**TRAINING KIT – OCEA06**

**ALTIMETRY USING SENTINEL-3 AND THE BRAT TOOLBOX**

Research and User Support for Sentinel Core Products

The RUS Service is funded by the European Commission, managed by the European Space Agency and operated by CSSI and its partners.

Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on training@rus-copernicus.eu

Cover image credits: contains modified Copernicus Sentinel data (2018), processed by ESA.

The following training material has been prepared by Serco Italia S.p.A. within the RUS Copernicus project.

Date of publication: July 2019

Version: 1.1

Suggested citation:

Serco Italia SPA (2018). *Altimetry using Sentinel-3 and the BRAT Toolbox (version 1.1)*. Retrieved from RUS Lectures at https://rus-copernicus.eu/portal/the-rus-library/learn-by-yourself/

---

DISCLAIMER

While every effort has been made to ensure the accuracy of the information contained in this publication, RUS Copernicus does not warrant its accuracy or will, regardless of its or their negligence, assume liability for any foreseeable or unforeseeable use made of this publication. Consequently, such use is at the recipient's own risk on the basis that any use by the recipient constitutes agreement to the terms of this disclaimer. The information contained in this publication does not purport to constitute professional advice.

# Table of Contents

# 1   Introduction to RUS

The Research and User Support for Sentinel core products (RUS) service provides a free and open scalable platform in a powerful computing environment, hosting a suite of open source toolboxes pre-installed on virtual machines, to handle and process data derived from the Copernicus Sentinel satellites constellation.

# 2   Introduction to BRAT

The Broadview Radar Altimetry Toolbox is a tool designed to use radar altimetry data. The toolbox is able to:

- Read all altimetry data from official data centres, from ERS-1 and 2, Topex/Poseidon, Geosat Follow-on, Jason-1, Envisat, Jason-2, Cryosat and Sentinel-3, from Sensor Geophysical Data Record to gridded merged data.
- Do some processing and computations.
- Visualise the results.

BRAT is an open source software with a GPL-3 license type. Its source code is publicly available on-line in a dedicated GitHub repository. Contributions from the altimetry community to the code are encouraged and everyone can propose new code to be committed to the master branch via the pull requests feature from GitHub.

BRAT can be downloaded along with a Radar Altimetry Tutorial at http://www.altimetry.info/.

# 3   Training - Proposed Exercises

Approximate duration of this training session is **one** hour.

**The Training Code for this tutorial is OCEA06. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal and open a User Service request from Your RUS service → Your dashboard.**

The following BRAT exercises will deal with:

- **Displaying variables in BRAT.**
- **Sea level and SWH at the coast with different retrackers.**
- **The importance of geophysical corrections.**

## 3.1   *Data used*

- 1 Official Sentinel-3 SRAL L2 WAT products [https://coda.eumetsat.int/#/home] and stored locally ***@/shared/Training/OCEA06_Altimetry_TutorialKit/Original/S3_data***
- S3A_SR_2_WAT____20180609T013721_20180609T022139_20180704T173753_2658_032_117_____MAR_O_NT_003

### 3.2 Software in RUS environment

BRAT

## 4 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on *Login/Register* in the upper right corner.
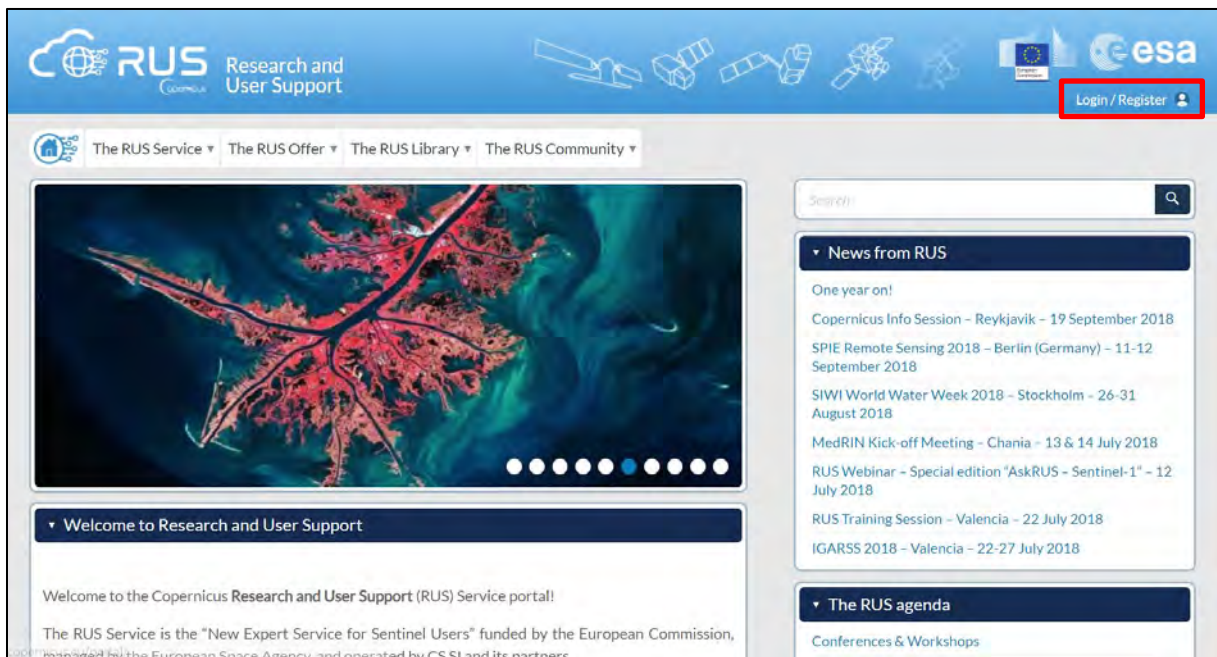


Select the option *Create my Copernicus SSO account* and then fill in ALL the fields on the Copernicus Users' Single Sign On Registration. Click *Register.*



Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

You can now return to https://rus-copernicus.eu/, click on *Login/Register*, choose *Login* and enter your chosen credentials.

Upon your first login you will need to enter some details. You must fill all the fields.



## 5 Request a RUS Copernicus Virtual Machine

Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on *Your RUS Service* → *Your Dashboard.*

Click on *Request a new User Service* to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.
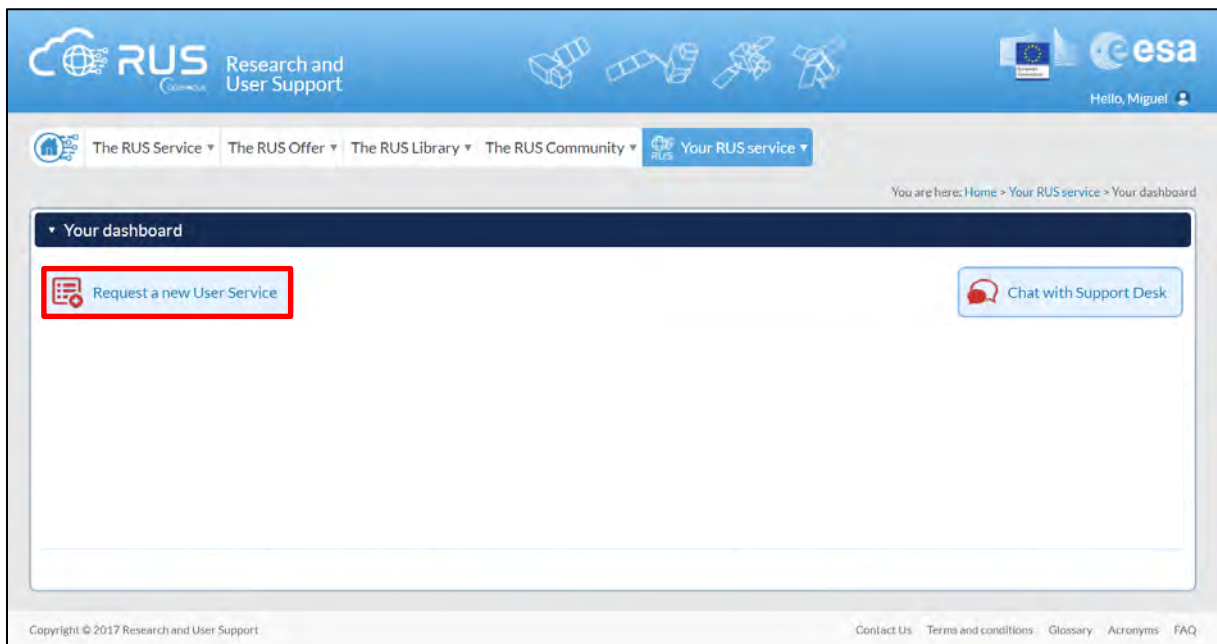


If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



Complete the remaining steps, check the terms and conditions of the RUS Service and submit your request once you are finished.

Further to the acceptance of your request by the RUS Helpdesk, you will receive a notification email with all the details about your Virtual Machine. To access it, go to *Your RUS Service → Your Dashboard* and click on *Access my Virtual Machine.*

Fill in the login credentials that have been provided to you by the RUS Helpdesk via email to access your RUS Copernicus Virtual Machine.
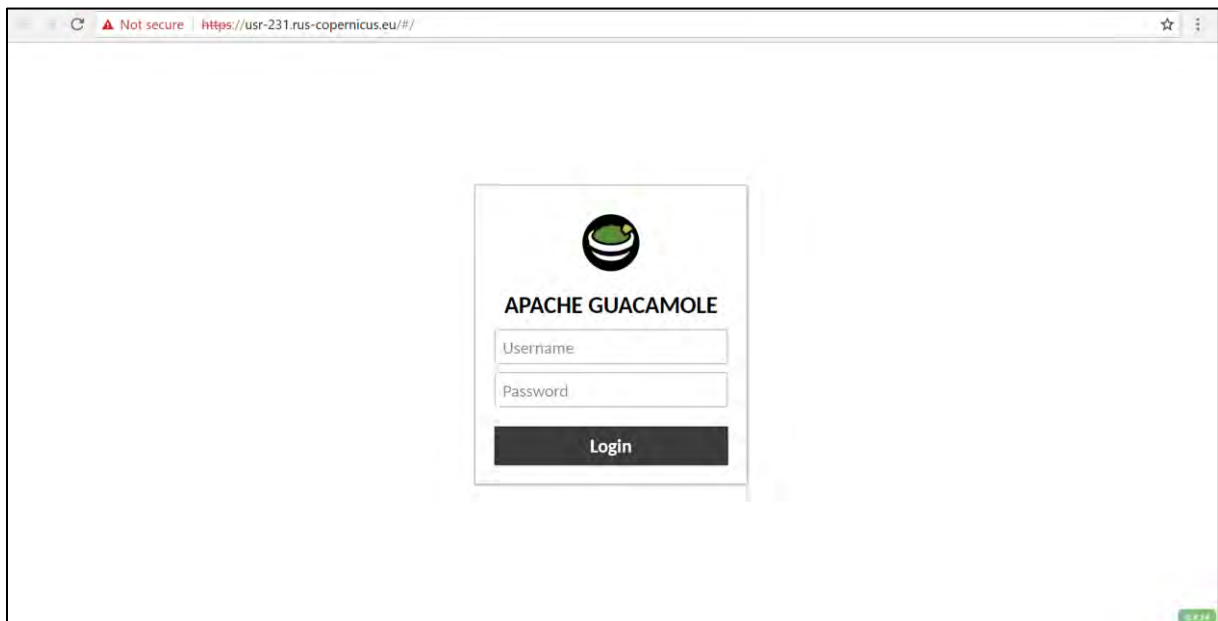


This is the remote desktop of your Virtual Machine.



# 6    Background on Radar Altimetry

Altimeters measure the **range** between the **satellite** and the **sea surface** observed at nadir (i.e. in the vertical direction pointing the direction of the force of gravity):

A reference ellipsoid shall be considered as baseline Datum (e.g. WGS84).

The satellite flies along the orbit in the along-track direction.

The orbit is typically determined with an accuracy (radial orbit error) of <2 cm by using SLR, GPS and DORIS data (10-100 m in '50s-'60s with optical data & 5-10 cm in current Near Teal Time, NRT, and Standard Time Critical, STC, L2 products discussed later).
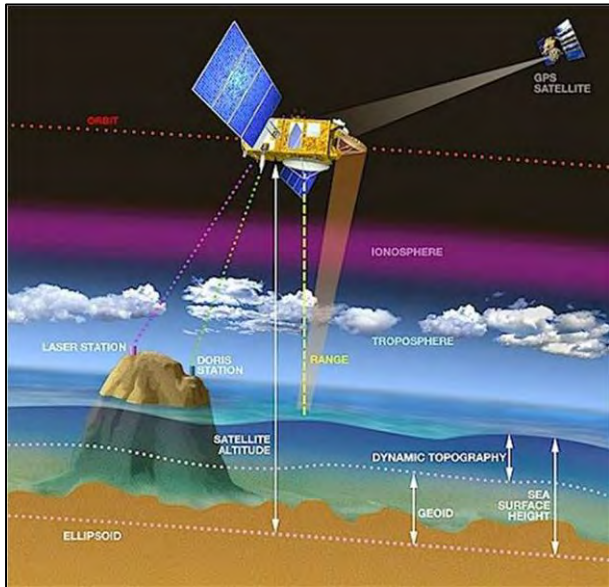
Geoids (i.e. the ocean surface excluding the influence of wind and tides) are obtained from other missions (e.g. GRACE, GOCE). No accurate oceanographic information can be obtained without an accurate geoid.

The range measurement shall be **corrected** for a series of effects related to the propagation into the Ionosphere/Troposphere, the instrument and the surface. We can write:

**Sea Surface Height (SSH): Satellite_Altitude - Corrected_Range.**

**Dynamic Topography: Mean Dynamic Topography (MDT) + Sea Level Anomaly.**

These quantities will be discussed in detail during the BRAT exercises. The aforementioned corrections are summarized in the figure below:
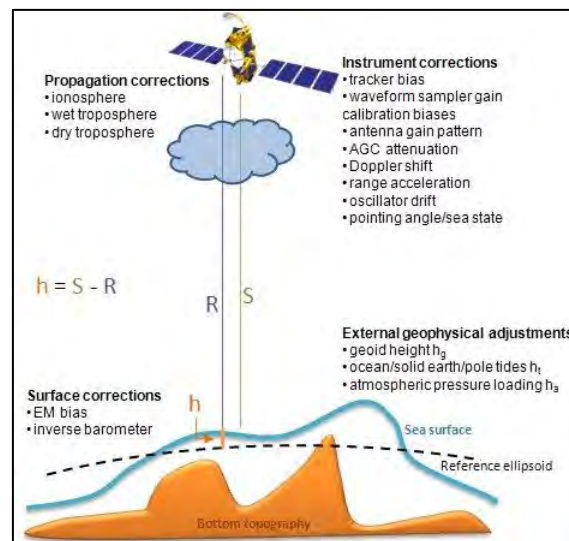


The resolution of the altimetry products will be discussed in the following 3 directions:

- **Along-track direction**: It is the direction of flight of the platform (blue box).

- **Across-track direction**: It is the direction perpendicular to the direction flight of the platform (red box).

- **Nadir direction**: vertical direction pointing the direction of the force of gravity (green box). The resolution in this direction is dictated by the bandwidth (350 MHz for the SRAL altimeter on board Sentinel-3) and is named range resolution (Res_range = speed_of light / 2 * Bandwidth = 0.43 m)

In general, the resolution indicates the capability of a system to sample the space in a direction. The

higher it is (lower in value) the better it is to study short scales phenomena, small water bodies (e.g. rivers & lakes) and retrieve the ocean surface parameters with the accuracy needed for oceanography studies (around 2 cm).
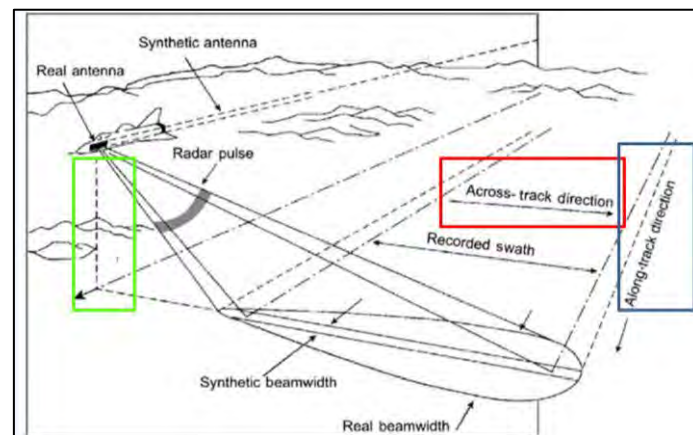


This scheme shall be considered only for the purpose of understanding these 3 directions. Altimetry sensors are in fact nadir-looking sensors and not side-looking as indicated in the figure.

Present, past and future altimetry missions are reported here:



The processing schemes that are currently adopted in radar altimetry are the **L**ow **R**esolution **M**ode (LRM) & the **S**ynthetic **A**perture **R**adar (SAR) mode. These will be discussed in the next sections. Sentinel-3 and Cryosat-2 missions operate the SAR mode. CryoSat-2 also includes LRM & SARin modes (in SARin two antennas are available for interferometry). All other missions are in LRM mode.

In the future, a new pulse transmission mode designed for Sentinel-6/Jason-CS will allow to obtain simultaneously SAR and LRM waveforms.

## 6.1    Processing schemes: Low Resolution Mode

Adopts a pulse limited acquisition. The pulse, propagating along the nadir direction as a spherical wave, strikes the surface and controls the area on ground from which the backscattering occurs (red area) over time. The time on target dictated by the beam illumination (blue area) during the overfly of a surface location is not exploited. The returned power (bottom panels) is typically formed by a flat region (noise, no power received power), a leading edge created by the first reflection up to the formation of the pulse limited footprint and the trailing edge related to the formation of annuli on ground whose backscattered power is constant but results attenuated by the non-constant gain at the border of the antenna pattern. The output LRM waveform is known in products as the **L1b waveform**.
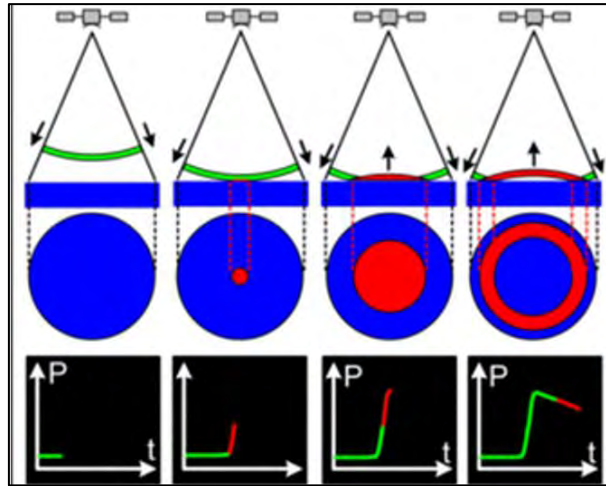
**Observed parameters:**

- **Significant Wave Height (SWH)**:  It is defined traditionally as the mean wave height (trough to crest) of sea waves and is related to the slope of the leading edge in the L1b waveform. The degree of steepness of the leading edge is related to the sea state (flat, SWH around 1m, or rough sea surface, typically 2m < SWH < 8m).
- **Range**: related to the mid-height value of the leading edge. It is independent from SWH.
- **Wind Speed (Power)**: related to the maximum received power at the end of the leading edge.

**Key points:**

- **Along/Across track resolution**: several km depending on the significant wave height (SWH). Typical values are from **2 km (SWH = 2m) to 12 km (SWH = 10m)**
- All estimates (SWH, Range, Wind Speed) are retrieved from the leading edge.
- A huge amount of power is wasted in constructing the trailing edge. This will not contribute to the retrieval of the estimates. This power is collected from the border of the antenna footprint (blue area).
- The transmitted pulse fully controls the creation of the echo, this is why this is also known as "*the pulse limited mode*".

The next figure relates the observed parameters with the received power.
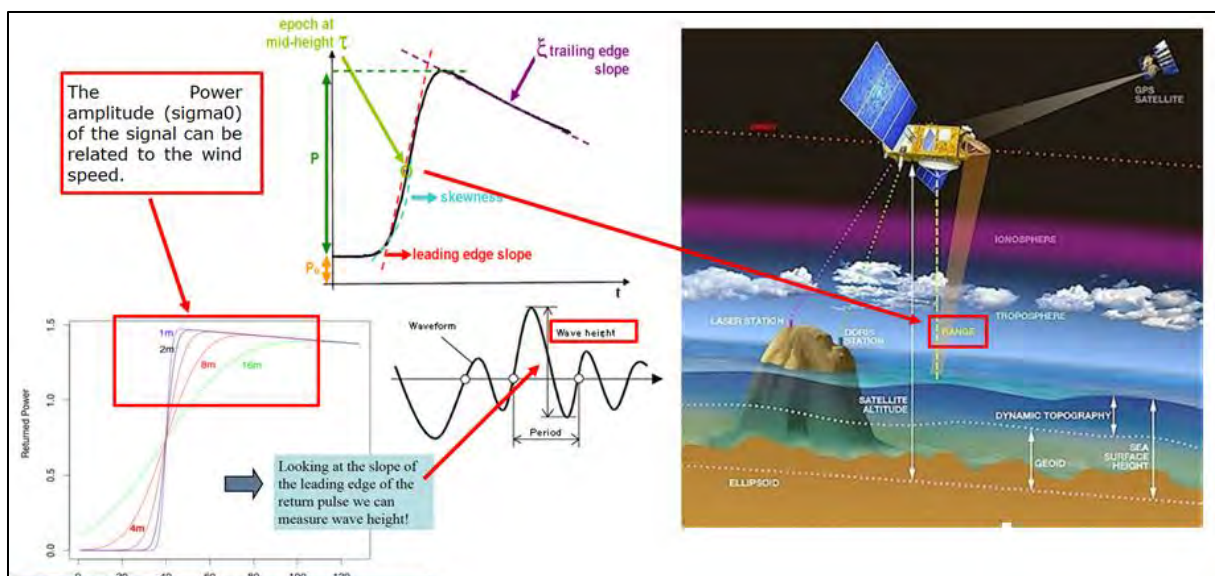
## 6.2   Processing schemes: Synthetic Aperture Radar
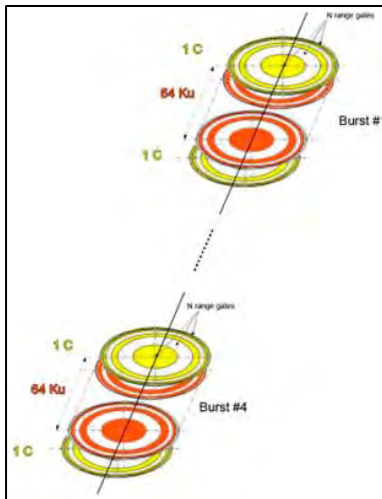


The time on target, dictated by the beam illumination and movement of the platform over the point, and the Doppler effect in the along-track direction are exploited in SAR mode.

A burst of pulses is transmitted (Sentinel-3, 66 pulses: 1 C-band pulse (**5.3 GHz**) / 64 Ku-band pulses (**13.575 GHz**) / 1 C-band pulse) and received.

Differently from the LRM, in which each pulse is received before the transmission of the next, in SAR, all the returns related to a burst shall be received before transmitting the successive burst.

Each pulse of the burst interacts as in the LRM mode, the SAR processing is performed after all data are collected.

The Doppler effect **induces a Doppler shift in the received frequency because of the relative motion between the moving sensor and the fixed point on ground.**
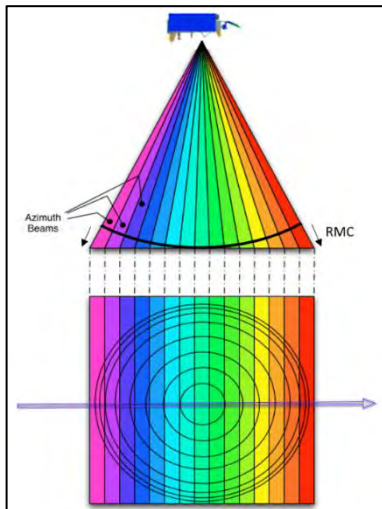


The Doppler shift is null at nadir where there is no relative movement between the satellite and the target point on ground. The SAR processing takes advantage of the Doppler effect to split the antenna beam in several beams whose width is related to the Doppler resolution.

Beams are then steered to specific surface locations. As a result, considering all the subsequent transmissions during the time on target, each point on ground results seen though different beams from different directions. For each surface point, beams are stacked and multi-looked (incoherently averaged) to reduce the speckle noise:
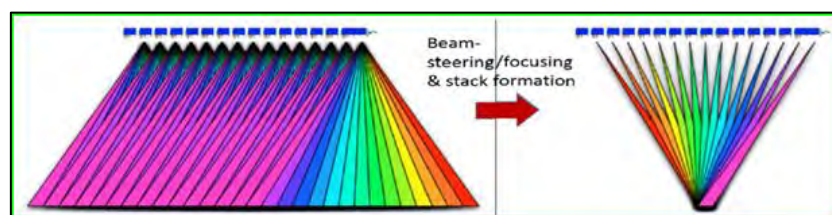


As a result, the SNR and along-track resolution are improved in comparison to the LRM mode.

By comparing to the LRM mode waveform construction (first figure of section 6.1), the power coming from the annuli and creating the LRM waveform trailing edge, is in SAR, collected by the outer beams (e.g. those colored in pink & red) and will contribute together with all other beams in the stack to reconstruct the power backscattered in all the investigated directions by the surface point on ground.

The power of the trailing edge, being relocated to the leading edge by the stacking (all beams point the surface location observed by the nadir beam, the reference), is lower if compared to that in the LRM waveform. The SNR of the leading edge will therefore improve as depicted later in figures.

Again, as not only the nadir direction but all the directions allowed by the SAR processing formulation are considered, the surface state (flat or rough) does not affect the capability of recovering all the backscattered power (returning at nadir if the surface is flat or distributed in various directions if the surface is rough).

Therefore, the resolution in the along-track direction is in SAR fixed in value and independent from the SWH.

**Key points**:

- The time on target dictated by the satellite speed and beam illumination is exploited.
- **Along track resolution**: improves **up to 300 m (independent from SWH)**. The Doppler effect can be exploited only in this direction.
- **Across track resolution**: same as LRM (**dependent upon SWH**, typically **2-12 Km**).
- Higher SNR due to the SAR processing beam segmentation, stacking & integration.

The figure below clarifies the difference of LRM and SAR L1b waveforms underlining the improvement in SNR (higher leading edge power) and the reduction of power wasted in the trailing edge.
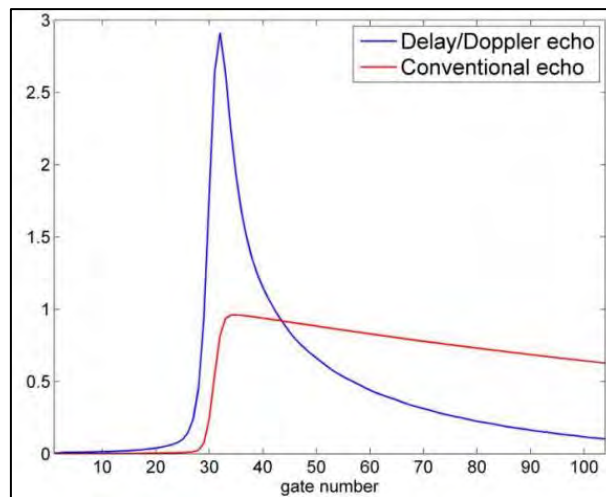


The SAR processing is currently adopted on Sentinel-3 and Cryosat-2. More information about the SAR processing can be found in this paper:

R. K. Raney, "The delay/Doppler radar altimeter," IEEE Trans. Geosci. Remote Sens., vol. 36, no. 5, pp. 1578–1588, Sep. 1998. DOI: 10.1109/36.718861

The future of SAR processing is the **F**ully-**F**ocused **SAR** developed in the paper "*Fully Focused SAR Altimetry: Theory And Applications*" by Egido And Smith (2016) Doi: 10.1109/Tgrs.2016.2607122

- FF SAR processing can reduce the along-track resolution down to the theoretical limit equal to half the antenna length (i.e. 0.5 m).

- The footprint of an FF-SAR altimeter measurement is a narrow strip on the surface, which is pulse limited across track (LRM mode) and SAR focused along track.

The following figure compares the along- and across-track resolution in the 3 modes:
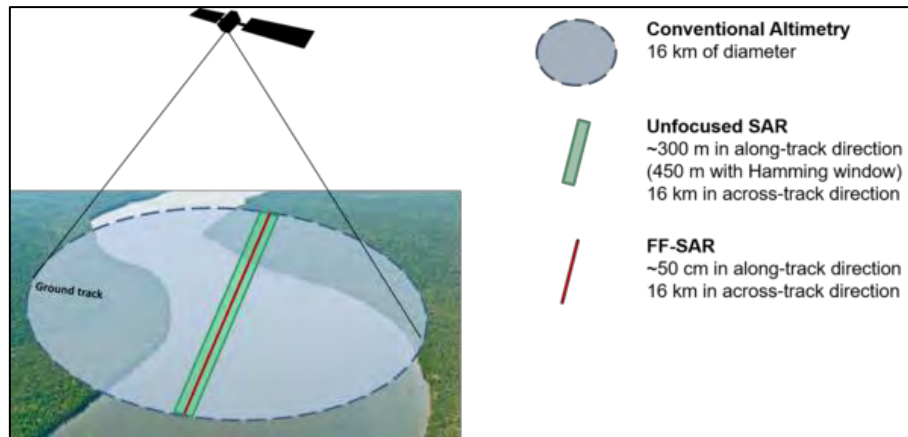
The Fully-Focused SAR is not implemented in current altimetry missions.

## 6.3 L1b waveforms

The shape of L1b waveforms acquired in open ocean, depends on the operative mode (LRM/Conventional or SAR/Delay-Doppler). LRM and SAR L1b waveforms are different and require different L2 processors (retrackers) to correctly estimate the quantities of interest (range, SWH, wind speed). L1b waveforms processed over different scenarios (open ocean, coastal zone and inland water) require different retrackers.
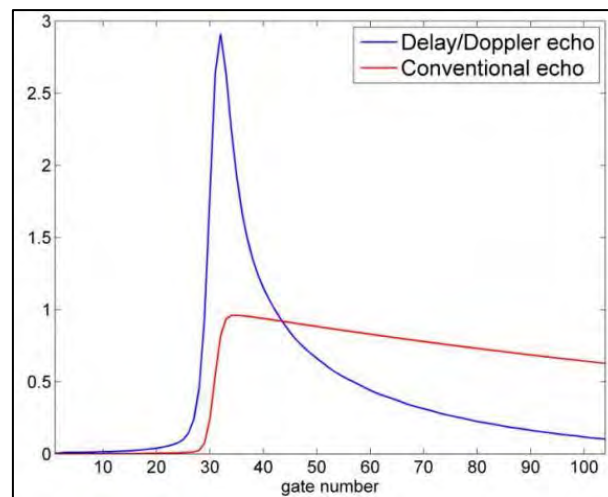


L1b waveforms acquired in the coastal zone can be significantly distorted due to the presence of the coast in the radar footprint. Moreover, troposphere corrections obtained from the on-board radiometer are contaminated and models are required. Altimetry estimates from such L1b waveforms are not reliable and shall not be used without applying filtering criteria. The SAR operative mode (300 m resolution in along-track) allows to acquire more valid waveforms in approaching the coast than the LRM mode (7 km in along-track). The shape of the waveform can be checked for filtering purposes.
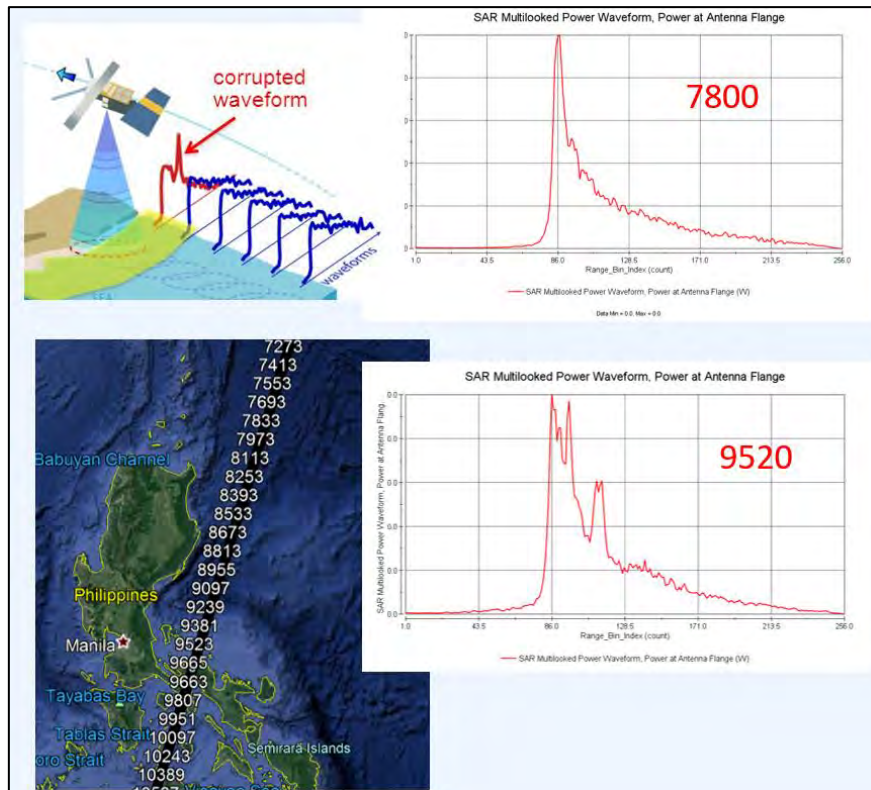
Jason-2 SIGDR products include LRM L1b waveforms and can be opened in BRAT v.4.2.1 and plotted creating a video.

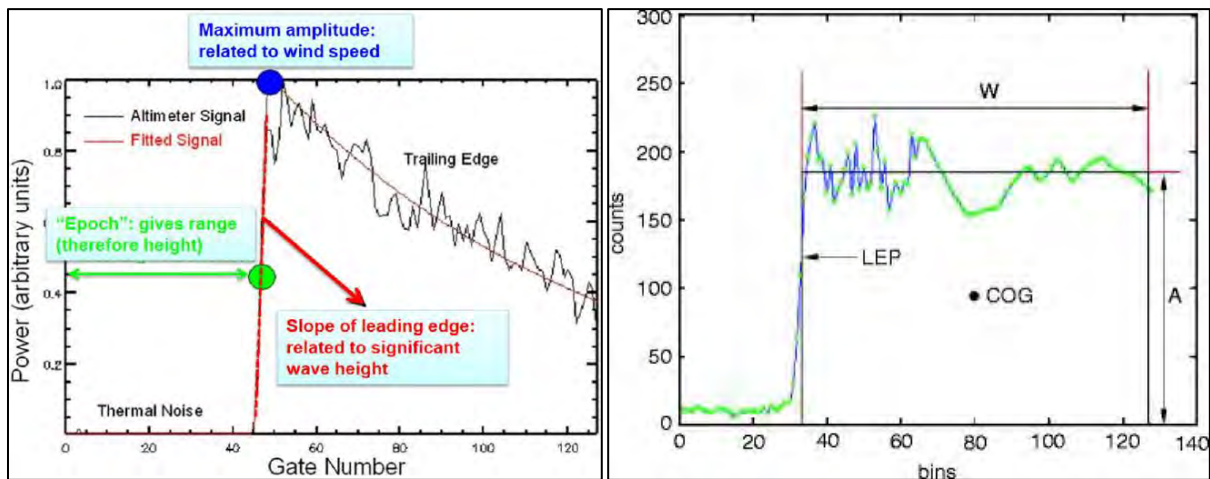## 6.4    Retracking & L2 Products

The Retracking processing is applied on L1b waveforms (SAR, LRM) and can be based on a model (analytical) or be empirical.

In the **Analytical retracking** (left image below), the algorithm:

- Finds the gate of the mid-height of leading edge in the return L1b waveform which is associated with the range.
- Fits the returned echo to a waveform model corresponding to the observed target (e.g. the Brown model for rough ocean): Several models will be tested and fitted to the altimeter signal, by varying **SWH**, **range** and **power**, the best fit will minimize the error according to some criteria, e.g. the **N**ormalized **R**esidual **E**rror (NRE).
- Corrects the range measurements from the on-satellite tracking algorithm according to the departure between the mid-gate and original measurement.

The time over which the above LRM L1b waveform is constructed, is sampled in gates whose width is dictated by the range resolution of the radar in the nadir direction discussed in section 3.

Differently, **Empirical retrackers** (right image below) (e.g. OCOG, threshold, β retracker) work on the statistics of the waveform to extract only the leading edge position and the power. In OCOG retracking, the echo is replaced with a box that has the same center of area as the echo (Center of Gravity - CoG). The **L**eading **E**dge **P**osition (**LEP**) is taken as the point on the echo that first crosses the amplitude **A**, where **A** is an empirically determined threshold. No functional fitting is applied, it is fast and easy to implement but less accurate than physical retrackers.

**L2 products** are created after the retracking process and include the estimated **SWH** (only in the analytical retracking), **range** & **power** (named also **sigma0)**. Geophysical corrections are also included in the typical output netCDF/binary files.

Estimates are provided with a specific sampling along the track. This is dictated by the operative mode (SAR, LRM) and by the need of creating accurate products for applications such as oceanography and coastal/inland water altimetry.

Posting rates in L2 products are the following:

- **1-Hz:** from LRM mode (7 km sampling in the along-track direction). Individual L1b waveforms are averaged over 7 km to obtain a smooth signal suitable for oceanographic estimation (high accuracy, ~4 cm).

- **20-Hz:** from SAR mode (~300 m sampling in the along-track direction, see figure below) or LRM mode (by averaging a lower number of individual waveforms over 50 ms).
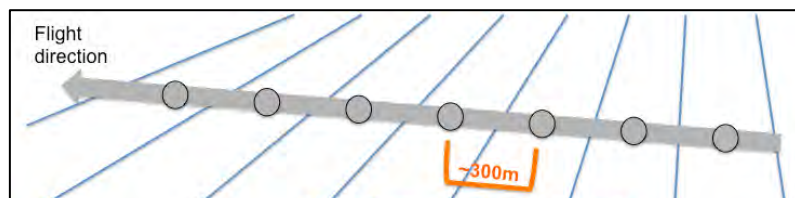


It is important to keep in mind that:

1. In the LRM mode a certain number of individual waveforms is averaged to reduce the speckle noise, allow the analytical retracking through models expecting smooth waveforms and produce data with the two posting rates above (1Hz, 20Hz),
2. In the SAR mode, a 20Hz estimate is produced differently by using a Doppler processing which is able to reduce the footprint to 300 m.

Even if the posting rate can be at 20Hz (300 m) for both SAR and LRM, the along-track resolution of these estimates is not comparable.

At the moment, SAR mode is operative on Sentinel-3 and Cryosat-2 missions. Many present and all past missions are in LRM mode. SAR waveforms can be degraded to produce ReDuced-SAR (RDSAR)/pseudo-LRM waveforms at 1Hz (7-km spacing). A SAR 4-burst cycle is ~ 1 LRM cycle of 50 ms (20Hz). pLRM mode is used to derive pseudo LRM waveforms from 4 SAR bursts. Therefore, the RDSAR processing allows to produce data which are not statistically equivalent to LRM data but that can be

combined with past LRM missions' data to increase the length of the time series for climate studies. This demonstrates the effort put in establishing a continuity with previous altimeter datasets.

In the next exercises, both 1Hz & 20Hz data from Sentinel-3 will be considered. Typical Sentinel-3 netCDF products include data at different posting rates (01,20) and from different retrackers (_ice_, _ocean_,_ocog_,_sea_ice_):

| | |
|---|---|
| range_ice_20_c | corrected 'ice' altimeter range : 20 Hz C band |
| range_ice_20_ku | corrected 'ice' altimeter range : 20 Hz Ku band |
| range_ice_20_plrm_ku | corrected 'ice' altimeter range : 20 Hz Plrm Ku band |
| range_ice_sheet_20_c | corrected 'ice-sheet' altimeter range : 20 Hz C band |
| range_ice_sheet_20_ku | corrected 'ice-sheet' altimeter range : 20 Hz Ku band |
| range_ocean_01_c | corrected 'ocean' altimeter range : 1 Hz C band |
| range_ocean_01_ku | corrected 'ocean' altimeter range : 1 Hz Ku band |
| range_ocean_01_plrm_ku | corrected 'ocean' altimeter range : 1 Hz Plrm Ku band |
| range_ocean_20_c | corrected 'ocean' altimeter range : 20 Hz C band |
| range_ocean_20_ku | corrected 'ocean' altimeter range : 20 Hz Ku band |
| range_ocean_20_plrm_ku | corrected 'ocean' altimeter range : 20 Hz Plrm Ku band |
| range_ocean_numval_01_c | number of valid points used to compute the 'ocean' altimeter ra... |
| range_ocean_numval_01_ku | number of valid points used to compute the 'ocean' altimeter ra... |
| range_ocean_numval_01_plrm_ku | number of valid points used to compute the 'ocean' altimeter ra... |
| range_ocean_qual_01_c | quality flag for the 'ocean' altimeter range : 1 Hz C band |
| range_ocean_qual_01_ku | quality flag for the 'ocean' altimeter range : 1 Hz Ku band |
| range_ocean_qual_01_plrm_ku | quality flag for the 'ocean' altimeter range : 1 Hz Plrm Ku band |
| range_ocean_qual_20_c | quality flag for the 'ocean' altimeter range : 20 Hz C band |
| range_ocean_qual_20_ku | quality flag for the 'ocean' altimeter range : 20 Hz Ku band |
| range_ocean_qual_20_plrm_ku | quality flag for the 'ocean' altimeter range : 20 Hz Plrm Ku band |
| range_ocean_rms_01_c | RMS of the 'ocean' altimeter range : 1 Hz C band |
| range_ocean_rms_01_ku | RMS of the 'ocean' altimeter range : 1 Hz Ku band |
| range_ocean_rms_01_plrm_ku | RMS of the 'ocean' altimeter range : 1 Hz Plrm Ku band |
| range_ocog_20_c | corrected ocog altimeter range : 20 Hz C band |
| range_ocog_20_ku | corrected ocog altimeter range : 20 Hz Ku band |
| range_sea_ice_20_ku | corrected 'sea ice' altimeter range : 20 Hz Ku band |

Some other information about the Sentinel-3 mission are reported below:
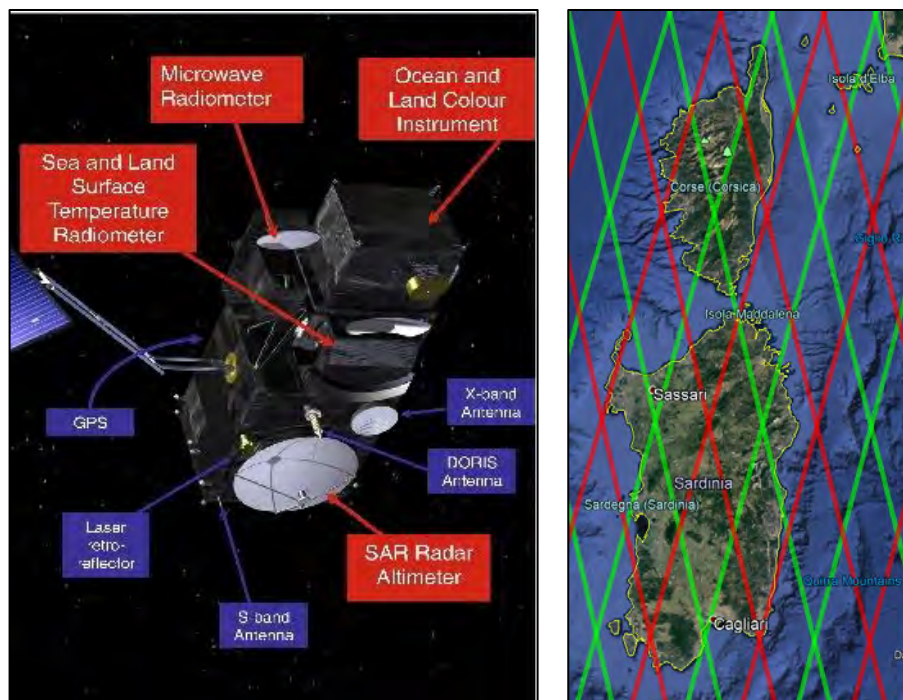


- The main objective of the Sentinel-3 mission is to measure: sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring.

18

- The satellite orbit provides a **27-day repeat cycle** for the topography package. Latitude is up to **82 degrees** (Cryosat-2 reaches 88 degrees).

- A **Sea and Land Surface Temperature Radiometer (SLSTR)** to determine **global sea-surface temperatures**.

- An **Ocean and Land Colour Instrument (OLCI)** is also part of the payload.

- A **dual-frequency** (Ku and C band) **advanced Synthetic Aperture Radar Altimeter (SRAL)** is based on CryoSat-2 heritage and provides 20 Hz measurements at a resolution of ~300m in SAR mode along track.

- SRAL is supported by a microwave radiometer for atmospheric correction and a DORIS receiver for orbit positioning.

Data are distributed in 3 timeliness (NRT, STC, NTC) according to the accuracy of the orbit:

**POD radial accuracy requirements (rms)**
- Near Real Time (NRT < 3h): 10 cm (8 cm goal)
- Short Time Critical (STC < 48h): 4 cm (3 cm goal)
- Non Time Critical (NTC < 1 month): 3 cm (2 cm goal)

Sentinel-3 tracks in .kml format (see figure above, right panel) can be downloaded from:
https://sentinel.esa.int/web/sentinel/missions/sentinel-3/satellite-description/orbit

## 6.5    Auxiliary data

Gauges locally measure relative sea level, absolute level if they are referenced to an ellipsoid (e.g. WGS84) with a GPS.

Tide gauge measurements (e.g. collected every 10 min, every hour…) are made with respect to a local fixed reference level on land. Local vertical land motion can be corrected by using GPS data.

When reference datums are different, a de-meaning (subtracting the mean from each set of observations so that they are zero-mean) shall be applied when comparing TG and Altimeter dataset.
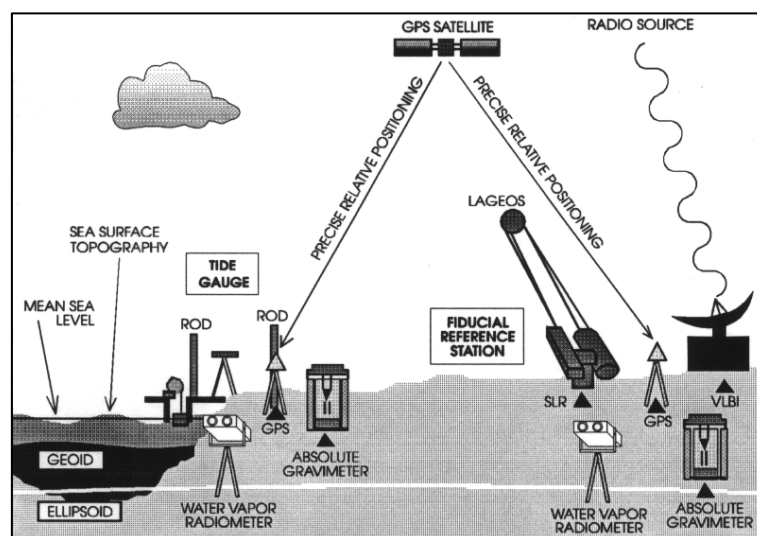


In the next figures, the RMS difference of de-meaned water lavel from altimetry and tide gauges as a function of the search radius around the tide gauges is reported. This kind of analyses can be made by

considering altimetry estimates acquired in approaching the coast (image credit: ESA/CP4O (left), ESA/SLCCI-BP (right)).
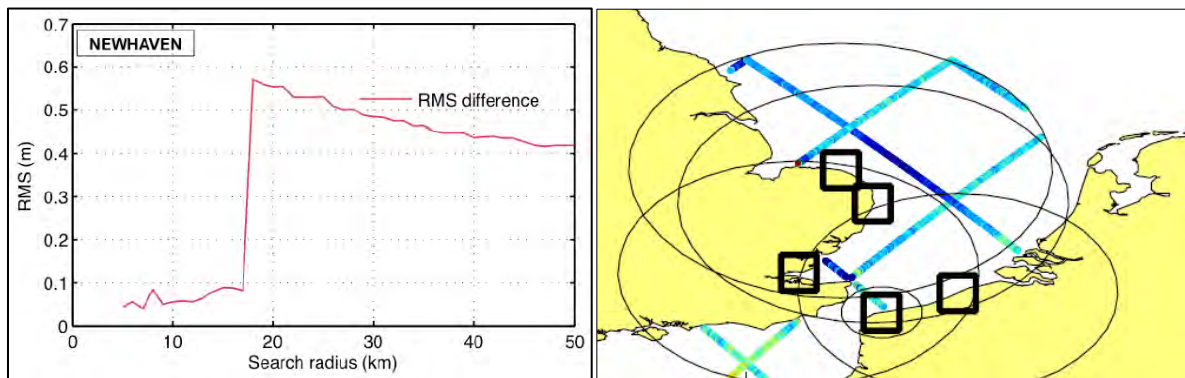


# 7   Step by step

## 7.1   Data download – EUMETSAT CODA portal

L2 Sentinel-3 altimetry data from SRAL are available in two types:

- Land Products "S3A_SR_2_**LAN**_XXX" (**distributed by ESA** at https://scihub.copernicus.eu) including inland water areas & coastal zone.
- Water Products "S3A_SR_2_**WAT**_XXX" (**distributed by EUMETSAT** at: https://coda.eumetsat.int/#/home) including coastal zone & open ocean.

The interface is the same on both websites and lower level products (e.g. L1B data) are available from both repositories.

In this training we will use **Sentinel-3 L2 WAT** products from **EUMETSAT**.

Before starting the exercise, make sure you are registered in the EUMETSAT Copernicus Online Data Access (CODA) repository so that you can access the free data provided by the Sentinel satellites.

Open an Internet Browser and go to https://coda.eumetsat.int/#/home (Instructions here on how to download, are given using Internet Explorer).

If you do not have an account, create an account using the button located in the lower left corner. Please fill in the details and conclude the registration. Once the registration procedure is over and the account created, log-in.

Afterwards, access the data catalouge by clicking on the Copernicus Online Data Access section indicated below:
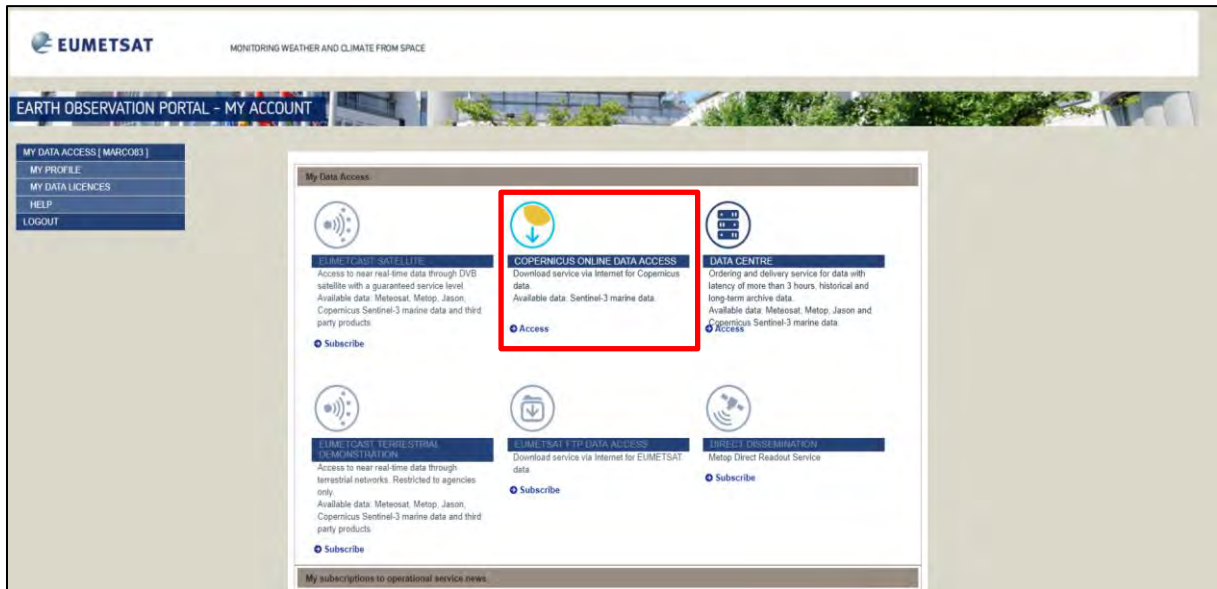


The data catalogue interface will show up:



For these exercises, we will use one track acquired in East China on June 9$^{th}$ 2018 by Sentinel-3A.

By holding the wheel button, or the right button, move the map to East China and then zoom (wheel button of the mouse) to obtain the following view:

To collect the data:

- draw a rectangle indicated below by holding the left mouse button,
- open the search menu by clicking at the left of the search bar (≡),
- specify the following parameters and press the search button (🔍):

**Sort by:** Sensing Date
**Sensing period:** From 2018/06/09 to 2018/06/09 (1 day)
**Check Mission:** Sentinel-3
**Product type**: SL_2_WAT__
**Timeless**: "Non Time Critical"
**Instrument:** SRAL
**Product Level**: "L2"
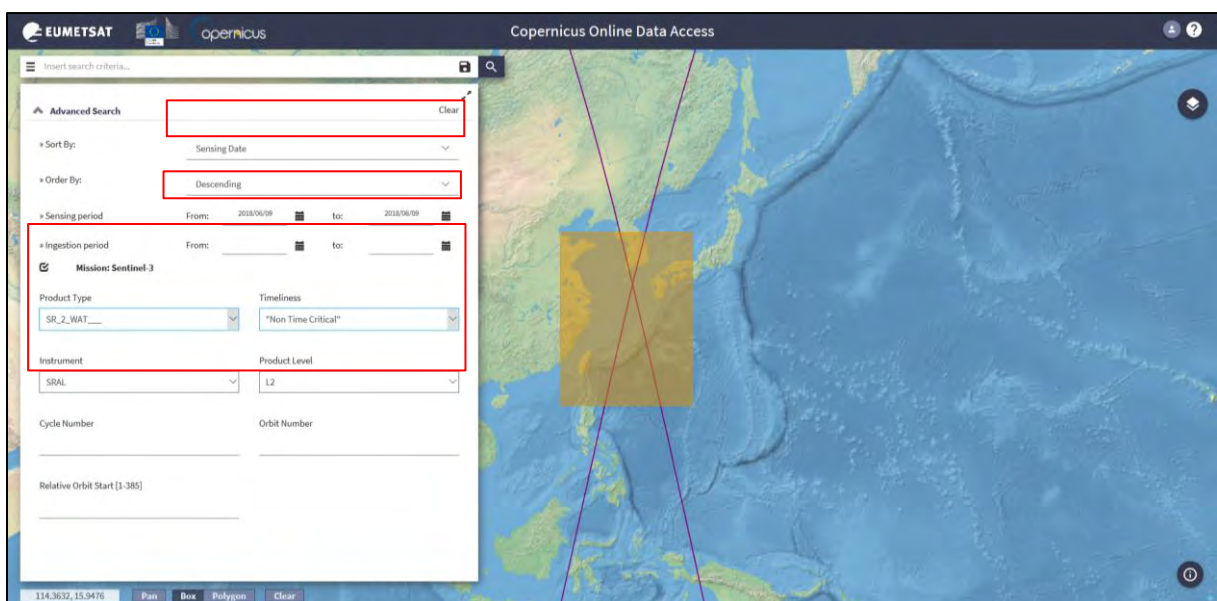


Select the product:

**S3A_SR_2_WAT____20180609T013721_20180609T022139_20180704T173753_2658_032_117____ __MAR_O_NT_003**

The track will be highlighted in purple on the map. Click on the arrow icon ⬇ to download it.
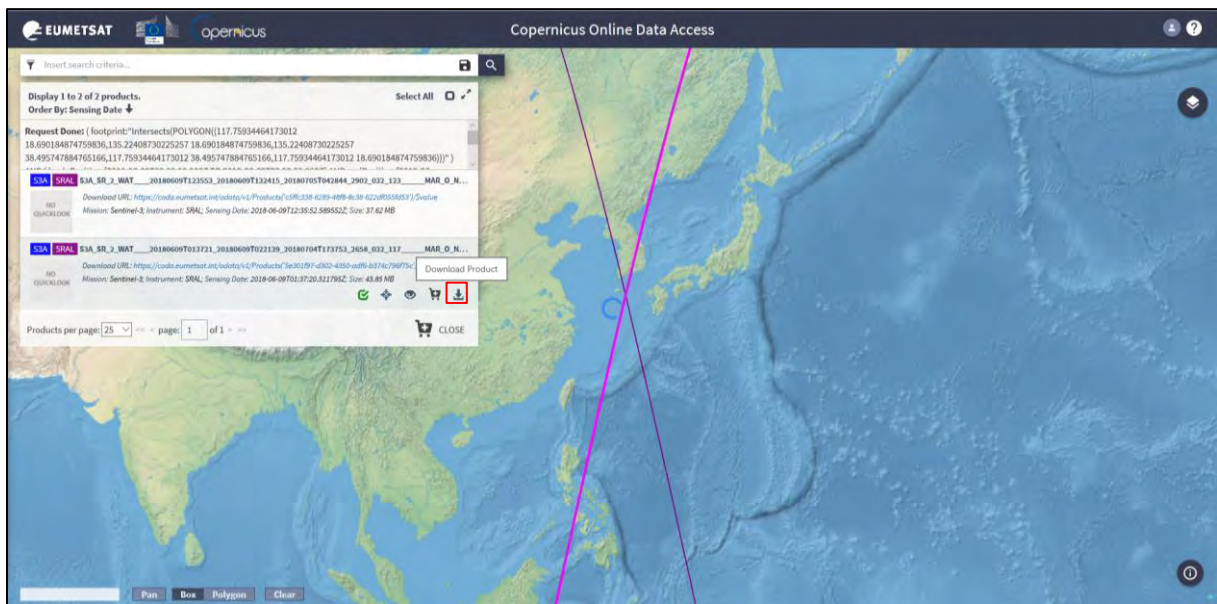


Once downloaded (*@/home/rus/Downloads*), move it to the following path and unzip it (*right click on the product → Extract Here*).

**Path: */shared/Training/OCEA06_Altimetry_TutorialKit/Original/S3_data***

Other data used in the training are from CMEMS (http://marine.copernicus.eu/) and SLCCI (http://www.esa-sealevel-cci.org/products) and are already present in the **Original** folder of the Tutorial Kit. Data will be discussed in the correspondent sections. Links provided include more information about the data and on how to download them.

## 7.2    BRAT – Overview

### 7.2.1    Create a workspace

Open **BRAT** software from the icon located on the desktop 🖼 or go to **Applications → Processing → BRAT GUI**.

When you open the BRAT GUI, click on "**New**" or go to **Workspace → New** and give a name to it (e.g. "**Webinar**").

Then click on "**Browse**" and locate the "Workspace" you will use.
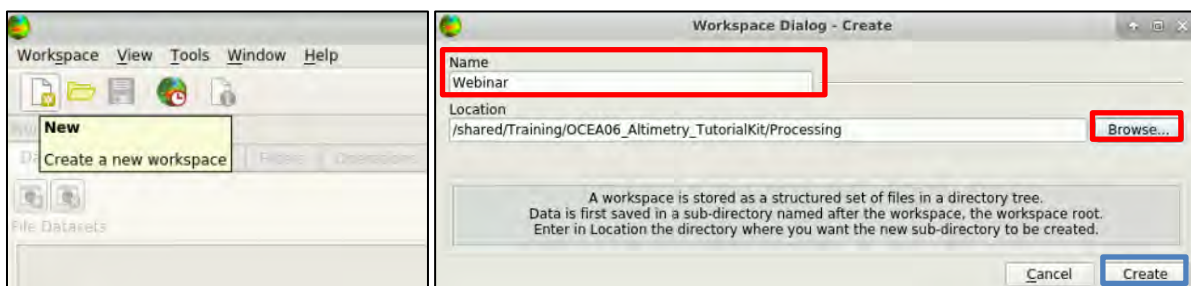


Go to "**Look in**" and set as path: ***shared/Training/OCEA06_Altimetry_TutorialKit/Processing***.

Then click on "**Choose**" without writing anything at the "Directory" and finally click on "**Create**".
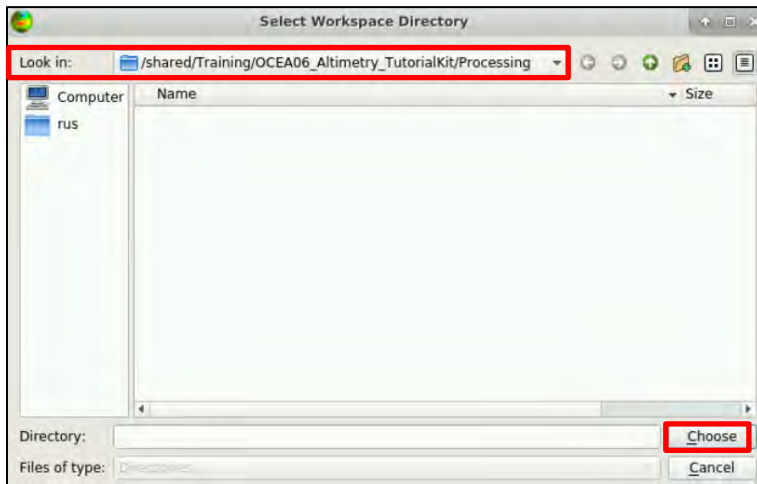
A "**Workspace**" is a way of saving your preferences, computations and generally the work done with BRAT GUI. Some or all elements of a workspace can be imported into another workspace. The "**Workspace**" menu (and also the main toolbar) allow the user to create, open, close, save, import, rename or delete a workspace.

It is highly recommended to save your workspace (**Ctrl+S**, or "**Save**" in the "**Workspace**" menu) while working. You will be asked whether or not you wish to save the workspace when you quit BRAT GUI.

> NOTE 1: Remember that if you select "No" and have not saved anything previously, none of your work can be recalled later. BRAT GUI recalls the last used Workspace by default.

### 7.2.2 Select the Map layer

BRAT offers 3 Main Map Base Layers accessible from **Tools → Options → Startup**. You can select the appropriate one and then click **OK**. You need to restart the software every time you select a layer in order to apply it and visualise it.
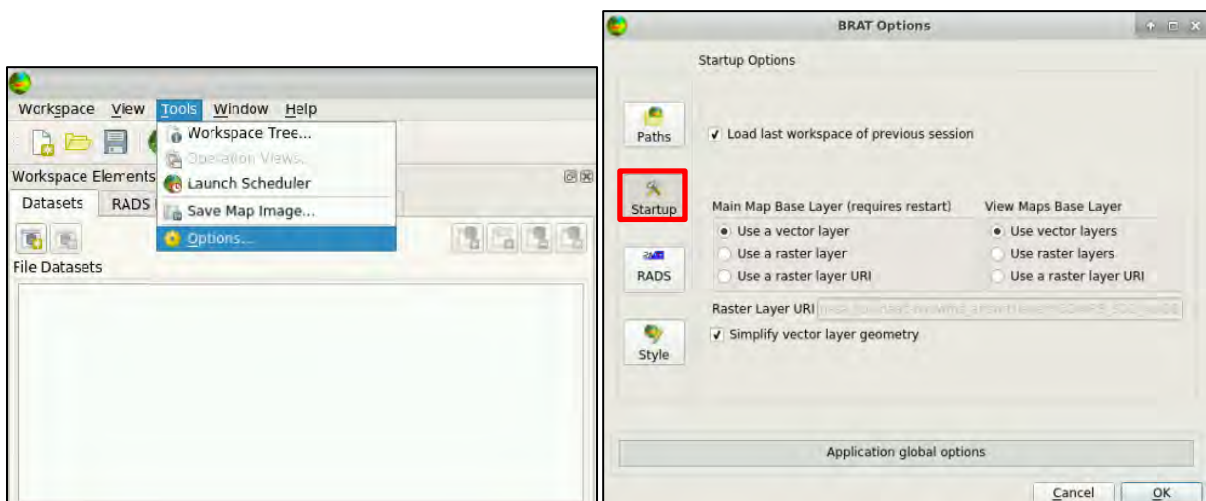
Example of how a **Vector layer** looks like:
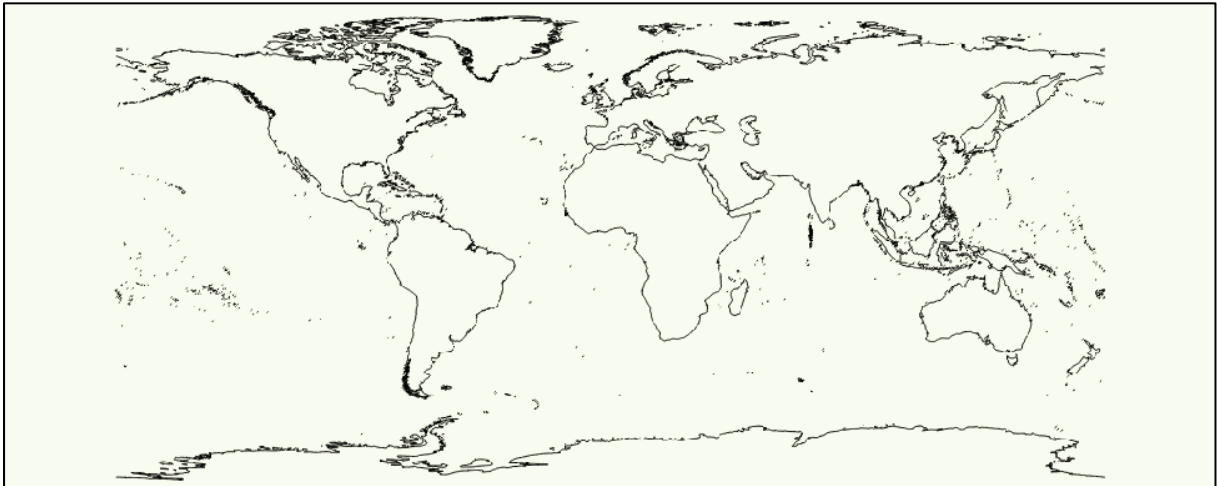


**Raster layer:**



For this exercise, choose the second option "**Use a raster Layer**" click on "**OK**" and restart the program (**Workspace tab → Exit**). At the window dialog that appears: "**Do you want to save any workspace changes?**", click "**Yes**".

### 7.2.3 Understand the BRAT GUI

Open **BRAT** software again. *Using BRAT GUI is basically a 3-step process:*

- Define one or several **Dataset(s)**: the product data you want to work on (see data required in each exercise, they will be imported from this tab).
- Add one or more **Filters**: this step is optional and allows the creation of data filters (for your input datasets) using time or location criteria.
- Create an **Operation** (**Quick or Advanced**): configure the data fields you want to visualize and respective process parameters that are used for generating the plots.
- The *Datasets, Filters and Operations* tabs are within the **'Workspace Elements'** dock.

Each tab corresponds to a different function, and to a different step in the process, so you have to use them ('Filters' in optional) one after the other.
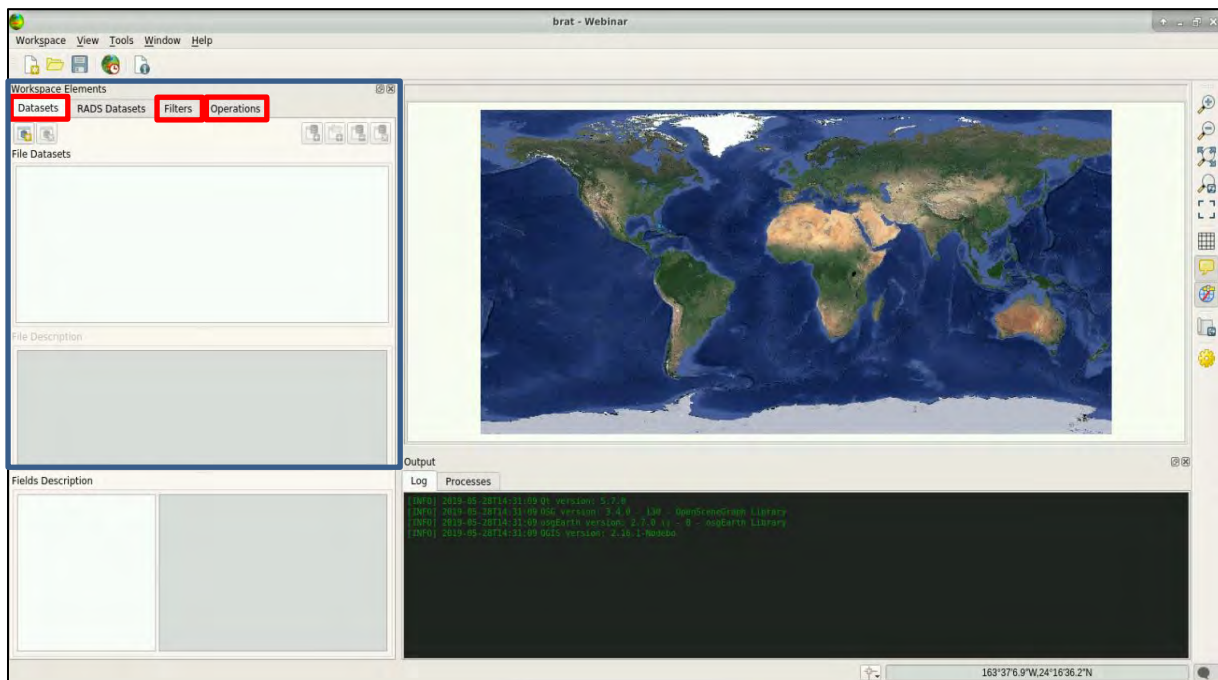
## 7.3    Preliminary operations

At the beginning of each BRAT exercise, please either delete all data, filters & operations used in the previous session or delete the entire workspace (fastest and easiest approach):

### 7.3.1    To delete a Workspace

Click on the **Workspace** tab and select **Delete…** . Then click "**Delete**" at the window dialog as well.
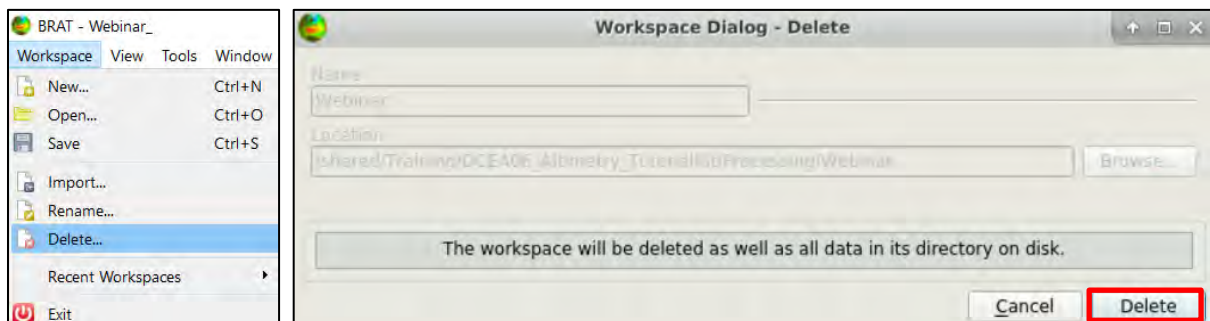


> NOTE 2: If you use BRAT for the first time, do not apply this step at this moment since you will delete the Workspace you have previously created for this exercise.

### 7.3.2    To delete an operation

Go to the **Workspace Elements** panel → **Operations** and click on "**Advanced**".

If *Filters* are present, these shall be disabled by clicking on the filter name [Filter_0] and then click on the **Delete operation** icon. Click on "**Yes**" when the system messages appear. (*Left* image below).

Only the "**Quick Operation**" shall remain available in the Operations menu. Filters have to be disabled also for the quick operation in a similar way.

Sometimes an operation can be cancelled only if the filters associated with the operation are disabled and deleted (see next section).
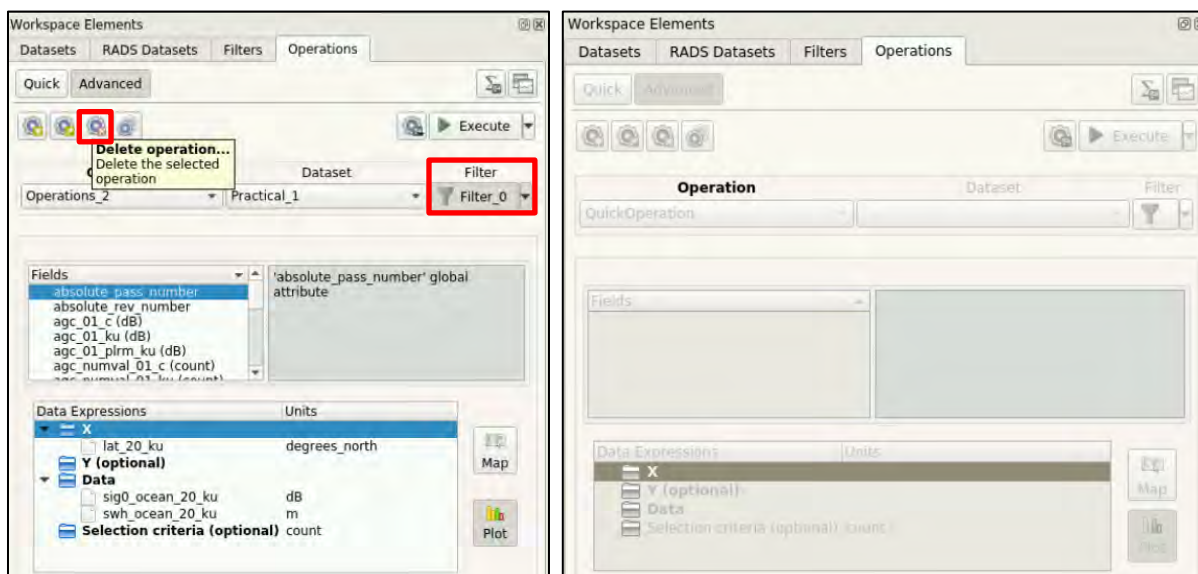
### 7.3.3 To delete a filter
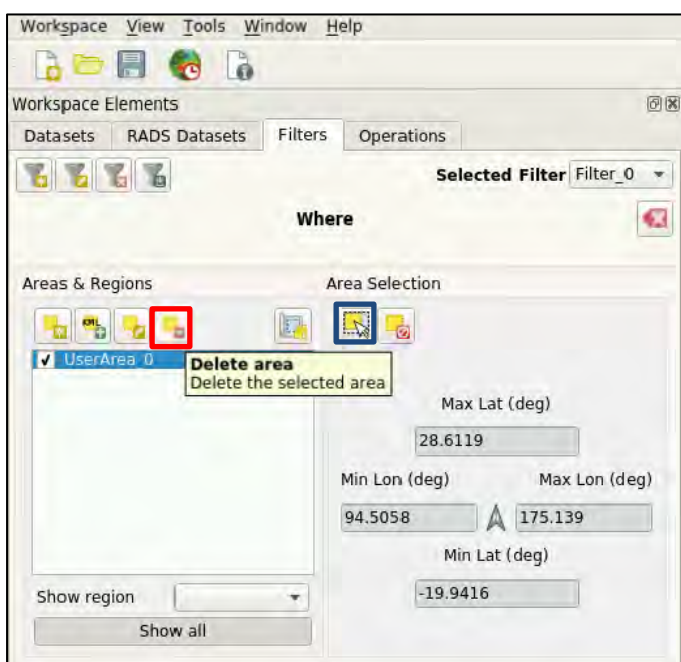


Filters have to be disabled also for the operations (Quick/Advanced).

Then, go to the **Workspace Elements** panel → **Filters**

If there is one area or more available in the "**Areas & Regions**" list, select them one by one using the "**Selection Tool**" button and:

1) uncheck all the entries of the "**Areas & Regions**" list,

2) click on the "**Delete area**" button and on "**Yes**" when the system message appears.
If a "Warning" window appear, click **OK** and apply the next step.
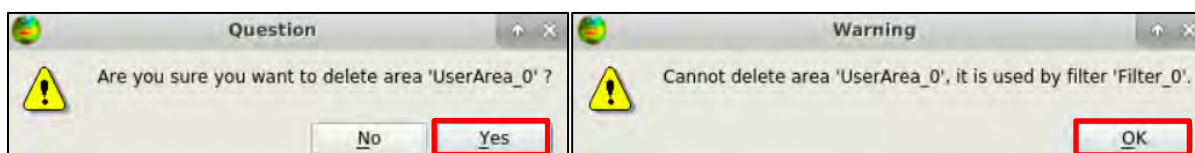


To delete a filter e.g. "**Selected Filter** Filter_0 ▾ " click on the delete filter icon and then on "**Yes**" when the system message appears. *(Left* image below).

**Reminder: The filters have to be deselected from _both Quick_ and _Advanced_ operations before being cancelled. After the cancellation of the filter, the operation can be cancelled.**

### 7.3.4 To delete a dataset
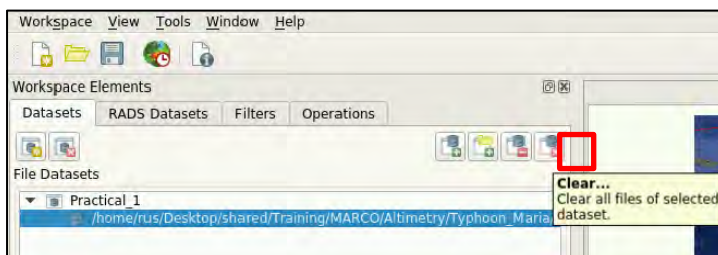


Go to the **Workspace Elements** panel → **Datasets**, select the dataset you want to delete and then click on "**Clear...**" icon.

> NOTE 5: If you use BRAT for the first time and there is no previous Dataset created or stored, the whole tab will be empty, and you cannot apply this step. (See image below).
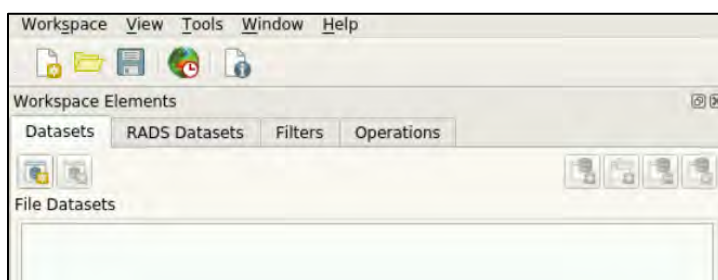


## 7.4 Exercise n. 1 – Displaying variables in BRAT

### 7.4.1 Loading the data
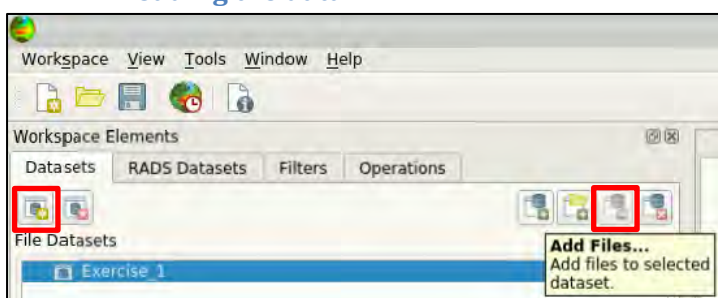


Go to the **Workspace Elements** panel → **Datasets**.

Click on "**Create New Dataset**".

Name the dataset as "**Exercise_1**".

Then, click on "**Add Files**".

Select the track downloaded from the EUMETSAT Data Hub from the folder: ***/shared/Training/OCEA06_Altimetry_TutorialKit/Original/S3_data***

"*S3A_SR_2_WAT____20180609T013721_20180609T022139_20180704T173753_2658_032_117____ __MAR_O_NT_003*".

Select the "***standard_measurement.nc***" file and click "**Open**".
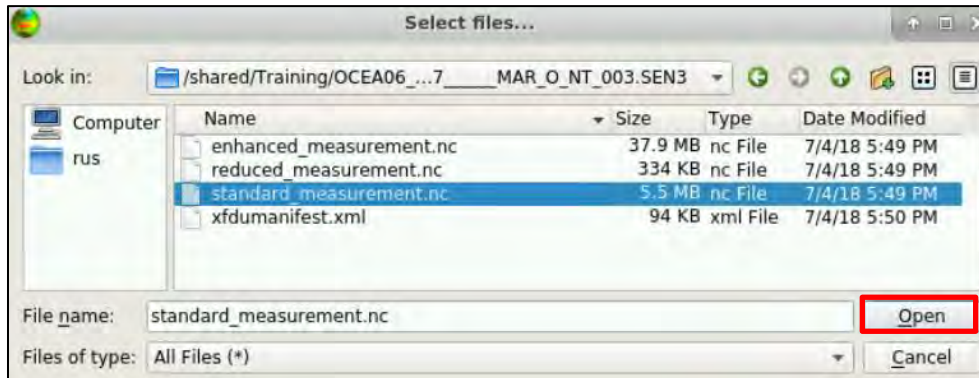


The track orbit will appear in red on the BRAT map.
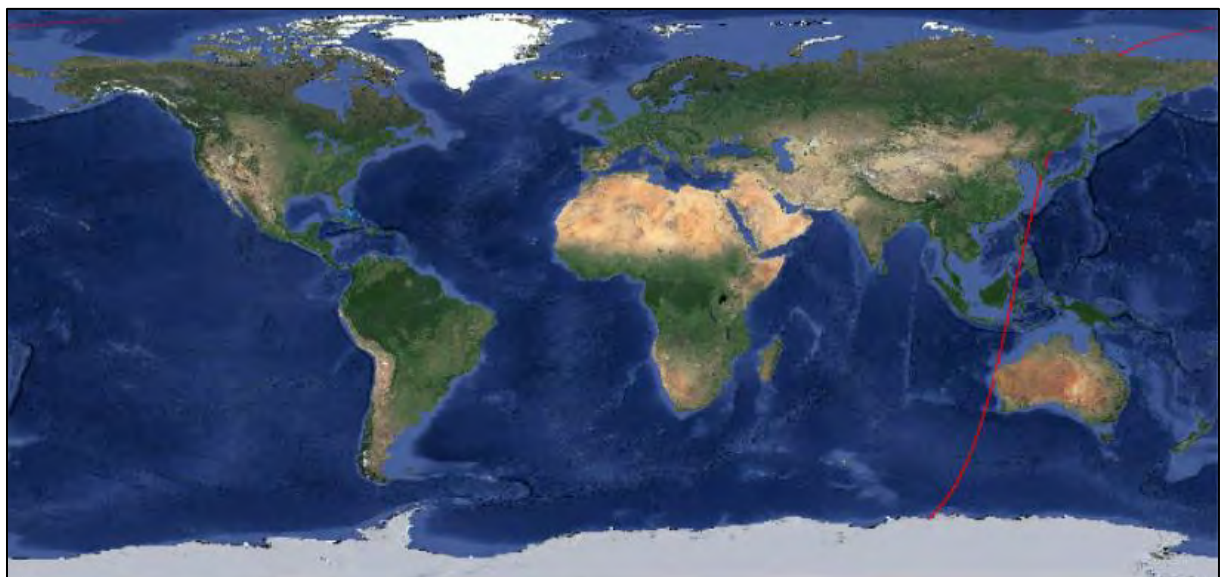


### 7.4.2 Quick and Advanced Operations with filtering for plotting and statistics calculation

To perform a **Quick Operation**:

Go to the **Workspace Elements** panel → **Operations** and click on the "**Quick**" Quick button.

Under "fields" , check "**SWH**" and  then press the "**Plot**" Plot... button.

Click "**Yes**" when the system message appears:
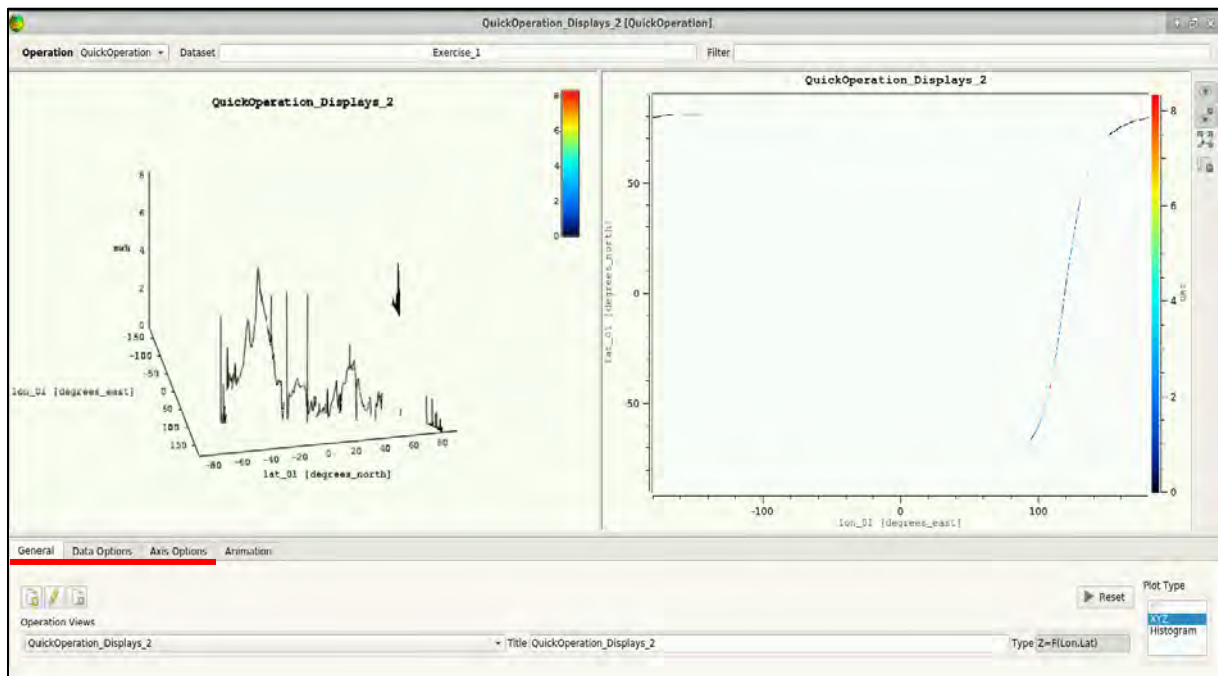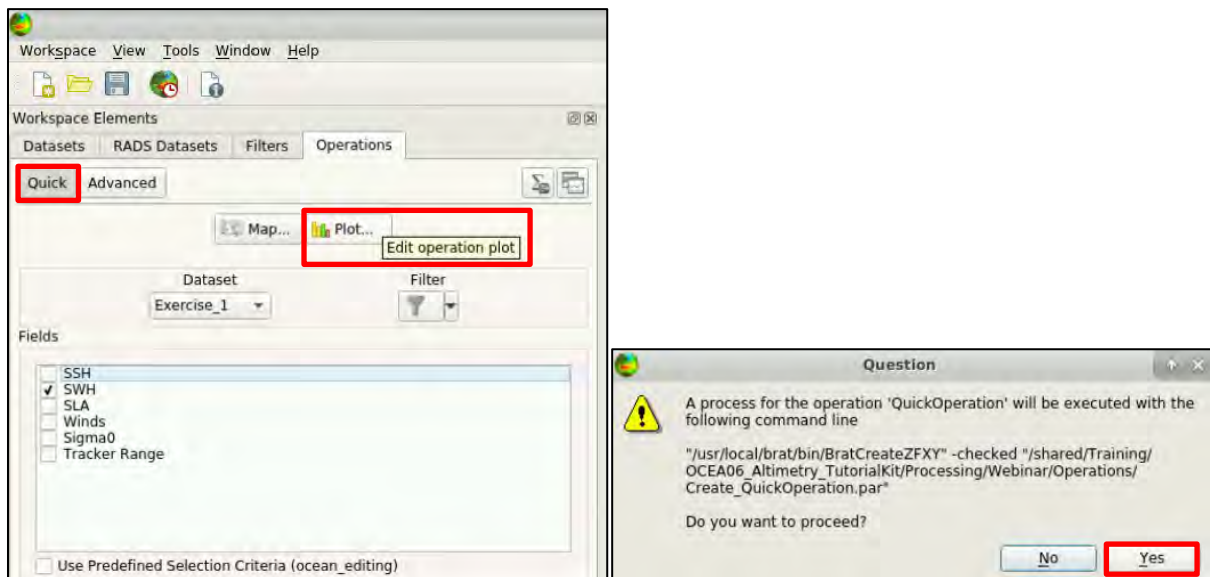
The tabs **General**, **Data Options**, **Axis Options** offer control on the plots above, as well as the icons placed vertically on the right. Use the mouse wheel button over the plots to zoom in & out.

> NOTE 6: Close the current figure before launching the next processing or BRAT will display an error message.

To perform an **Advanced Operation**:

Go to the **Workspace Elements** panel → **Operations**, click on the "**Advanced**" Advanced button, click on "**Create Operation**" and name the operation (keep the default name: "**Operations_2**"). Click **OK**.
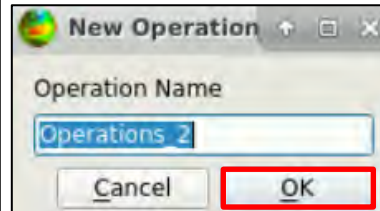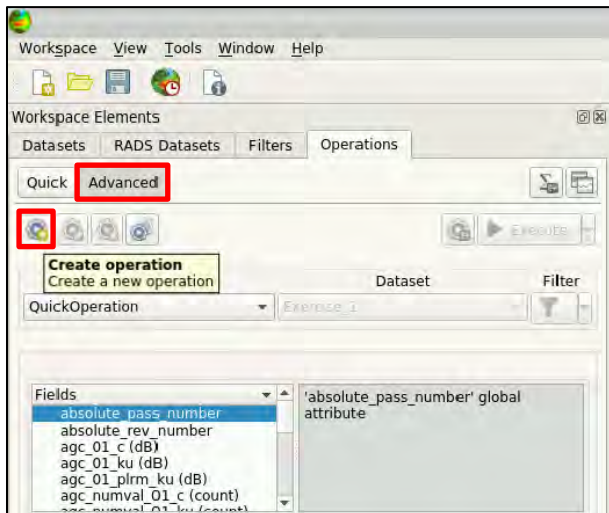
Then a **plot** or a **map** can be generated.

**To make a Plot**:

Select the **Plot** button ![Plot] and then use the left button of the mouse, go to the "Fields" and drag and drop "**lat_20_ku**" on the "**X**" folder and "**swh_ocean_20_ku**" on "**Data**" folder.
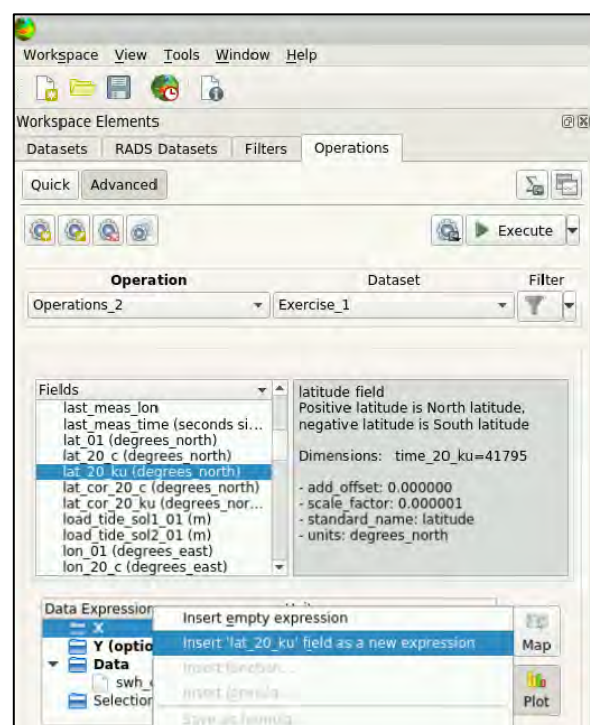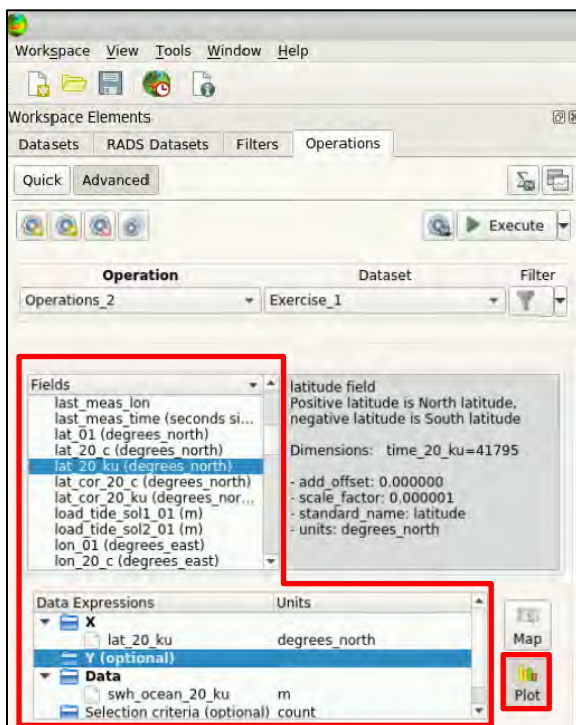


**Alternatively** to the drag and drop, the "**X**", "**Y**" and "**Data**" in "**Data expressions**" can be filled by evidencing the chosen vector in "Fields" (e.g. "**lat_20_ku (degrees_north)**") and by right clicking on "**X**", select "**Insert 'lat_20_ku' field as a new expression**". The result is equivalent.

> 📄  NOTE 7: Please keep this second option in mind ("**Insert empty expression**") as BRAT is capable not only of visualizing variables but also of performing simple operations with two or more data vectors, as it will be reported in the next exercises.

Once **X** and **Data** have been filled, the plot can be generated by clicking on "**Execute**" ![Execute] and on "**Yes**" when the system message appears. <u>Make sure that all fields are at 20Hz. If not, an error occurs</u>.
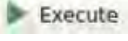
The colour of the plot can be changed in the "**Data Options**" tab, by clicking on "**Color**" Color 🖌 .



> 📄 NOTE 7: Typically, high SWH values are recorded at low latitudes. Estimates are missing over islands and inland water (these are Sentinel-3 WAT products). Abrupt and unrealistic values are recorded in coastal zones where the ocean retracker (swh_ocean_20_ku), tailored for the ocean, does not work properly. Land contaminates the footprint and is not considered in the formulation of the retracking model for ocean surfaces. No retracker can work in all scenarios (open ocean, coastal zone, inland water, ice sheets, sea ice…).

**To make a Map**:

Close the current figure & select the **Map** button Map . Drag and drop "**lat_20_ku**" in "**Lat**", "**lon_20_ku**" in "**Lon**", "**swh_ocean_20_ku**" in "**Data**". Make sure that all fields are at 20Hz. If not, an error occurs.

The map can be generated by clicking on "**Execute**" ▶ Execute and on "**Yes**" when the system message appears. You can navigate to the "**Data Options**" tab for more information.
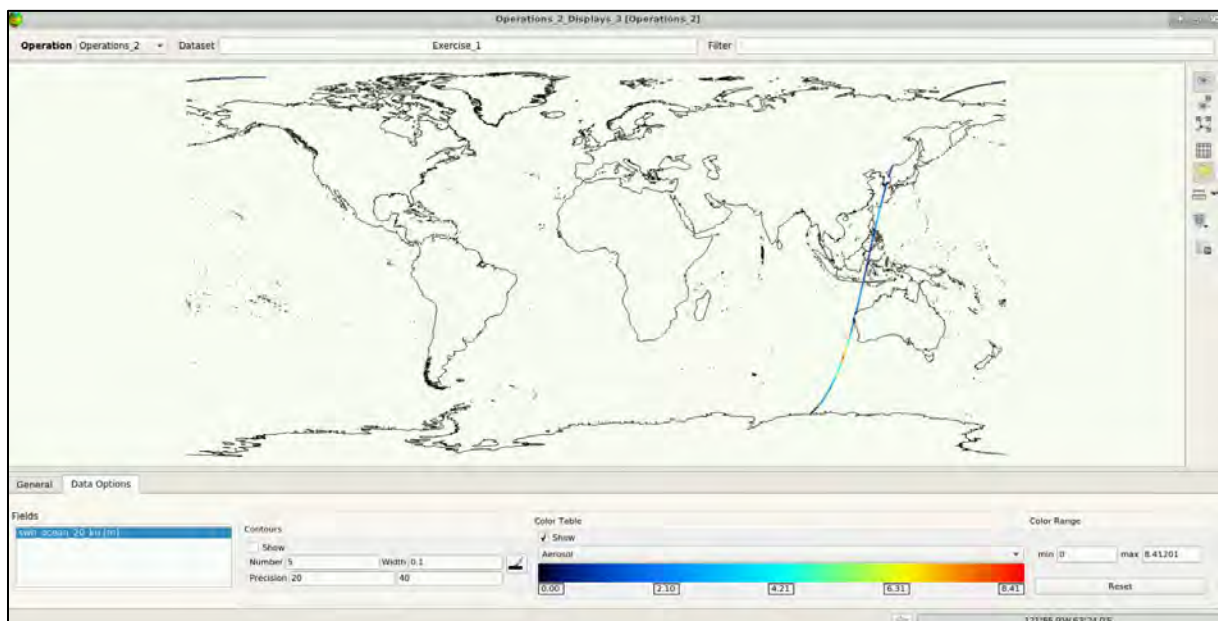
While at this window, click on the 3D icon for the globe view  :
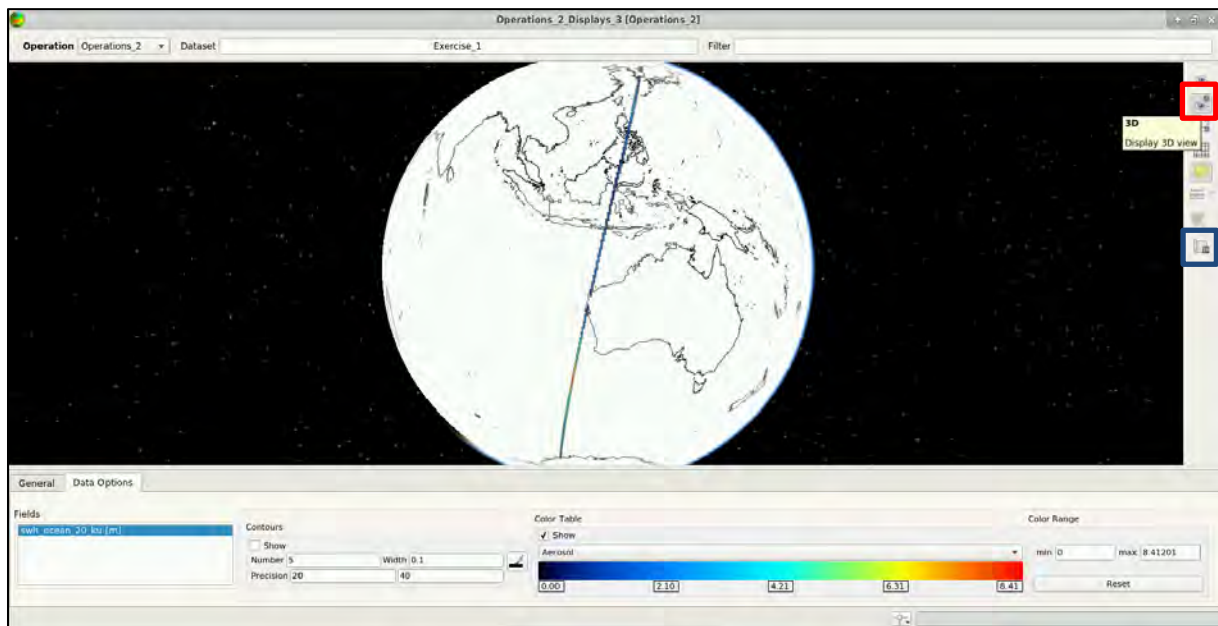


You can use the left button of the mouse to rotate the globe and view the track. For every BRAT figure you want to save, use the "*Save view as image file under selected format*" icon  .

First select the "**Image and File Type**" you want to save as, e.g. tif, then click on "**Browse**" and define the appropriate path you want it to be saved at the "**Look in**", e.g. */shared/Training/OCEA06_Altime try_TutorialKit/Processing*. Define a name at the "**File name**", e.g. "**Operations_2_Displays_3_3D.tif**" and click on "**Save**" in both windows.
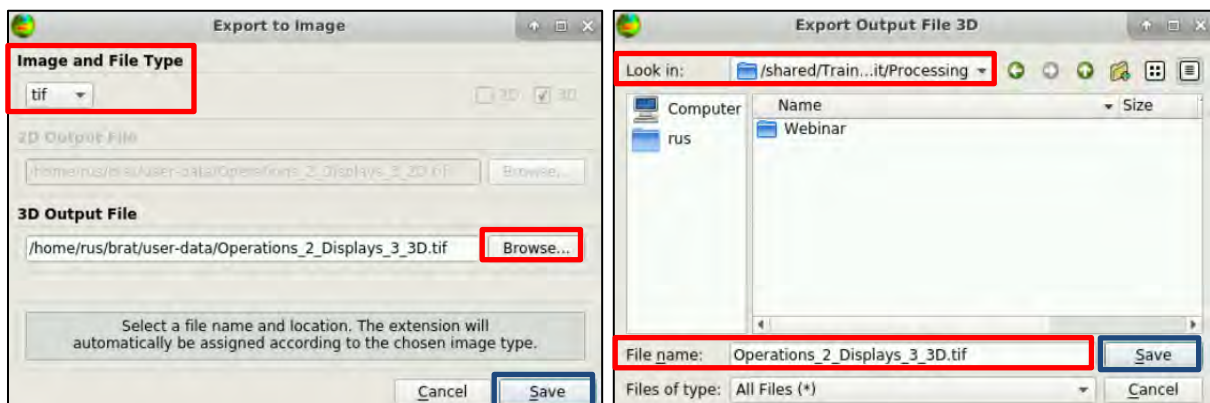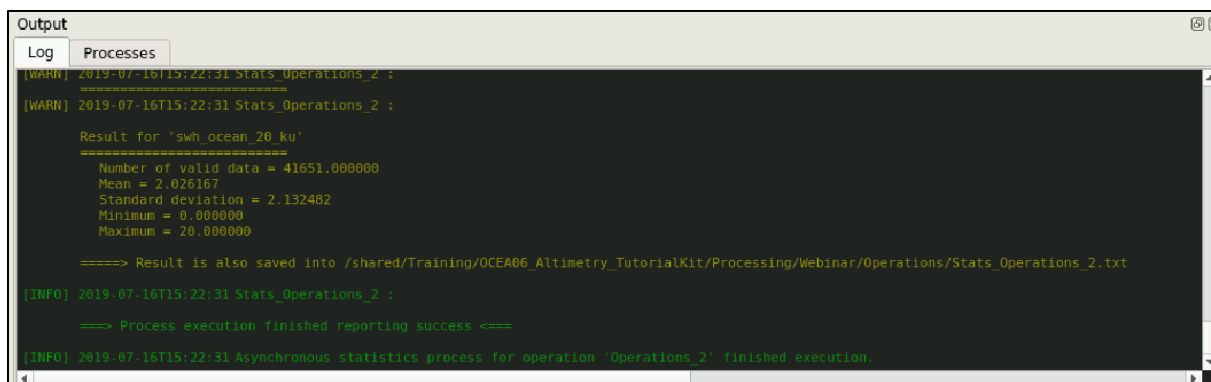


Then you can close the 3D view window.

Each execution (Map/Plot) creates a *netCDF* (.nc) file in the output folder indicated in the log of BRAT:
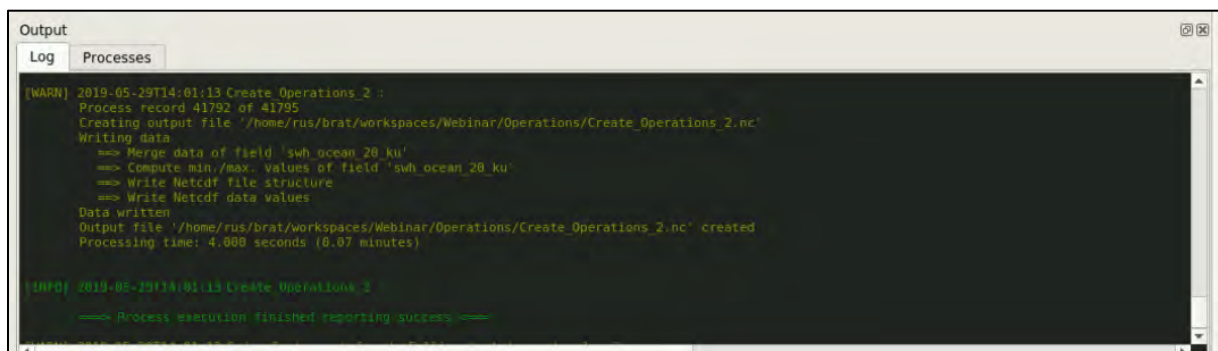
To **calculate the statistics** over the track/s, press the sigma button ![sigma] and press "**Yes**" when the system message appears.



The log will indicate the statistics and the .txt in which they are contained:



> 📄 NOTE 8: As it will be demonstrated in one of the next exercises, the **statistics** can be successfully used to evaluate the monthly/annual maps of sea level anomaly and could be used in the inland water domain to average a certain number of valid measurements acquired over a river or lake.

## 7.5 *Exercise n. 2 – Sea level and SWH at the coast with different retrackers.*

If you wish to plot more variables in a single run, this is possible by adding more variables to the Data menu in the "**Data Expressions**" section. As anticipated in the theory section, retrackers can be physical and empirical. Empirical retrackers, by conception, do not estimate the significant wave height but provide estimates of power (sigma0) and range (from which the sea surface height is derived, see **section 6**).

In this exercise, we continue using the product considered in Exercise 1 to plot the power (sigma0) retrievals of two retrackers (physical & empirical) available in the Sentinel-3 WAT products for a section of the track in which the coast is approached.
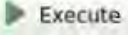
This section is in the range of latitudes between **28 and 36 degrees**. To filter 20Hz estimates in latitude in S3 products, we <u>cannot</u> use the **Workspace Elements** panel → **Filters** tab (adoptable with 1 Hz estimates) but we can use the selection criteria field as indicated below:

Highlight "**Selection Criteria (optional)**", insert the formula in the box **"(lat_20_ku > 28) & (lat_20_ku < 36)"**, check its correctness by clicking on the ![check] button (log reports: "**Data expression OK**" in <u>yellow</u>) and then click ![icon] to save the formula. **If the formula is not saved the selection criteria will not be applied during the execution**. The "**Units**" are **degrees_north** and shall be set manually by double clicking on the right to "Selection criteria (optional)", write it and click "**Enter**".

To complete the exercise, drag and drop to "**Data**" the two **sig0_xxx** ("**sig0_ocean_20_ku**" and "**sig0_ice_sheet_20_ku**") reported in the figure as indicated in the previous exercise (use the left mouse button to drag, and drop exactly on "**Data**").

Delete all other expressions that might exist under "**Y (optional)**" and "**Data**" by right clicking on them and then on "**Delete 'swh_oean_20_ku' expression**". Repeat for the rest non-necessary expressions.
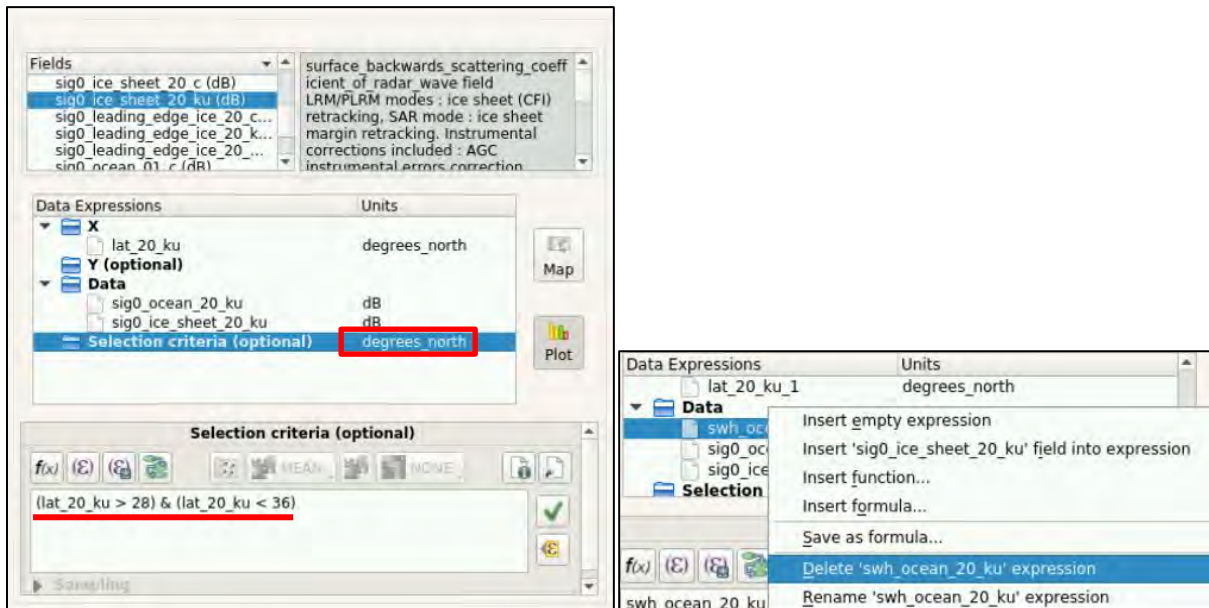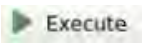
Click on "**Execute**" , then on "**Yes**" when the system message appears and go to the "Data Options" tab:
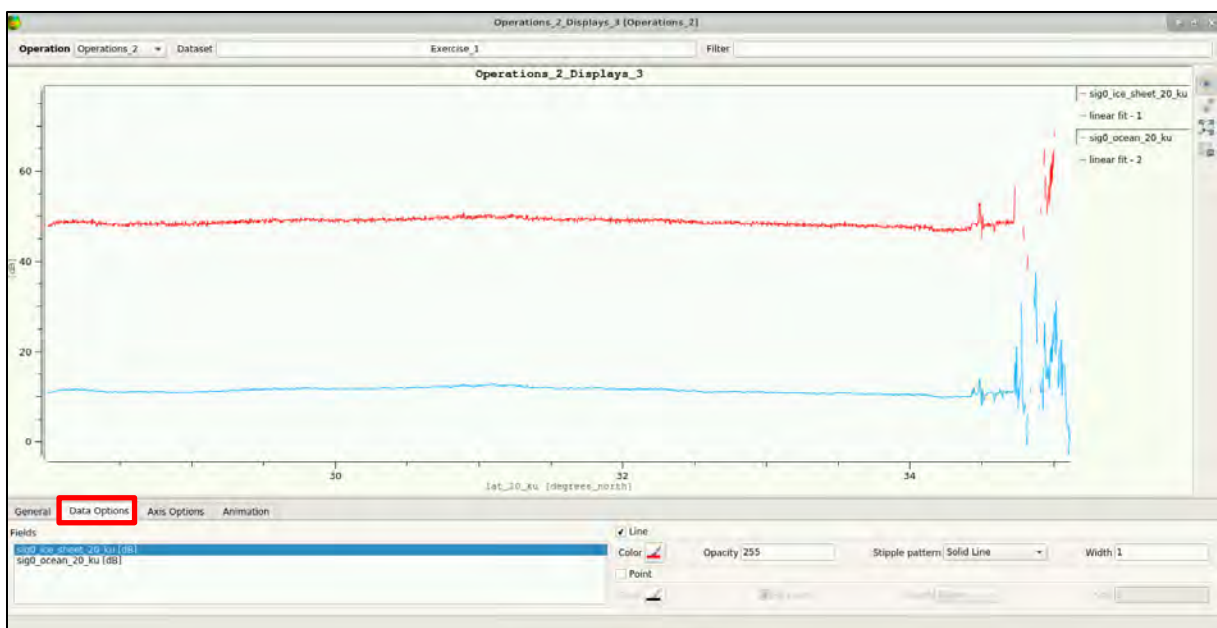


>  NOTE 9: Retrackers tailored for different applications provide quite different results. Coastal zone is approached at the highest latitudes and the estimates result corrupted (oscillating) until the coast is reached (big oscillations).
>
> By using the **Selection Criteria (optional)** box, not only the latitude range can be set but also quality flags can be adopted to discard bad data points and improve the quality of the results.

It is also possible to plot two different variables (e.g. SWH & sigma0) at the same time, in two separated plots by clicking on the "**Split plots**" button . Please modify the variables in data as indicated under the "**Data Expressions**" window in "**Data**", click on  and then on "**Execute**"  :
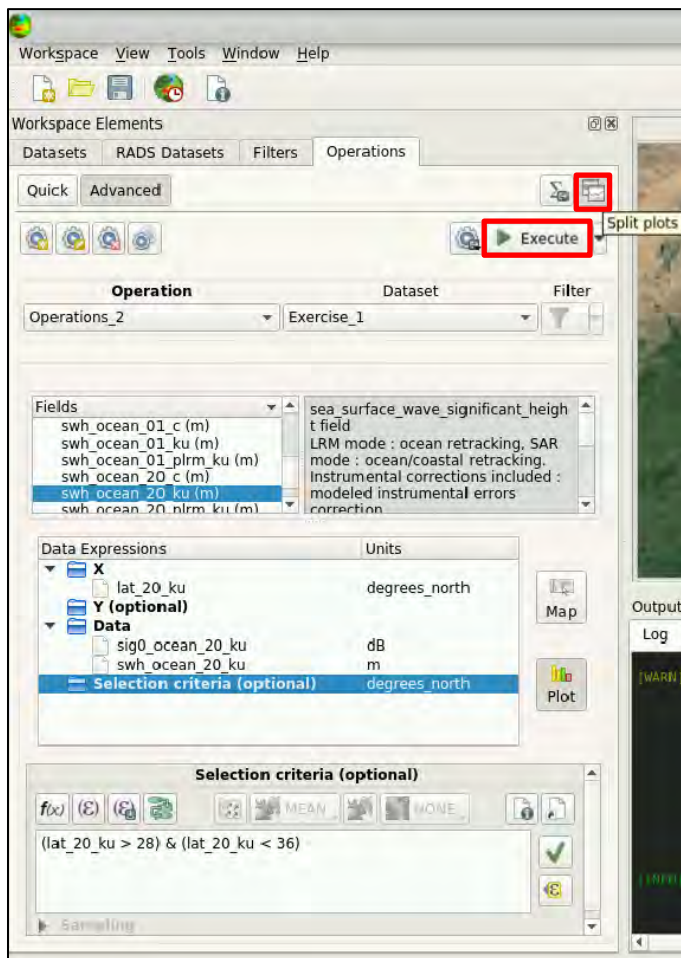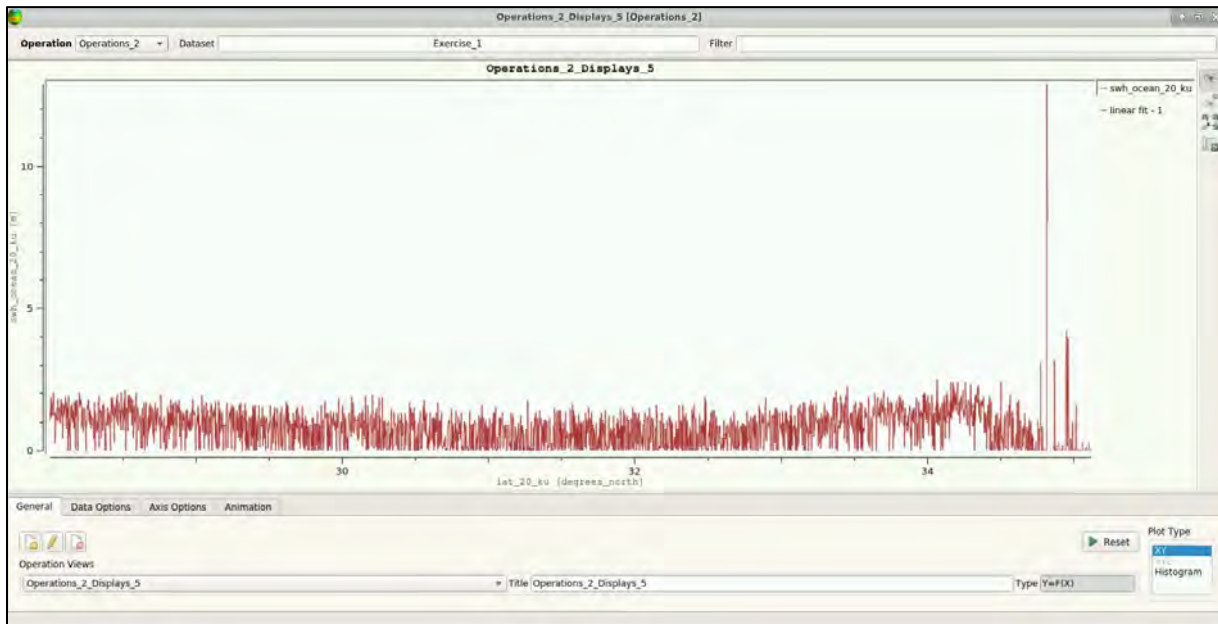
A figure will be created with the possibility of selecting the desired plot in the **Operation Views** tab.

For "**sig0_ocean_20_ku**" we have:
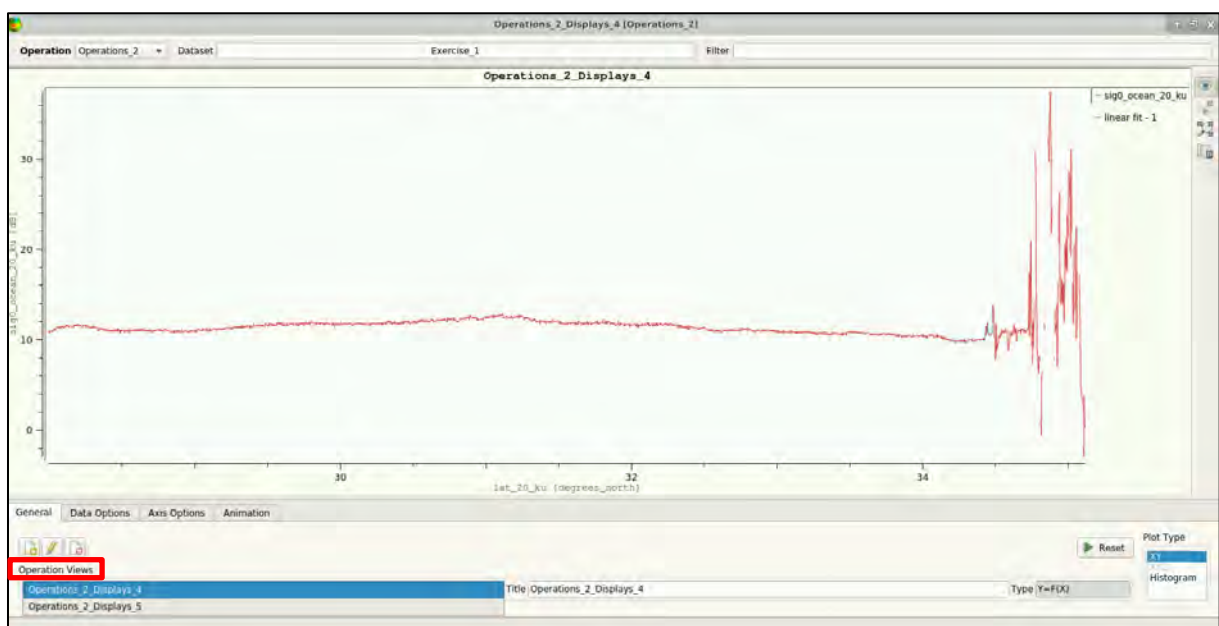


For "**swh_ocean_20_ku**" we have:

SWH estimates away from the coast are below 2 m (calm sea state). In approaching the coast, as seen for sigma0, the L1b waveforms get corrupted by the presence of land in the altimetry footprint and the retracker returns unrealistic estimates.

## 7.6 Exercise n. 3 – The importance of geophysical corrections

As indicated in the theory section, the sea surface height **SSH = Altitude-Range**. The **Range** has to be corrected for a series of degrading effects. In this exercise we consider the corrected SSH to the uncorrected SSH and we include also a few corrections to underline their impact. We make this by studying the **sea level anomaly (SLA)** given by **SLA = (Altitude-Range) – Mean_Sea_Surface** which is equal to the **SLA = SSH-MSS**.

We will use the same track of the previous exercises but

- 1Hz data will be used.
- Filtering will be made using the **Workspace Elements** panel → **Filters** tab.

Therefore, we:

- delete the operation used so far (see **section 7.3.2**) and deactivate the split plots feature 
- create a Geographical Filter in latitude:

Go to **Workspace Elements** panel → **Filters** tab and create a new filter by clicking on the **Create filter** icon  (default name is "**Filter0**") and then click **OK**.

Name the filter and then move to the "**Area Selection**" subsection and click on the "**Selection Tool**" icon .

Zoom in to the area indicated below and draw the filter on the BRAT map using the mouse (hold the left mouse button to draw and then release):

Then go to the "**Areas & Regions**" subsection, click on **Create Area** , choose a name (e.g. "**UserArea0**"), click **OK** and <u>check</u> the box:
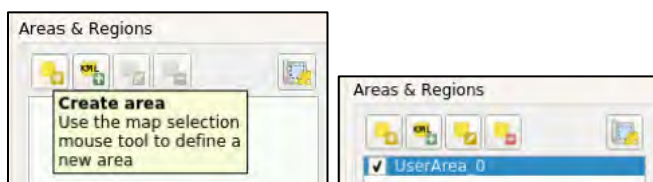


Now the filter is created and can be selected in the **Workspace Elements** panel → **Operations** tab to be used in the plot.

First, create a new Operation and name it e.g. "**Opertions_3**". One can go to "**Quick**" tab, <u>deselect SWH</u> option and **select SLA** option.

Go to "**Advanced**" tab and create a new plot  operation with **lat_01 (degrees north)** in "**X**".

In "**Data**", insert the following **empty expressions: Data → right click → "Insert Empty Expression",
as in section 7.4.2**.

Make sure that the "Name", "Units" & "Formulas" you will insert, have been ***checked and saved*** before writing the next mentioned in the screenshots below:

Uncorrected_SLA: (alt_01 - range_ocean_01_ku) - mean_sea_surf_sol1_01

SLA_iono_corrected: ((alt_01 - range_ocean_01_ku) – iono_cor_alt_01_ku) – mean_sea_surf_sol1_01

SLA_iono_wtc_corrected: (((alt_01 - range_ocean_01_ku) - iono_cor_alt_01_ku) - comp_wet_tropo_cor_01_ku)
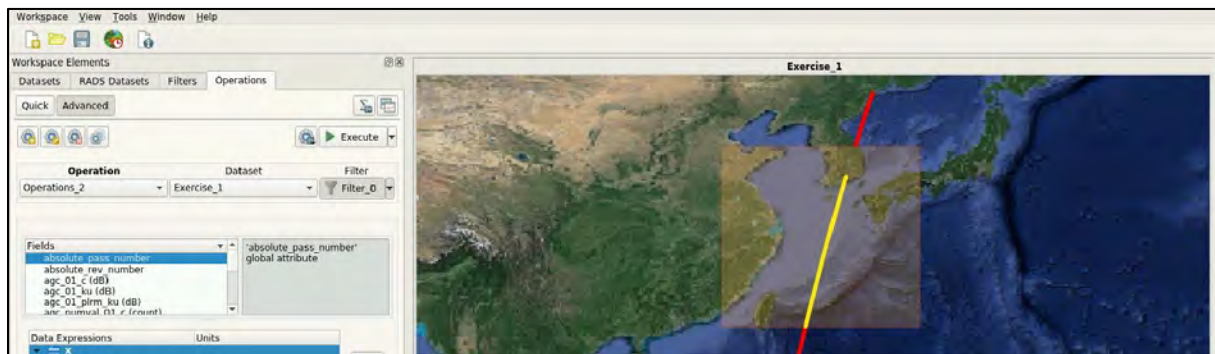– mean_sea_surf_sol1_01

SLA_Fully_corrected: ssha_01_ku
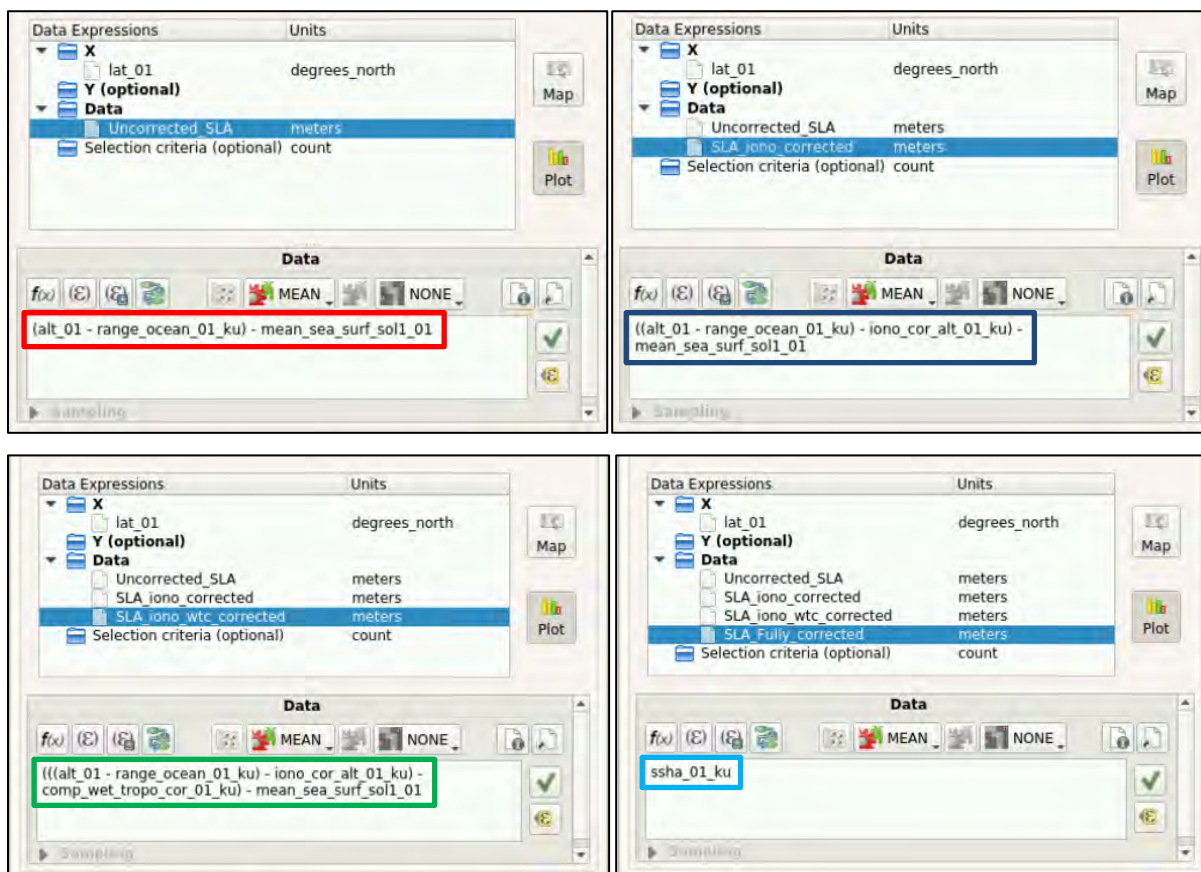
Before plotting, we activate the filtering on this operation by selecting **Filter_0** in the Filter section ![Filter icon] (click on ![icon]) and the click on "**Yes**" when the system message appears.
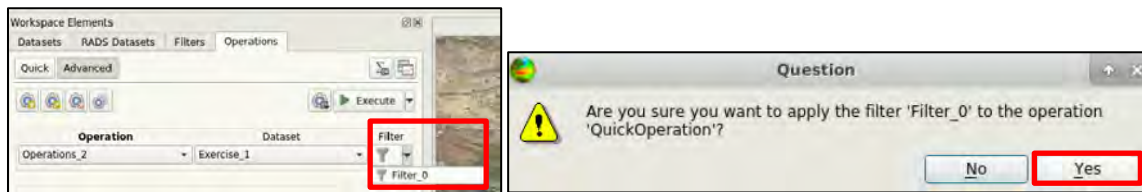


If the filter is correctly activated, the filtered track will be showed in yellow:



Now we can execute ![Execute button] the operation to conclude the exercise. After selecting the colour of each trend in **Data options → Colour** and zooming the figure:



The impact of the geophysical corrections is around 3 meters.
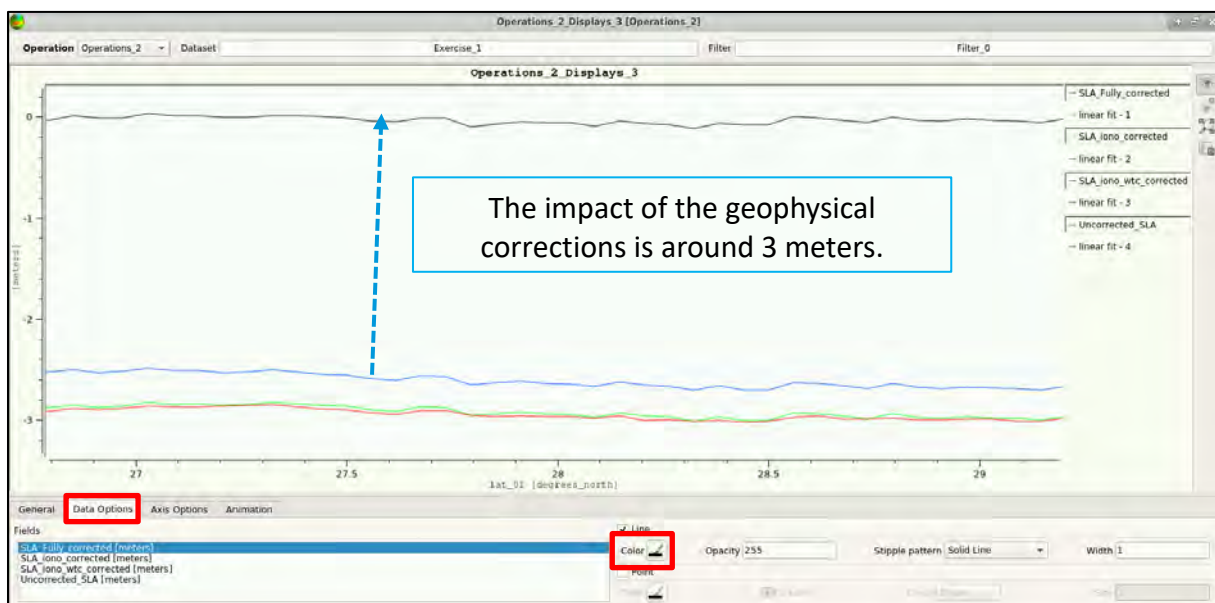
> ![note icon] NOTE 10: The impact of the geophysical corrections is huge. The ionosphere correction is of small entity. The wet tropospheric correction plays an important role.

# 8    Extra Steps

## 8.1    *Download files from VM*

In your VM, press **Ctrl+Alt+Shift.**

A pop-up window will appear on the left side of the screen. Click on the bar below **Devices**, navigate to the folders you have saved the files you want to download and **double click** on them. The downloading process to your local computer will start automatically.
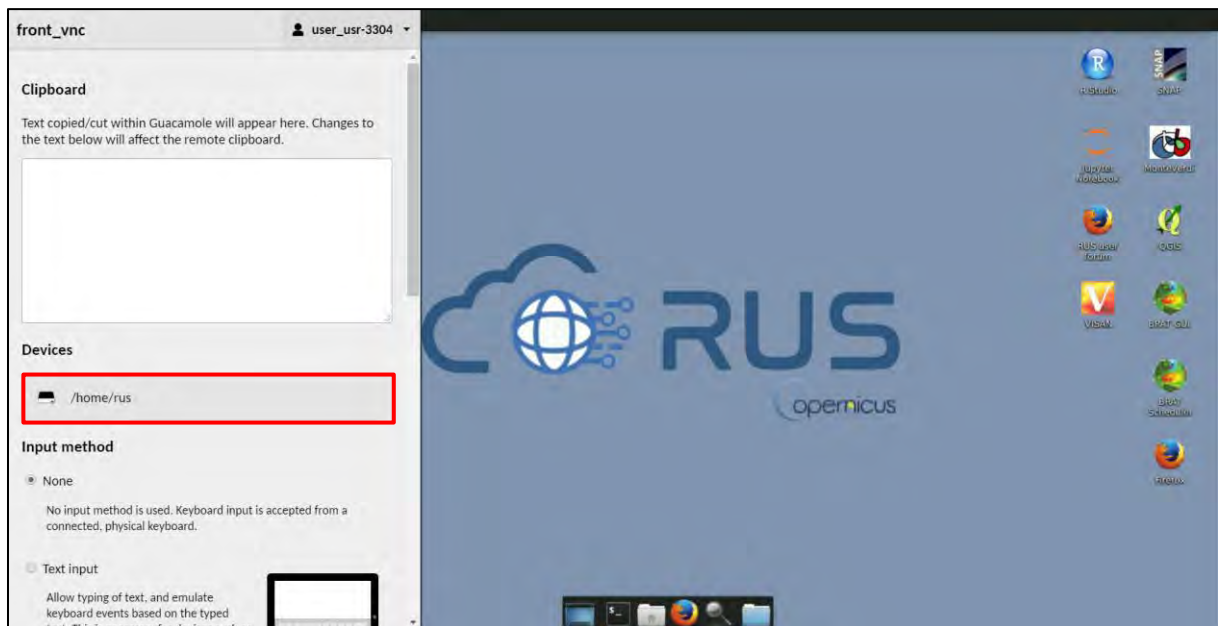
# THANK YOU FOR FOLLOWING THE EXERCISE!

## 9    Further reading and resources

- Sentinel-3 Altimetry User Guide

  https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-altimetry

- Sentinel-3 Altimetry Technical Guide

  https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-altimetry

- R. K. Raney, "The delay/Doppler radar altimeter," IEEE Trans. Geosci. Remote Sens., vol. 36, no. 5, pp. 1578–1588, Sep. 1998. DOI: 10.1109/36.718861
- *"Fully Focused SAR Altimetry: Theory And Applications"* by Egido And Smith (2016) Doi: 10.1109/Tgrs.2016.2607122

**FOLLOW US!!!**

@RUS-Copernicus

RUS-Copernicus

RUS-Copernicus

RUS Copernicus Training

RUS-Copernicus website

RUS-Copernicus Training website