
```

The complete Python command for Windows is:

```
python auscophub_searchSara.py -q "geometry=POLYGON((149.03 -35.18,149.23 -35.18,149.23 -35.38,149.03 -
35.38,149.03 -35.18))" -q "startDate=2018-08-20" -q "completionDate=2018-08-26" --curlscript
"Canberra_20180820_20180826_CURL.bat" --curloptions "-u email:password"
```

Depending on the size of the query, the command may take some time to run. When a new command prompt appears in the terminal, the command is finished.

Run this script to allow download of all the files. On Mac, modify file permissions to allow execution of the file using the ‘chmod’ command:

```
chmod u+x Canberra_20180820_20180826_CURL.sh
```

Then run the script using the following command:

```
./Canberra_20180820_20180826_CURL.sh
```

On Windows, there’s no need to modify the permissions. Execute the script with:

```
.\Canberra_20180820_20180826_CURL.bat
```

Or double click the .bat file from your file explorer.

If the correct SARA user email and password have been provided, the files should begin to download to the current folder (see Figure 50). If the download fails, a new text file called ‘download’ will appear in the folder, which should contain the reason the download was unsuccessful. If it contains the message: “the User profile has not been validated”, check the email and password supplied as part of the ‘—curloptions’ argument.

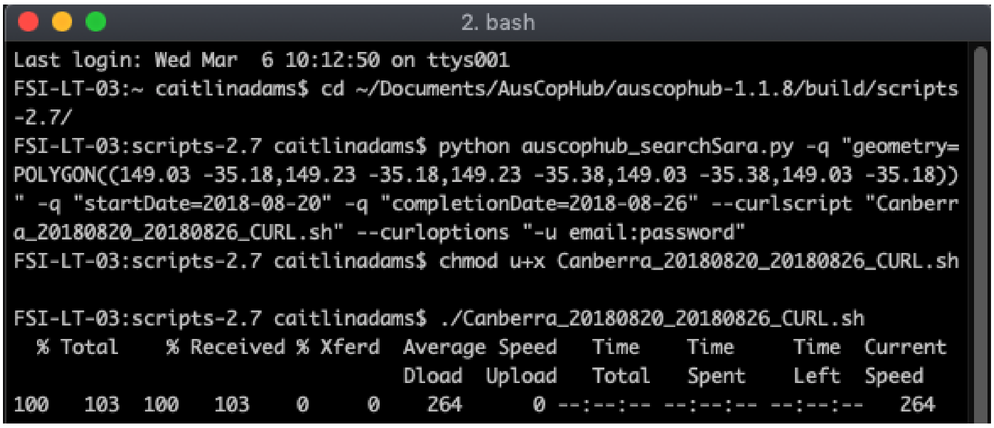


Figure 50 Download Files with Curl Script

If the download doesn’t work and there appears to be an issue about the server being insecure, rerun the Python command to create the curl script, and include ‘-k’ as part of the --curloptions argument, e.g. ‘--curloptions -k -u email:password“’.

Congratulations on successfully downloading Sentinel data using the SARA API! The data can now be used. If lower levels of processed data were downloaded, it may now need to be unpacked and processed to analysis ready data (ARD) for use in applications, which will all occur externally to the Hub. Some examples are provided in sub-sections 8 and 5.

The following page contains optional instructions for downloading some additional outputs, however these outputs are not required and are simply for reference.

7.2.4.3 List of URLs

This output provides a list of URLs from the query, which may be kept for your reference. Images cannot be directly accessed via the URLs in this file as it contains no user authentication information. The file is intended for use with a bulk download method.

When using this option, the SARA API will return URLs to the data that match the query. Store these in a file by including the '--urllist "URLLIST"' command, where URLLIST is the name of the file to store the output in. For example, store the returned URLs in 'Canberra_20180820_20180826_URL.txt'.

The Python command (for both Mac and Windows) is:

```
python auscophub_searchSara.py -q "geometry=POLYGON((149.03 -35.18,149.23 -35.18,149.23 -35.38,149.03 -
35.38,149.03 -35.18))" -q "startDate=2018-08-20" -q "completionDate=2018-08-26" --urllist
"Canberra_20180820_20180826_URL.txt"
```

Depending on the size of the query, the command may take some time to run. When a new command prompt appears in the terminal, the command is finished.

Open the file to see a list of URLs that were returned by the query.

7.2.4.4 JSON Feature Files

This output provides polygons of the image data extents and attributes and can be loaded into a Geographic Information System (GIS) to view.

This option will return a GeoJSON file for all features associated with the query. Store these in a file by including the '--jsonfeaturesfile "JSONFEATURESFILE"' command, where 'JSONFEATURESFILE' is the name of the file to store the output in. For example, store the returned GeoJSON features in 'Canberra_20180820_20180826_JSONFEATURES.json'.

The Python command (for both Mac and Windows) is:

```
python auscophub_searchSara.py -q "geometry=POLYGON((149.03 -35.18,149.23 -35.18,149.23 -35.38,149.03 -
35.38,149.03 -35.18))" -q "startDate=2018-08-20" -q "completionDate=2018-08-26" --jsonfeaturesfile
"Canberra_20180820_20180826_JSONFEATURES.json"
```

Depending on the size of the query, the command may take some time to run. When a new command prompt appears in the terminal, the command is finished. Now open the .json file in the preferred GIS program to see the features.

7.2.4.5 Simple JSON Files

This output provides a JSON file which contains the same information as the GeoJSON Feature File as above but in text (not spatial) format. It may be kept for your reference.

When using this option, the SARA API will return JSON objects that match the query. Store these in a file by including the '--simplejsonfile "SIMPLEJSONFILE"' command, where 'SIMPLEJSONFILE' is the name of the file to store the output in. For example, store the returned JSON objects in 'Canberra_20180820_20180826_ SIMPLEJSON.json'.

The Python command (for both Mac and Windows) is:

```
python auscophub_searchSara.py -q "geometry=POLYGON((149.03 -35.18,149.23 -35.18,149.23 -35.38,149.03 -
35.38,149.03 -35.18))" -q "startDate=2018-08-20" -q "completionDate=2018-08-26" --simplejsonfile
"Canberra_20180820_20180826_ SIMPLEJSON.json"
```

Depending on the size of the query, the command may take some time to run. When a new command prompt appears in the terminal, the command has finished running.

7.3 THREDDS Server

The THREDDS server is the NCI's general-purpose data server which allows users to navigate folders of files to download data. To download data using the THREDDS, follow the instructions below.

7.3.1 Access THREDDS

To access the THREDDS server go to http://dapds00.nci.org.au/thredds/catalogs/fj7/catalog.html (Figure 53).

Alternatively, from the Copernicus Australasia Regional Data Hubwebsite home page (http://www.copernicus.gov.au/ - Figure 51) click **Regional Data Access,** then as shown in Figure 52 click the **THREDDS server** link to open the THREDDS server data catalogue (Figure 17).

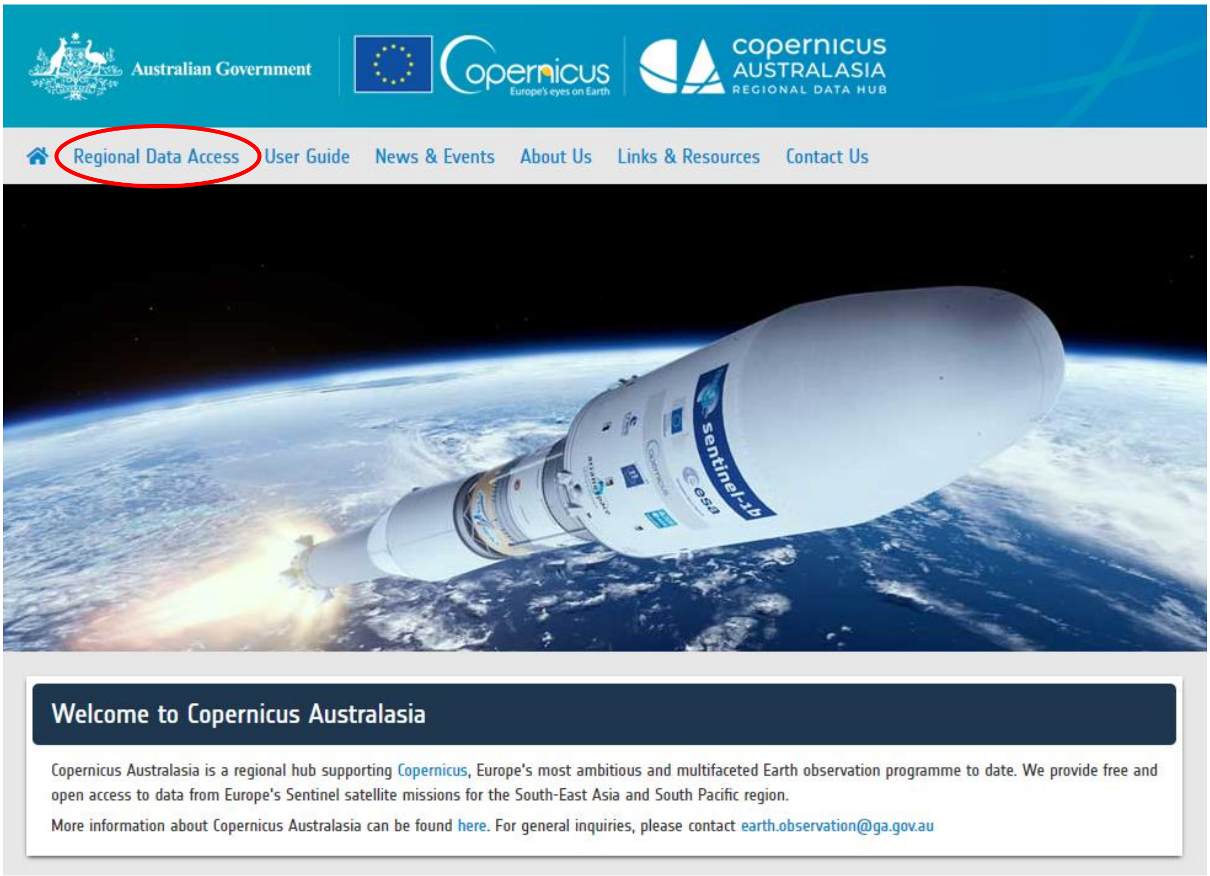


Figure 51 Copernicus Australasia Regional Data Hub home page

Figure 52 Copernicus Australasia Regional Data Hubregional data access

7.3.2 Download Data

Anyone can explore and download data from the THREDDS server (Figure 53). Registration is not required. The folder structure and file naming of data on THREDDS is the same as for the data on the NCI, with the file naming replicated from Europe.

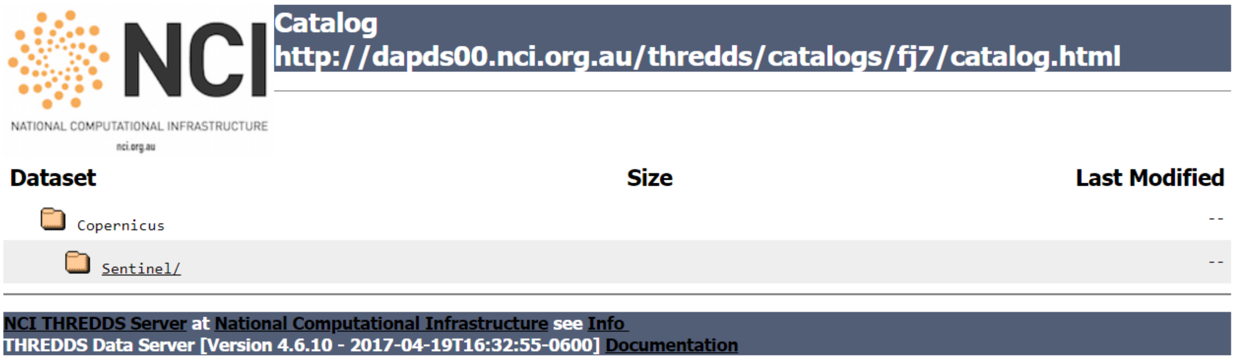


Figure 53 THREDDS server

The data is structured in folders for each Sentinel as described below. Given the folder structures, it is very useful at this point to know a bit about the data to be downloaded (based on application), including:

- the Sentinel mission (collection);
- the instrument (especially if interested in Sentinel-3 which has multiple instruments);
- the product name or processing level;
- the acquisition period of interest (year, month and day if S3); and
- the coordinates for the area of interest if S1 or S2.

For **Sentinel-1**, the folder structure is (example shown in Figure 54):

Copernicus/<Sentinel-collection>/<instrument>/<product name>/<year>/<year-month>/<5degLatitude-Cells>

E.g. Copernicus/Sentinel-1/C-SAR/SLC/2014/2014-10/25S180W-30S175W

File naming details can be found at https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/naming-conventions.

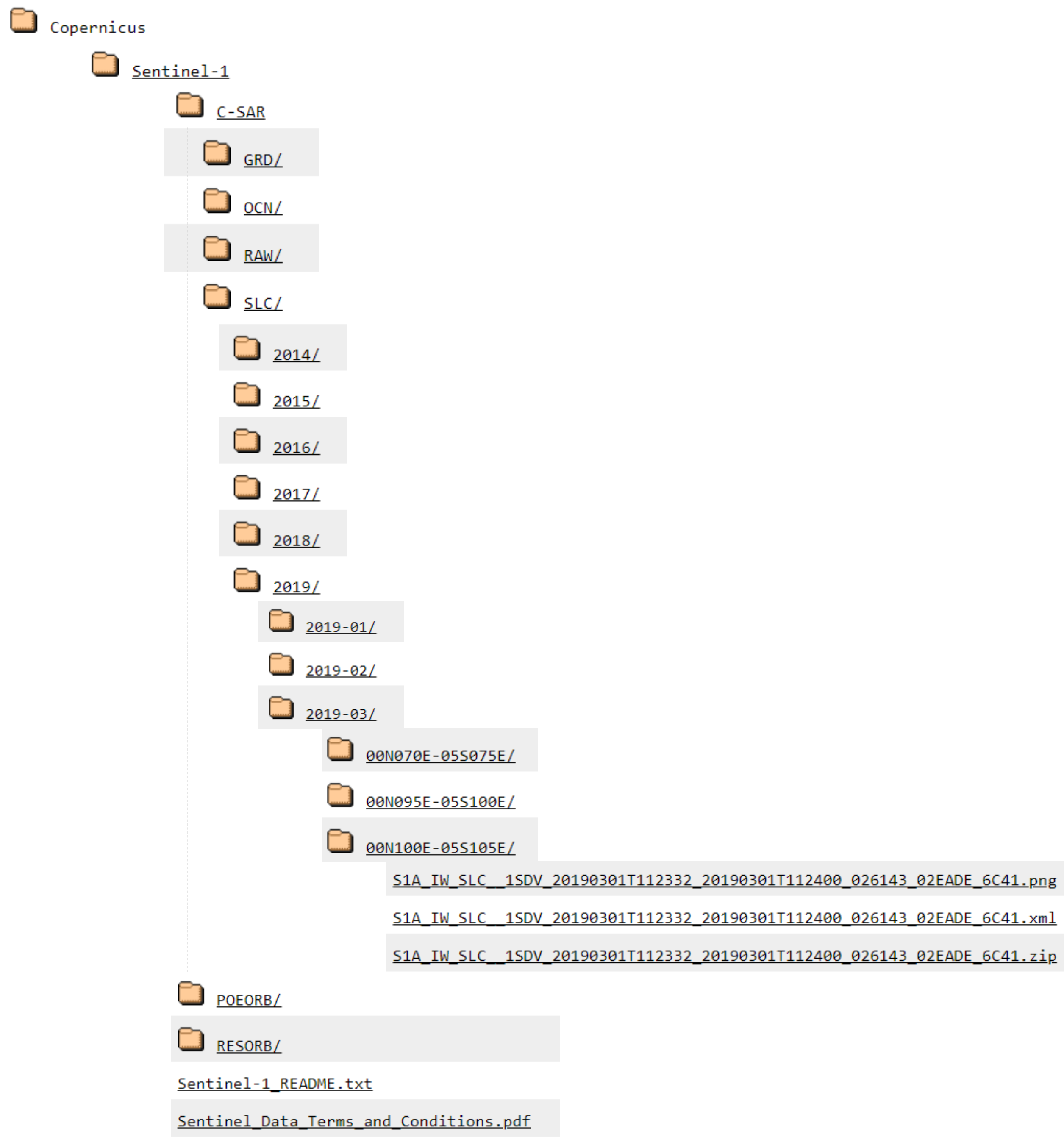


Figure 54 THREDDS Sentinel-1 folder structure expanded for SLC

For **Sentinel-2**, the folder structure is (example shown in Figure 55):

Copernicus/<Sentinel-collection>/<instrument>/<product level>/<year>/<year-month>/<5degLatitude-Cells>

E.g. Copernicus/Sentinel-2/MSI/L1C/2017/2017-01/00N070E-05S075E

File naming details can be found at https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/naming-convention.

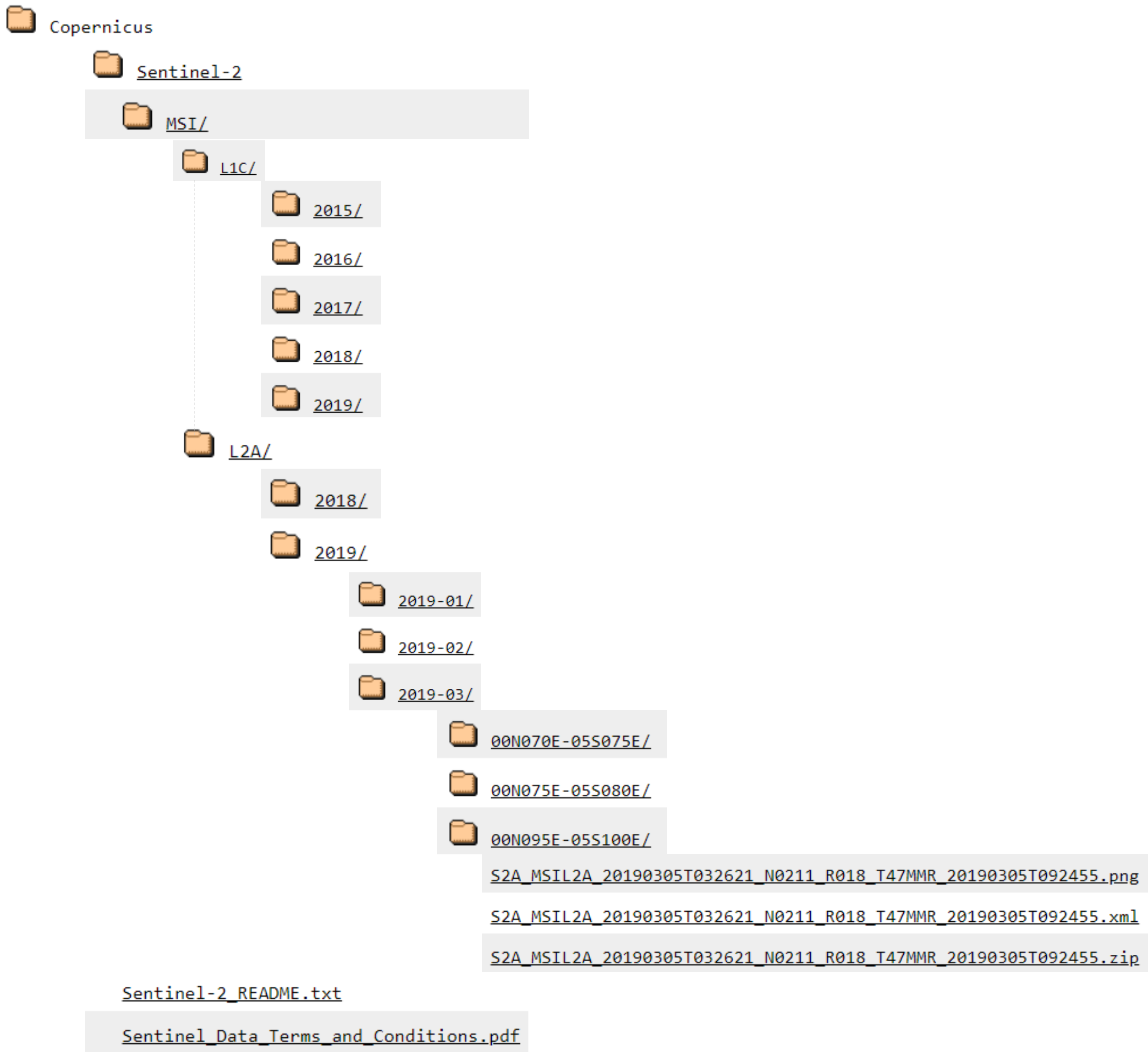


Figure 55 THREDDS Sentinel-2 folder structure expanded for L2A

For **Sentinel-3**, the folder structure is (example shown in Figure 56):

Copernicus/<Sentinel-collection>/<instrument>/<product name>/<year>/<year-month>/<year-month-day>

E.g. Copernicus/Sentinel-3/OLCI/OL_1_EFR__/2019/2019-03/2019-03-01

File naming details can be found at:

- OLCI - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-olci/naming-convention
- SLSTR - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/naming-convention
- SRAL - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/naming-conventions
- SYNERGY - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-synergy/naming-conventions

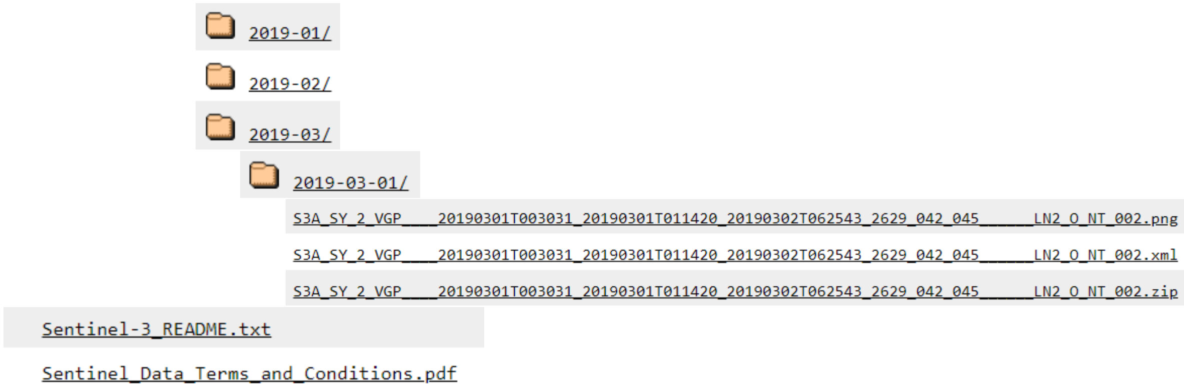


Figure 56 THREDDS Sentinel-3 folder structure, expanded for SYNERGY

Some things to note:

- For the folder named with the coordinate cell, the coordinate values represent a five degree latitude/longitude grid cell which the centroid of the imagery is within.
- The Sentinel-1 folder contains two additional folders POEORB (precise orbit ephemerides) and RESORB (restituted orbit). These contain Earth Explorer Precise Orbit Determination files for ground segment data exchange. The main data is in the C-SAR folder.
- Each Sentinel folder contains a README file with additional information.

The files available for download are:

- zip files of the imagery data
- PNG quick look preview images of the data
- xml simple metadata

To download imagery data simply click through the folders until the file level is reached (i.e. within the coordinate cell or day folder). Then click on the '***.zip**' file to download and under Access click on the **HTTPServer** link to download the zip file (Figure 57). Choose where to save the zip file.

Figure 57 Download a zip file from the THREDDS server

> *Congratulations on successfully downloading Sentinel data using the THREDDS server. The data can now be used. If lower levels of processed data were downloaded, it may now need to be unpacked and processed to ARD for use in applications, which will all occur external to the Hub. Some examples are provided in sub-sections 8 and 5.*

NOTE. A very rudimentary search tool for this server can be found in contributed code at http://auscophub.readthedocs.org/.

7.4 NCI File System

Please note that this sub-section is only relevant to users with approved NCI access i.e. existing NCI partners who already access Raijin for other work. Private companies may be able to negotiate access with the NCI.

Registered NCI users with the relevant project permissions can access data directly from the file system of the NCI's Raijin supercomputer. The Copernicus Australasia Regional Data Hub data is project 'fj7' on the NCI and is the source for THREDDS hence the folder structures are the same. The folder structure and file naming conventions of Sentinel data on the NCI are provided below to assist registered users in accessing the data.

7.4.1 Folder Structure

Copernicus Australasia Regional Data Hub data on the NCI is stored as project **fj7**. The high-level directory structure of the data is as shown in Figure 58. For further detail refer to sub-section 7.3.

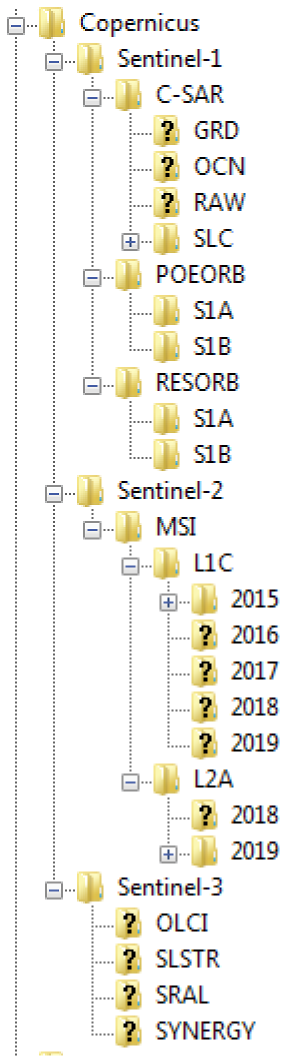


Figure 58 NCI Sentinel data folder structure

7.4.2 File Naming

File naming conventions of Sentinel data on the NCI are republished as they come from Europe. More information on file naming can be found using the below links.

- Sentinel-1 - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/naming-conventions
- Sentinel-2 - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/naming-convention
- Sentinel-3
  - OLCI - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-olci/naming-convention
  - SLSTR - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/naming-convention
  - SRAL - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/naming-conventions
  - SYNERGY - https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-synergy/naming-conventions

8 View, Process and Analyse Data

8.1 Importance of Analysis Ready Data (ARD)

The definition of ARD from http://ceos.org/ard/ is "ARD are satellite data that have been processed to a minimum set of requirements and organised into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets." This includes applying various corrections for problems such as cloud and cloud shadow, terrain shadow and atmospheric effects, depending on the type of data. Different 'flavours' of ARD can result depending on what corrections 'are' or 'are not' being applied, as well as differences in the algorithms used to apply these corrections. For example, for Sentinel-2 Level 2 Surface Reflectance ARD, ESA have a process which generates the product distributed by the Hub, and GA and the Joint Remote Sensing Research Program have slightly different processes to generate their own surface reflectance products. The Copernicus Australasia Regional Data Hub currently have a Working Group to analyse the differences between these ARD surface reflectance products and agree on the most suitable, common process.

Figure 59 shows a Sentinel-1 RADAR image before and after Radiometric Terrain Correction which is an important step in processing the data to ARD. In the uncorrected image on the left, mountains in Bolivia appear stretched on one side and compressed on the other. The corrected image on the right moves pixels to un-stretch the mountains and adjusts pixel values to subtract the effect of slopes on brightness. It provides a clear visual demonstration of the importance of ARD. If the image on the left were to be used in analysis, results would be very different than if using the corrected image.

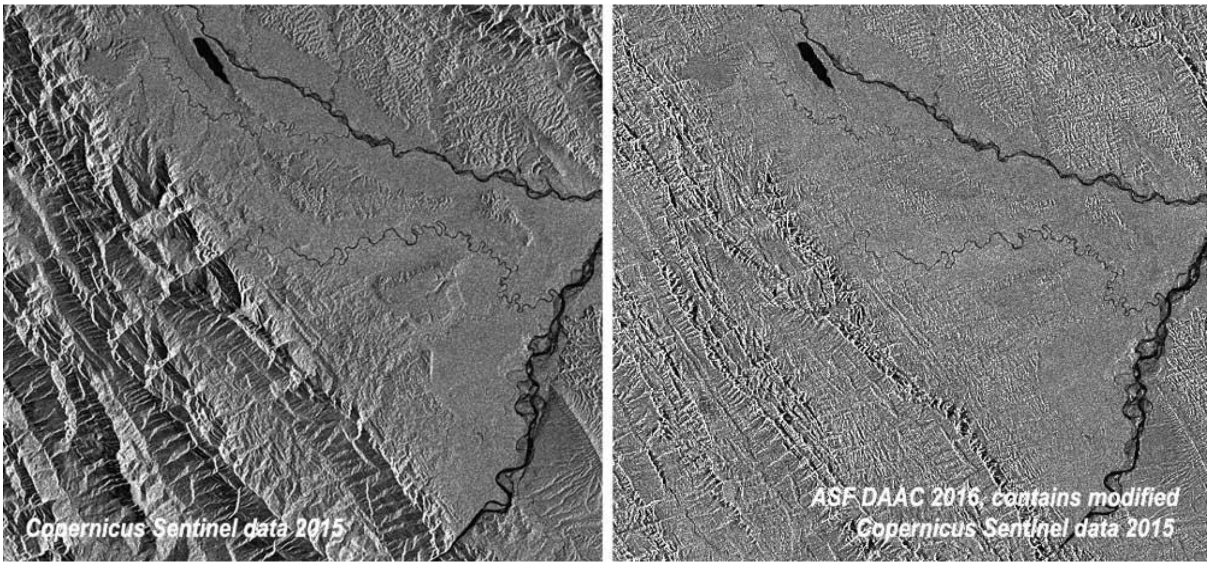


Figure 59 Credit left: Copernicus Sentinel data 2015. Credit right: ASF DAAC 2016, contains modified Copernicus Sentinel data 2015, processed by ESA.

8.2 Unpack, View and Process Data to ARD

There are many tools available to view and process Sentinel data (refer to Appendix A.5). This sub-section covers processing Sentinel-1 Level-1 Ground Range Detected (GRD) RADAR data downloaded from the Hub, to Level-2 RADAR Backscatter Analysis Ready Data (ARD) using the European Space Agency (ESA) Sentinel Application Platform (SNAP) toolbox. The processing workflow used will be that used by Geoscience Australia (GA) to produce RADAR Backscatter ARD. There are three parts:

1. Unpack & View the Data in SNAP
2. Process the Data to ARD
3. Export the ARD
4. Processing with the Graph Tool

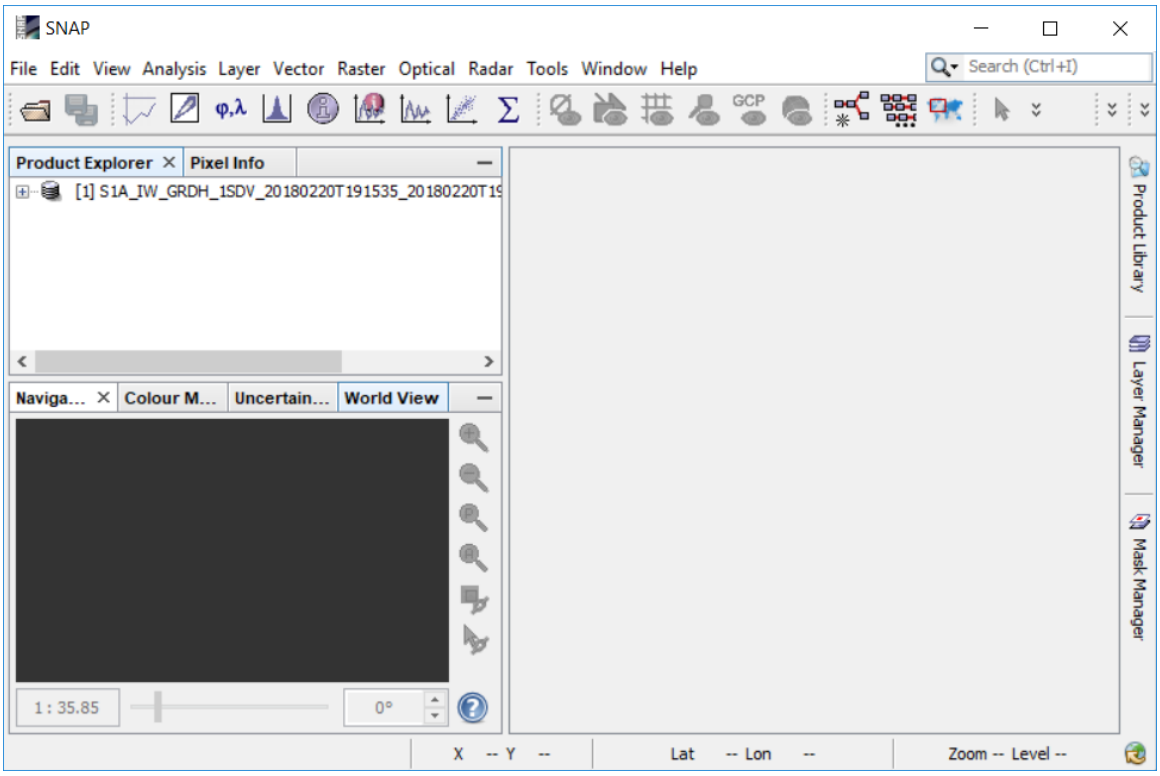
At the end you will know how to use SNAP to process S1 data to RADAR Backscatter ARD using GA's workflow. The session should take around half an hour to complete.

8.2.1 Unpack & View the Data in SNAP

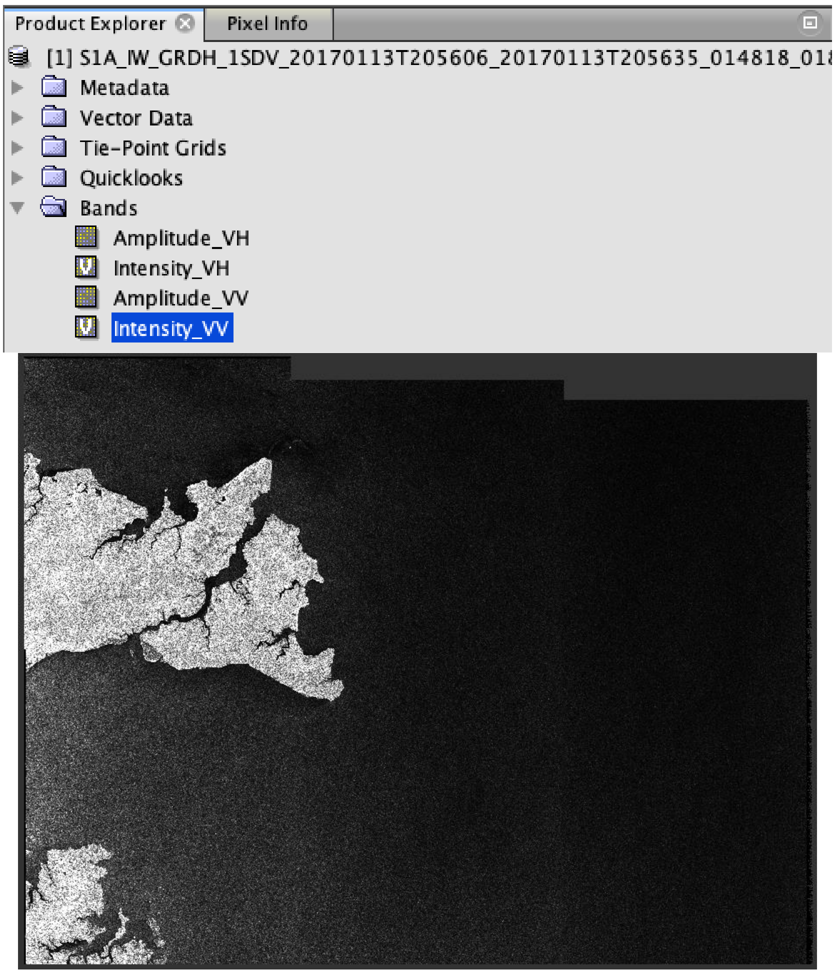
You should already have SNAP installed on your laptop. Open the SNAP program and open the *Help* menu then *About SNAP* to ensure you have version 6.0.

In your file explorer program, navigate to the folder where you saved the Sentinel-1 data "S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_014818_01824C_1934.zip" which was downloaded as part of the previous session (SARA Data Download).

Drag the zip folder into the upper left white window within SNAP, labelled "Product Explorer".

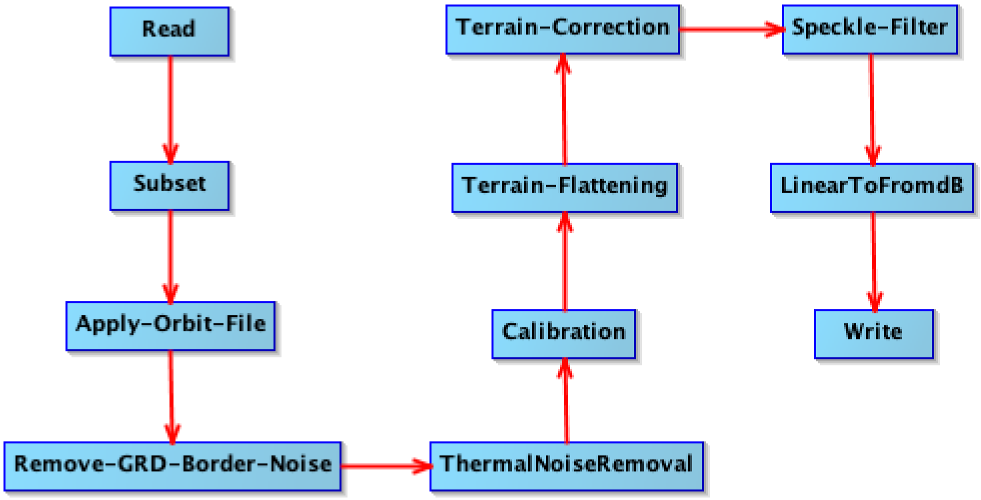


Expand the dataset by clicking the + to the left of it. Expand the *Bands* folder and then double click the *Intensity VV* band to view this data as shown below.



8.2.2 Process the Data to ARD

There are different 'flavours' of processing methods available to produce the same ARD product. This session uses GA's SNAP process for RADAR Backscatter.

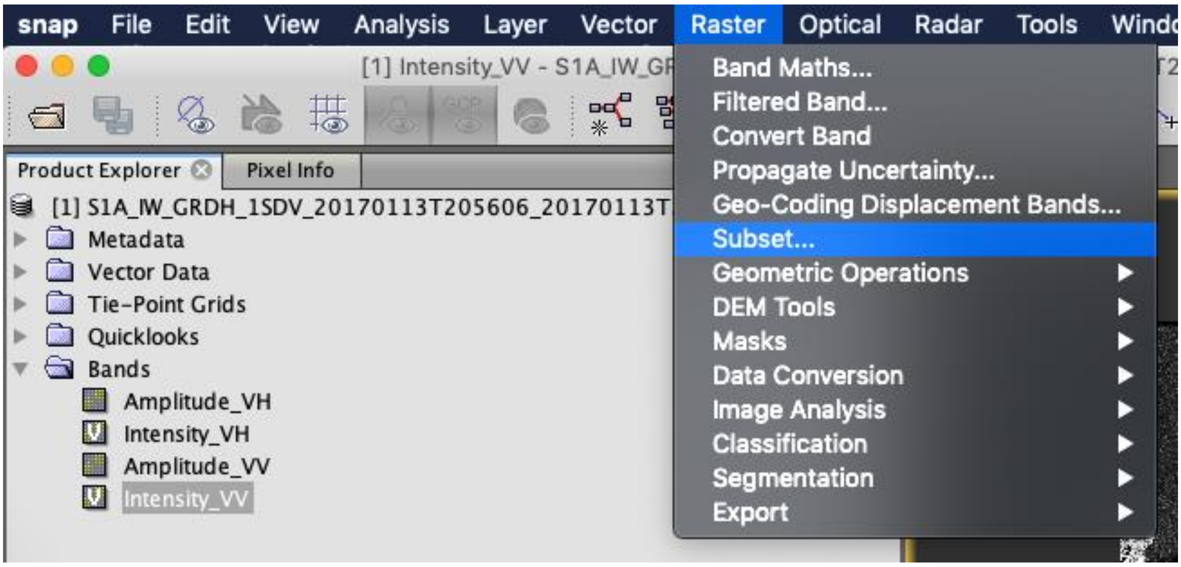


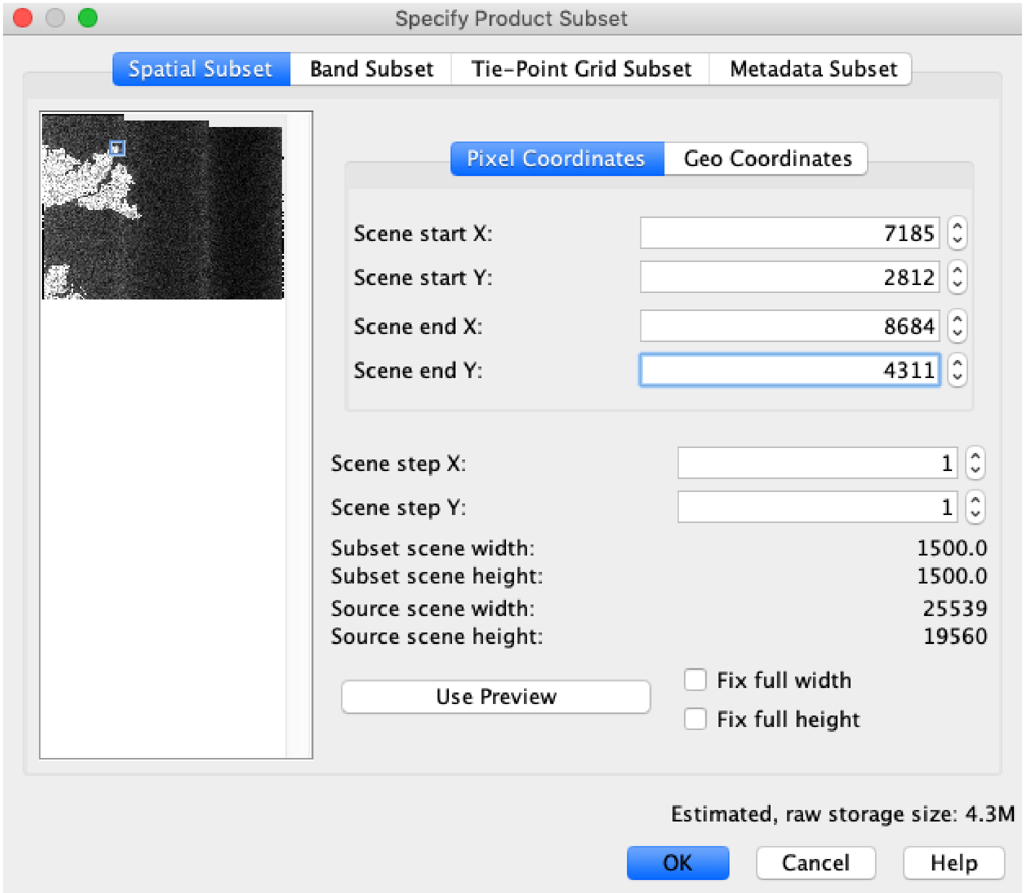
NOTE: For each processing step, SNAP will apply the method to all available bands by default (use this option). However, if running a step results in no bands, try rerunning the step and manually select all bands by clicking on them in the 'processing parameters' tab (the bands should become highlighted). The bands will appear in the 'processing parameters' tab for all processes other than the 'Subset' and 'Orbit File' processes. If the user wished to apply a method to a single band, select only that band by clicking on it in the 'processing parameters' tab.

The images in this sub-section have mostly been generated from the Mac version of SNAP. There may be minor differences in layout or processing parameters when working with the Windows version of SNAP.

8.2.2.1 Raster Subset

The data has been read into SNAP as part of 'Unpack & View' step so the first processing step is to create a raster subset. Open the *Raster* menu and select *Subset*. Fill in the *Spatial Subset Pixel Coordinates* parameters as shown in the image below and click *OK*.

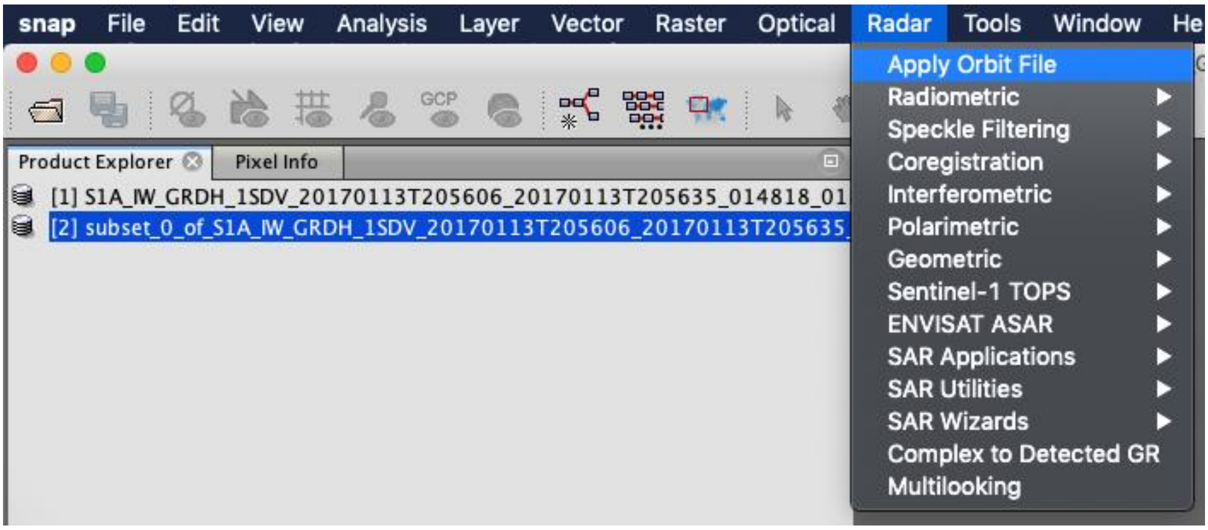


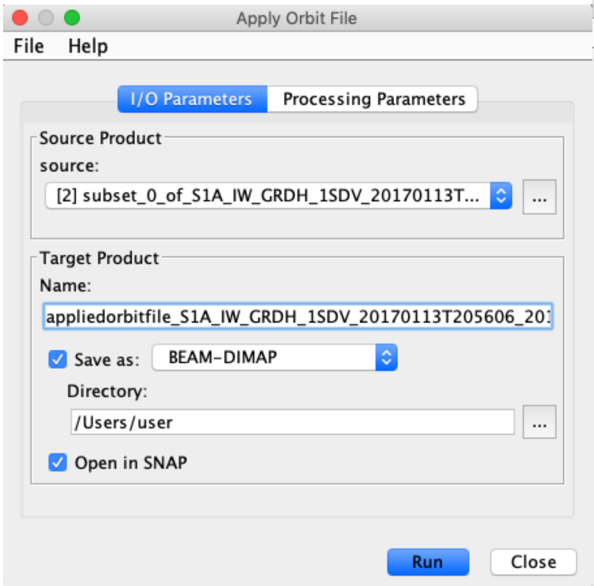


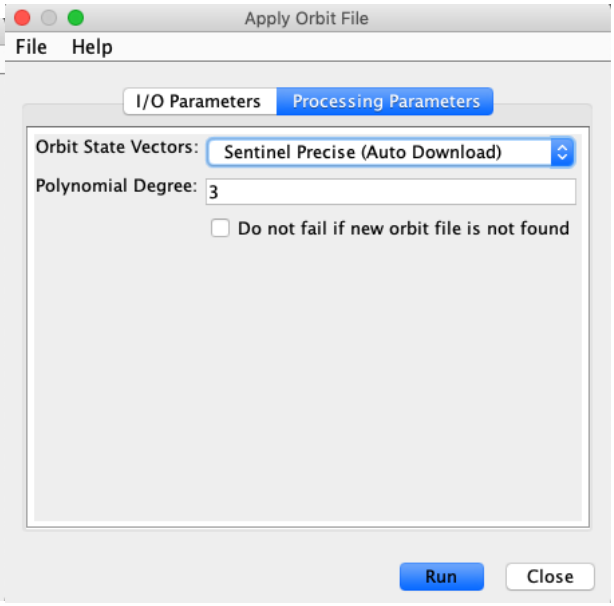
Now view the subset output by expanding the subset data and the *Bands* folder and double clicking the *Intensity VV* dataset. You will see the result is a smaller area of the original dataset which will make processing quicker.

8.2.2.2 Orbit File

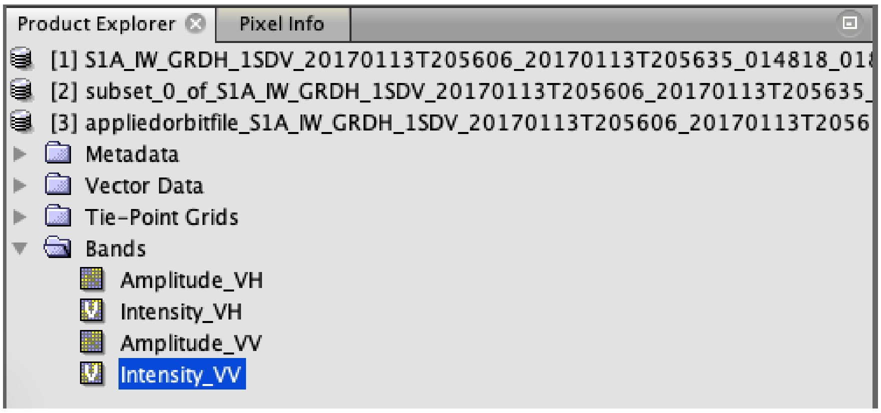
The second processing step is to apply the orbit file. Open the *RADAR* menu and select *Apply Orbit File*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*. For all of the following steps, change the *Directory* path to the desired folder. Outputs will be saved in the specified *Directory*.





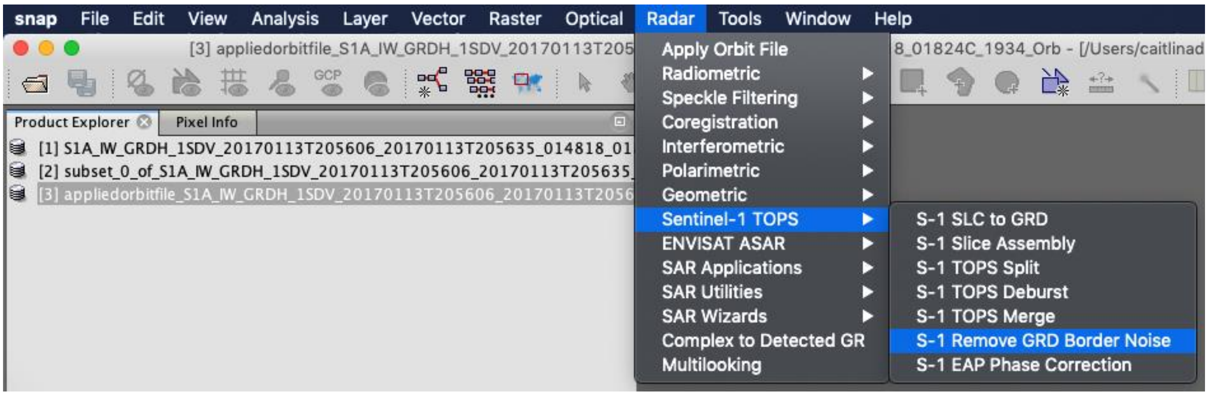


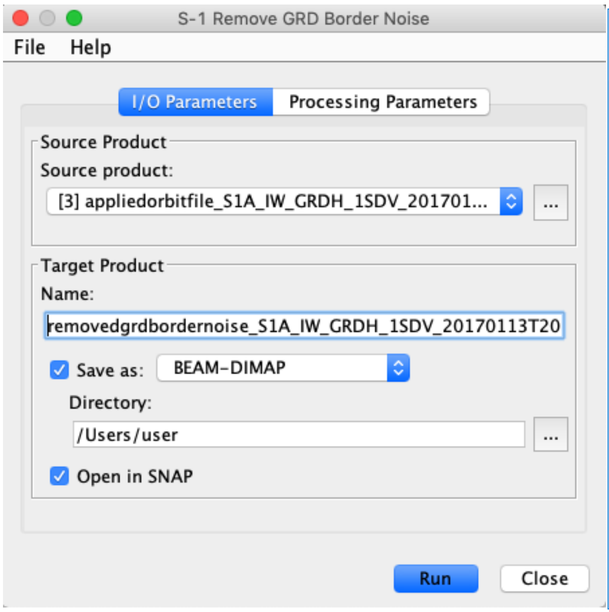
Now view the applied orbit output by expanding the applied orbit file data and the *Bands* folder and double clicking the *Intensity VV* dataset. The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available 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.

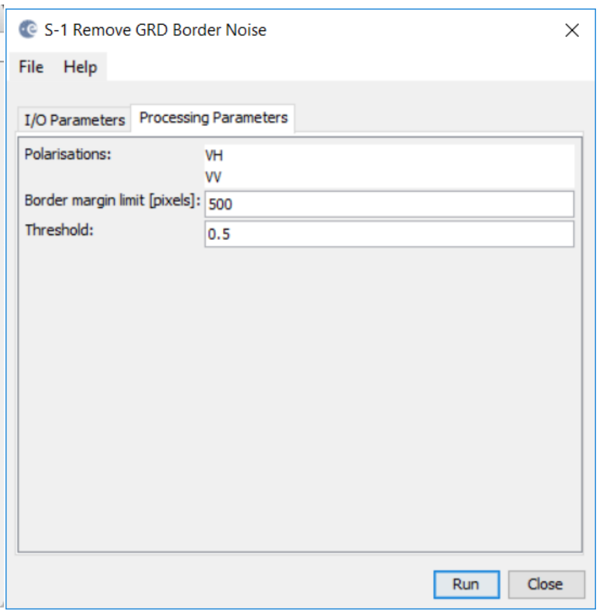


8.2.2.3 Remove GRD Border Noise

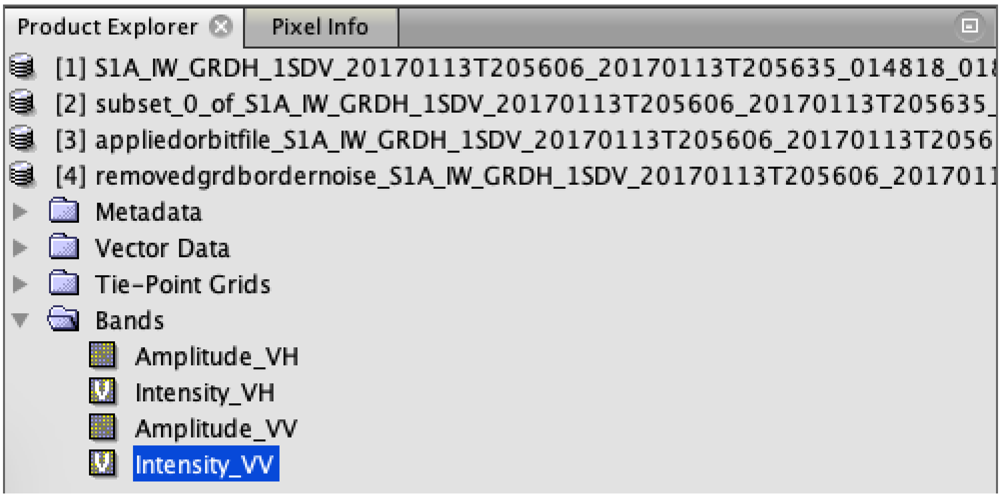
The third processing step is to remove the GRD border noise. Open the *RADAR* menu and select *Sentinel-1 TOPS* and then *S-1 Remove GRD Border Noise*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.

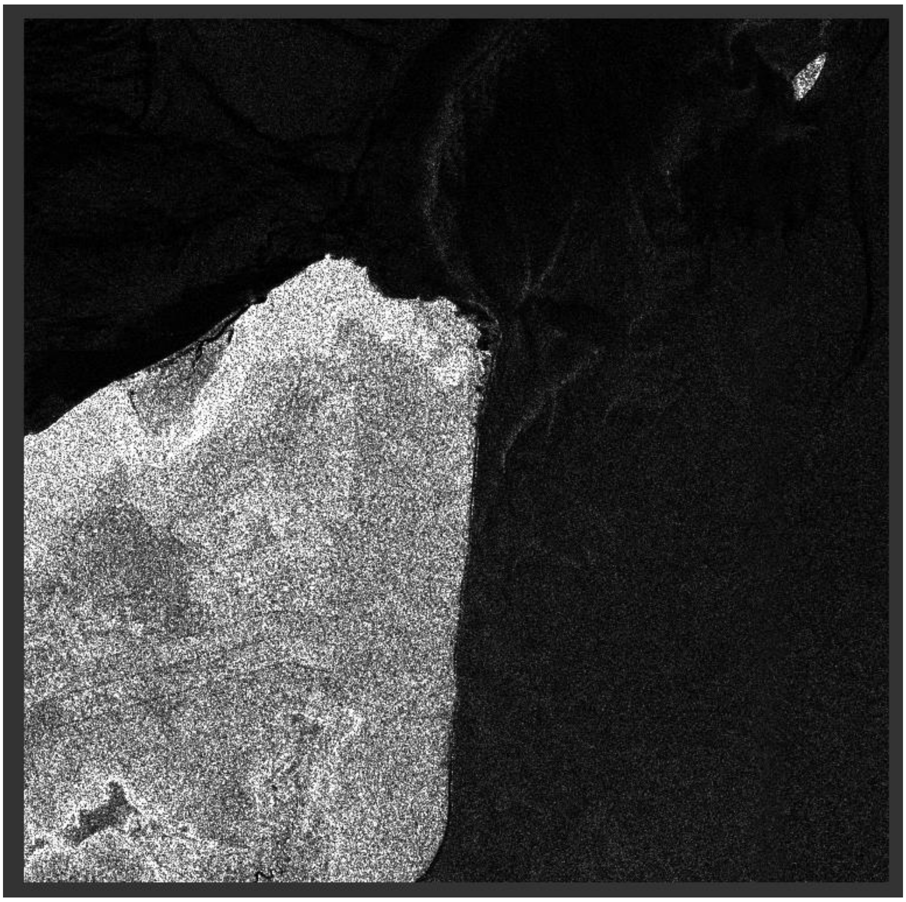






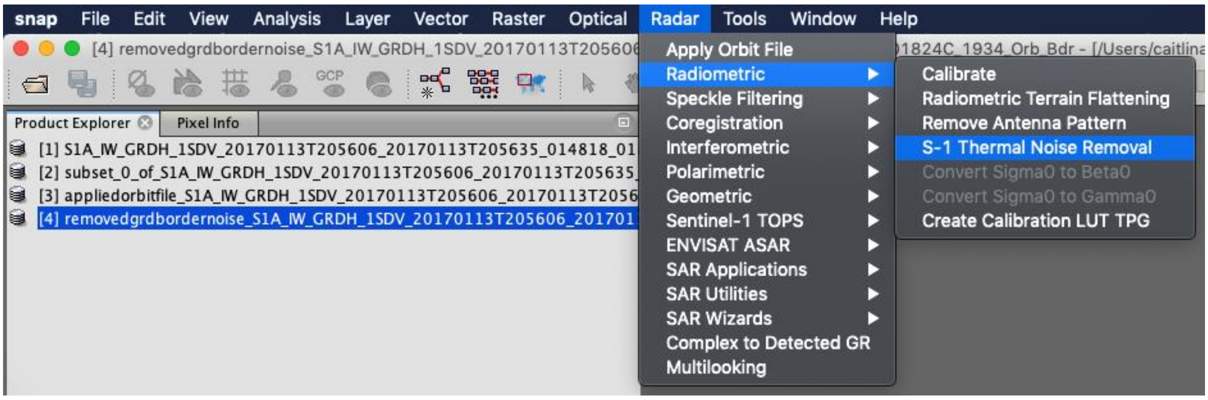
Now view the removed border noise output by expanding the removed border noise data and the *Bands* folder and double clicking the *Intensity VV* dataset. This step removes artefacts at the image borders, which come from the processing of RAW data into Level-1 products.

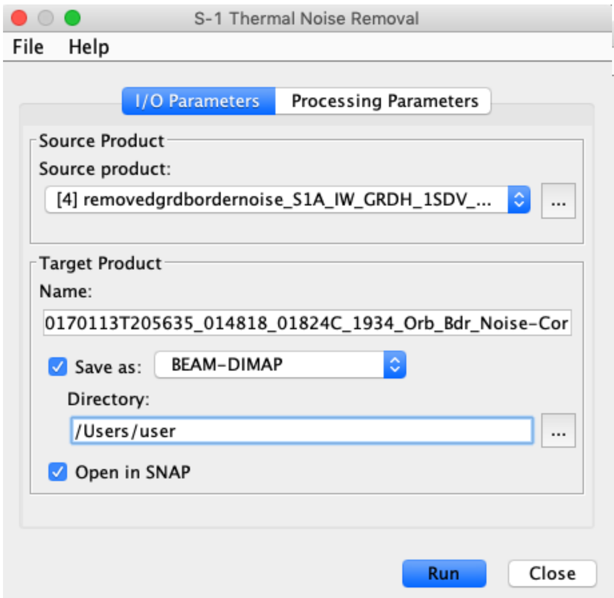


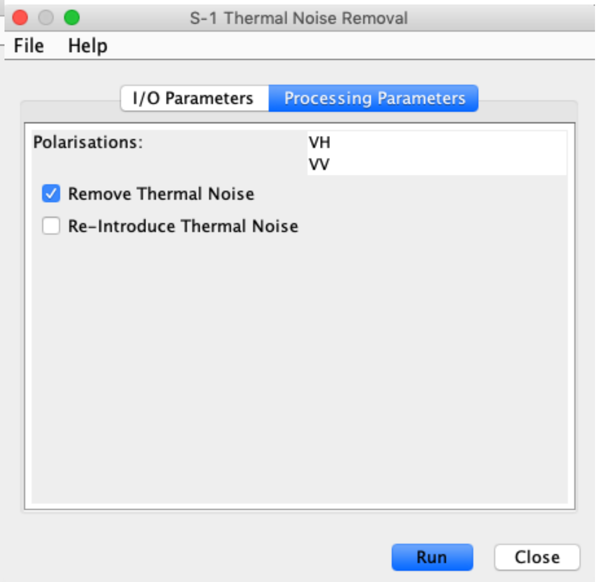


8.2.2.4 Thermal Noise Removal

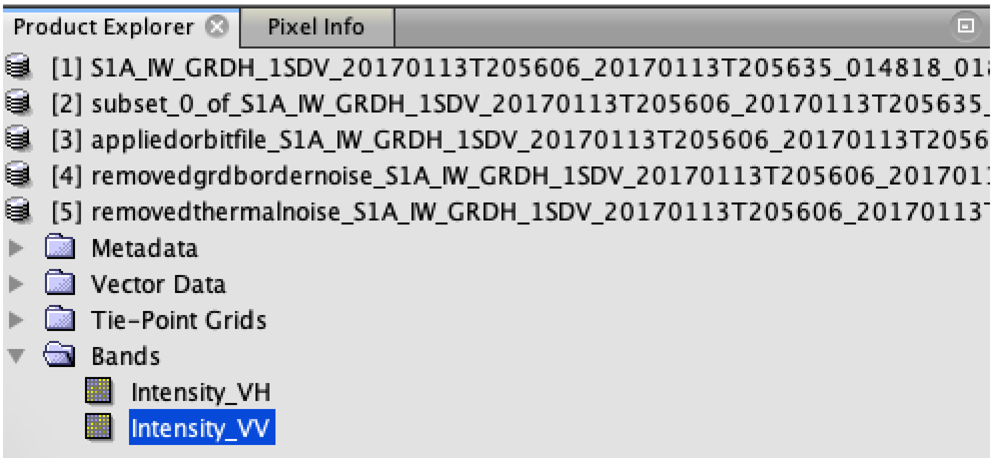
The fourth processing step is to remove thermal noise. Open the *RADAR* menu and select *Radiometric* and then *S-1 Thermal Noise Removal*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.





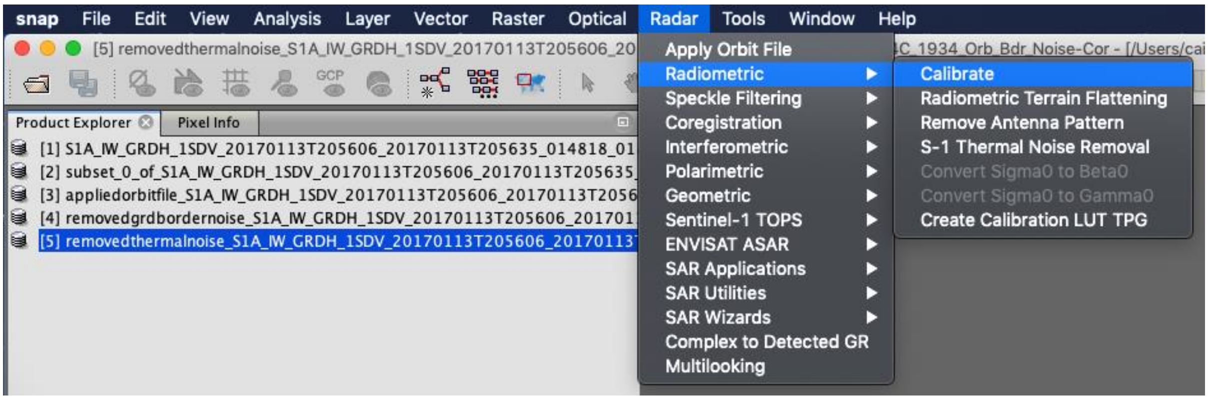


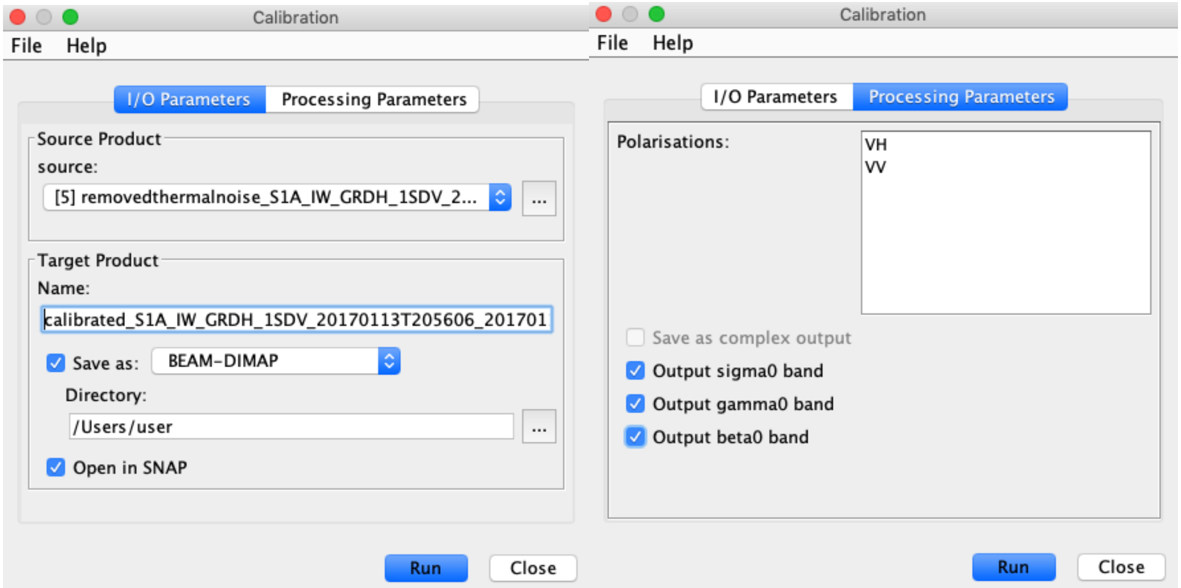
Now view the removed thermal noise output by expanding the removed thermal noise data and the *Bands* folder and double clicking the *Intensity VV* dataset. This step removes thermal noise that is generated by the instrument and emissivity from the Earth's surface.



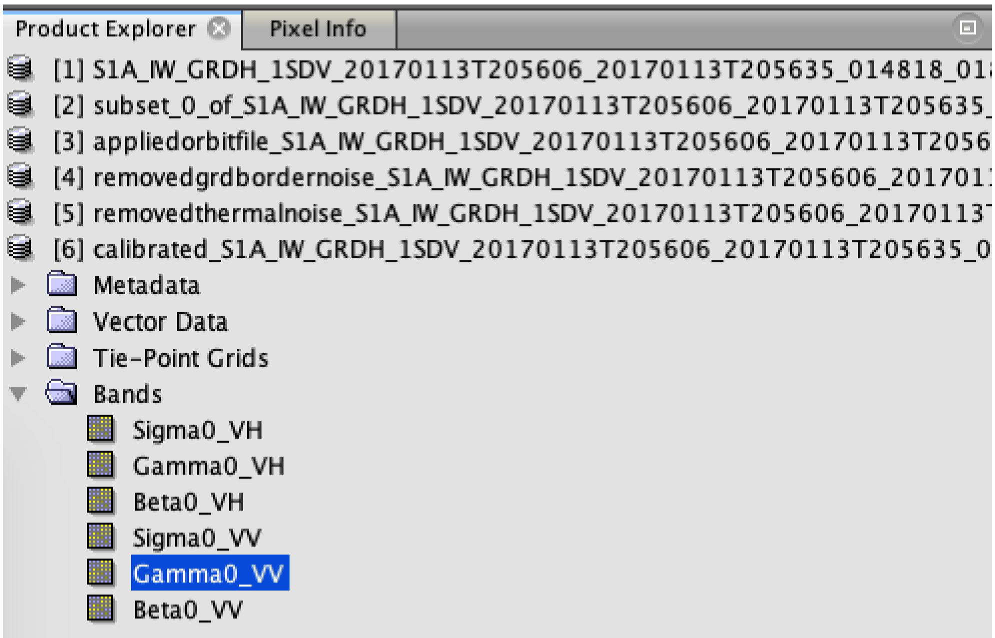
8.2.2.5 Calibrate

The fifth processing step is to calibrate the image. Open the *RADAR* menu and select *Radiometric* and then *Calibrate*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.



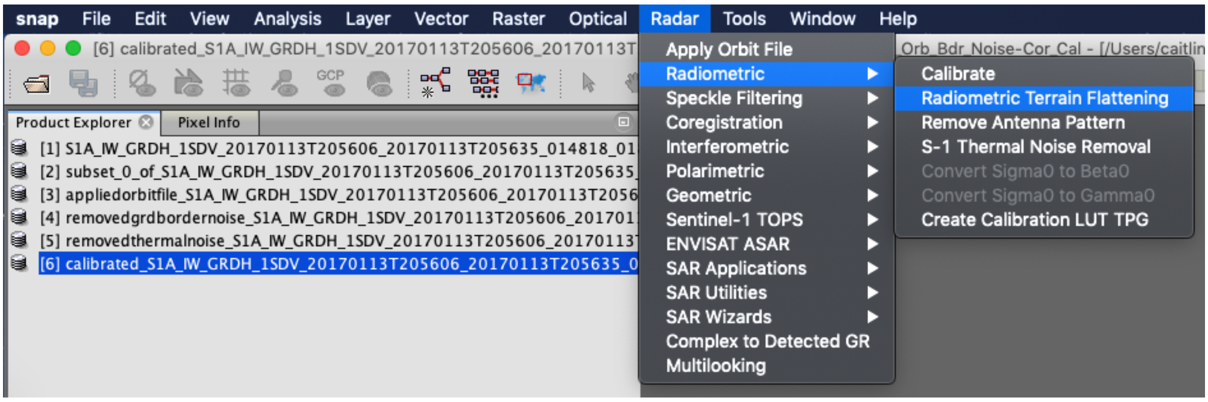


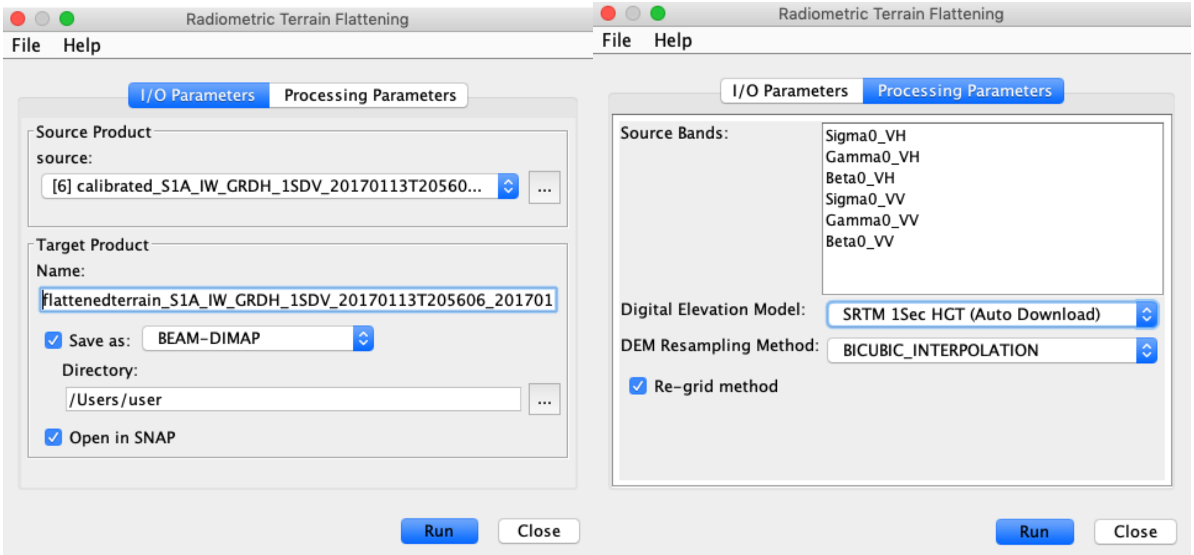
Now view the calibrated output by expanding the calibrated data and the *Bands* folder and double clicking the *Gamma0 VV* dataset. The objective of calibration is to provide imagery in which the pixel values can be directly related to the RADAR backscatter of the scene. It is necessary to apply the radiometric correction to SAR images so that the pixel values of the SAR images truly represent the RADAR backscatter of the reflecting surface.



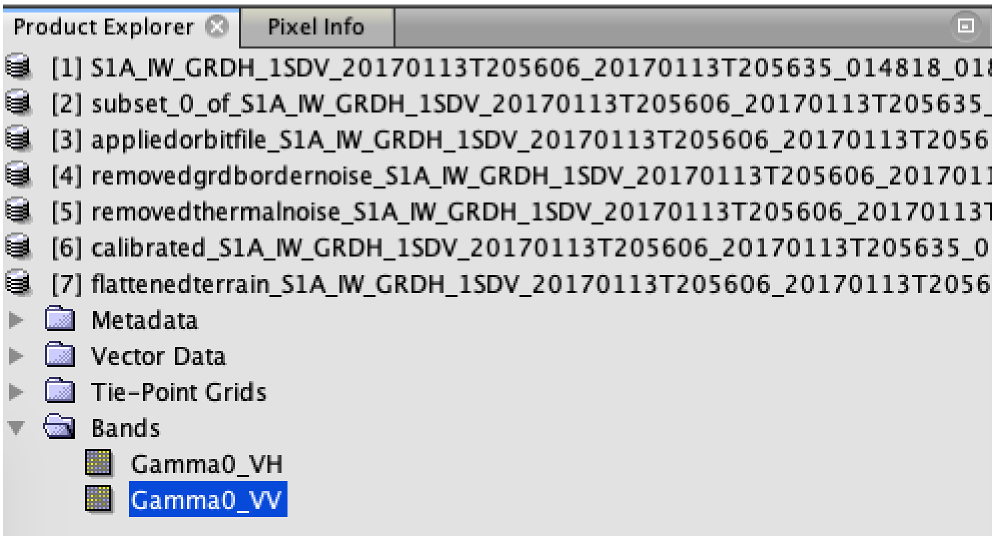
8.2.2.6 Terrain Flattening

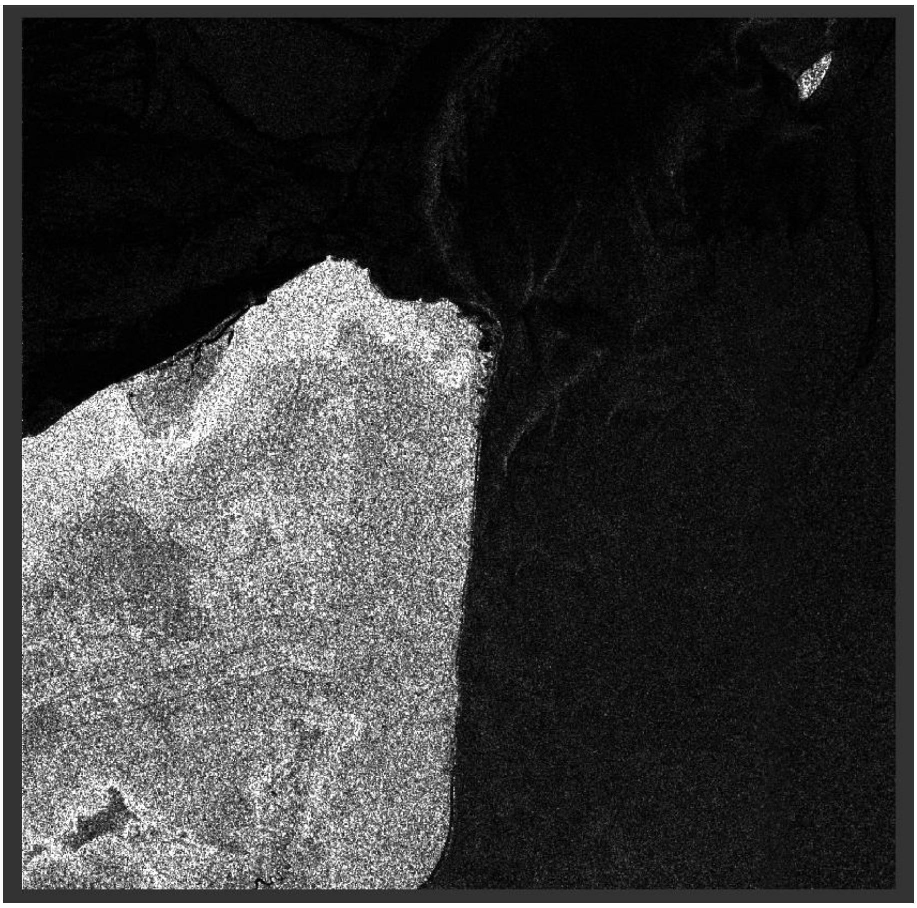
The sixth processing step is to terrain flatten the image. Open the *RADAR* menu and select *Radiometric* and then *Radiometric Terrain Flattening*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.





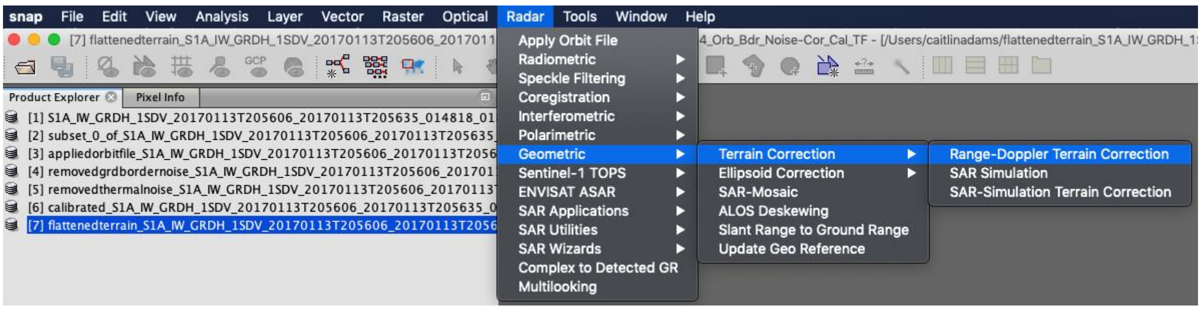
Now view the terrain flattened output by expanding the terrain flattened data and the Bands folder and double clicking the Gamma0 VV dataset. The objective of terrain flattening is to remove the radiometric variability associated with topography. Radiometric terrain flattening alters pixel values to more accurately reveal surface features such as vegetation and soil moisture. This means removing distortions in the brightness of the RADAR return. These are caused by the angle of the sensor and terrain variations and appear as in shadowing and layover in the uncorrected RADAR data. Our area is relatively flat so the effects cannot be clearly seen in the output image.

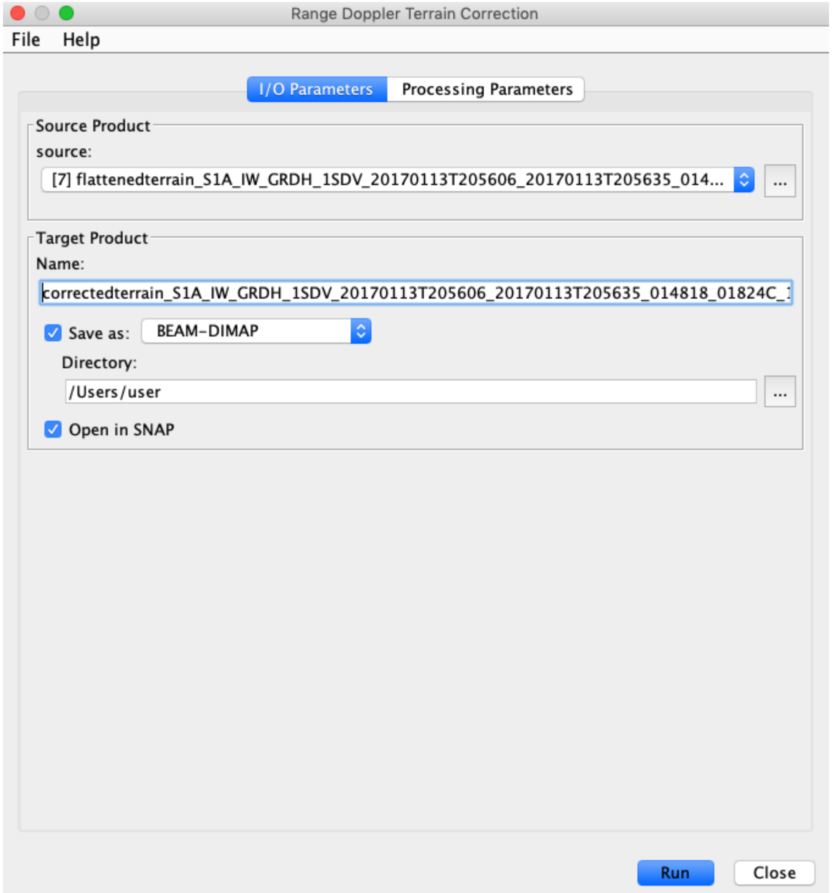


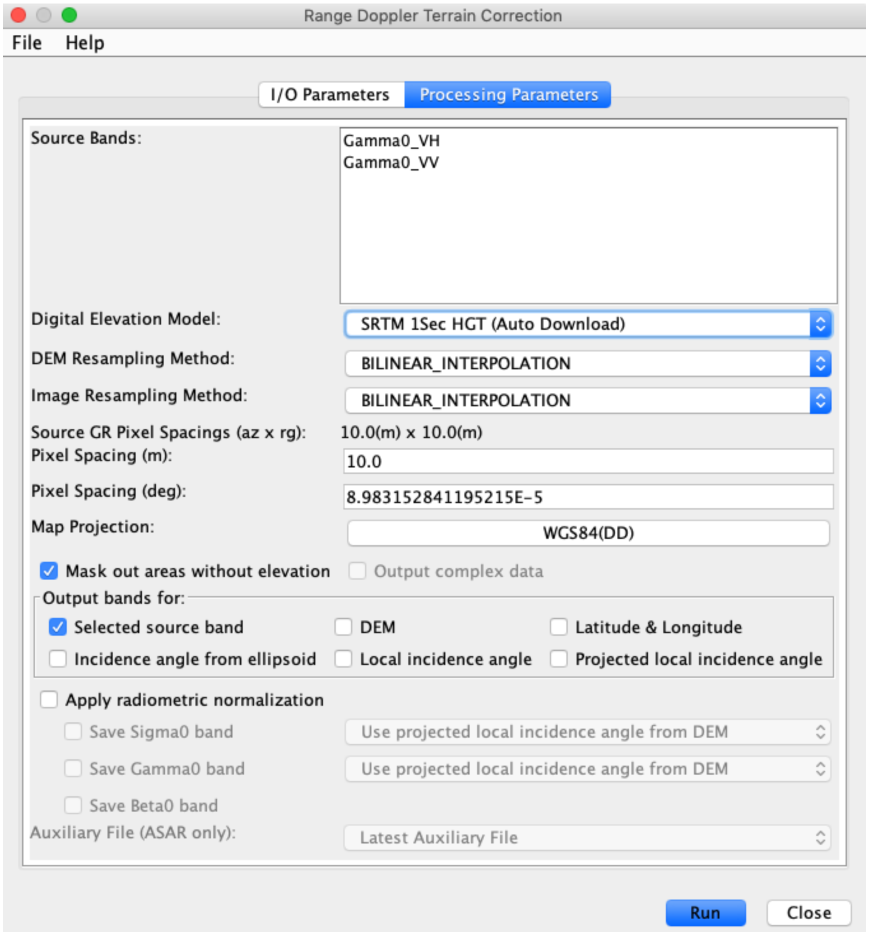


8.2.2.7 Terrain Correction

The seventh processing step is to terrain correct the image. Open the *RADAR* menu and select *Geometric* and then *Terrain Correction* and then *Range-Doppler Terrain Correction*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.

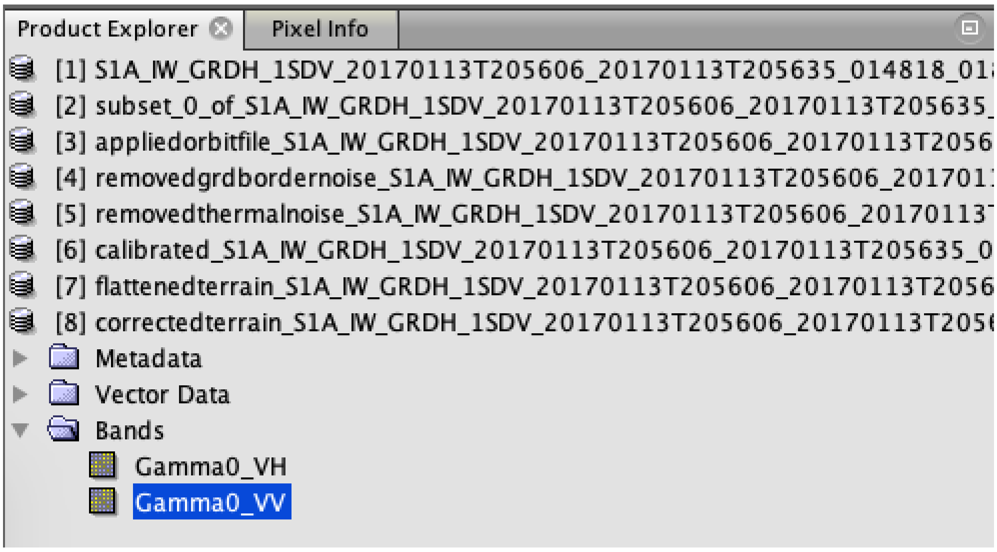


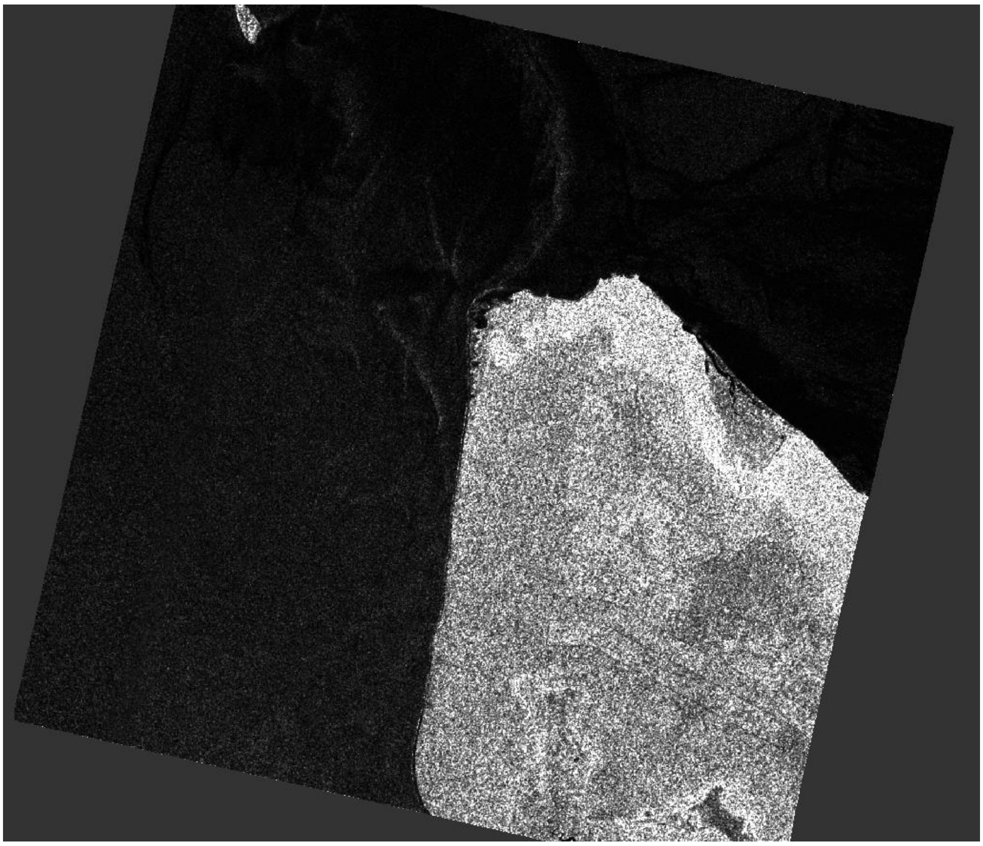

Range Doppler Terrain Correction
File
Help
I/O Parameters
Processing Parameters
Source Product
source:
[7] flattenedterrain_S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_014...
Target Product
Name:
correctedterrain_S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_014818_01824C_
Save as:
BEAM-DIMAP
Directory:
/Users/user
Open in SNAP
Run
Close


Range Doppler Terrain Correction
File
Help
I/O Parameters
Processing Parameters
Source Bands:
Gamma0_VH
Gamma0_VV
Digital Elevation Model:
SRTM 1Sec HGT (Auto Download)
DEM Resampling Method:
BILINEAR_INTERPOLATION
Image Resampling Method:
BILINEAR_INTERPOLATION
Source GR Pixel Spacings (az x rg):
10.0(m) x 10.0(m)
Pixel Spacing (m):
10.0
Pixel Spacing (deg):
8.983152841195215E-5
Map Projection:
WGS84(DD)
Mask out areas without elevation
Output complex data
Output bands for:
Selected source band
DEM
Latitude & Longitude
Incidence angle from ellipsoid
Local incidence angle
Projected local incidence angle
Apply radiometric normalization
Save Sigma0 band
Use projected local incidence angle from DEM
Save Gamma0 band
Use projected local incidence angle from DEM
Save Beta0 band
Auxiliary File (ASAR only):
Latest Auxiliary File
Run
Close

Now view the terrain corrected output by expanding the terrain corrected data and the Bands folder and double clicking the Gamma0 VV dataset. 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 (directly below) 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. Terrain correction moves pixels to more accurately represent features such as mountains.

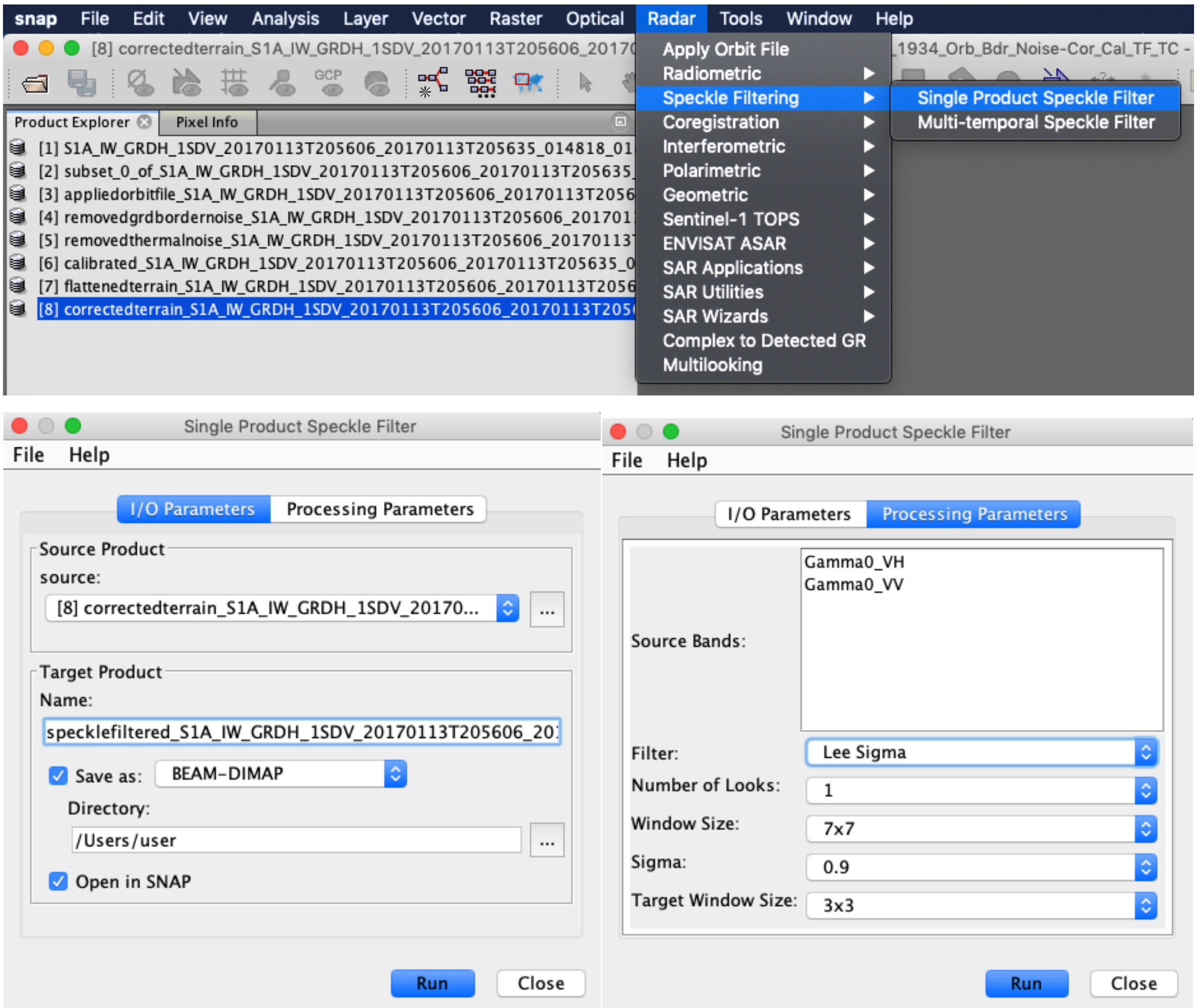
The terrain correction step also corrects the geographic projection of the image. This results in the image appearing flipped relative to earlier steps. The original image projection is a result of the satellite orbit: ascending orbits return images with a North/South flip (relative to Earth) and descending orbits return images with an East/West flip (relative to Earth).



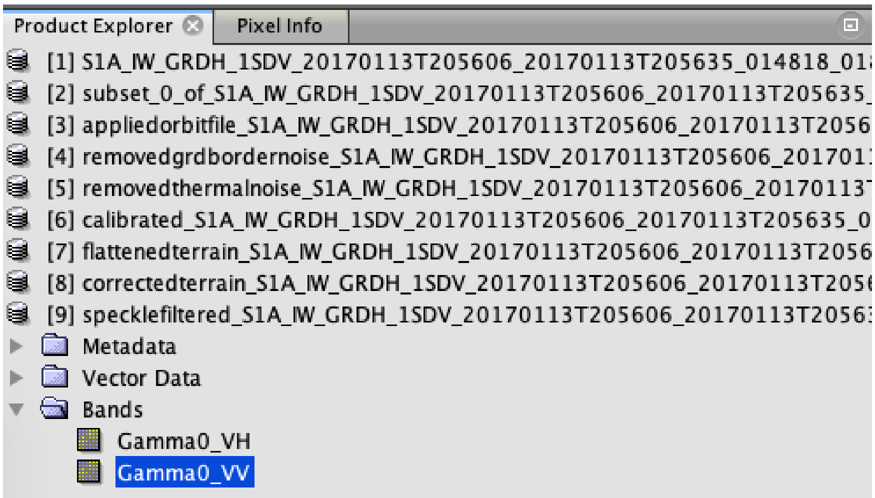


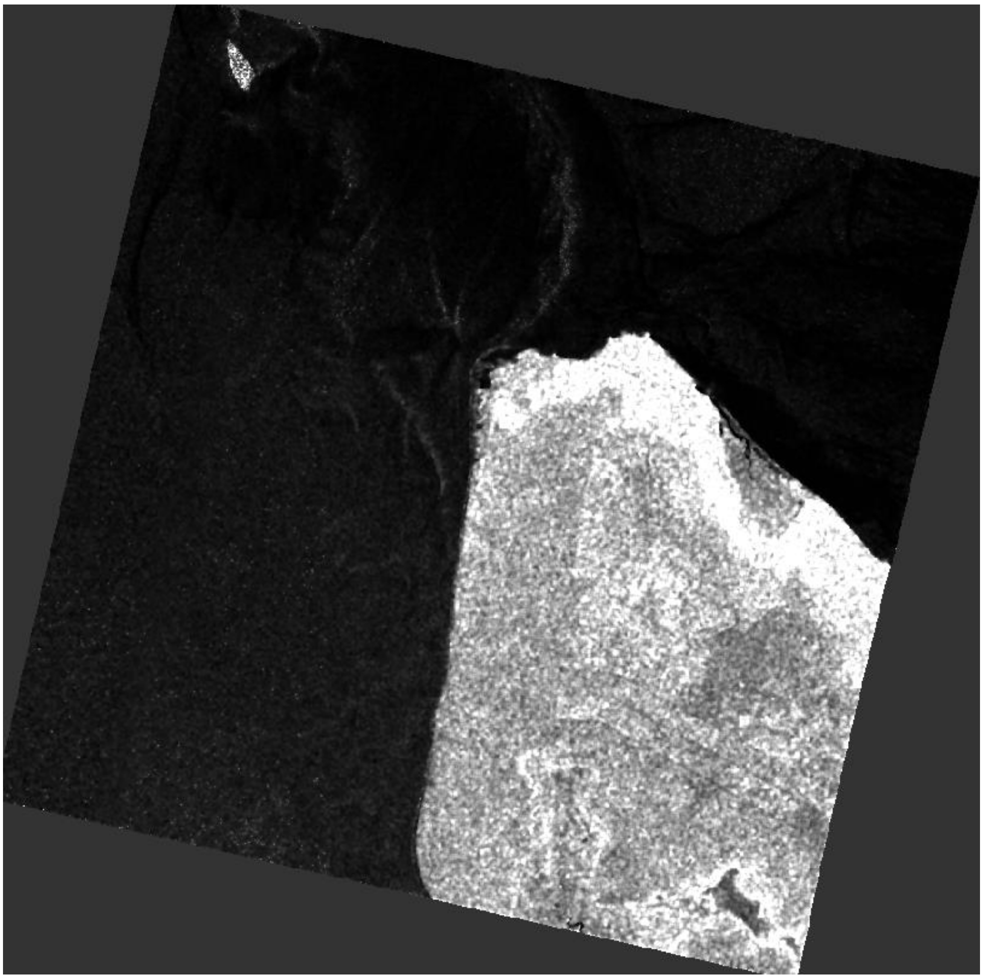
8.2.2.8 *Speckle-Filter*

The eighth processing step is to filter speckle noise from the image. Open the *RADAR* menu and select *Speckle Filtering* and then *Single Product Speckle Filter*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.



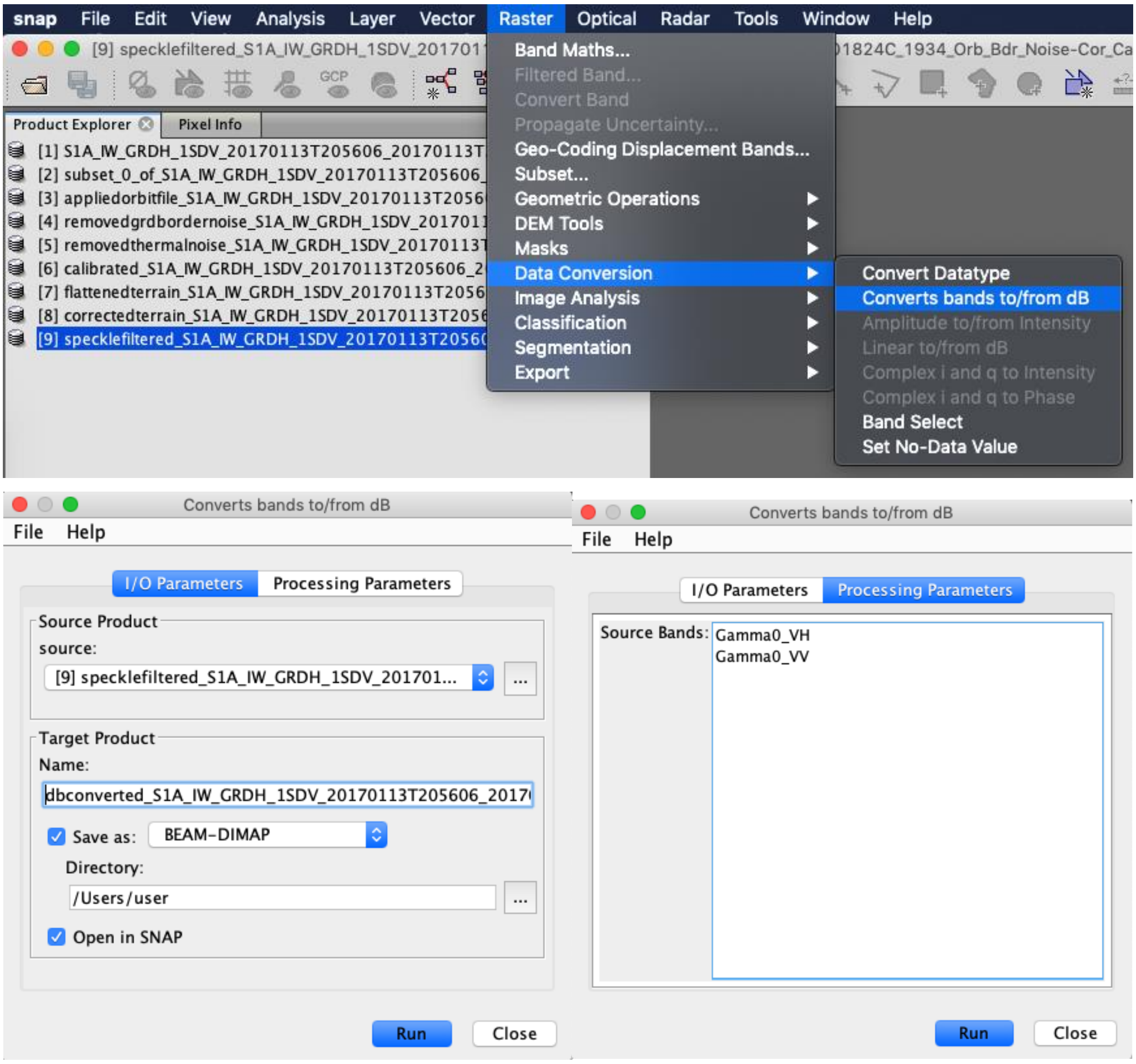
Now view the speckle filtered output by expanding the speckle filtered data and the *Bands* folder and double clicking the *Gamma0 VV* dataset. SAR images have inherent salt and pepper like texturing called speckles which degrade the quality of the image and make interpretation of features more difficult. Speckles are caused by random interference. Comparison of the speckle filtered image to the terrain corrected image shows a clear reduction in speckle, with lighter and darker areas more homogeneous.



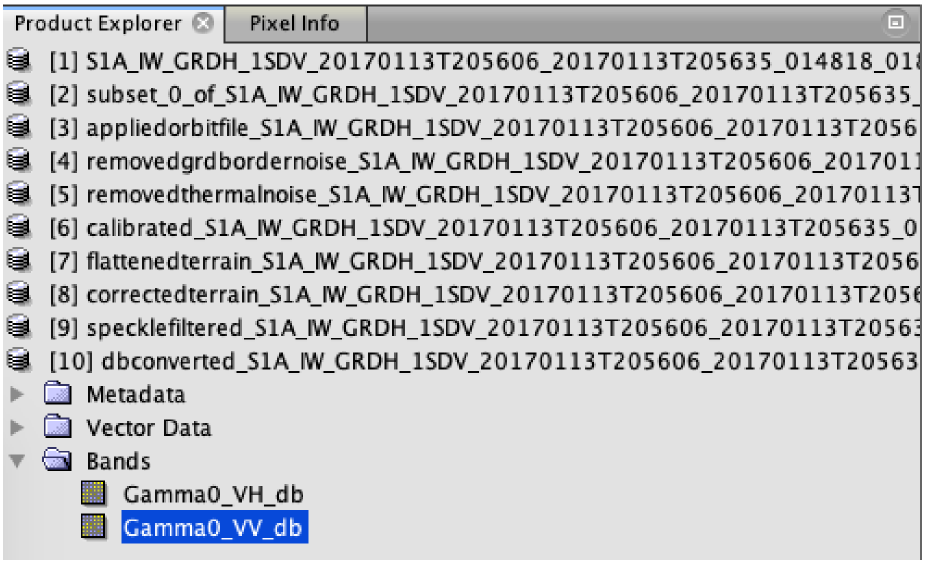


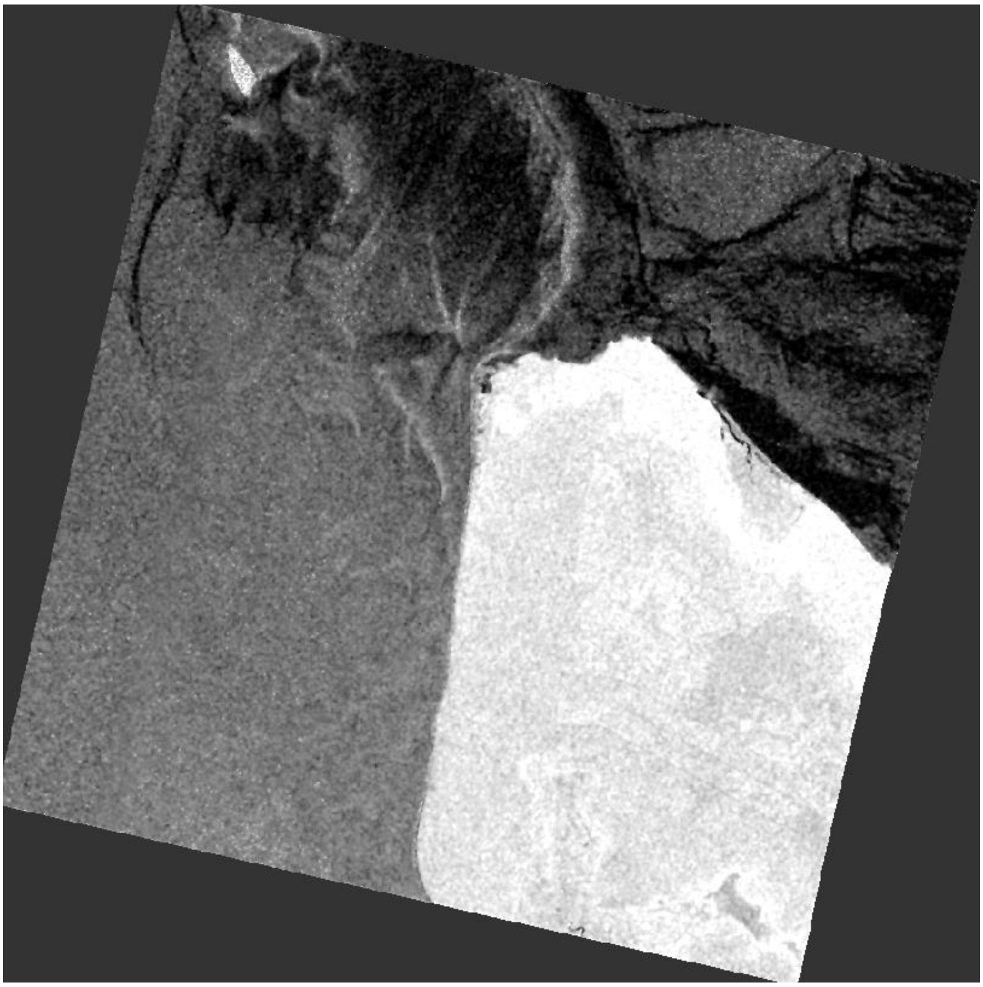
8.2.2.9 Data Conversion

The final processing step is to convert the data. Open the *Raster* menu and select *Data Conversion* and then *Converts bands to/from dB*. Fill in the *I/O* and *Processing Parameters* as shown in the images below and click *Run*.



Now view the dB converted output by expanding the dB converted data and the *Bands* folder and double clicking the *Gamma0 VV* dataset. The conversion applies a base-10 logarithmic scaling function to the pixel values. When processing data, the pixel values are given as digital numbers (measure of RADAR return intensity), but it is common practice to work in decibels, calculated as the base-10 logarithm of the digital number.

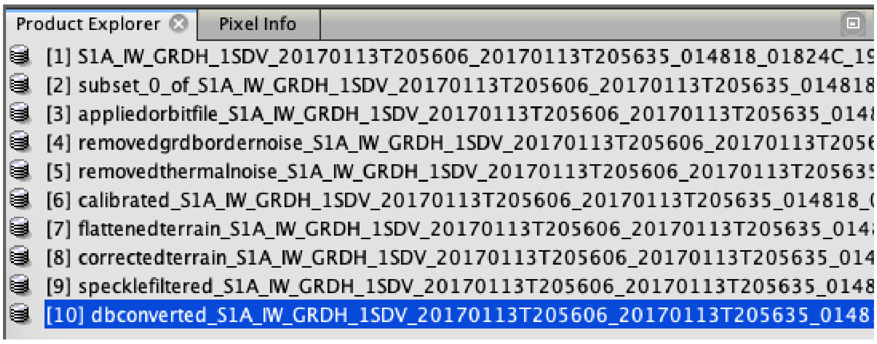

Product Explorer
Pixel Info
[1] S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_014818_01
[2] subset_0_of_S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_
[3] appliedorbitfile_S1A_IW_GRDH_1SDV_20170113T205606_20170113T2056
[4] removedgrdbordernoise_S1A_IW_GRDH_1SDV_20170113T205606_2017011
[5] removedthermalnoise_S1A_IW_GRDH_1SDV_20170113T205606_20170113T
[6] calibrated_S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_0
[7] flattenedterrain_S1A_IW_GRDH_1SDV_20170113T205606_20170113T2056
[8] correctedterrain_S1A_IW_GRDH_1SDV_20170113T205606_20170113T2056
[9] specklefiltered_S1A_IW_GRDH_1SDV_20170113T205606_20170113T20563
[10] dbconverted_S1A_IW_GRDH_1SDV_20170113T205606_20170113T20563
Metadata
Vector Data
Bands
Gamma0_VH_db
Gamma0_VV_db

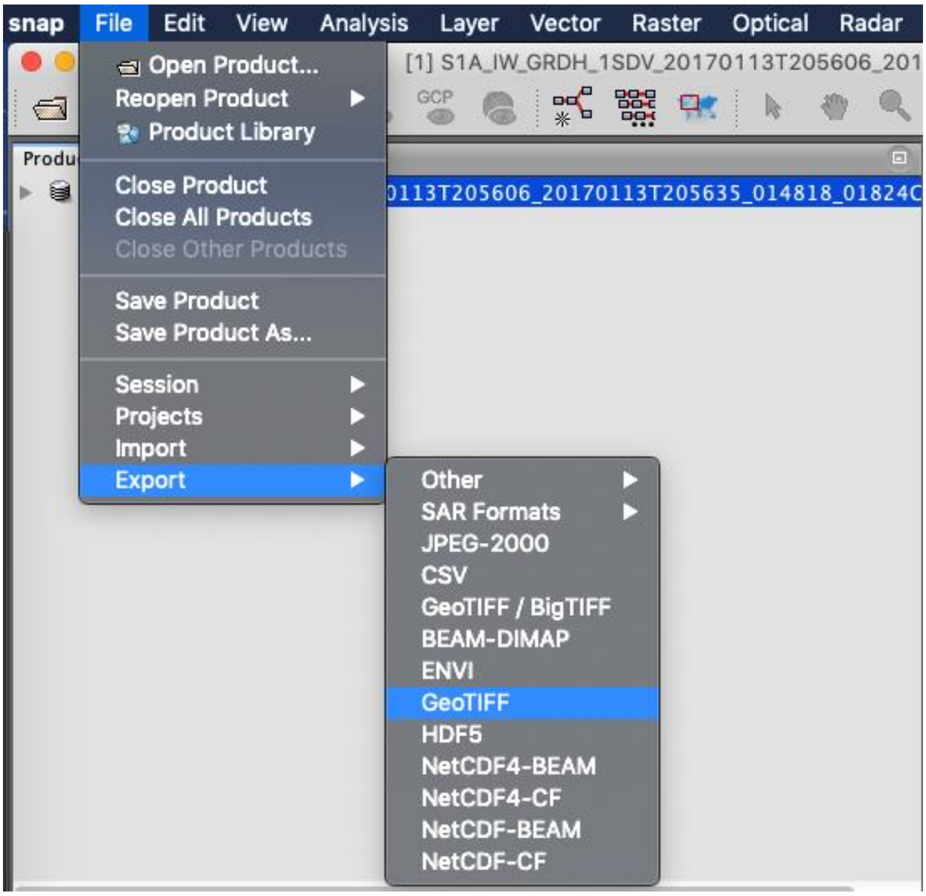


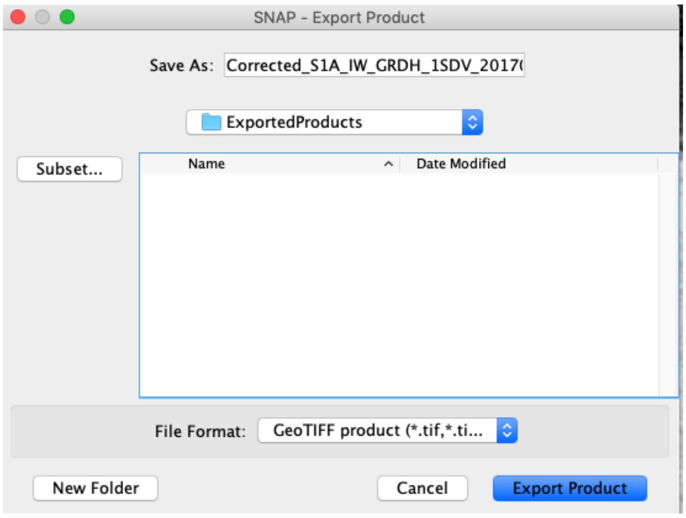
8.2.3 Export the ARD

Congratulations on successfully using SNAP to process S1 data to RADAR Backscatter ARD using GA's processing workflow! The ARD can now be exported for use in analysis.

Select the product to export. In this case, select the final product produced from running the decibel conversion. Then, from the menu bar, select *File* and then *Export* and then the file format of your choice. *GeoTIFF* is recommended.

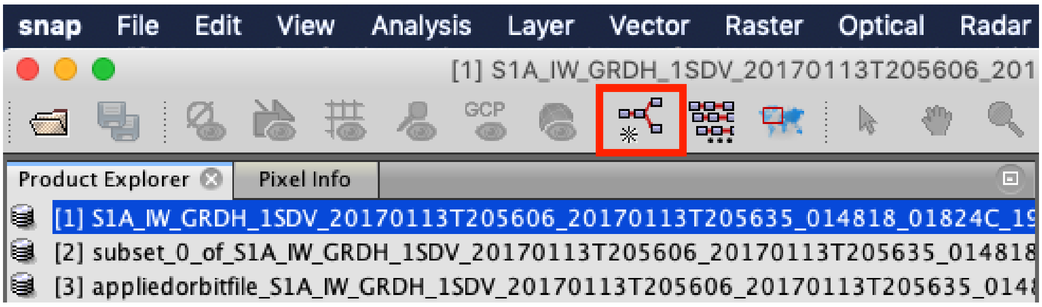




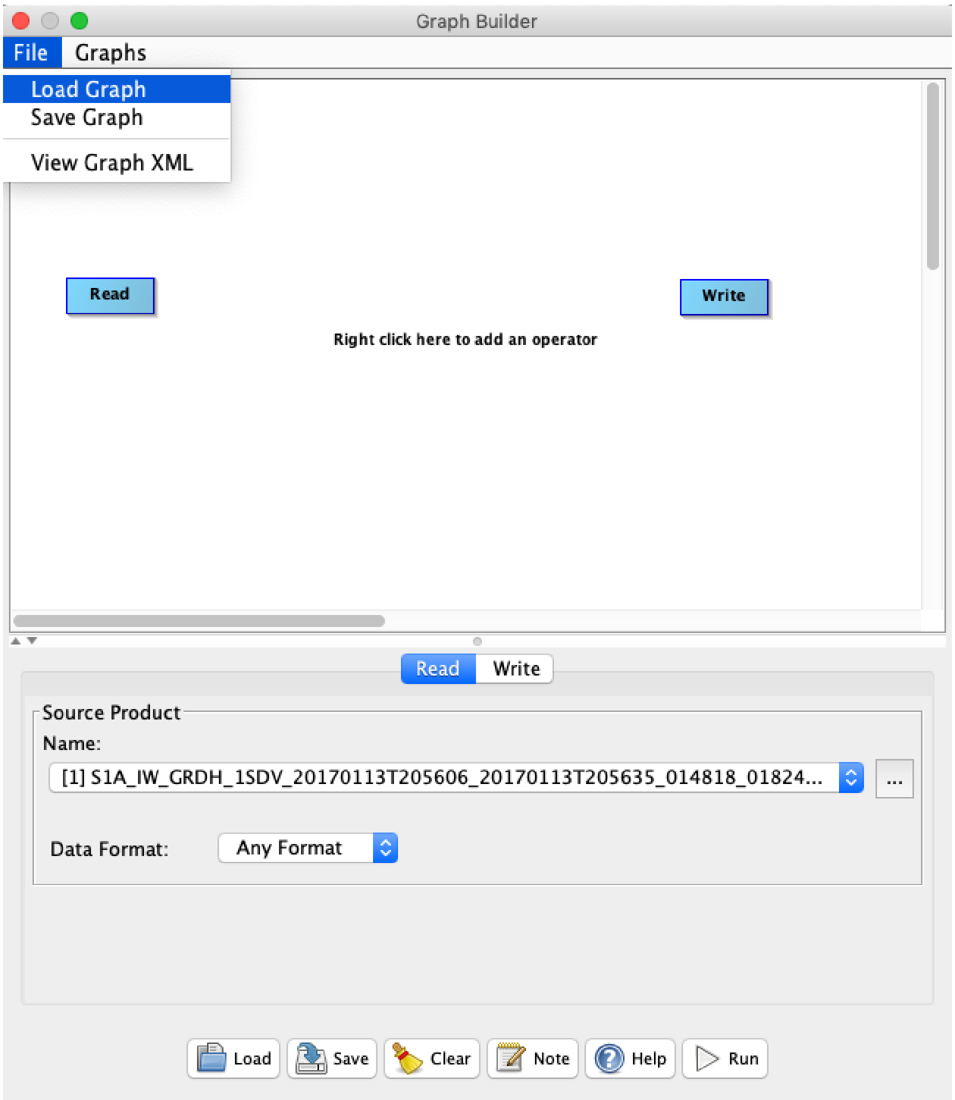


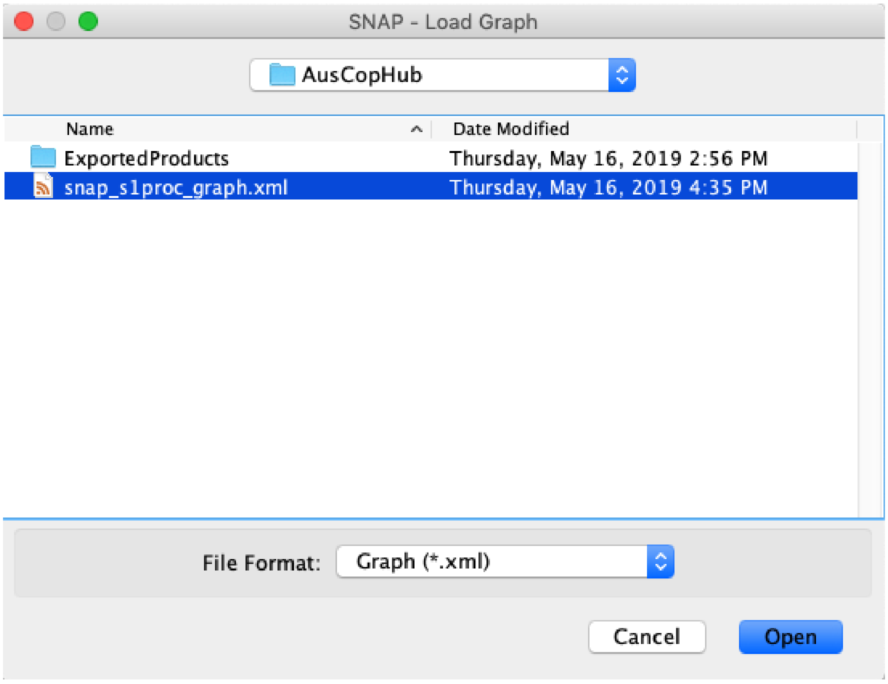
8.2.4 Processing with the Graph Tool

Using the graph tool in SNAP, the above steps can be chained together to develop a processing workflow. The process can then be easily re-run, applied to new images, or shared with others. Graphs are stored as *.xml* files. To see the corresponding graph for the above steps, select the original data product and open the GraphBuilder tool, as shown below.

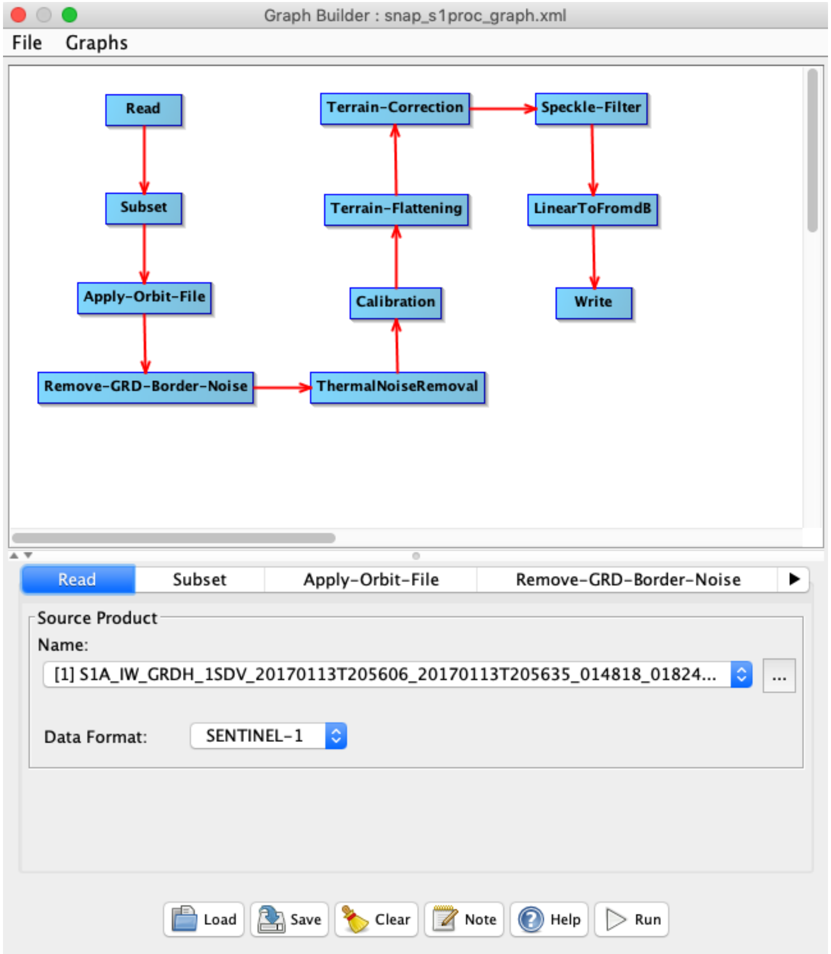


Then, load the provided graph file “snap_s1proc_graph.xml”

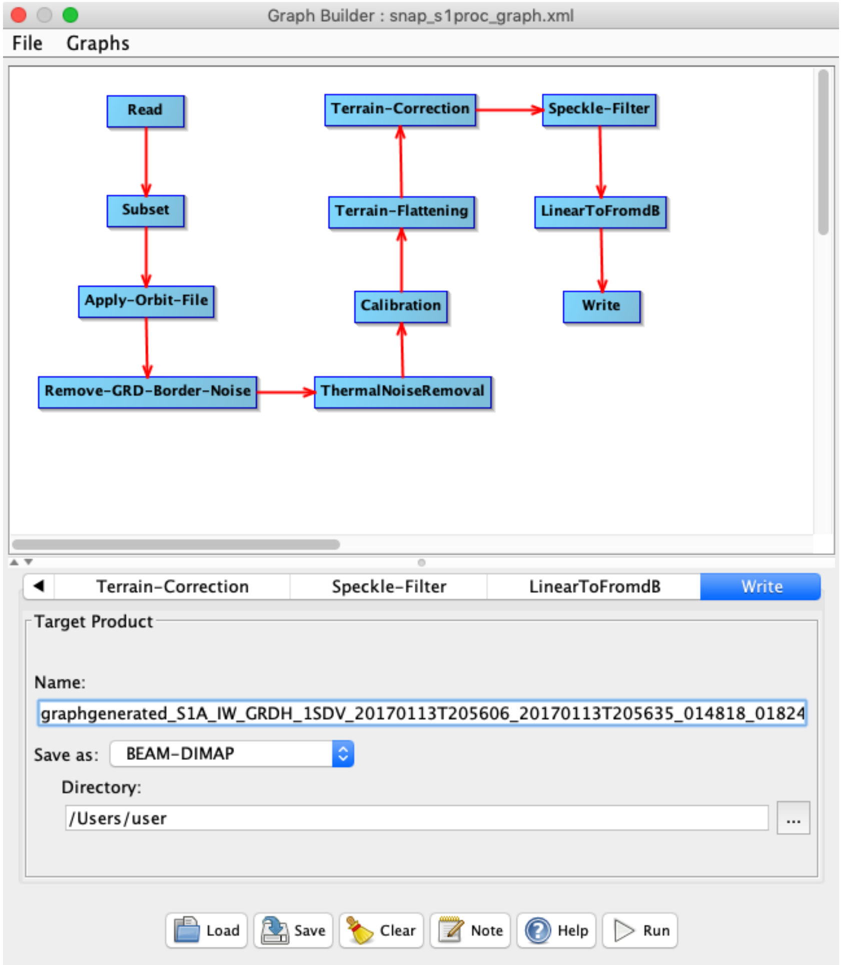

Graph Builder
File
Graphs
Load Graph
Save Graph
View Graph XML
Read
Write
Right click here to add an operator
Read
Write
Source Product
Name:
[1] S1A_IW_GRDH_1SDV_20170113T205606_20170113T205635_014818_01824...
Data Format:
Any Format
Load
Save
Clear
Note
Help
Run


SNAP - Load Graph
AusCopHub
Name
Date Modified
ExportedProducts
Thursday, May 16, 2019 2:56 PM
snap_s1proc_graph.xml
Thursday, May 16, 2019 4:35 PM
File Format:
Graph (*.xml)
Cancel
Open

The graph will be displayed along with tabs for each processing step. Click through the tabs to view the processing parameter settings for each step.

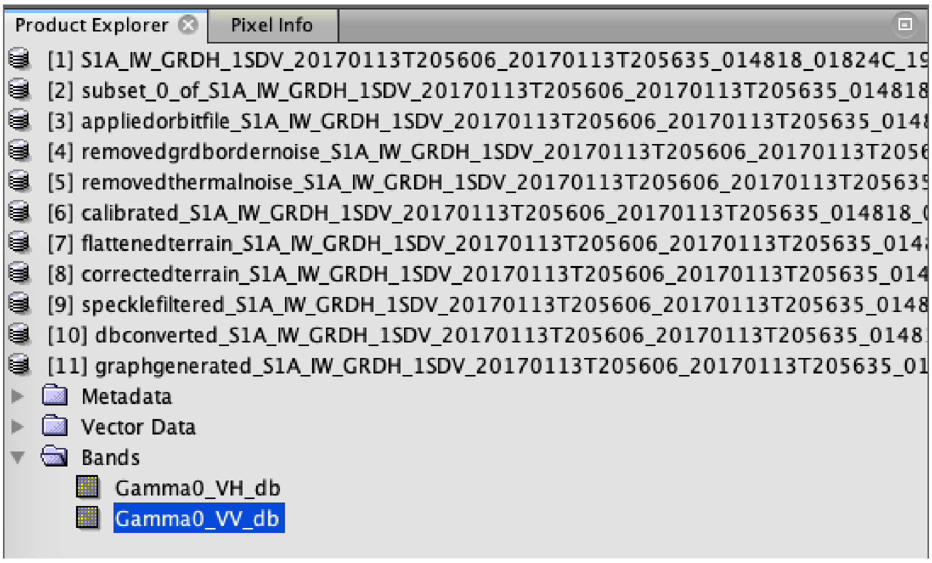


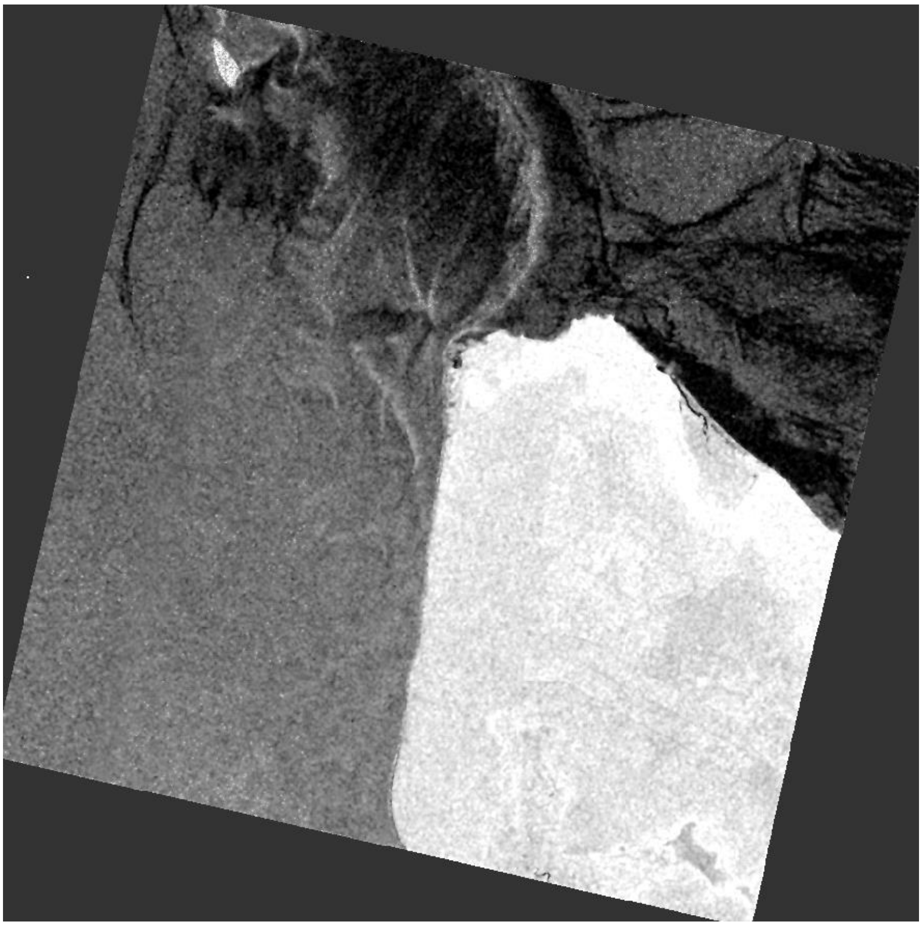
Before running the graph, find the *Write* command by panning through the tabs. Change the name for the output to avoid overwriting the existing data products and ensure the output Directory is set appropriately.



Press the *Run* button in the bottom right-hand corner to run the graph. This can take up to a few minutes, so be patient. A progress bar will appear shortly after pressing the *Run* button.

Once complete, open the resulting processed image and compare it to the final image from the manual processing. The images should match.





Congratulations on successfully automating the SAR processing pipeline! Graphs can be customised by adding and connecting processing steps in the GraphBuilder tool. It is also possible to use Graphs as the basis for batch processing larger numbers of files.

8.3 Analyse the ARD – Intro to Jupyter

The next sub-section (8.4) details a Water Detection Analysis on the Sentinel-1 ARD produced with SNAP in sub-section 8.2. The analysis will be run in a Jupyter Notebook, hence this section first introduces Jupyter Notebooks. This section will introduce working with Digital Earth Australia (DEA) Sentinel-2 data in the FrontierSI Sandbox environment for the Open Data Cube (ODC). It is broken into the four parts:

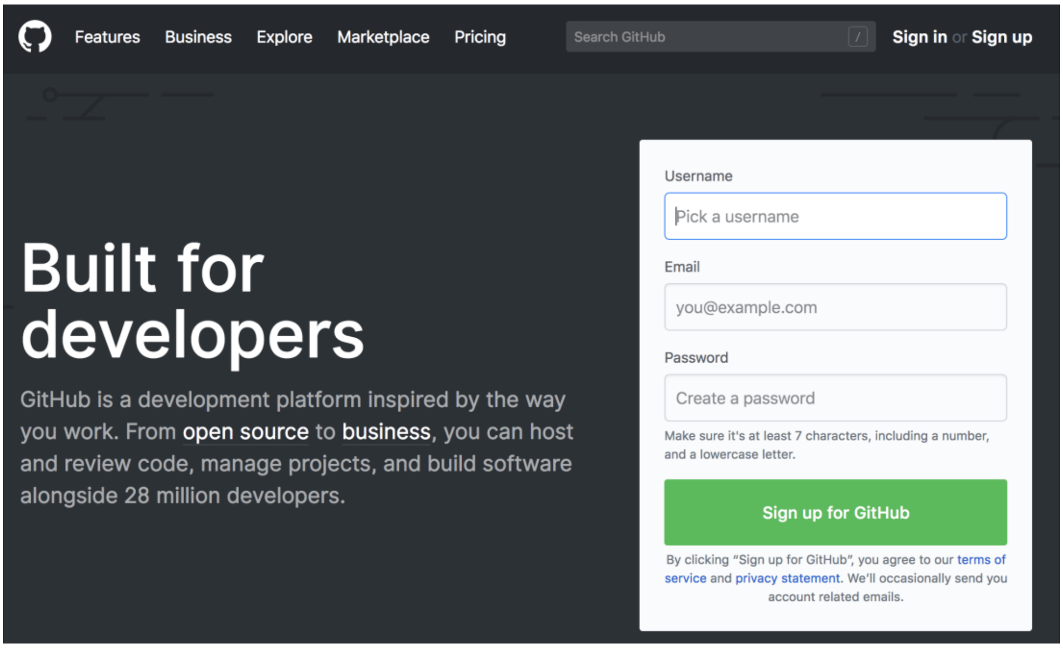
1. Getting started – access the sandbox
2. Learning Jupyter – explore what a Jupyter Notebook is
3. Using Apps – run a simple app demonstrating a case study
4. Do it yourself – run and modify Python code to load, analyse and visualise data

At the end you will know how to use a Jupyter Notebook in conjunction with the ODC to access DEA Sentinel-2 data. It should take around half an hour to complete.

8.3.1 Getting started

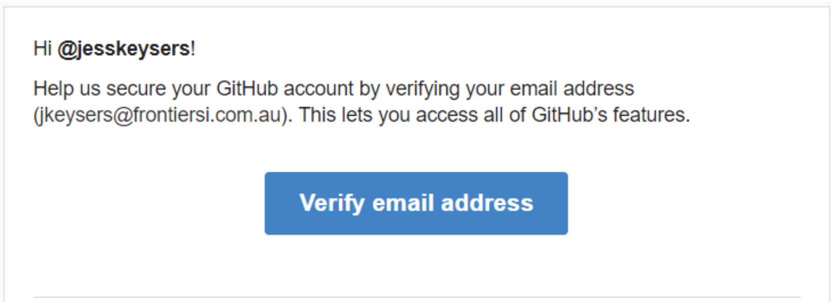
8.3.1.1 Sign in or Sign up for a GitHub account

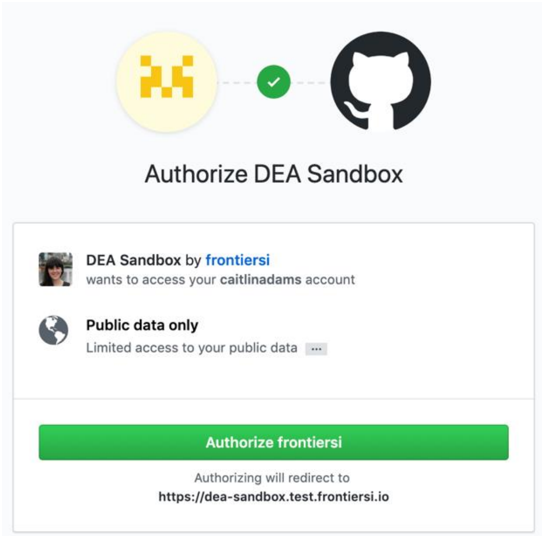
The FrontierSI Sandbox uses GitHub accounts for authentication. Please visit https://github.com to sign up for GitHub, otherwise, please sign in.



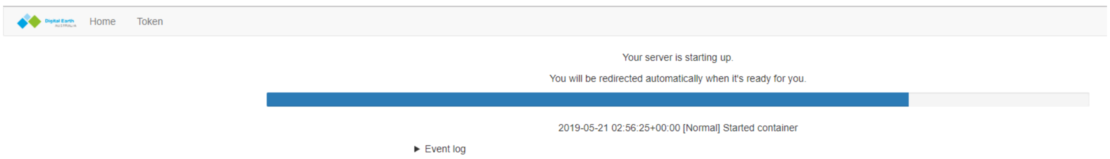
8.3.1.2 Accessing the FrontierSI Sandbox

After signing into GitHub, visit the FrontierSI Sandbox at https://dea-sandbox.test.frontiersi.io and sign in with your GitHub credentials. If using a newly created account, verify the email address used and authorize the FrontierSI JupyterHub to access the account.

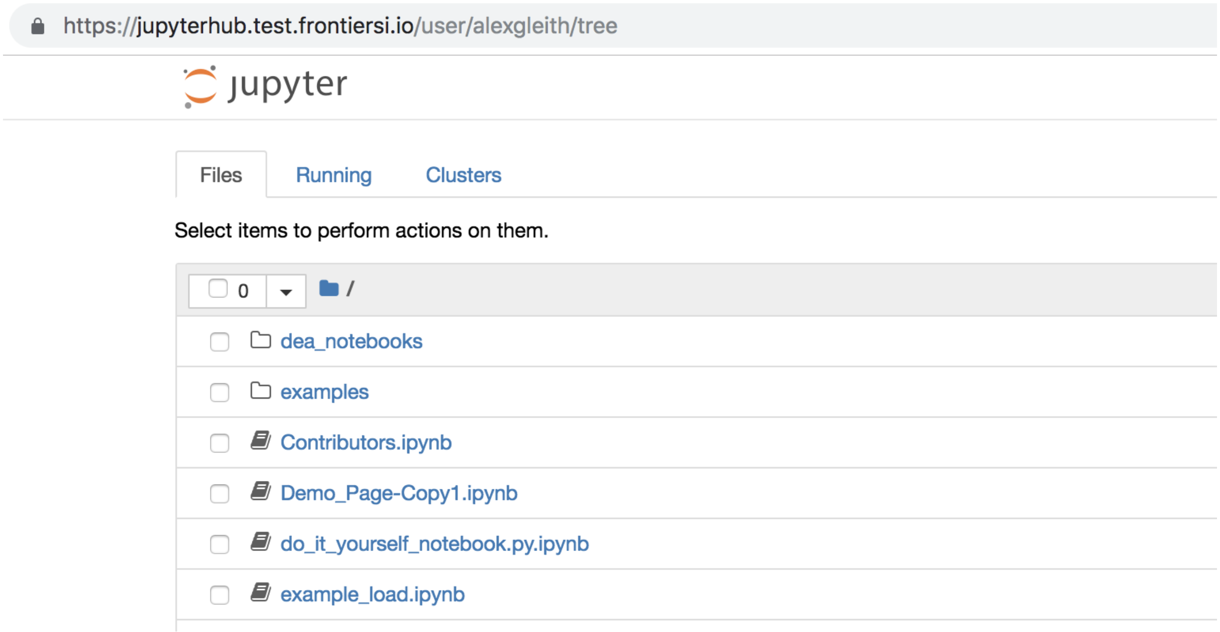




Following this, the below loading screen will display while the Amazon instance is set up.



Once signed in, the Jupyter Hub homepage should appear (as below), although it may only contain the 'examples' folder. The activities will be conducted in this folder.



8.3.2 Learning Jupyter

8.3.2.1 Overview

Jupyter is an interactive coding environment. The name 'Jupyter' comes from Julia, Python and R, which are all programming languages that are used in scientific computing. Jupyter started as a purely Python-based environment, called iPython, but there has been rapid progress over the last few years, and now many large organisations like Netflix (https://medium.com/netflix-techblog/notebook-innovation-591ee3221233) are using the system to analyse data.

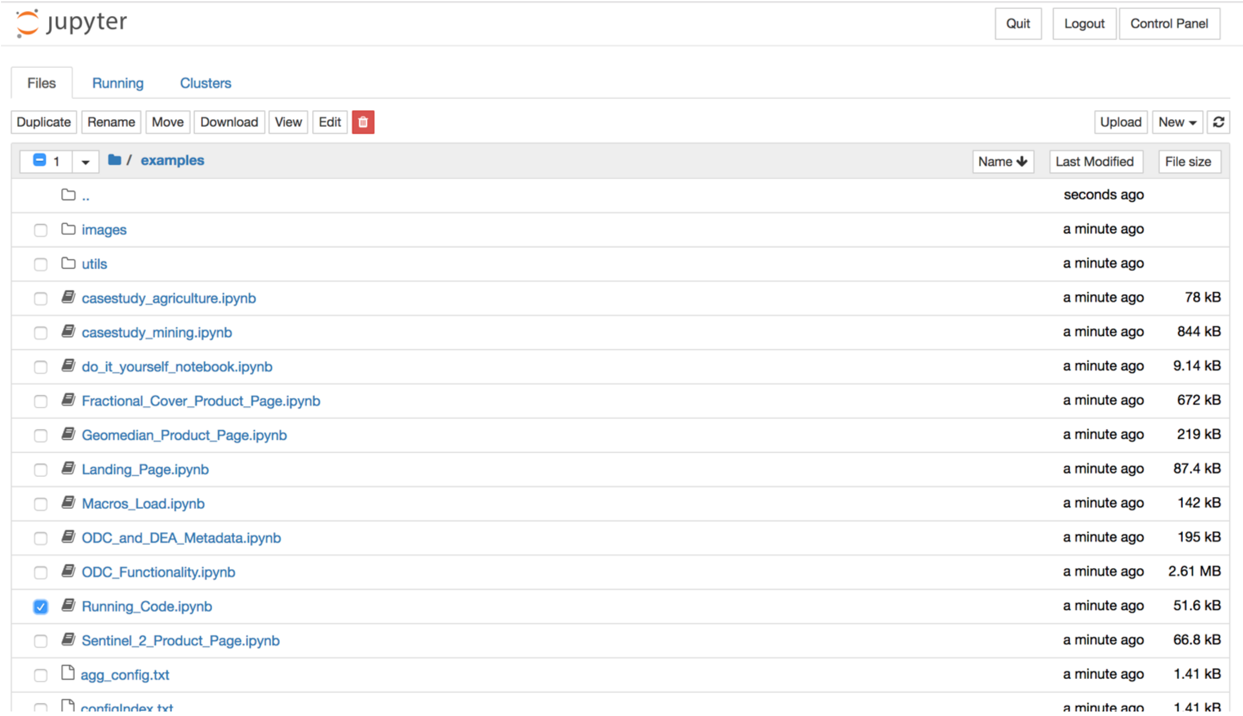
Since the ODC is a Python library, the session will cover working with earth observation data in Python-based notebooks.

8.3.2.2 Explore a basic notebook

The first exercise is to explore a very basic notebook (sourced from the Jupyter GitHub https://github.com/jupyter/jupyter/wiki/A-gallery-of-interesting-Jupyter-Notebooks#introductory-tutorials). The goal is to understand the key features of notebooks.

If you've used Jupyter before, you may want to skip this step.

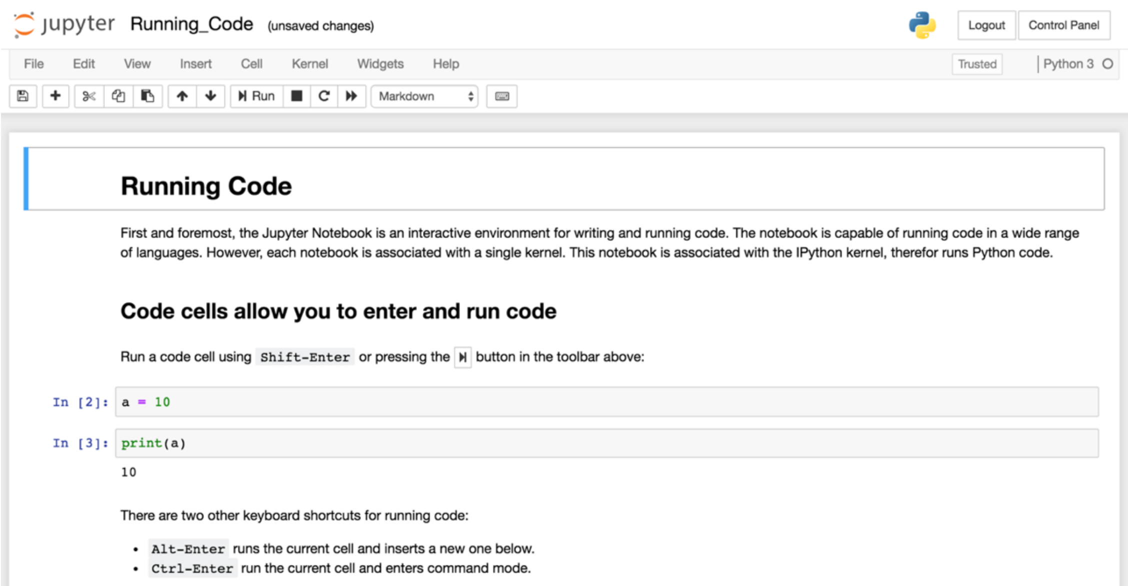
Open the 'examples' folder, and then open the file named 'Running_Code.ipynb'.



The notebook should look like the image below. To learn about the notebook, read through the text in the notebook and run each code cell step (using ‘shift + enter’). Feel free to change the code sections to explore how it works.

> *Note that when the section to the side of a cell is showing an asterisk, that means it is running. This is most important when running a data load that may take more than a few seconds (example follows).* **In [*]:**

The next image displays two executed cells.



8.3.3 Using Apps

The next example makes use of Python functions, which is where more complex code has been wrapped up into simple expressions. In this document, these functions are referred to as ‘apps’. The ‘apps’ make it simple to change an analysis, as they provide ways to interact with the analysis that don’t require changes to the underlying code.

This section uses a notebook to demonstrate how apps can be used in the context of a real-world case study.

8.3.3.1 Agriculture app

Return to the ‘examples’ folder and load the notebook named ‘casestudy_agriculture.ipynb’.

Read through the notes at the top of the notebook, and then run the first cell of code. This cell loads the two functions that will be used: ‘load_agriculture_data’ and ‘run_agriculture_app’. Then run the second cell, which loads the available Sentinel-2 data and stores it in the ‘dataset_sentinel2’ variable. This process involves several steps, which are summarised in the description above the cell, and as output below the cell. The near real time Sentinel-2 data covers the last 90 days, so different data might be loaded compared to the data shown in this document.

In [1]:
```
%matplotlib notebook

from utils.casestudy_agriculture_functions import load_agriculture_data, run_agriculture_app
```

Load the data

The `load_agriculture_data()` command performs several key steps:

- identify all available Sentinel-2 near real time data in the case-study area over the last 90 days
- remove any bad quality pixels
- keep images where more than half of the image contains good quality pixels
- collate images from Sentinel-2a and Sentinel-2b into a single data-set
- calculate the NDVI from the red and near infrared bands
- return the collated data for analysis

The cleaned and collated data is stored in the `dataset_sentinel2` object. As the command runs, feedback will provided below the cell, including information on the number of cleaned images loaded from each satellite.

To run the following cell, click inside and either press the `Run` button on the tool-bar or press `Shift+Enter` on the keyboard.

In [2]:
```
dataset_sentinel2 = load_agriculture_data()
```

```
Loading s2a pixel quality
    Loading 3 filtered s2a timesteps
Loading s2b pixel quality
    Loading 4 filtered s2b timesteps
Combining and sorting s2a, s2b data
    Replacing invalid -999 values with NaN (data will be coerced to float64)
```

Once the data has finished loading, run the third cell, which contains the ‘run_agriculture_app’ function. This function takes the loaded data as an argument and launches an interactive app.

```
In [3]: run_agriculture_app(dataset_sentinel2)
```

```
Draw a polygon within the red box to view a plot of average NDVI over time in that area.
```


```
Plot status:
```

The red bounding box represents the spatial limits of the loaded data. This app makes a plot of the average NDVI for each area drawn on the map using the ‘Draw a polygon’ tool . Draw polygons around different fields to generate the average NDVI plot. The polygons will change colour to match the lines on the NDVI plot once completed.

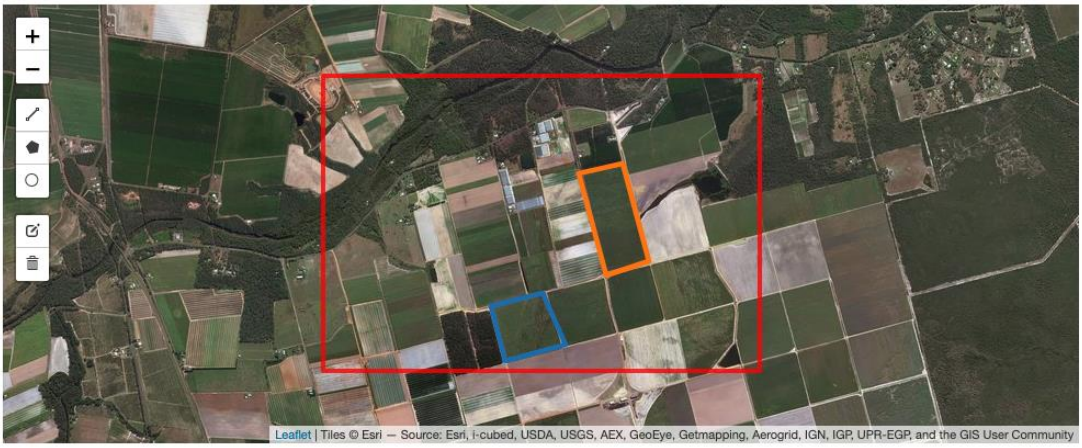
```
In [3]: run_agriculture_app(dataset_sentinel2)
```

```
Draw a polygon within the red box to view a plot of average NDVI over time in that area.
```


```
Plot status:
```

```
In [3]: run_agriculture_app(dataset_sentinel2)
```

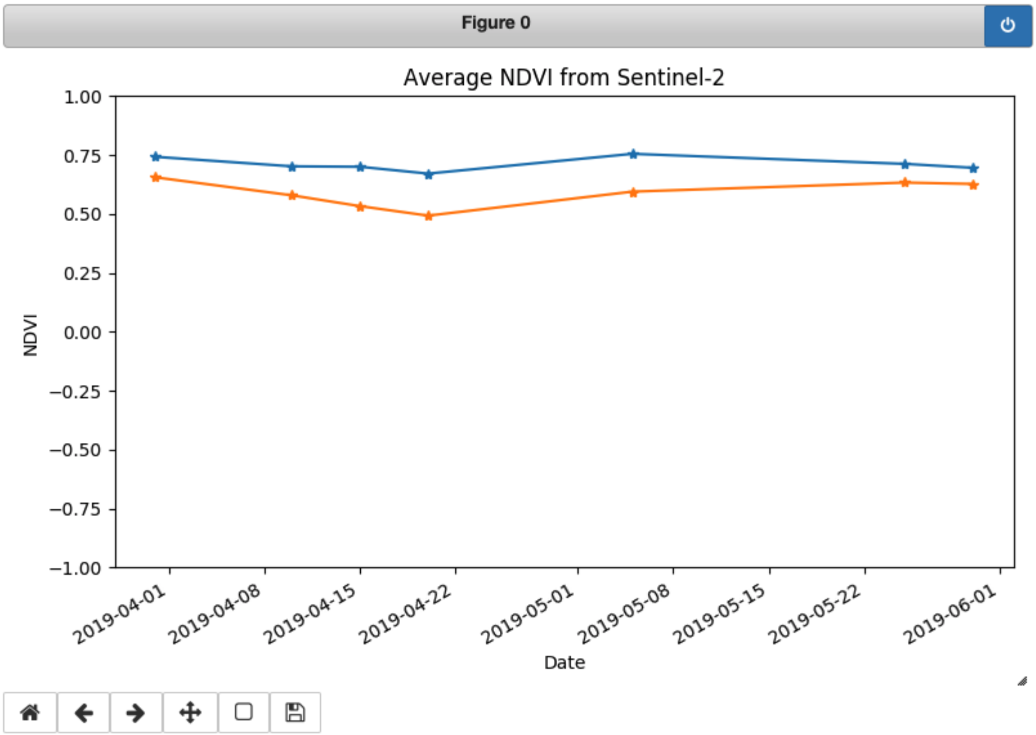
```
Draw a polygon within the red box to view a plot of average NDVI over time in that area.
```




```
Plot status: polygon sucessfully added to plot.
```

After drawing both polygons, look at the graph produced. Identify the differences between fields. The graph displays the normalised difference vegetation index (https://en.wikipedia.org/wiki/Normalized_difference_vegetation_index), which indicates the presence of vegetation. High values (approaching one) indicate dense vegetation, while low values (approaching negative one) are often cloud or snow.

> *Note that the graph will look different to the one below, as the Sentinel near real-time data being used has been captured in the last 90 days.*



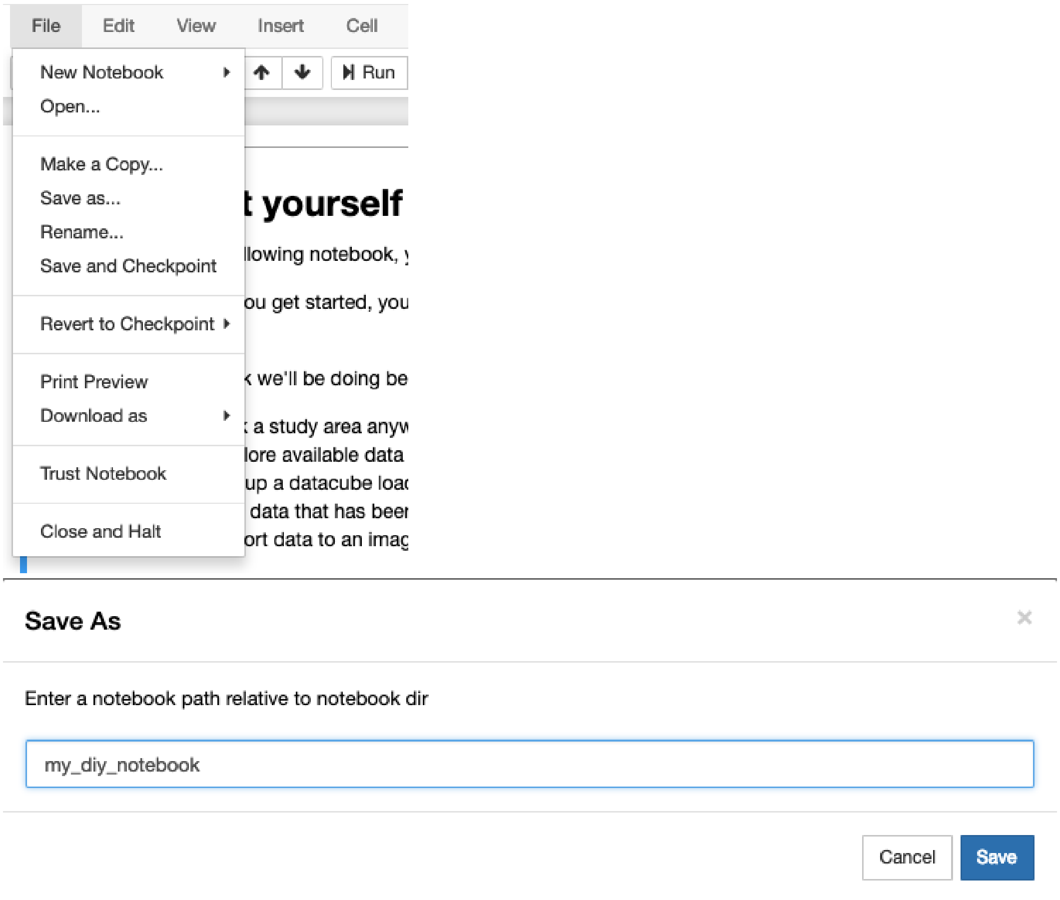
8.3.4 Do it yourself

8.3.4.1 Overview

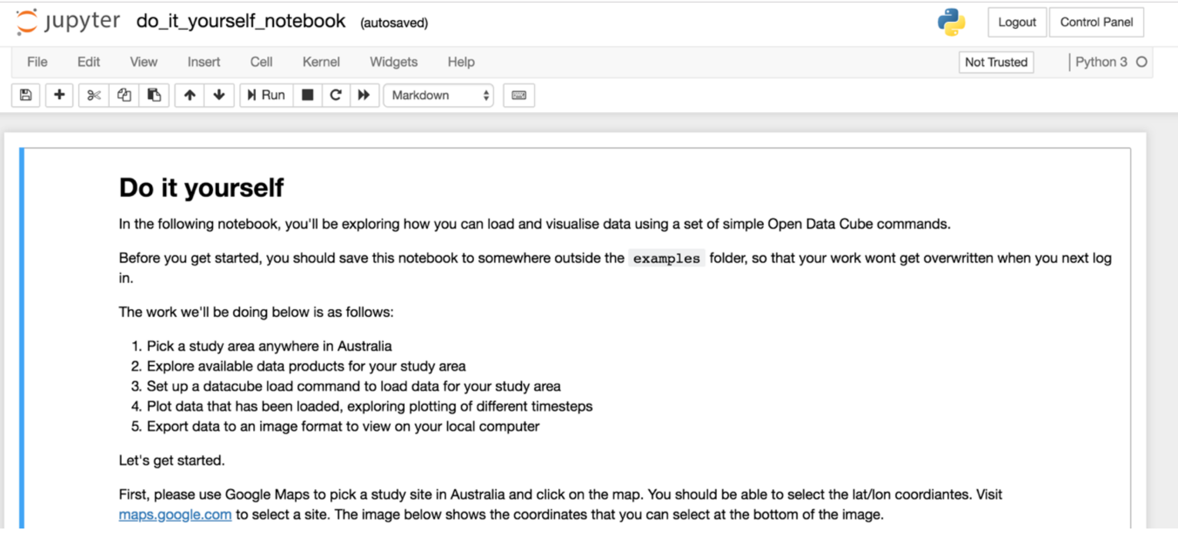
This activity uses a code-based (rather than app-based) notebook, to demonstrate how the ODC Python API works. This will be a simple example of picking a study site in Australia, loading data for that area and plotting bands into the red, green and blue channels of an image.

Load the notebook named ‘do_it_yourself_notebook.ipynb’.

> *To keep any changes, save this file somewhere outside the examples folder. This is because the ‘examples’ folder gets reset at each log in. After opening the notebook, go to File > Save as…, then enter the name for the copy of the notebook.*

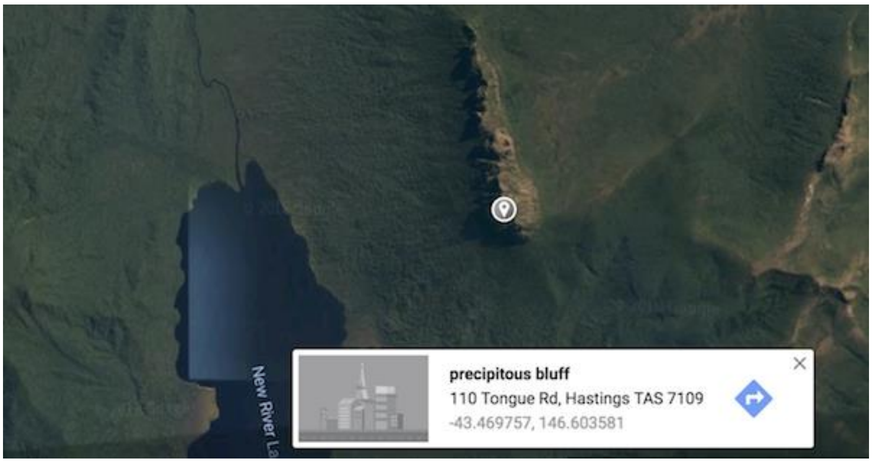


Next, read through the notebook and follow the steps. Feel free to run the cells, as this will work for the example study sites.



8.3.4.2 Pick a study site

To set a study site, provide the latitude and longitude for the centre of an area, and the notebook will turn this into a bounding box, which is passed to the datacube load command. To get the latitude and longitude for any area in Australia, visit Google maps (https://maps.google.com), find somewhere that looks interesting, and then left-click on the map. A small info panel will pop up with some information including coordinates.



Paste these coordinates into square brackets in the bottom line of the appropriate cell, uncomment the line and comment the top coordinates line.

```
In [ ]: # Example study site one, Dead Dog Creek in Queensland
        coordinates = [-14.642744, 144.899747]

        # Example study site two, Giles Creek near Alice Springs
        # coordinates = [-23.765165, 134.724024]

        # Example study site three, Lake Disappointment in WA
        # coordinates = [-23.481127, 122.817712]

        # Paste your coordinates here, and remove the hash to uncomment
        # coordinates = []
```

8.3.4.3 Load data

To perform the datacube load, run the cells below the coordinates cell, including the one with the datacube load command.

Note that the load command will take around one minute to fetch data from the AWS S3 cloud storage.

```
In [ ]: import datacube
        import warnings
        warnings.filterwarnings('ignore')  # suppress warnings

        dc = datacube.Datacube(app='do-it-yourself')

        # This command here does the loading of data
        # Please be patient, it can take some time to load, depending on the size of your study area
        # For the example study area, this took 1 minute
        data_cube = dc.load(
            product='s2a_nrt_granule',
            x=bounding_box_x,
            y=bounding_box_y,
            resolution = (-10, 10),
            output_crs='epsg:3577',
            measurements=(
                'nbar_red',
                'nbar_green',
                'nbar_blue',
                'nbar_nir_1'
            )
        )
```

After the data is loaded, run the cell below. This cell calls the 'data_cube' object created in the previous cell, which will return some information about it.

Specifically, 'data_cube' is an 'XArray' object containing the loaded data. It has three dimensions: time, longitude (x), and latitude (y). For the Dead Dog Creek example, 'data_cube' should contain around 22 timesteps, 2387 cells in longitude and 2400 cells in latitude. This information comes from the 'Dimensions' heading. Note that the exact number of time steps will depend on when the analysis is run, since this analysis uses near real time Sentinel-2 data from the last 90 days.

Each timestep is an occasion that the satellite captured an image. To view the date of each timestep, run 'print(data_cube.time)' after the 'print(data_cube)' command. The satellite also captures several different spectral 'bands', which are listed under the 'Data variables' heading. The returned variables correspond to the 'measurements' requested as part of the load command in the previous cell. Here, the 'nbar' word refers to processed data, which means the data has been adjusted to Australian conditions (this is called 'analysis ready data').

```
In [4]: # This will give information on how much data was loaded
        # Most interesting is the 'Dimensions' section, that tells you how many timesteps were loaded
        # and the x/y resolution of the cube.
        print(data_cube)

        <xarray.Dataset>
        Dimensions:     (time: 22, x: 2387, y: 2400)
        Coordinates:
          * time        (time) datetime64[ns] 2019-01-07T00:40:48.851000 ... 2019-03-28T00:41:09.096654
          * y           (y) float64 -1.611e+06 -1.611e+06 ... -1.635e+06 -1.635e+06
          * x           (x) float64 1.389e+06 1.389e+06 ... 1.413e+06 1.413e+06
        Data variables:
            nbar_red    (time, y, x) int16 214 216 221 210 214 ... -999 -999 -999 -999
            nbar_green  (time, y, x) int16 368 379 377 362 393 ... -999 -999 -999 -999
            nbar_blue   (time, y, x) int16 376 378 375 378 371 ... -999 -999 -999 -999
            nbar_nir_1  (time, y, x) int16 222 232 220 210 222 ... -999 -999 -999 -999
        Attributes:
            crs:      epsg:3577
```

8.3.4.4 Visualise the site

After loading data, it is important to visualise it. Run the cell under the heading 'Plotting data'. To get more experience with interacting with Python code, change the timestep being plotted, and the band combination. Note that some of the case study areas can be quite cloudy. Since the data are updated in near real time, cloud-free images are not guaranteed. Run the cell with different 'time' values to check through the loaded images. If all images contain clouds, try running a different case study by changing the coordinates in the first cell and reloading the data. As a stretch goal, include more bands in the datacube load command, and plot other measurements (https://en.wikipedia.org/wiki/Sentinel-2#Instruments), such as Coastal Aerosol.

```
# Change these!
# You can change the time to anything from 0 to the number of timesteps - 1.
time = 0

# And bands can be any of the bands that we loaded above, so any of:
# 'nbar_red', 'nbar_green', 'nbar_blue', 'nbar_nir_1'
# You can experiment with plotting in false-colour, for example, try ['nbar_nir_1', 'nbar_green', 'nbar_blue']
bands = ['nbar_red', 'nbar_green', 'nbar_blue']
# bands = ['nbar_nir_1', 'nbar_green', 'nbar_blue']
```

The data is formatted by a function called 'three_band_image()' which takes the 'data_cube' object, as well as the bands and time step chosen above.

Finally, the plotting code constructs the figure and displays the image created.

```
# And plot it
plt.figure(figsize=(10,10))
ax = plt.gca()
ax.set_title("Timestep {}".format(time_string), fontweight='bold', fontsize=16)
ax.set_xticklabels(data_cube.x.values)
ax.set_yticklabels(data_cube.y.values)
ax.set_xlabel('Easting', fontweight='bold')
ax.set_ylabel('Northing', fontweight='bold')

plt.imshow(img_toshow)
```

Here, you can change the size of the image, title, or axis labels.

8.3.4.5 Save and download data

Once you have a site and timestep worth saving, run the next cell to write it out as a GeoTIFF, which can be loaded into a desktop GIS (e.g. QGIS) for further analysis. To download the rendered image, navigate to the Jupyter folder and find the image, select it, and choose 'download'.

Exporting data

The last task here is to export the data for your study site. You can change the name of the filename so that you know what the file is going to be called. After the file has been created, you can download it from the Jupyter directory it was exported into.

```
In [ ]: from datacube import helpers

        # You can change this, if you like.
        filename = "example.tiff"

        helpers.write_geotiff(dataset=data_cube.isel(time=0), filename=filename)
```

After saving the GeoTIFF, return to the cell defining the latitude and longitude coordinates for analysis and choose another set. Then rerun the analysis and visualise the newly selected area.

8.3.4.6 Stretch goal (Optional)

The final stretch goal, if there is time remaining in the session, is to do a simple band index calculation, manually calculating NDVI. See the notebook for tips on how to do this.

Stretch goal: Calculate NDVI

If you've come this far and you'd like to do something a bit fancier, you can have a go at calculating the normalised difference vegetation index (NDVI) over your study site. There is a definition of what NDVI is on Wikipedia.

Basically, you need to use the following formula:

$$ndvi = \frac{(nir - red)}{(nir + red)}$$

8.4 Analyse the ARD – Water Detection

This sub-section will cover a coastal zone analyses using Digital Earth Australia (DEA) Sentinel-1 data in the FrontierSI Sandbox environment for the Open Data Cube (ODC). The hour-long workshop focuses on:

1. Water identification using RADAR (Sentinel-1) data.

Each section will involve running and modifying a Jupyter notebook. At the end you will understand how to use the ODC for RADAR data in the context of coastal analyses.

> *This session is about becoming more familiar with writing code using the Open Data Cube. When running the cells, take the opportunity to understand what each line of Python code is doing.*

8.4.1 Getting started

8.4.1.1 Accessing the FrontierSI Sandbox

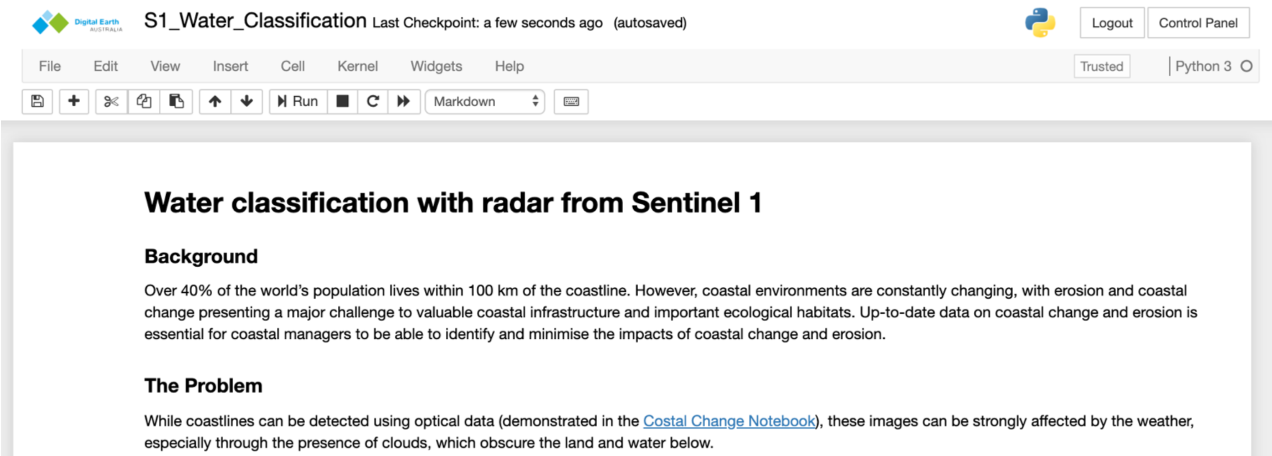
As with the previous workshop session, notebooks will be run in the FrontierSI Sandbox environment. Visit https://dea-sandbox.test.frontiersi.io and log in. The GitHub account previously used should already be authorised, so log in to the Sandbox. If having login difficulty, refer to the previous workshop manual (Introduction to Jupyter) for instructions on accessing the Sandbox.

8.4.2 Water Classification with Sentinel-1

8.4.2.1 Overview

This activity features an analysis to identify water in Sentinel-1 RADAR data. This exercise begins by running the analysis for a pre-selected area and is followed by changing the area and running the analysis again. This exercise also includes sections for users to contribute code to complete the analysis.

Open the ‘examples’ folder from the Sandbox page and load the notebook named ‘S1_Water_Classification.ipynb’. Read through the introduction to learn about the analysis.



8.4.2.2 Set up

This notebook loads the necessary Python modules as they are required. Pay attention to why certain modules are being used while working through the analysis.

The first step of the analysis is to specify the latitude and longitude range for the study. At the moment, the values are configured to look at the coast of Melville Island, off the coast of the Northern Territory, Australia. Run the first two cells to define the extent and visualise the area. Zoom in and out to get a better understanding of the study site. Make a note of which areas in the image are water and which are land.

```
In [1]: latitude = (-11.287611, -11.085876)
        longitude = (130.324262, 130.452652)

In [2]: from utils.display import display_map
        display_map(latitude=latitude, longitude=longitude)
```

Out[2]:

8.4.2.3 Load data

Before loading the data, import the 'datacube' module and define the data cube object.

```
In [ ]: import datacube
        dc = datacube.Datacube(app = 'sentinel-1-water-classifier')
```

This notebook uses the 'dc.load()' command to load the data but changes the way parameters are specified for this function compared to other notebooks covered during the workshop. The next two cells define the product and area parameters in Python dictionaries that can be directly passed to the 'dc.load()' function.

The 'product_information' dictionary contains all the variables necessary to provide the product. The product used is 's1_gamma0_geotif_scene' which has been processed to gamma nought data (backscatter with terrain removed) from Sentinel-1 C-SAR Level 1 Ground Range Detected data.

```
In [ ]: product_information = {
            'product': "s1_gamma0_geotif_scene",
            'output_crs': "EPSG:4326",
            'resolution': (0.00013557119,0.00013557119)
        }
```

The 'area_information' dictionary contains the latitude and longitude values that were defined at the start of the notebook.

```
In [ ]: area_information = {
            'latitude': latitude,
            'longitude': longitude
        }
```

Once the dictionaries are defined, pass them to the 'dc.load()' function by including them as arguments, with the variable names prefaced by '**'.

```
In [ ]: dataset = dc.load(**product_information, **area_information)
```

Note that the dictionaries above did not specify a time range to load the data over. By default, this means that the 'dc.load()' function will return data for all available times.

After loading the data, run 'print(dataset)' to view the returned 'XArray'.

```
In [7]: print(dataset)

        <xarray.Dataset>
        Dimensions:    (latitude: 1489, longitude: 948, time: 27)
        Coordinates:
          * time       (time) datetime64[ns] 2017-01-01T20:56:21.755236 ... 2017-12-27T20:56:23.550695
          * latitude   (latitude) float64 -11.29 -11.29 -11.29 ... -11.09 -11.09 -11.09
          * longitude  (longitude) float64 130.3 130.3 130.3 130.3 ... 130.5 130.5 130.5
        Data variables:
            vh         (time, latitude, longitude) float32 0.00464751 ... 0.000134575
            vv         (time, latitude, longitude) float32 0.143749 ... 0.0184914
        Attributes:
            crs:      EPSG:4326
```

8.4.2.4 Visualise the site

It's important to note that the Sentinel-1 RADAR data used in this example has two observations (called bands in this analysis), *VV* and *VH*, which correspond to the polarisation sent and received by the satellite. For example, VV is single polarisation for vertical transmit and vertical receive. Visualising the site involves plotting the intensity of the light received back by the satellite, rather than a true colour plot. In raw form, the *VV* and *VH* intensities are measured as digital numbers (DN), but when processing, it's typical to apply a base-10 logarithm to obtain the intensity in decibels (dB). Throughout the analysis, there will be various instances when the 'log10()' command from the 'numpy' Python package is used to perform this conversion.

Start by loading the necessary Python packages.

```
In [ ]: import matplotlib.pyplot as plt
        import numpy as np
```

The next two cells focus on visualising the *VH* band. This is where the C-band SAR instrument on Sentinel-1 sends out vertically-polarised light and records the intensity of horizontally-polarised light that comes back.

The steps are to visualise the data for each available time step, then calculate and display a composite image. In this case, the composite image is made by taking the mean of each pixel, as RADAR data isn't as affected by outliers as optical data, though it is noisier.

Visualize VH bands

```
In [ ]: # Plot all VH observations for the year

        converted_vh = np.log10(dataset.vh)  # Scale to plot data in decibels

        converted_vh.plot(cmap="Blues", col="time", col_wrap=5)
        plt.show()
```

```
In [ ]: # Plot the average of all VH observations

        mean_converted_vh = converted_vh.mean(dim = "time")

        fig = plt.figure(figsize=(7,9))
        mean_converted_vh.plot(cmap = "Blues")
        plt.title("Average VH")
        plt.show()
```

When taking the base-10 logarithm, the following warning may appear. The code will still run despite the warning.

```
/usr/local/lib/python3.6/dist-packages/xarray/core/computation.py:561: RuntimeWarning: invalid value encountered in log10
  result_data = func(*input_data)
```

After visualising the *VH* band, write the corresponding code to visualise the *VV* band. To gain experience in programming using the Open Data Cube it is highly recommended to complete this exercise by typing the required code, using the code for the *VH* band as a guide. There are two empty cells to work with.

```
In [ ]: # Plot all VV observations for the year
```

```
In [ ]: # Plot the average of all VV observations
```

Hint: the VH visualisation is made using the 'vh' data variable. Go back to the printed loaded data to find the data variable name for the VV band.

8.4.2.5 Preparing the data for analysis

Look back at the visualisations for the two bands and notice how the water appears grainy in the images. This is a type of noise known as speckle. In this section, the notebook covers an additional step to reduce this noise before we proceed to the analysis. To learn more about speckle and speckle filtering, follow the link in the notebook. Otherwise, define the function for filtering the data by running the first cell in the 'Speckle Filtering using Lee Filter' section. This function makes use of two functions from the 'scipy' Python package, which are imported at the beginning of the cell.

```
In [ ]: # Adapted from https://stackoverflow.com/questions/39785970/speckle-lee-filter-in-python

        from scipy.ndimage.filters import uniform_filter
        from scipy.ndimage.measurements import variance

        def lee_filter(da, size):
            img = da.values
            img_mean = uniform_filter(img, (size, size))
            img_sqr_mean = uniform_filter(img**2, (size, size))
            img_variance = img_sqr_mean - img_mean**2

            overall_variance = variance(img)

            img_weights = img_variance / (img_variance + overall_variance)
            img_output = img_mean + img_weights * (img - img_mean)
            return img_output
```

After defining the filter function, apply it to both bands using the '.apply' method for the datacube object. Before doing this, it's important to make sure there are no NULL values in the data set. The first line of code in the cell identifies any entries where the data set has a NULL value and replaces these with 0.

```
In [ ]: # Set any null values to 0 before applying the filter to prevent issues
        dataset_zero_filled = dataset.where(~dataset.isnull(), 0)

        # Create a new entry in dataset corresponding to filtered VV and VH data
        dataset["filtered_vv"] = dataset_zero_filled.vv.groupby('time').apply(lee_filter, size=7)
        dataset["filtered_vh"] = dataset_zero_filled.vh.groupby('time').apply(lee_filter, size=7)
```

After applying the filter, run the cells to visualise the filtered *VH* bands. Take the opportunity to look at the unfiltered plots from the previous section of the notebook and investigate the difference made by using the filter.

Visualize Filtered VH bands

```
In [ ]: # Plot all filtered VH observations for the year

        converted_filtered_vh = np.log10(dataset.filtered_vh)  # Scale to plot data in decibels

        converted_filtered_vh.plot(cmap="Blues", col="time", col_wrap=5)
        plt.show()
```

```
In [ ]: # Plot the average of all filtered VH observations

        mean_converted_filtered_vh = converted_filtered_vh.mean(dim = "time")

        fig = plt.figure(figsize=(7,9))
        mean_converted_filtered_vh.plot(cmap = "Blues")
        plt.title("Average filtered VH")
        plt.show()
```

As in the previous section, there are two blank cells to add the code to visualise the filtered *VV* band. Again, typing out the code is recommended, using the code for visualising the filtered *VH* band as a guide.

Visualise Filtered VV bands

```
In [ ]: # Plot all filtered VV observations for the year
```

```
In [ ]: # Plot the average of all filtered VV observations
```

8.4.2.6 Visualising the impact of filtering through a histogram

Rather than viewing the 2-dimensional images, the analysis condenses information by plotting a histogram of the pixel values in each image. Given that it's possible to visually distinguish land and water in the 2-dimensional images, a histogram can help determine if there's a meaningful separation in pixel value between land and water. Run the two cells to plot the histograms for the *VH* and *VV* bands. These plots have histograms for the data before and after filtering, so take the opportunity to observe the impact of filtering.

```
In [ ]: fig = plt.figure(figsize = (15,3))
        _ = np.log10(dataset.filtered_vh).plot.hist(bins = 1000, label = "VH filtered")
        _ = np.log10(dataset.vh).plot.hist(bins = 1000, label = "VH", alpha = .5)
        plt.legend()
        plt.title("Comparison of filtered VH bands to original")
        plt.show()
```

```
In [ ]: fig = plt.figure(figsize = (15,3))
        _ = np.log10(dataset.filtered_vv).plot.hist(bins = 1000, label = "VV filtered")
        _ = np.log10(dataset.vv).plot.hist(bins = 1000, label = "VV", alpha = .5)
        plt.legend()
        plt.title("Comparison of filtered VV bands to original")
        plt.show()
```

Note that the filtered data will appear as the solid blue histogram, and that the original data will appear as the transparent orange histogram. The bimodal distribution in the histograms corresponds to the fact that water pixels have a lower pixel value than land pixels. Confirm this by looking back at the 2-dimensional images, where the water appears lighter than the land.

Given that the two distributions are easily distinguished in the filtered *VH* data, this will form the basis for a classifier in the next section.

8.4.2.7 Designing the water classifier

The classifier will take the form of a step function: if a pixel value is below the threshold, it will be classified as water; if it's above the threshold, it will be classified as not water (land).

$$\text{water}(VH) = \begin{cases} \text{True} & : VH < \text{threshold} \\ \text{False} & : VH \geq \text{threshold} \end{cases}$$

Setting a reasonable threshold is the most important aspect of using this classification approach. The difference between the two distributions in the histograms from the last section is strongest in the filtered *VH* band, so the analysis will use this as the basis for the threshold. Then it's a matter of selecting a *VH* band pixel value to act as the threshold. Looking at the histogram, -2 looks like a reasonable value, so this has been chosen as the default. Experiment with other values, as long as they cleanly separate the two *VH* band pixel distributions.

```
In [ ]: threshold = -2.0
```

After running the cell to define the threshold, visualise the position of the threshold on the histogram by running the following two cells. This should help determine if the threshold value meaningfully separates the pixel distributions.

```
In [ ]: fig = plt.figure(figsize = (15,3))
        plt.axvline(x=-2, label='Threshold at {}'.format(threshold), color = "red")
        _ = np.log10(dataset.filtered_vh).plot.hist(bins = 1000, label = "VH filtered")
        _ = np.log10(dataset.vh).plot.hist(bins = 1000, label = "VH", alpha = .5)
        plt.legend()
        plt.title("Histogram Comparison of filtered VH bands to original")
        plt.show()
```

```
In [ ]: fig, ax = plt.subplots(figsize = (15,3))
        _ = np.log10(dataset.filtered_vh).plot.hist(bins = 1000, label = "VH filtered")
        ax.axvspan(xmin=-2,xmax = -.5, alpha=0.25, color='red', label = "Not Water")
        ax.axvspan(xmin=-3.7,xmax = -2, alpha=0.25, color='green', label = "Water")
        plt.legend()
        plt.title("Effect of the classifier")
        plt.show()
```

8.4.2.8 Build and apply the classifier

Now that the threshold is defined, the next step of the analysis is to build a function to classify the pixels in the data set. The basic steps involved in classifying the data are:

1. Check the data set has a *VH* band to classify.
2. Clean the data by applying the speckle filter.
3. Convert the *VH* band measurements from digital number (DN) to decibels (dB) by taking the base-10 logarithm.
4. Find all pixels that have filtered dB values lower than the threshold; these are the ‘water’ pixels.
5. Return a data set containing the ‘water’ pixels.

The function has been defined already but take some time to match the steps in the Python function to the steps outlined above. Run the cell to define the function.

```
In [ ]: import numpy as np
        import xarray as xr

        def s1_water_classifier(ds:xr.Dataset, threshold = -2) -> xr.Dataset:
            assert "vh" in ds.data_vars, "This classifier is expecting a variable named `vh` expressed in DN, not DB values"
            filtered = ds.vh.groupby('time').apply(lee_filter, size=7)
            water_data_array = np.log10(filtered) < threshold
            return water_data_array.to_dataset(name = "s1_water")
```

Note that the default threshold is defined as -2. Running the function without specifying the threshold will automatically use the default value.

After defining the function, run it on the data set using the following cell. This adds ‘s1_water’ as a variable to ‘dataset’.

```
In [ ]: dataset["s1_water"] = s1_water_classifier(dataset).s1_water
```

8.4.2.9 Validation

It’s important to assess how well the classifier has performed. Importantly, recall that the classifier function is asking “is this pixel water?”, resulting in ‘True’ if yes, and ‘False’ if no. Since Python encodes ‘True’ as 1 and ‘False’ as 0, the ‘s1_water’ dataset will be made up of zeros and ones.

8.4.2.9.1 Using the mean

Calculating the mean of the ‘s1_water’ dataset over all time steps provides an assessment of how often a particular pixel is classified as ‘water’ or ‘not water’. If a pixel is always classified as water, it should have a mean of 1, and if it's always classified as 'not water', it should have a mean of 0. Pixels that are sometimes water and sometimes not will have an average between these two values.

Plot the 2-dimensional image of the mean classified value by running the cell in the 'Validation with mean' section.

In [ ]:
```
# Plot the mean of each classified pixel value

plt.figure(figsize = (15,12))
dataset.s1_water.mean(dim = "time").plot(cmap = "RdBu")
plt.title("Average classified pixel value")
plt.show()
```

8.4.2.9.2 Using the standard deviation

It's also possible to use the standard deviation of 's1_water' to assess the classifier. In this case, pixels that are consistently 'water' or 'not water' will have a standard deviation of 0, and pixels that vary will have non-zero standard deviation.

Write the code to plot this image. Follow the code for plotting the mean of 's1_water' but replace the 'mean' function with the standard deviation function 'std'. Again, typing out the code is recommended to practice using the Open Data Cube package.

In [ ]:
```
# Plot the standard deviation of each classified pixel value
```

8.4.2.10 Detecting Coastal Change

While the mean and standard deviation for the data set show an estimate of the shoreline for the entire data set, it may also be useful to see which pixels change between individual timesteps. This last section of the notebook demonstrates how to perform a simple difference calculation and inspect the results.

Start by selecting the images to compare. This is done by specifying the start and end timesteps to compare. Go back to the summary of the data set to check the number of time steps. Remember that Python indexing starts at 0, so choose any index between 0 and one fewer than the number of time steps. The default choices are the first and last steps.

In [ ]:
```
start_time_index = 0
end_time_index = 26
```

Next, take the difference by subtracting the water classification image at the first time step from that at the final time step. Notice that the analysis changes any cells that had the exact same classification (a difference of 0) to 'NaN' so that they don't display in the plot. The change data is then added to the data set so it can be plotted in the final cell.

In [ ]:
```
change = dataset.s1_water.isel(time = start_time_index) - dataset.s1_water.isel(time = end_time_index)
change = change.where(change != 0)  # set all '0' entries to NaN, which prevents them from displaying in the plot.
dataset["change"] = change
```

Now that we've added change to the data set, you should be able to plot it below to look at which pixels changed. You can also plot the original mean *VH* composite to see how well the change matches our understanding of the shoreline location.

In [ ]:
```
plt.figure(figsize = (15,12))
dataset.filtered_vh.mean(dim = "time").plot(cmap = "Blues")
dataset.change.plot(cmap = "RdBu", levels = 2)
plt.title('Change in pixel value between time={} and time={}'.format(start_time_index, end_time_index))
plt.show()
```

8.4.2.11 Drawing conclusions from the analysis

The ‘Drawing conclusions’ section of the notebook provides some questions following the analysis. Spend some time thinking about how best to answer these.

8.4.2.12 Next steps

Spend any remaining time exploring how to change the notebook. The primary change is to run the analysis again for a different latitude and longitude. As long as the DEA Dashboard has data, the analysis can be run there. Check the availability of Sentinel-1 data at https://dashboard.dea-sandbox.test.frontiersi.io/s1_gamma0_geotif_scene.

Use the interactive map cell from the beginning of the notebook to capture a similar area as the dashboard. Then click the interactive map to return the latitude and longitude values for any point and use these for analysis.

8.4.2.13 Challenge!

For a challenge, think about how to extract a shapefile for the shoreline given the mean and standard deviation plots developed when verifying the classifier. Think about both how to identify which pixels are shoreline, as well as how to build code to trace the shoreline. Look at the functions in ‘utils/waterline_funcs.py’ for inspiration about how to solve this problem. You’ll need to be very comfortable programming with Python if you want to attempt to build this. If you’re not comfortable, even thinking about how you might do it is a very valuable exercise and will stand you in good stead for using the Open Data Cube library for your own analyses.

There is also another interesting Jupyter Notebook available to work through in the FrontierSI sandbox examples folder called ‘casestudy_shipping_dask.ipynb’ at https://dea-sandbox.test.frontiersi.io/user/sandbox/notebooks/examples/casestudy_shipping_dask.ipynb. This notebook identifies ships and shipping lanes from Sentinel-1 data.

APPENDIX Resources

The following sections provide links to many other sources of information for the Hub and Copernicus Sentinel data.

A.1 The Hub

This section focusses on the Copernicus Australasia Regional Data Hub and links to access data and related information for the Hub.

- Home page – http://www.copernicus.gov.au/
- SARA access – https://copernicus.nci.org.au/sara.client/#/explore
- SARA help - https://copernicus.nci.org.au/sara.client/#/help
- Current collections xml - https://copernicus.nci.org.au/sara.server/1.0/collections.xml
- Current collections json - https://copernicus.nci.org.au/sara.server/1.0/collections.json
- SARA API source code - https://bitbucket.org/chchrsc/auscophub/overview
- SARA API package information - https://auscophub.readthedocs.io/en/latest/auscophub_saraclient.html
- SARA API query parameters –
  - S1 http://copernicus.nci.org.au/sara.server/1.0/api/collections/S1/describe.xml
  - S2 http://copernicus.nci.org.au/sara.server/1.0/api/collections/S2/describe.xml
  - S3 http://copernicus.nci.org.au/sara.server/1.0/api/collections/S3/describe.xml
  - All http://copernicus.nci.org.au/sara.server/1.0/api/collections/describe.xml
- SARA map interface bulk download guide – https://docs.google.com/document/d/1nfxWJe2YdXrcdko595DOwlsfPlj83WuGpdPvDPwYrwo/edit
- DownThemAll! - https://www.downthemall.net/
- aria2 - https://aria2.github.io/
- webui-aria2 - https://github.com/ziahamza/webui-aria2
- THREDDS access – http://dapds00.nci.org.au/thredds/catalogs/fj7/catalog.html
- Factsheet - http://www.copernicus.gov.au/__data/assets/pdf_file/0009/74682/PP-2519-Copernicus-Australiasia-factsheet_FA2-WAGC.PDF
- Contact - http://www.copernicus.gov.au/contact-us

A.2 About Copernicus

This section provides links to European websites with information on the Copernicus Programme and each organisations role.

- European Commission Copernicus - https://www.copernicus.eu/en
- ESA Copernicus - http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus
- EUMETSAT Copernicus - https://www.eumetsat.int/website/home/Copernicus/AboutCopernicus/index.html

A.3 ESA Sentinel Online

This section provides ESA Sentinel Online web page links to descriptions of the missions, the user guides, the technical guides, the thematic areas, data access and Sentinel toolboxes. This is the primary source of Sentinel user guide information.

- Home page - https://sentinels.copernicus.eu/web/sentinel/home
- Missions - https://sentinels.copernicus.eu/web/sentinel/missions
  - S1 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1
  - S2 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2
  - S3 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3
  - S5P https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-5p
- User guides - https://sentinels.copernicus.eu/web/sentinel/user-guides
  - S1 https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar
  - S2 https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi
  - S3 OLCI https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-3-olci
  - S3 SLSTR https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-3-slstr
  - S3 SYNERGY https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-3-synergy
  - S3 SRAL https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-3-altimetry
  - S5P https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-5p-tropomi
- Technical guides - https://sentinels.copernicus.eu/web/sentinel/sentinel-technical-guides
  - S1 https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-1-sar
  - S2 https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi
  - S3 OLCI https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-olci
  - S3 SLSTR https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-slstr

– S3 SYNERGY https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-synergy

– S3 SRAL https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry

– S5P https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms

- Thematic areas - https://sentinels.copernicus.eu/web/sentinel/thematic-areas
- Data access - https://sentinels.copernicus.eu/web/sentinel/sentinel-data-access
- Toolboxes - https://sentinels.copernicus.eu/web/sentinel/toolboxes

A.4 Alternative Copernicus Data Access

This section provides links to alternative ways to access Sentinel data.

A.4.1 Data Hubs and National Mirrors

Official datahubs and mirrors by the Copernicus partners and Collaborative Ground Segment members.

- ESA Copernicus Open Access Hub - https://scihub.copernicus.eu/
- Austria National Mirror - https://data.sentinel.zamg.ac.at/#/home
- Finland National Mirror - https://finhub.nsdc.fmi.fi/#/home
- France National Mirror (PEPS) - https://peps.cnes.fr/rocket/#/home
- Germany National Mirror (CODE-DE) - https://code-de.org/
- Greece National Mirror - https://sentinels.space.noa.gr/
- Italy National Mirror - http://collaborative.mt.asi.it/#/home
- Norway National Mirror - https://colhub.met.no/#/home
- Portugal National Mirror - https://ipsentinel.ipma.pt/dhus/#/home
- Sweden National Mirror (SWEA) - https://www.rymdstyrelsen.se/satellitdata/nyheter/rymdstyrelsen-avvecklar-satellitdataverktyget-swea
- United Kingdom National Mirror (SEDAS) - http://sedas.satapps.org/

A.4.2 Partial Mirrors

Initiatives to integrate specific Sentinel data into existing search and discovery platforms.

- EUMETSAT Copernicus Online Data Access - https://coda.eumetsat.int/#/home

- EUMETCAST - https://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/index.html
- Alaska Satellite Facility - https://www.asf.alaska.edu/sentinel/
- Centre for Environmental Data Analysis (CEDA) - https://catalogue.ceda.ac.uk/?q=sentinel&record_types=Observation
- Theia - https://theia.cnes.fr/atdistrib/rocket/#/search?collection=SENTINEL2
- NOAA CoastWatch - https://coastwatch.noaa.gov/cw/index.html
- NASA Earthdata - https://search.earthdata.nasa.gov/search
- USGS EarthExplorer - https://earthexplorer.usgs.gov/

A.4.3 DIAS and Cloud Providers

Copernicus DIAS cloud environments and providers that host Copernicus Sentinel data and allow users to bring their own code to process it without the need to download the data.

- Amazon Web Services - https://registry.opendata.aws/sentinel-2/
- CREODIAS - https://creodias.eu/
- Google - https://cloud.google.com/storage/docs/public-datasets/sentinel-2
- mundi - https://mundiwebservices.com/
- ONDA - https://www.onda-dias.eu/cms/
- Planet - https://www.planet.com/pulse/sentinel-2-and-landsat-8-data-now-available-on-the-planet-platform/
- Sobloo - https://sobloo.eu/
- WEkEO - https://www.wekeo.eu/

A.4.4 Australian Data Access

Links to other Australian specific means to access Sentinel data.

- DEA –
  - Dashboard to search data https://dashboard.dea-sandbox.test.frontiersi.io
  - Sandbox to interact with data https://dea-sandbox.test.frontiersi.io
- National Map - https://nationalmap.gov.au/

A.5 Tools for Sentinel Data

This section provides links to tools specific to Copernicus Sentinel data discovery, download and processing.

A.5.1 Search & Download

GitHub tools for searching and downloading Sentinel data.

- auscophub - https://bitbucket.org/chchrsc/auscophub
- SARA - https://copernicus.nci.org.au/sara.client/#/home
- awsdownload - https://github.com/kraftek/awsdownload
- aws-sat-api - https://github.com/RemotePixel/aws-sat-api
- sentinelsat - https://github.com/sentinelsat/sentinelsat
- peps_download - https://github.com/olivierhagolle/peps_download
- sat-download - https://github.com/sat-utils/sat-download
- sat-api - https://github.com/sat-utils/sat-api
- Sentinel-download - https://github.com/olivierhagolle/Sentinel-download
- sentinelhub-py - https://github.com/sentinel-hub/sentinelhub-py
- Sentinel2ProductIngestor - https://github.com/sinergise/Sentinel2ProductIngestor
- sentinel2-search-api - https://github.com/beaorn/sentinel2-search-api
- sentinel2_aws - https://github.com/beaorn/sentinel2_aws

A.5.2 Viewers & Portals

Tools for viewing Sentinel data.

- AWS/Sinergise "Sentinel Image Browser" - https://apps.sentinel-hub.com/eo-browser/
- EOS "Land Viewer" - https://eos.com/landviewer/
- ESRI Sentinel-2 Explorer - https://sentinel2explorer.esri.com/
- jeobrowser "Rocket" - https://mapshup.com/projects/rocket/#/home
- mundialis "EO-me" - https://eome.mundialis.de/eome/client/index.html
- OceanDataLab - https://www.oceandatalab.com/8369d04b-9c25-4489-b3ca-70b96b30e42a
- RemotePixel "Viewer" - https://viewer.remotepixel.ca/#3/40/-70.5
- RemotePixel "Satellite Search" - https://remotepixel.ca/projects/satellitesearch.html
- Research and User Support - https://rus-copernicus.eu/portal/

- Sinergise "Sentinel Playground" - https://apps.sentinel-hub.com/sentinel-playground
- Sinergise "Sentinel-Hub" - https://www.sentinel-hub.com/
- SnapPlanet - https://snapplanet.io/
- Spectator - https://spectator.earth/
- Thematic Exploitation Platforms - https://tep.eo.esa.int/
- USGS "Sentinel2Look" - https://landsatlook.usgs.gov/sentinel2/viewer.html

A.5.3 Process

Tools for processing Sentinel data.

- SNAP (Sentinel Application Platform) - http://step.esa.int/main/toolboxes/snap/
- ARCSI (Atmospheric and Radiometric Correction of Satellite Imagery) - https://www.arcsi.remotesensing.info/
- ENVI - https://www.harrisgeospatial.com/Software-Technology/ENVI
- EOS Processing - https://auth.eos.com/#!/sign-in?return_url=https:%2F%2Fprocessing.eos.com%2F
- GAMMA - http://www.gamma-rs.ch/
- Google Earth Engine - https://earthengine.google.com/
- iCOR - https://blog.vito.be/remotesensing/icor_available
- MAJA (MACCS ATCOR Joint Algorithm) - https://logiciels.cnes.fr/en/content/maja
- ODC cube-in-a-box - https://github.com/opendatacube/cube-in-a-box
- panoply - https://try.panoply.io/data-warehouse-remarketing/
- PyRate - https://github.com/GeoscienceAustralia/PyRate (for processed InSAR)
- Sen2-Agri - https://github.com/Sen2Agri/Sen2Agri-System
- Sen2Cor - http://step.esa.int/main/third-party-plugins-2/sen2cor/
- sen2r - https://github.com/ranghetti/sen2r
- s2cloudless - https://github.com/sentinel-hub/sentinel2-cloud-detector
- wagl - https://github.com/GeoscienceAustralia/wagl

A.6 Copernicus Service Information products

This section provides links to European Copernicus global scale service information products.

- Copernicus Global Land service products - https://land.copernicus.eu/global/products/
- Copernicus Atmosphere service catalogue - https://atmosphere.copernicus.eu/
- Copernicus Marine Monitoring catalogue - http://marine.copernicus.eu/services-portfolio/access-to-products/
- Copernicus Emergency Management Service - https://emergency.copernicus.eu/
- Copernicus Climate Change service - https://climate.copernicus.eu/

The following product is also of interest:

- EOX "Sentinel-2 cloudless" - https://s2maps.eu/