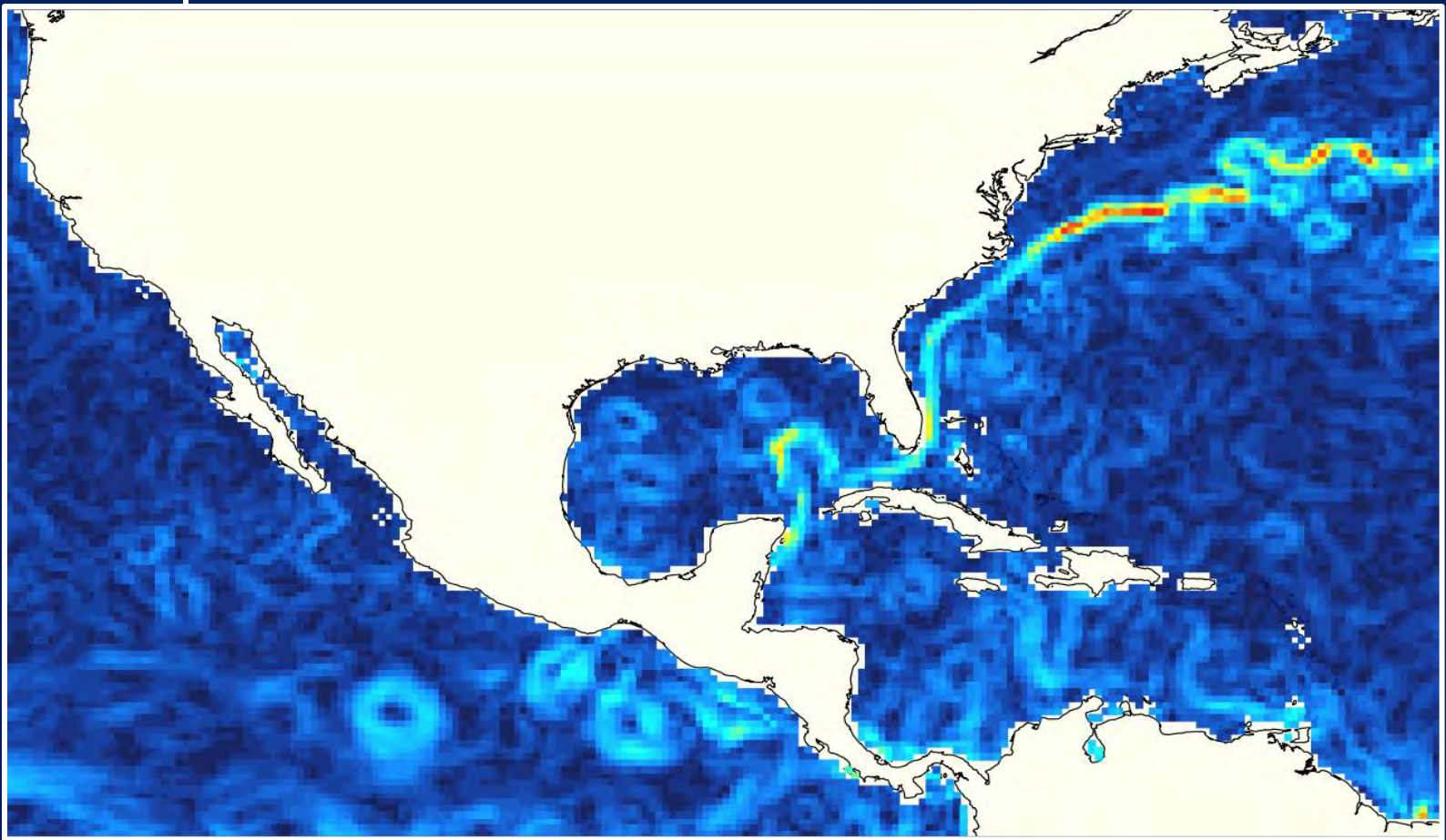


RUS

Copernicus



TRAINING KIT – OCEA07

**OCEANOGRAPHY 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

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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 OCEA07. 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:

- **The impact of a Typhoon the estimates**
- **Global and Mean Sea Level Anomaly**
- **Geostrophic currents & Current Speed**

3.1 Data used

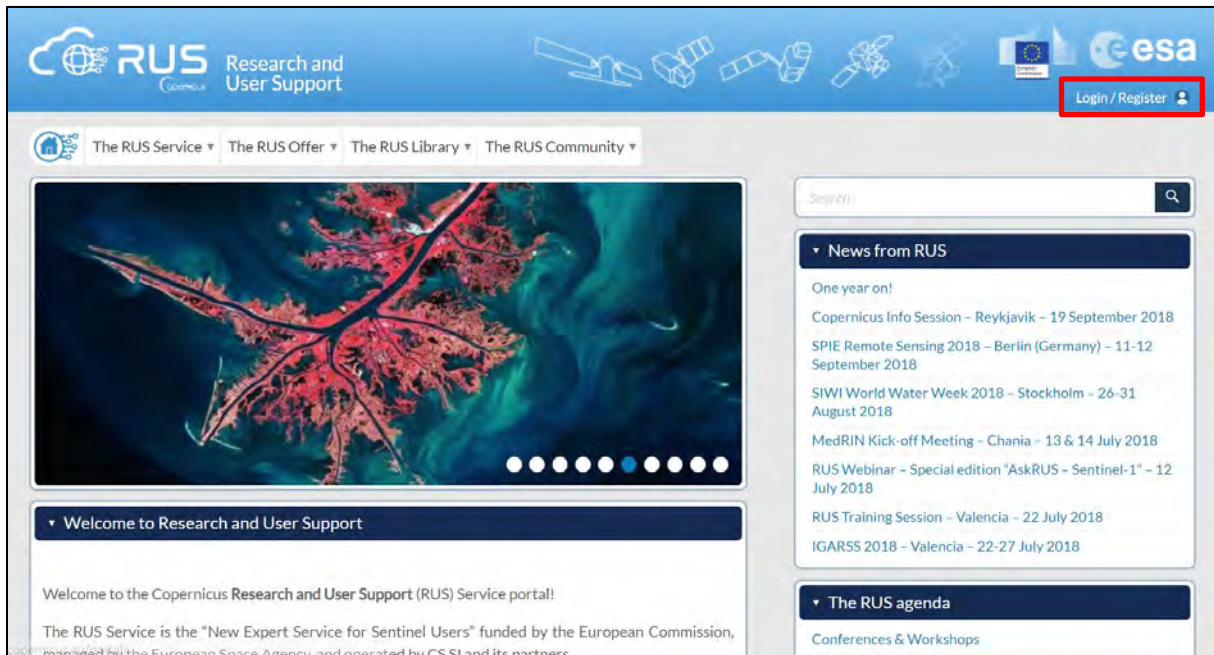
- 2 Official Sentinel-3 SRAL L2 WAT products [<https://coda.eumetsat.int/#/home>] and stored locally *@/shared/Training/OCEA07_Oceanography_TutorialKit/Original/S3_data*
- CMEMS L3 along-track Sentinel-3 products (Global & Regional) [<http://marine.copernicus.eu/>] stored locally *@/shared/Training/OCEA07_Oceanography_TutorialKit/Original/CMEMS_data*
- Pre-processed data [<http://www.esa-sealevel-cci.org/products>] stored locally *@/shared/Training/OCEA07_Oceanography_TutorialKit/Original/SLCCI_data*

3.2 Software in RUS environment

BRAT, SNAP

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.

Login / Register

The registration system to access the RUS service platform has moved toward the COPERNICUS Single Sign On authentication server.

- New Users who have not yet registered to the RUS portal shall first create a COPERNICUS SSO account.

Note that your Copernicus SSO account will be activated only after the reception of the third email sent by the Copernicus service. We advise you to consult [this document](#) and [this page](#) to facilitate your registration procedure.

REGISTER COPERNICUS SSO account

Users who already have a COPERNICUS SSO account can login here:

Login

[Close](#)

Credentials

CDS-SSO ID

Password

Max Idle Time half a day

Max Session Time Until browser close

Login

Reset

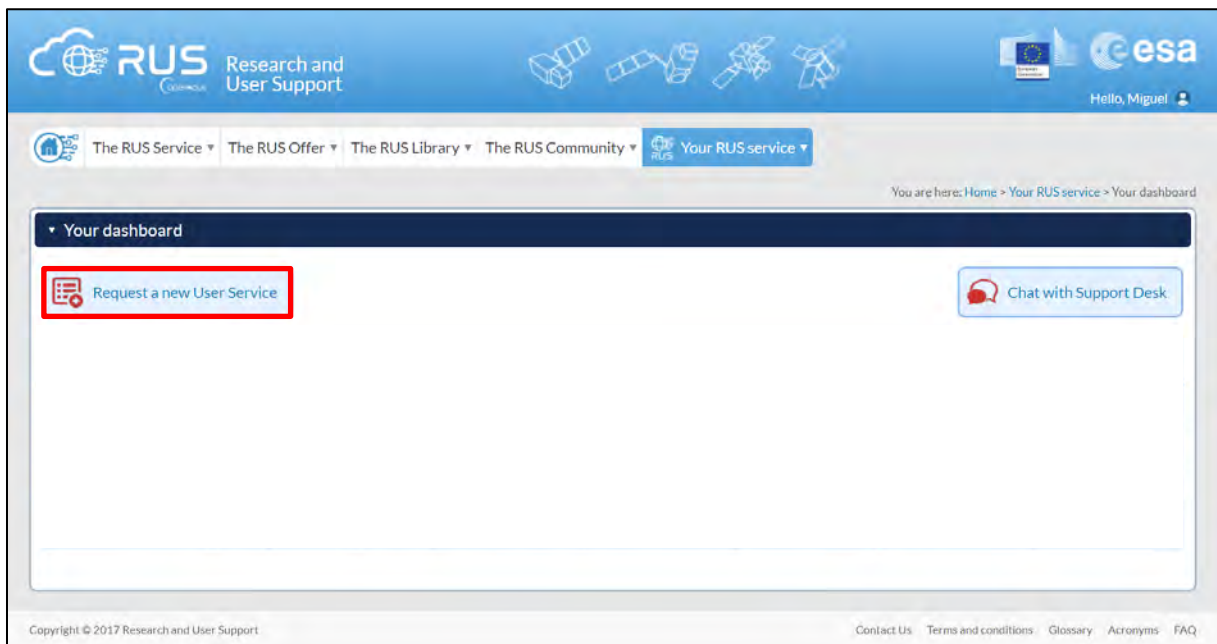
[Forgot your password?](#)

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.

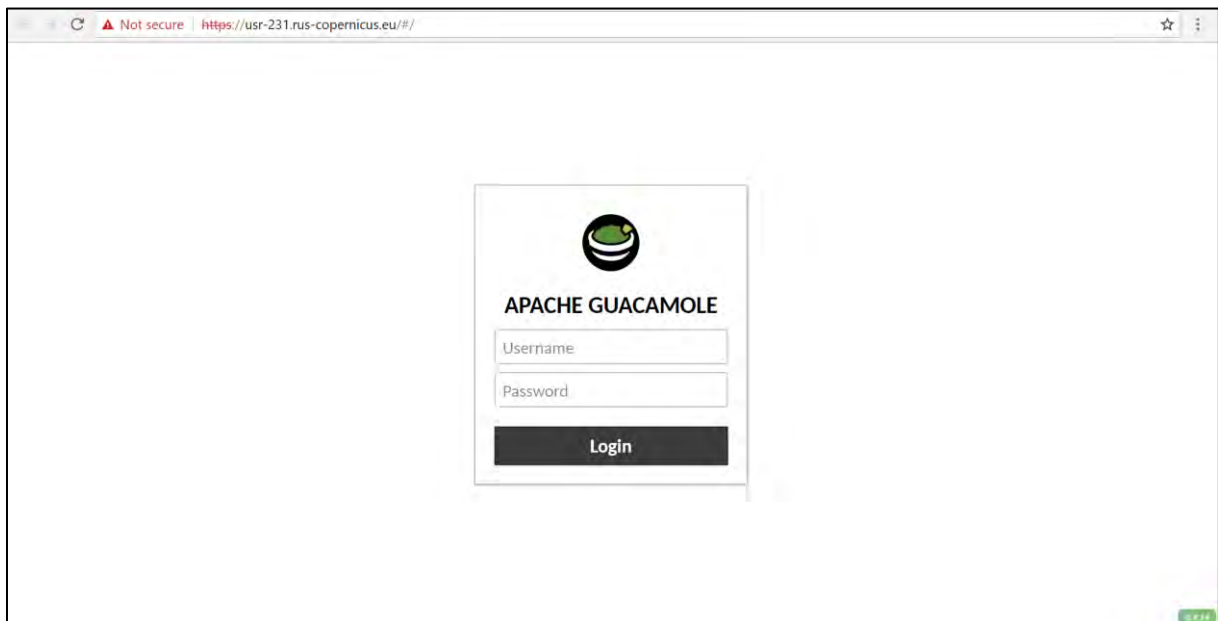


If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.

The image shows the 'User Support Request' form, specifically Step 1/3 titled 'Your experience'. The form asks the user to provide background information. It includes questions about years of experience in Remote Sensing and whether the user has downloaded or handled Copernicus data. A red rectangular box highlights a section titled 'Do you wish to practice a tutorial exercise shown in a RUS webinar? If yes, please select your choice (hold down CTRL key for multiple selections)'. This section contains a list of tutorial exercises: HAZA01 - Flood Mapping in Malawi, HAZA02 - Burned Area Mapping in Portugal, HYDR01 - Water Bodies Mapping over Northern Poland, LAND01 - Crop Mapping in Seville, LAND04 - Land Monitoring in Cyprus, and OCEA01 - Ship Detection in Gulf of Trieste. Below this list is a text input field for requesting exercises not in the list. At the bottom of the form are 'Cancel' and 'Next' buttons.

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

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.

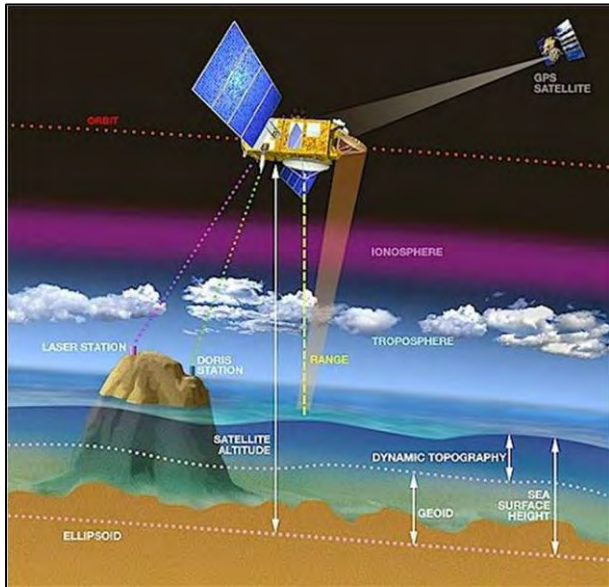


6 Background on Radar Altimetry

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 Real 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.

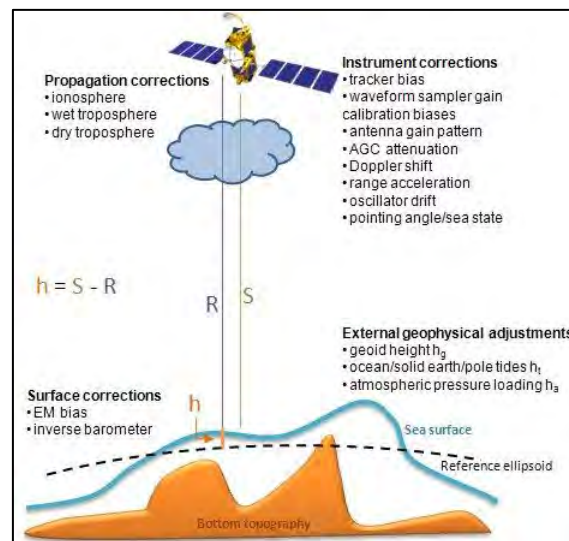
The range measurement shall be **corrected** for a series of effects related to the propagation into the Ionosphere/Troposphere, the instrument

and the surface. We can write:

Sea Surface Height (SSH): $\text{Satellite_Altitude} - \text{Corrected_Range}$.

Dynamic Topography: $\text{Mean Dynamic Topography (MDT)} + \text{Sea Level Anomaly}$.

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

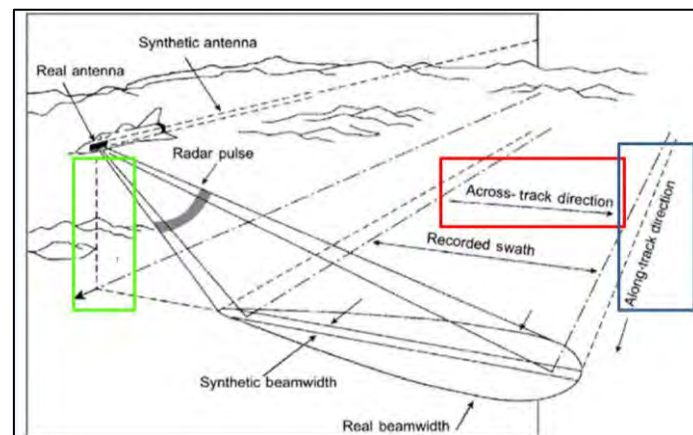


The resolution of the altimetry products will be discussed in the following 3 directions:

- **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 ($\text{Res_range} = \text{speed_of_light} / 2 * \text{Bandwidth} = 0.43 \text{ m}$)

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.

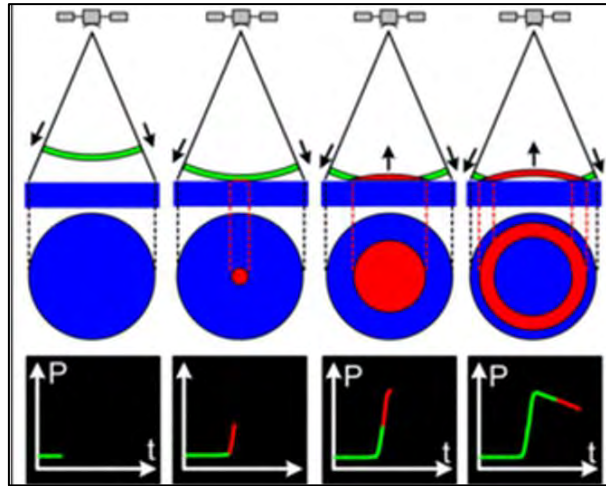
Present, past and future altimetry missions are reported here:



The processing schemes that are currently adopted in radar altimetry are the **Low Resolution Mode (LRM)** & the **Synthetic Aperture Radar (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**.



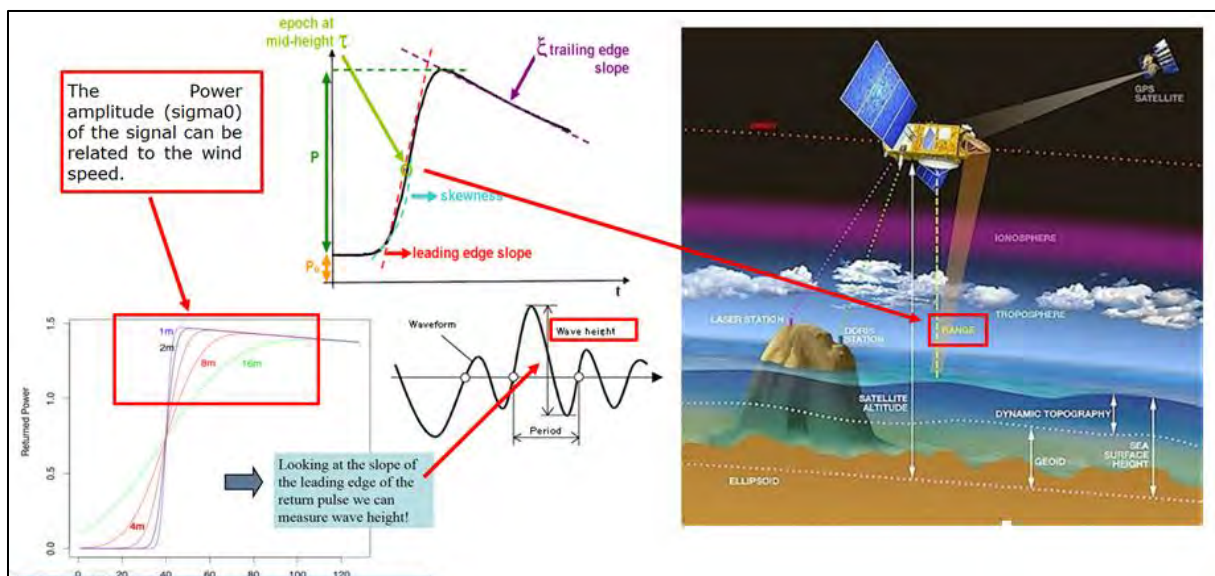
Observed parameters:

- **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 $2\text{m} < \text{SWH} < 8\text{m}$).
- **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.

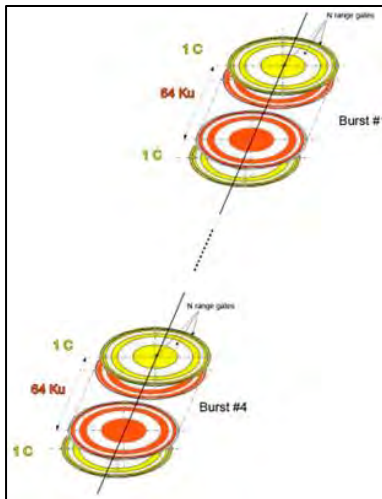
Key points:

- **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



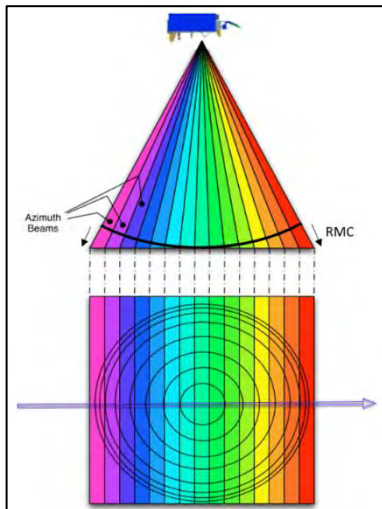
The time on target, dictated by the beam illumination and movement of the platform over the point, and the Doppler effect in the along-track direction are exploited in SAR mode.

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.

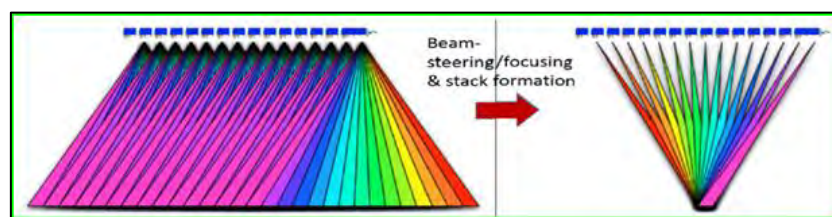
Each pulse of the burst interacts as in the LRM mode, the SAR processing is performed after all data are collected.

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 through 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.

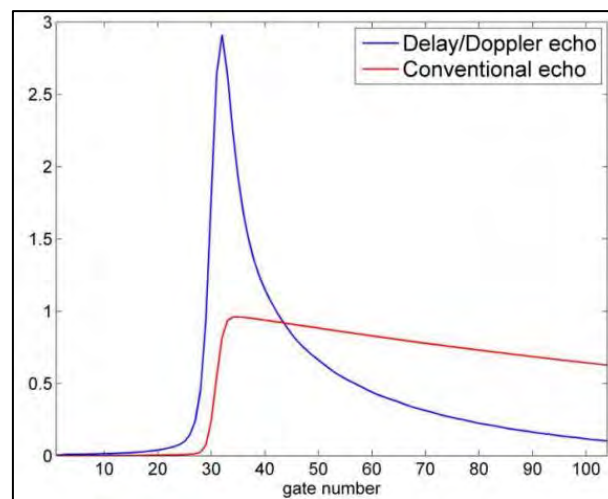
Again, as not only the nadir direction but all the directions allowed by the SAR processing formulation are considered, the surface state (flat or rough) does not affect the capability of recovering all the backscattered power (returning at nadir if the surface is flat or distributed in various directions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



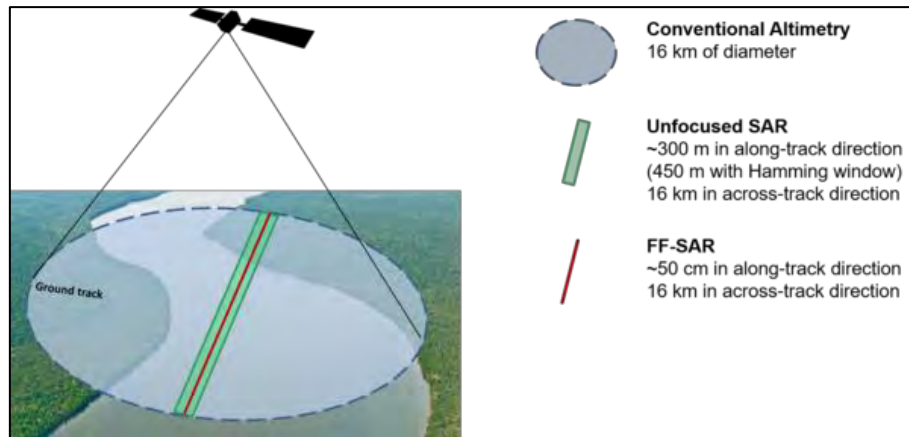
The SAR processing is currently adopted on Sentinel-3 and Cryosat-2. More information about the SAR processing can be found in this paper:

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 **Fully-Focused 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.

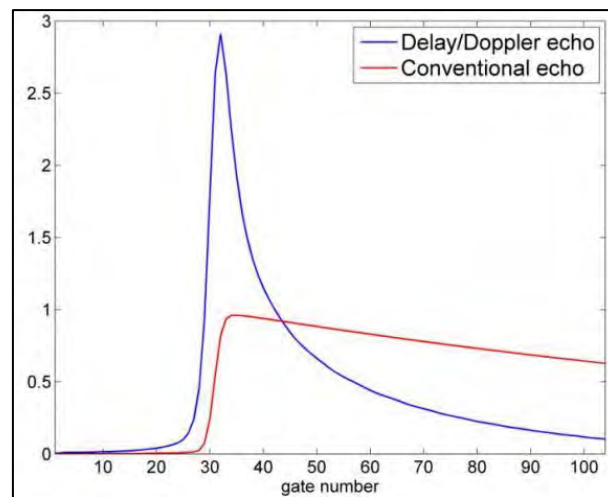
The following figure compares the along- and across-track resolution in the 3 modes:



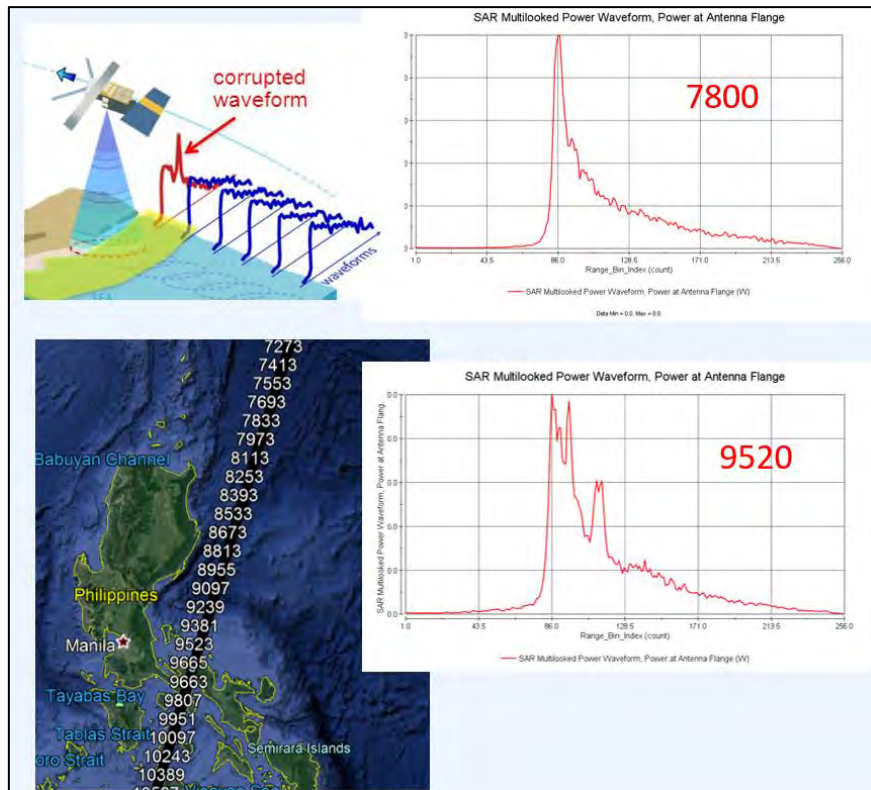
The Fully-Focused SAR is not implemented in current altimetry missions.

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

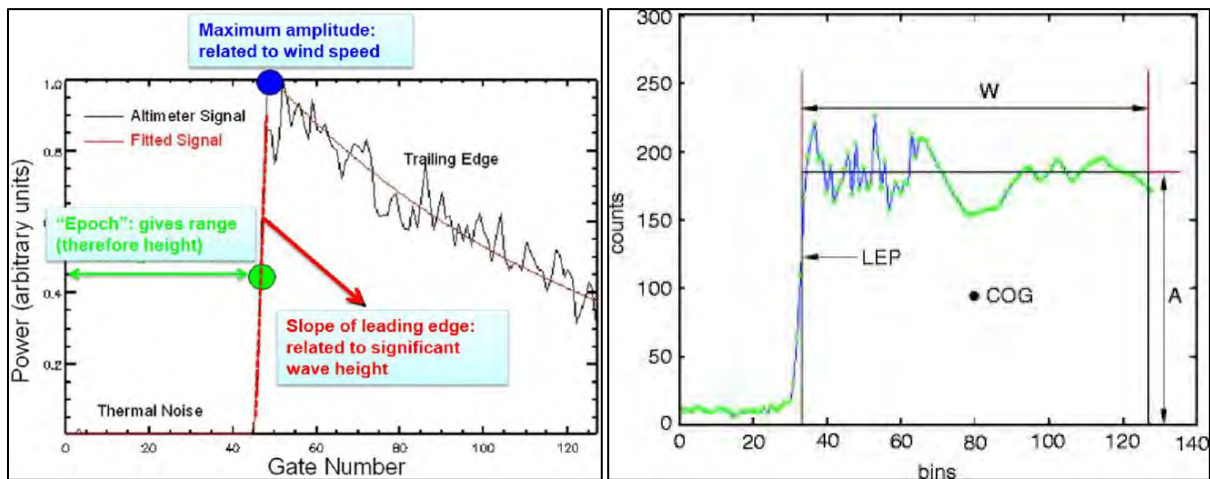
The Retracking processing is applied on L1b waveforms (SAR, LRM) and can be based on a model (analytical) or be empirical.

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 **Normalized Residual Error (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 retracers** (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 **Leading Edge Position (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 retracers.

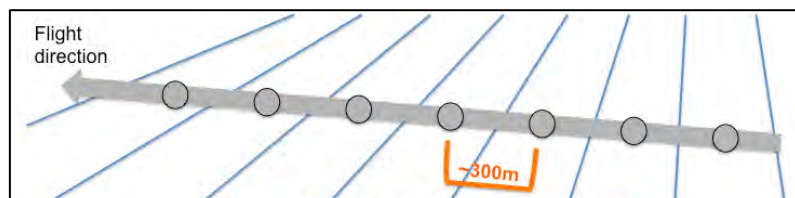


L2 products are created after the retracking process and include the estimated **SWH** (only in the analytical retracking), **range & power** (named also **sigma0**). Geophysical corrections are also included in the typical output netCDF/binary files.

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.

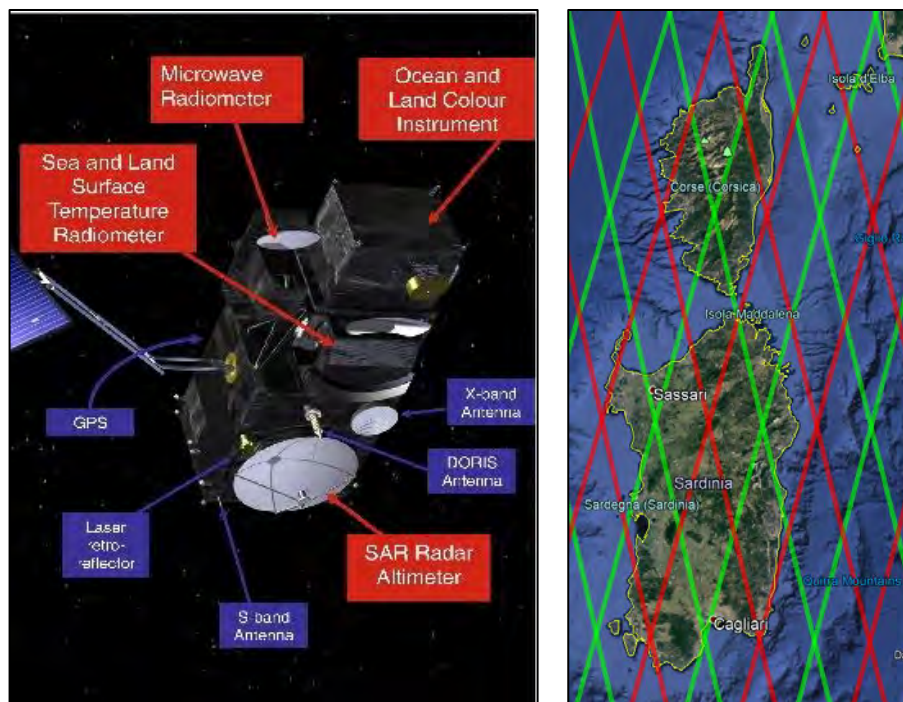
At the moment, SAR mode is operative on Sentinel-3 and Cryosat-2 missions. Many present and all past missions are in LRM mode. SAR waveforms can be degraded to produce ReDuced-SAR (RDSAR)/pseudo-LRM waveforms at 1Hz (7-km spacing). A SAR 4-burst cycle is ~ 1 LRM cycle of 50 ms (20Hz). pLRM mode is used 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.

- 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 timelines (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)**

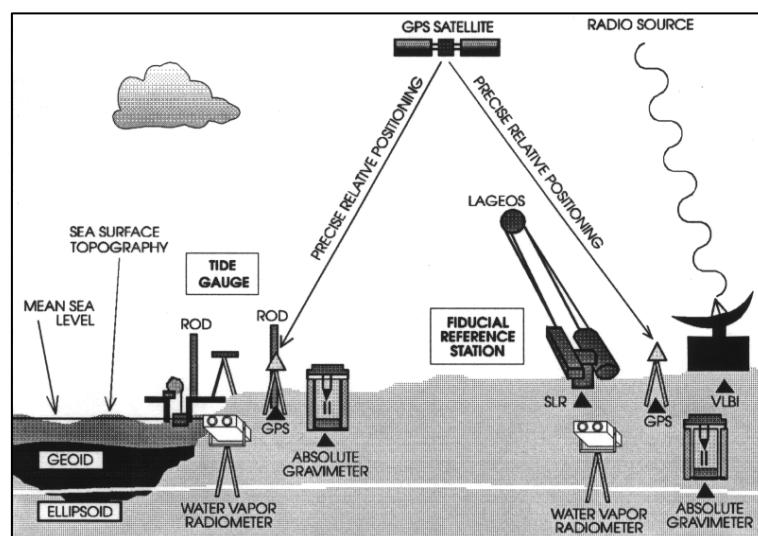
Sentinel-3 tracks in .kml format (see figure above, right panel) can be downloaded from: <https://sentinel.esa.int/web/sentinel/missions/sentinel-3/satellite-description/orbit>

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.

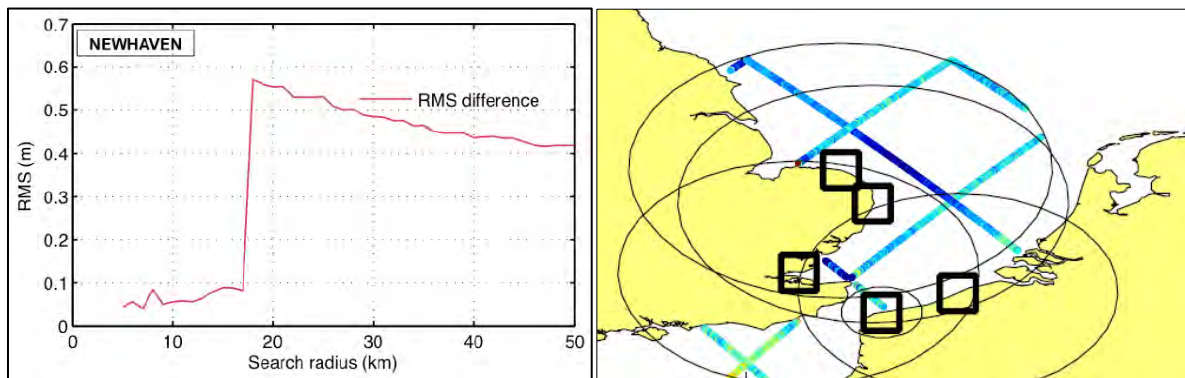
Tide gauge measurements (e.g. collected every 10 min, every hour...) are made with respect to a local fixed reference level on land. Local vertical land motion can be corrected by using GPS data.

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-measured water level 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://codal.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.

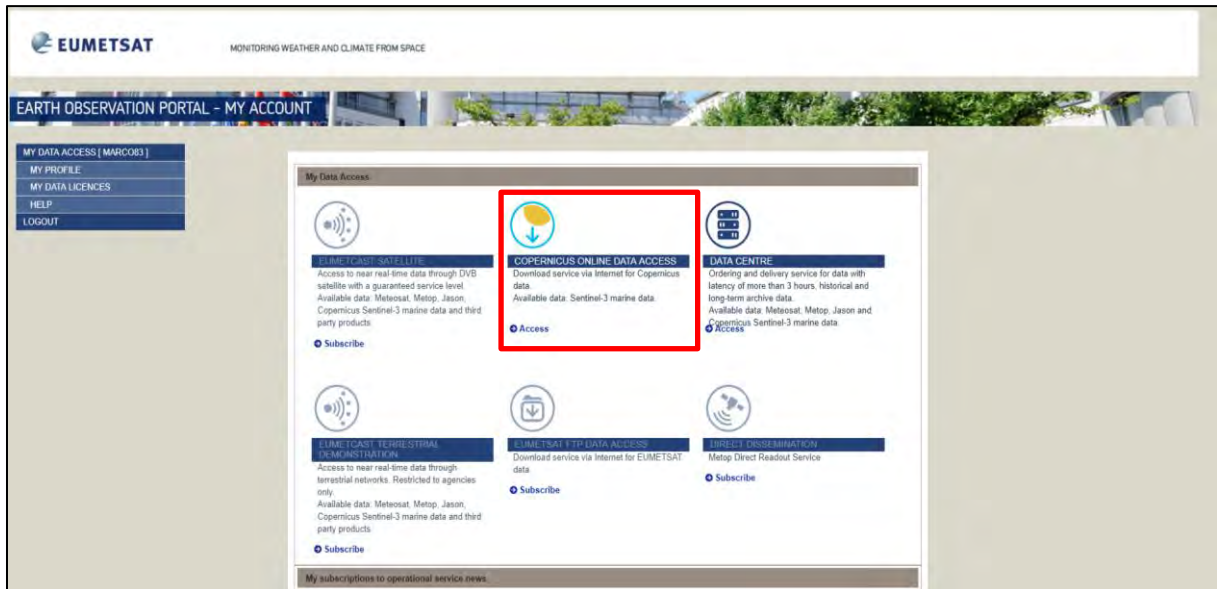
In this training we will use **Sentinel-3 L2 WAT** products from **EUMETSAT**.

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://codal.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 catalogue by clicking on the Copernicus Online Data Access section indicated below:

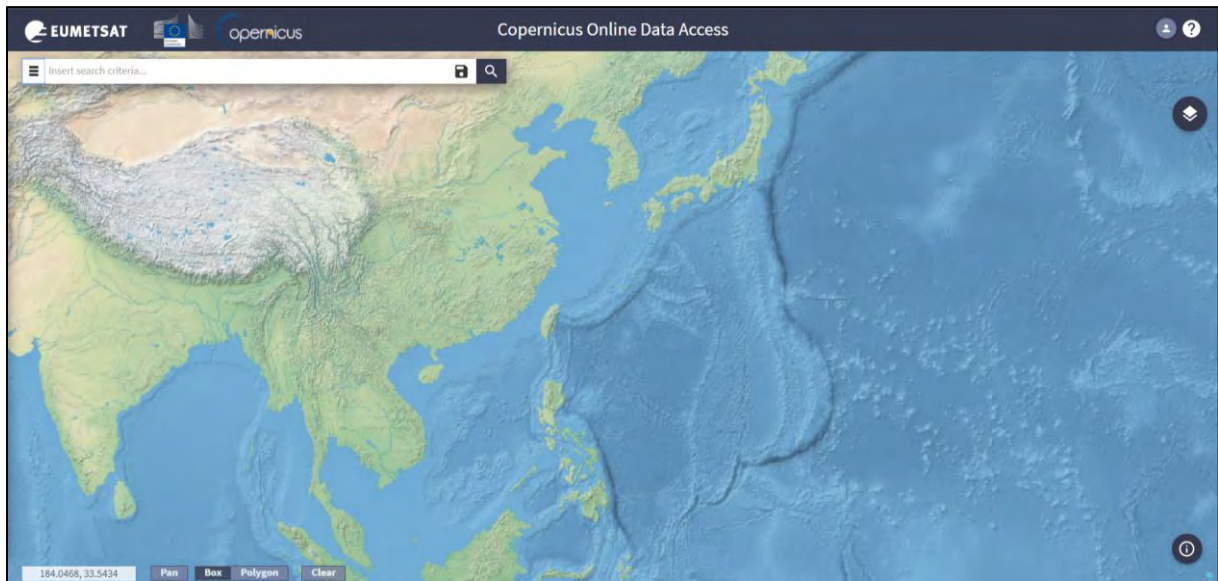


The data catalogue interface will show up:



For the first series of exercises, we will use two tracks acquired in East China. They are separated by the repeat cycle of Sentinel-3 (27 days) and have been acquired over the same position on June 9th 2018 & July 10th 2018 by Sentinel-3A, respectively.

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)

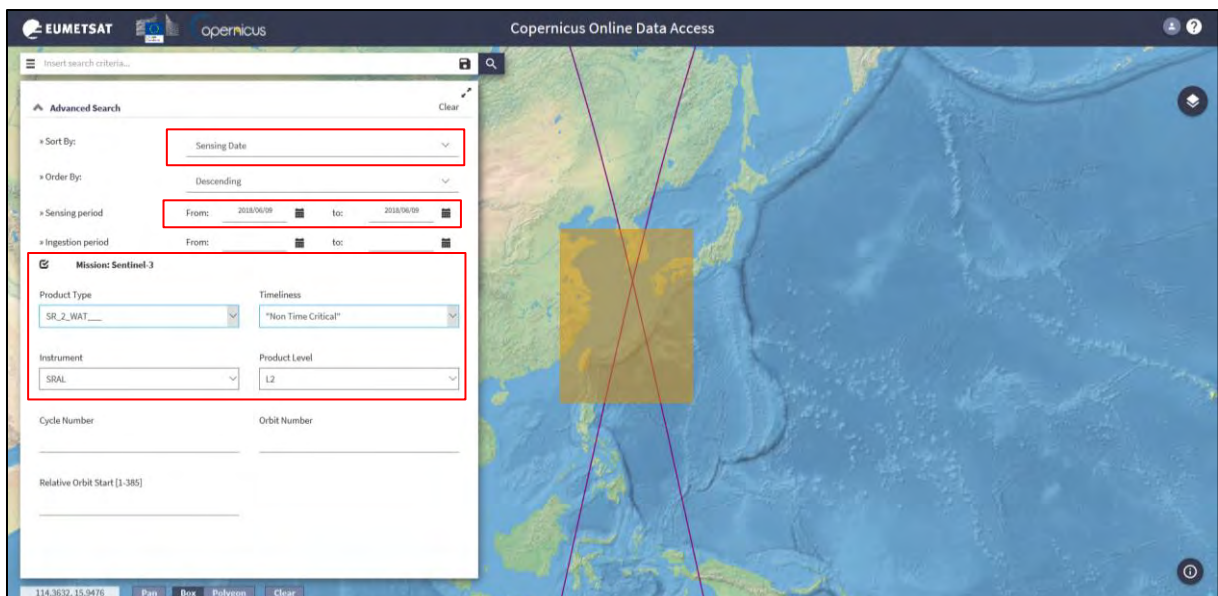
Check Mission: Sentinel-3

Product type: SL_2_WAT__

Timeless: "Non Time Critical"


Instrument: SRAL

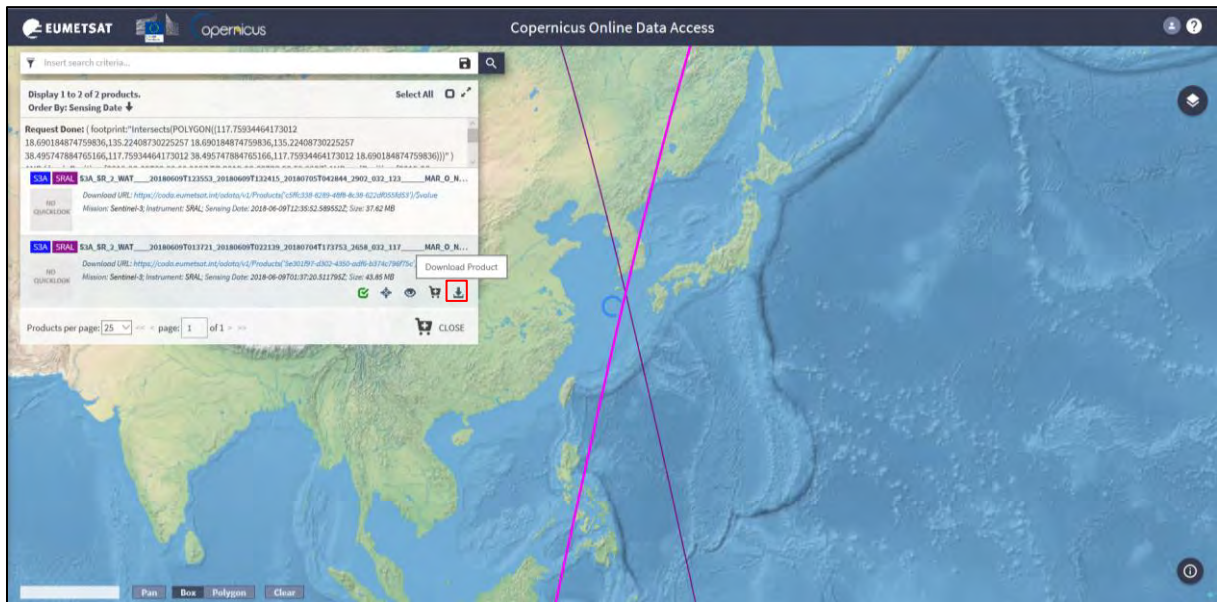
Product Level: "L2"



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/OCEA07_Oceanography_TutorialKit/Original/S3_data

To download the second, change the Sensing period in the query to:

Sensing period: From 2018/07/10 to 2018/07/10 (1 day)


Download the following product, move it to the same path and unzip it there as well.

**S3A_SR_2_WAT____20180710T013336_20180710T021747_20180804T173801_2651_033_174____
_MAR_O_NT_003**

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.

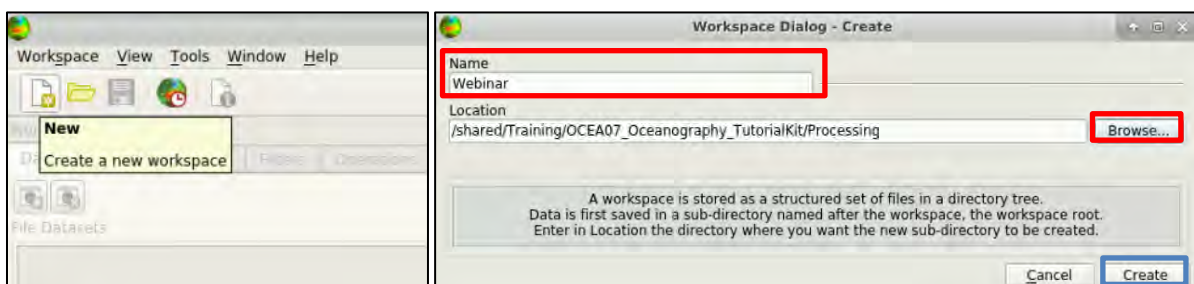
7.2 BRAT – Overview

7.2.1 Create a workspace

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

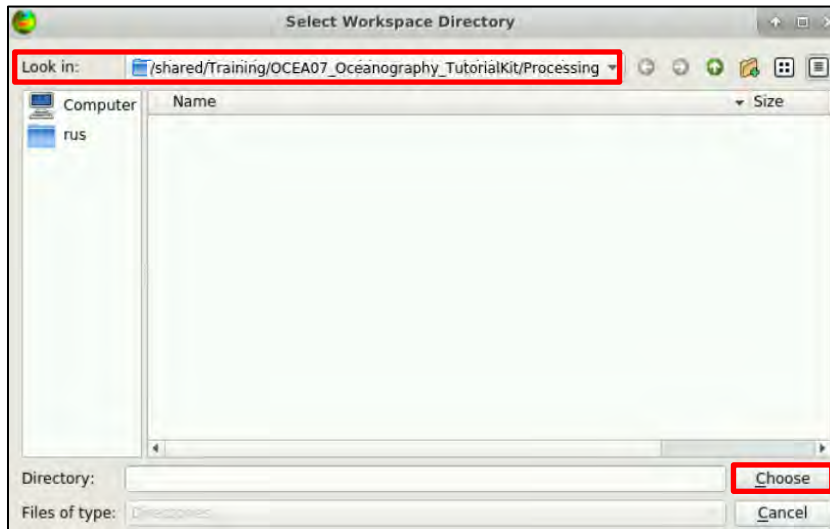
When you open the BRAT GUI, click on “**New**” or go to **Workspace → New** and give a name to it (e.g. “**Webinar**”).

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




Go to “Look in” and set as path: **shared/Training/OCEA07_Oceanography_TutorialKit/Processing**.

Then click on “Choose” without writing anything at the “Directory” and finally click on “Create”.



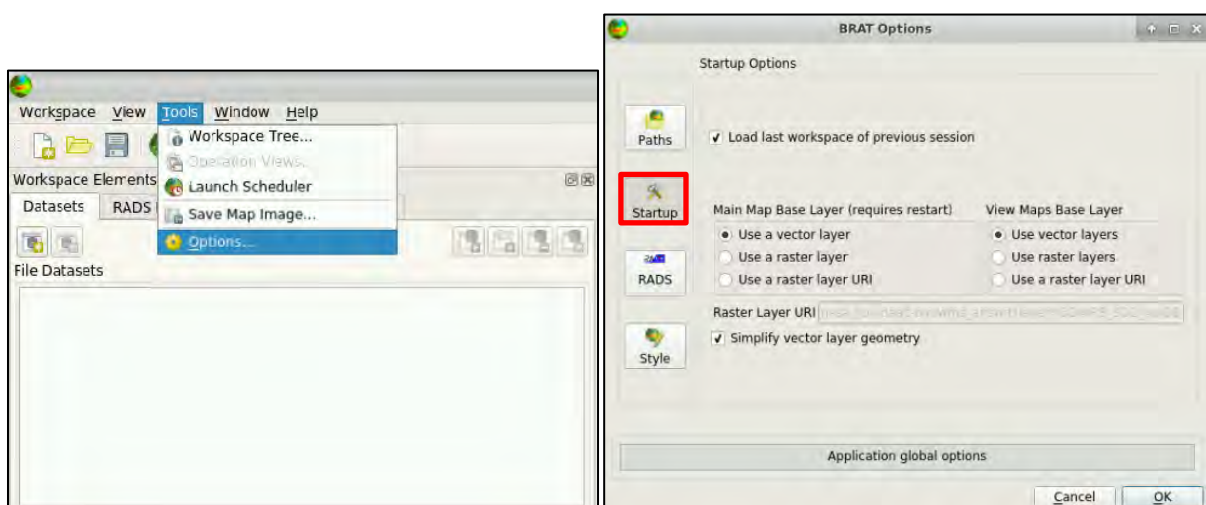
A “**Workspace**” is a way of saving your preferences, computations and generally the work done with BRAT GUI. Some or all elements of a workspace can be imported into another workspace. The “**Workspace**” menu (and also the main toolbar) allow the user to create, open, close, save, import, rename or 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:



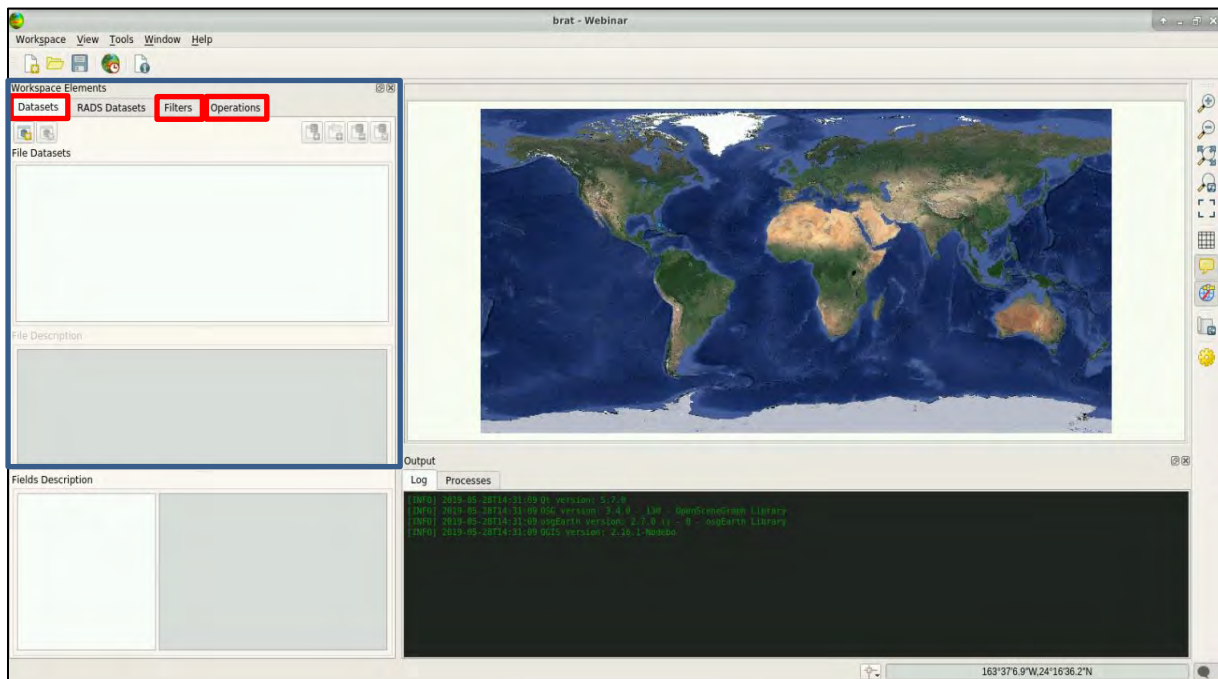
For this exercise, choose the second option “**Use a raster Layer**” click on “**OK**” and restart the program (**Workspace tab** → **Exit**). At the window dialog that appears: “**Do you want to save any workspace changes?**”, click “**Yes**”.

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.

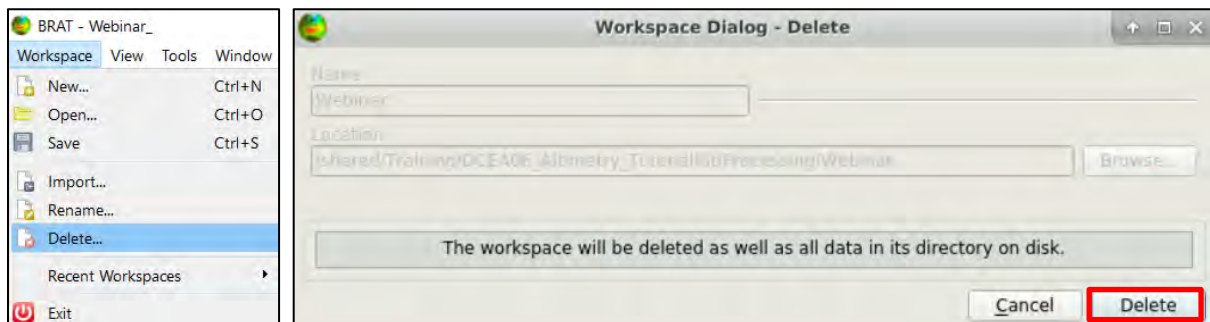


7.3 Preliminary operations

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

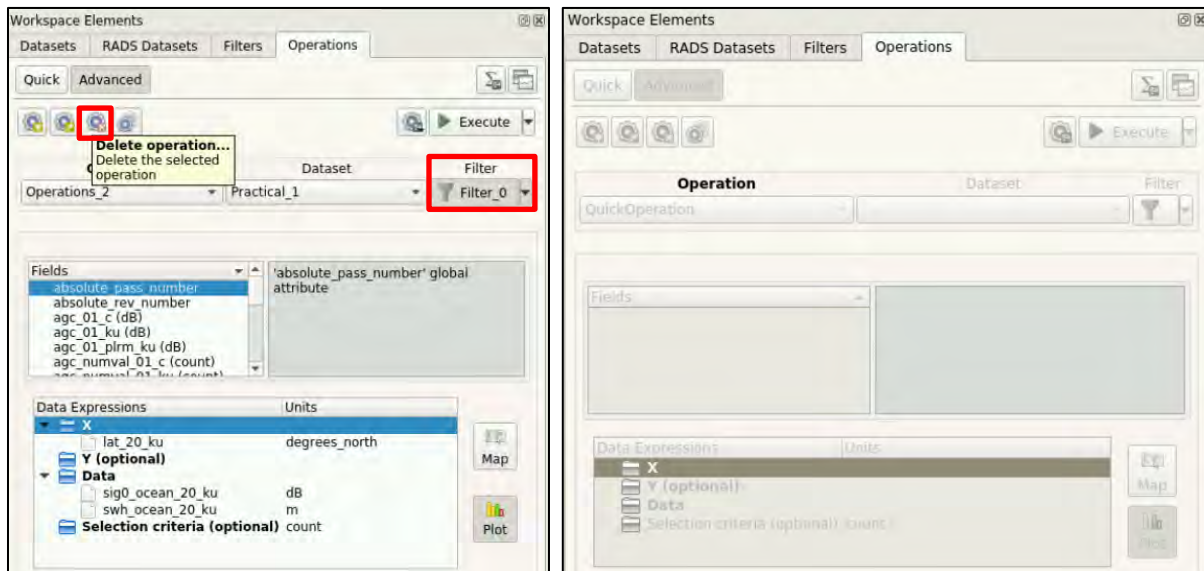
Go to the **Workspace Elements** panel → **Operations** and click on **"Advanced"**.

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).

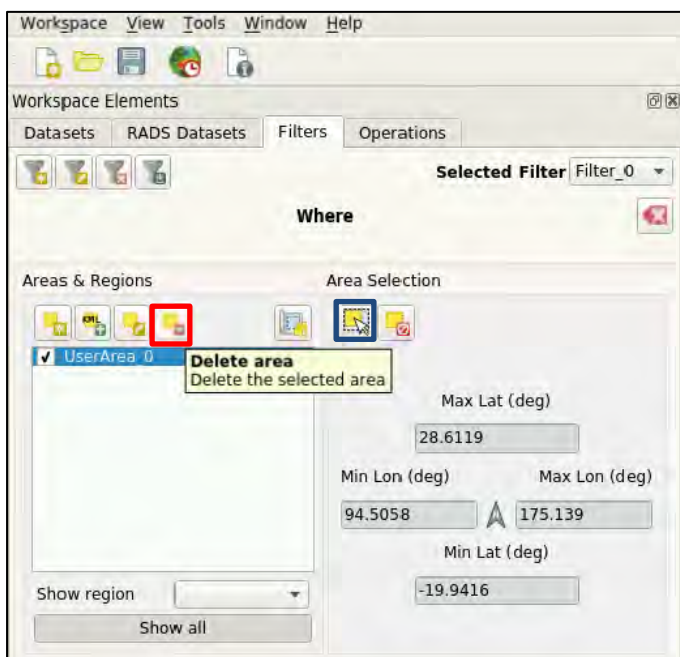
Only the **"Quick Operation"** shall remain available in the Operations menu. Filters have to be disabled also for the quick operation in a similar way.

Sometimes an operation can be cancelled only if the filters associated with the operation are disabled and deleted (see next section).

 **NOTE 3:** If you use BRAT for the first time, there will be no previous operations stored and you will not be able to click on “**Advanced**”. The whole tab will be inactive. (*Right* image below).





7.3.3 To delete a filter



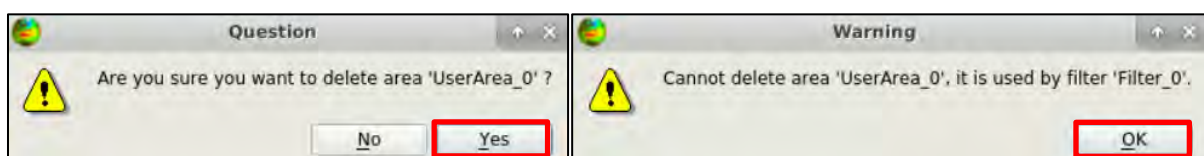
Filters have to be disabled also for the operations (Quick/Advanced).

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:

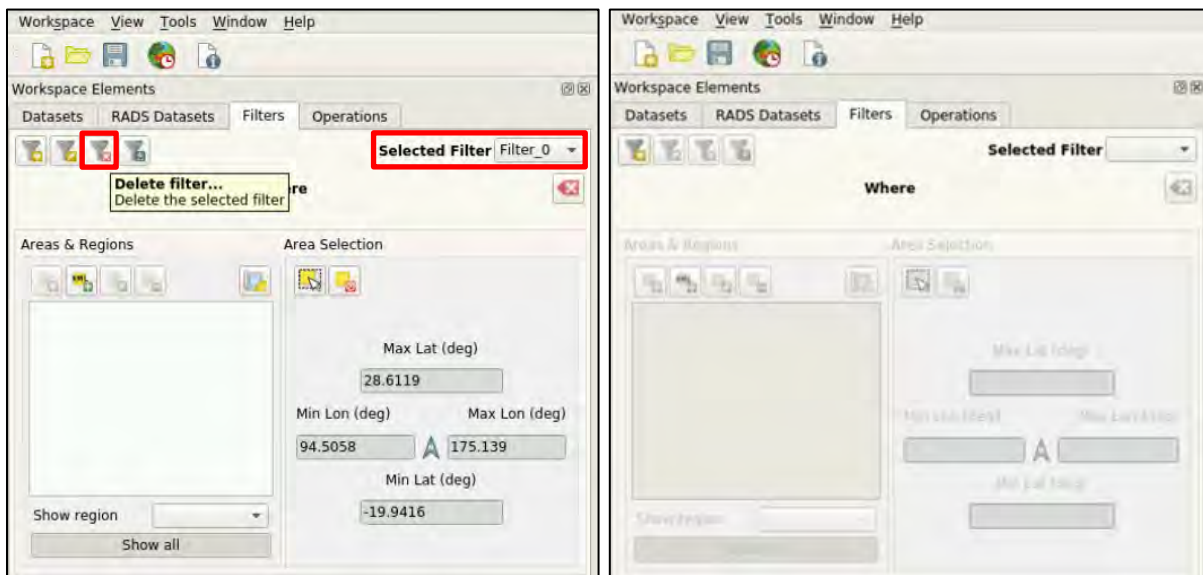
- 1) uncheck all the entries of the “**Areas & Regions**” list,
- 2) click on the “**Delete area**” button  and on “**Yes**” when the system message appears.

If a “Warning” window appear, click **OK** and apply the next step.



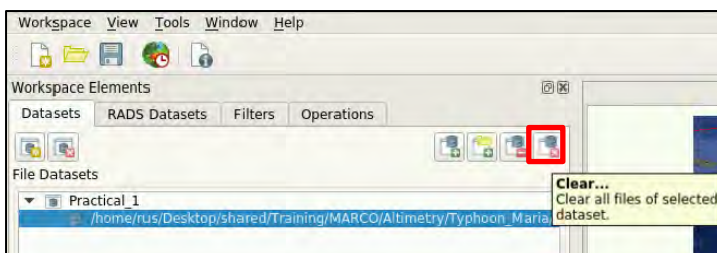
To delete a filter e.g. “**Selected Filter** **Filter_0**” click on the delete filter icon  and then on “**Yes**” when the system message appears. (*Left* image below).


 **NOTE 4:** If you use BRAT for the first time and there are no previous filters created or stored, the whole “Filters” tab will be inactive, and you cannot apply this step. (*Right* image below).




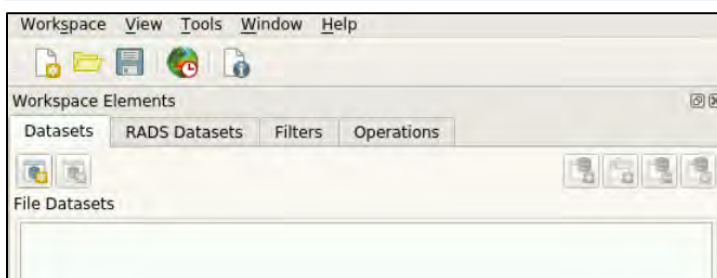
Reminder: The filters have to be deselected from *both Quick* and *Advanced* operations before being cancelled. After the cancellation of the filter, the operation can be cancelled.

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).

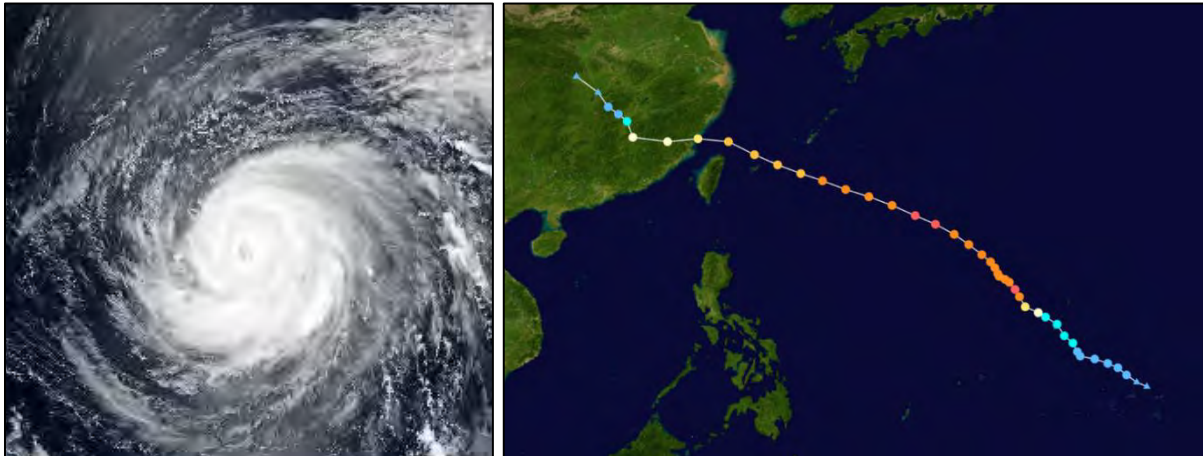


7.4 Exercise n. 4 – The impact of a Typhoon the estimates.

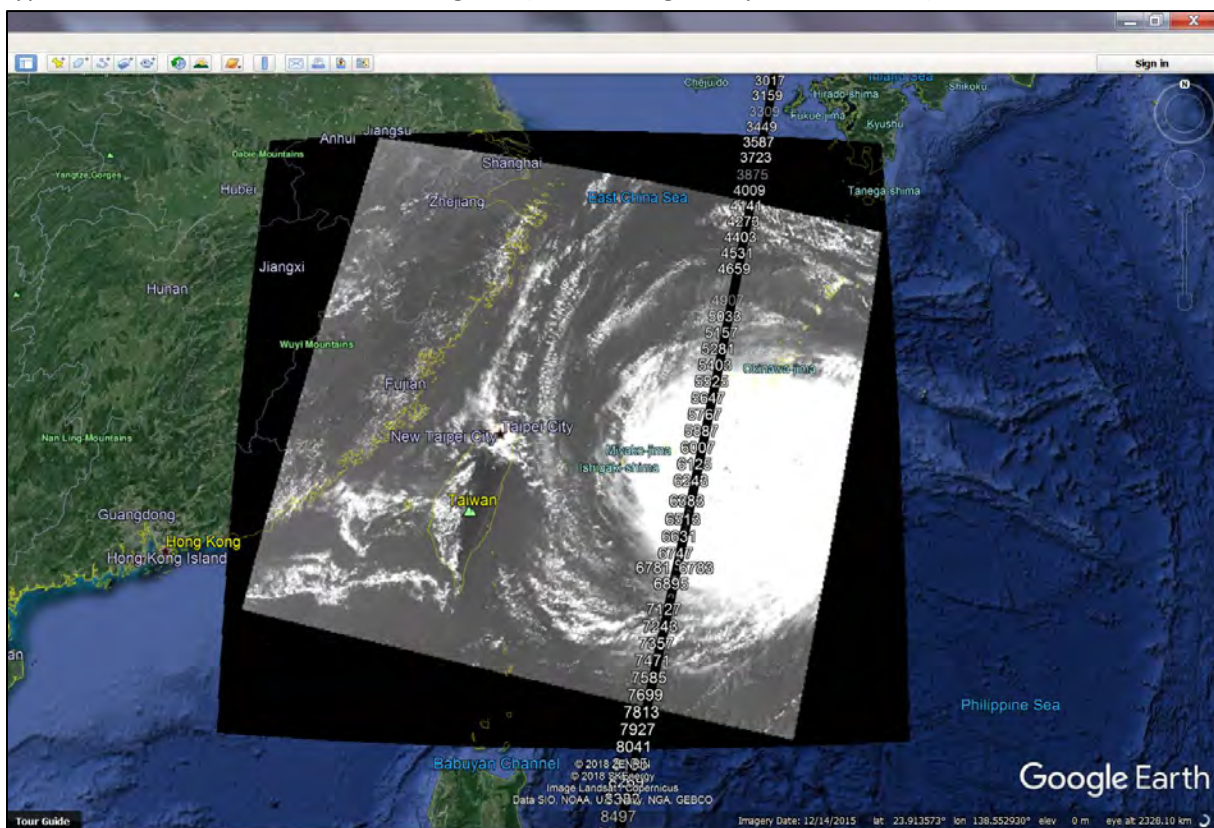
The track used in **OCEA06 Training Kit**, has been acquired one month before the passage of Typhoon Maria. Typhoon Maria was a powerful tropical cyclone that affected Taiwan & China.

The typhoon reached its first peak intensity (rightmost figure below; red dots on the right) on July 6, 2018; subsequently, Maria weakened due to an eyewall replacement cycle, but it re-intensified and reached its second peak intensity on July 8. Later, it started to gradually weaken due to colder sea surface temperatures. After hitting the Yaeyama Islands and affecting Taiwan on July 10, Maria

ultimately made landfall over Fujian, China, early on July 11, before dissipating on the next day (rightmost figure below; orange, yellow and cyan dots on the left).



On July 10th, Sentinel-3 collected data during the typhoon event. To locate the satellite track and the typhoon, both OLCI (**O**cean **L**and **C**olour **I**nstrument) providing optical images (see the left-most image above) and SRAL instruments on-board Sentinel-3 can be used. In the following figure, the OLCI image geo-located using the SNAP toolbox is reported along with the satellite track. The track intersects the typhoon at a latitude of around 25 degrees (not crossing the eye of the storm).

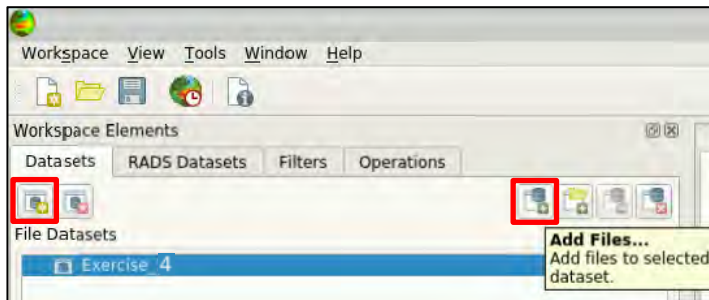




 **NOTE 6:** To process OLCI Sentinel-3 products in SNAP as made for this exercise, please check [section 8.1](#).

In this exercise:

- Variations in SWH, SLA, wind speed and Sigma0 will be investigated.
- We compare the track used in the previous exercises of **OCEA06 Training Kit** collected in the same region 27 days before the event, with one acquired during the typhoon event.

If you currently have a workspace loaded, **delete** it as indicated in *section 7.3.1* and **Create a New Workspace** as in *section 7.2.1*.

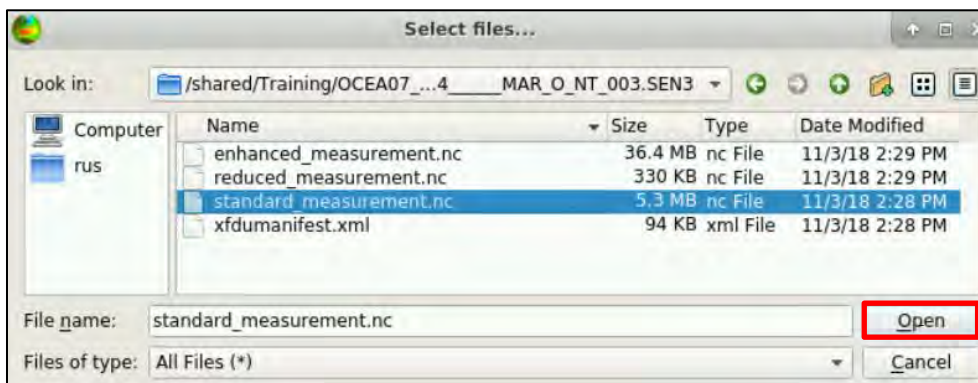


Go to the **Workspace Elements** panel → **Datasets**. Click on “**Create New Dataset**” . Name the dataset as “**Exercise_4**”. Then in order to load the required track, click on “**Add Files**” . Select the track downloaded from the EUMETSAT Data Hub from the folder:

/shared/Training/OCEA07_Oceanography_TutorialKit/Original/S3_data

“**S3A_SR_2_WAT____20180710T013336_20180710T021747_20180804T173801_2651_033_174____MAR_O_NT_003**”.

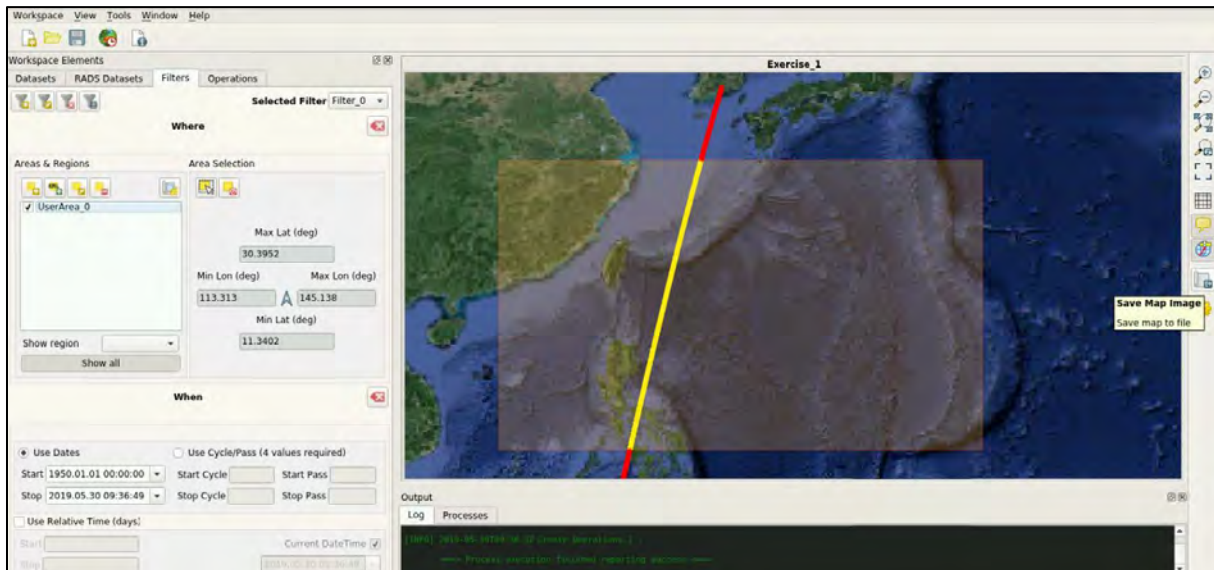
Select the “**standard_measurement.nc**” file and click “**Open**”.




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

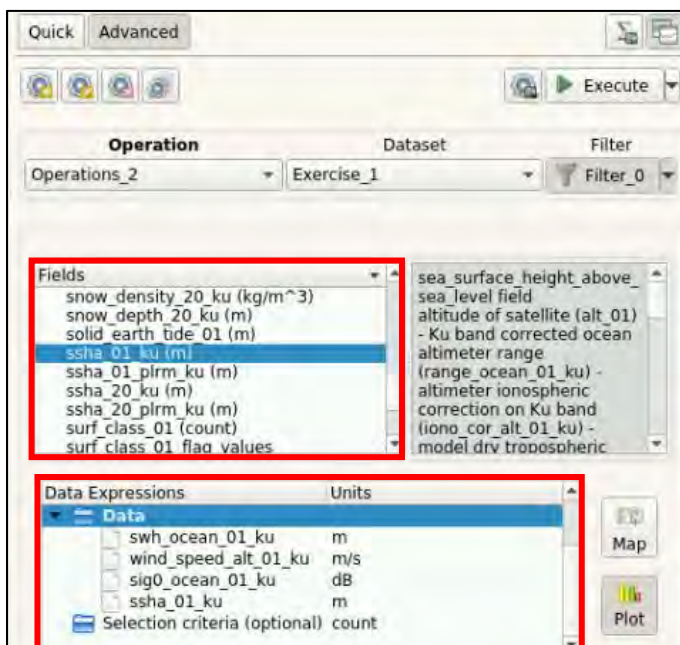


Create a filter in the following region (near Taiwan) using the instructions indicated at the *section 7.6* of **OCEA06 Training Kit** and include the area below:



Now select the filter you have created, plot the 4 variables shown below and then activate the “**Split plots**” function  by following the instructions indicated in *section 7.4.2* of **OCEA06 Training Kit** for **Advanced Operation**. Drag from the “**Fields**” field the variables and drop them in the “**Data Expressions**” field. Use:

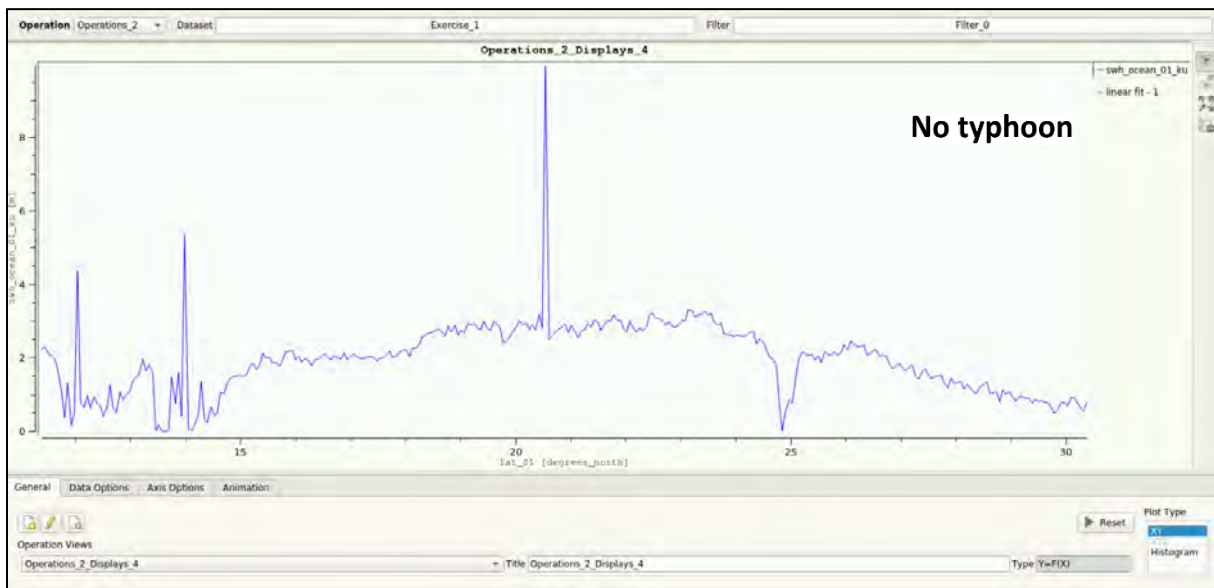
- in X: **lat_01 (degrees north)**
- in Data: **swh_ocean_01_ku (m)**
wind_speed_alt_01_ku (m/s)
sig0_ocean_01_ku (dB)
ssha_01_ku (m)



By re-doing the same filtering/operations considering the track in which the typhoon is present (see *section 7.3.4* to delete the previous and import a new track) and comparing, we have:

SWH (Top: No typhoon, Bottom: Typhoon)

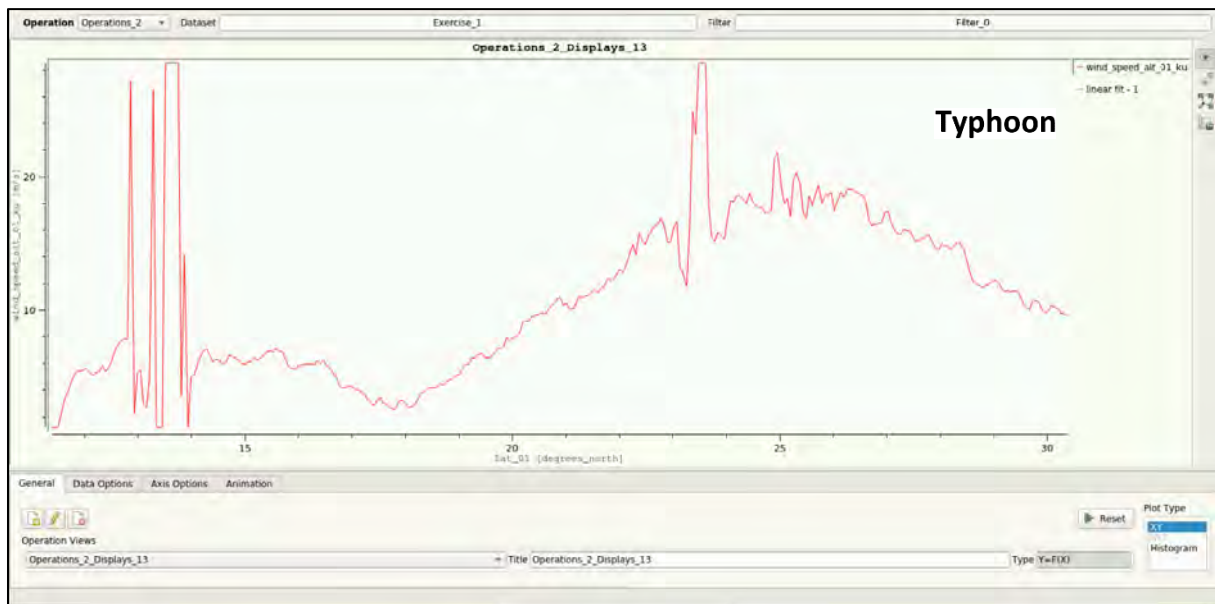
The track intersects the typhoon at a latitude of around 25 degrees (not crossing the eye of the storm). Please note that the latitude interval may varies according to the selected latitude filter.



Wind speed (Top: No typhoon, Bottom: Typhoon):

The track intersects the typhoon at a latitude of around 25 degrees (not crossing the eye of the storm).

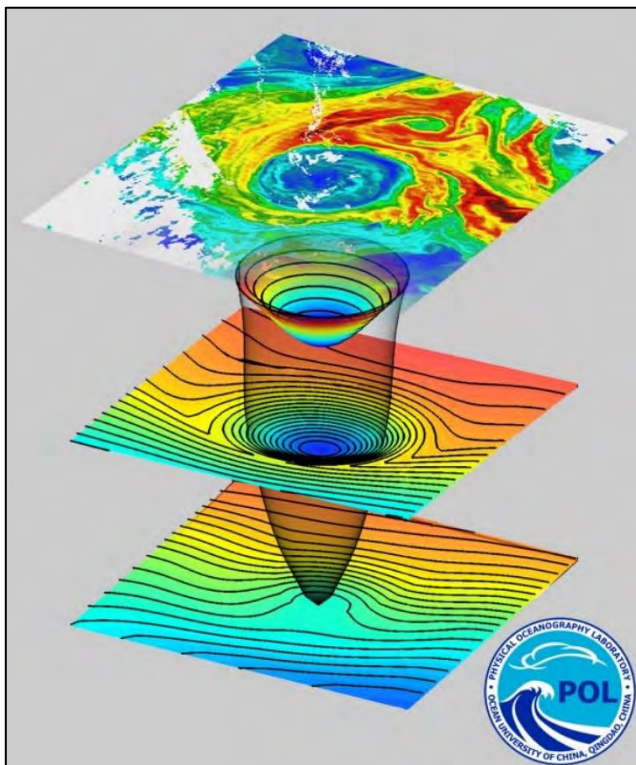




NOTE 7: SWH may reach very high values during a typhoon event. The wind, sigma0 and sea level anomaly result impacted as well.

7.5 Exercise n. 5 – Global and Mean Sea Level Anomaly

7.5.1 Sea level anomalies



Sea level anomalies are **sea surface heights** (SSH) with respect to the **mean sea surface** (MSS). It is not to be confused with what is usually called “**Mean Sea Level**” (MSL), which is a measure of the **sea level** variations over time.

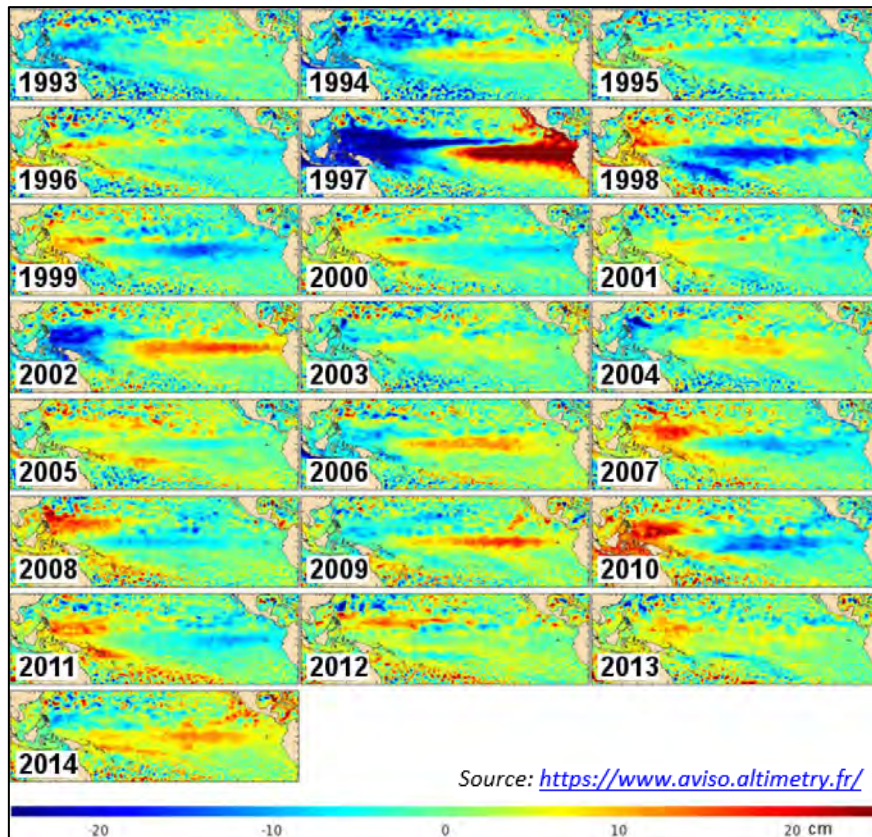
They contribute to the calculation of the **Absolute Dynamic Topography (ADT)**, which is given by the sum of **Sea Level Anomaly (SLA)** and **Mean Dynamic Topography (MDT)**.

Usage: Sea level anomaly data derived from satellite altimetry can be analyzed to **investigate mesoscale eddies**.

The **mesoscale variability** generally refers to ocean signals with **space scales of 50-500 km** and time scales of **10-100 days**. The Kuroshio region is one of the most active regions of eddies.

As an example, below are depicted the El Niño / La Niña maps: Monthly averages maps of Sea Level Anomalies (in cm) on November each year since 1993, over the Equatorial Pacific from the [El Niño Bulletin](#).

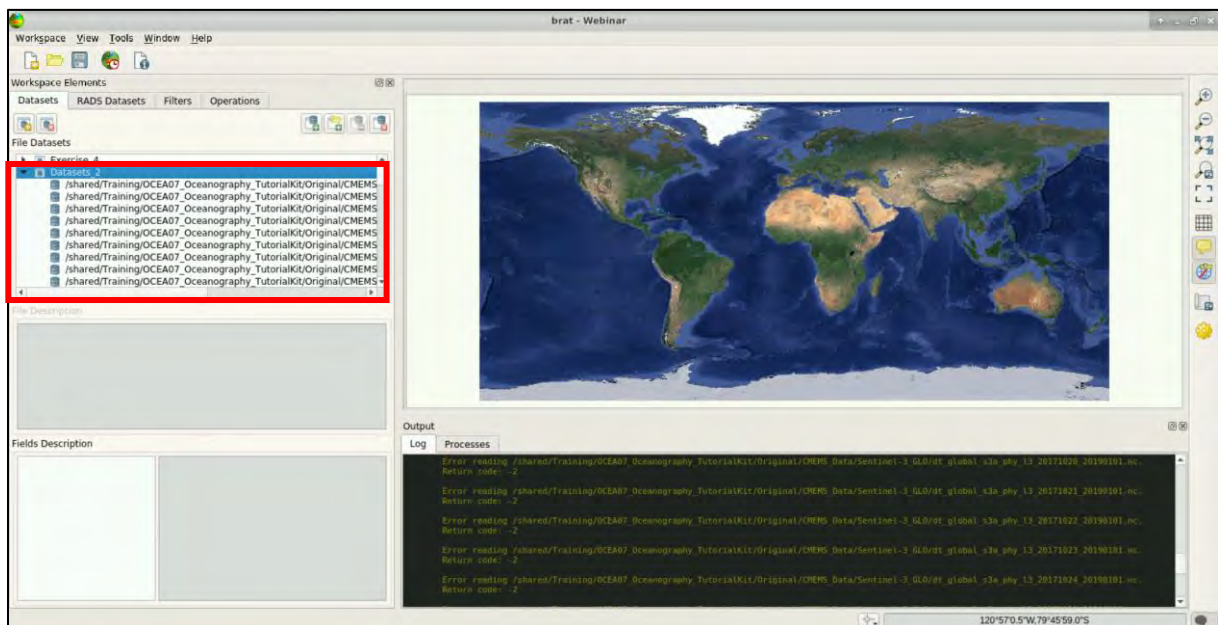
La Niña is a climate pattern that describes the cooling of surface ocean waters along the tropical west coast of South America. La Nina is considered to be the counterpart to El Niño, which is characterized by unusually warm ocean temperatures in the equatorial region of the Pacific Ocean.




7.5.2 Global Sea Level Anomaly

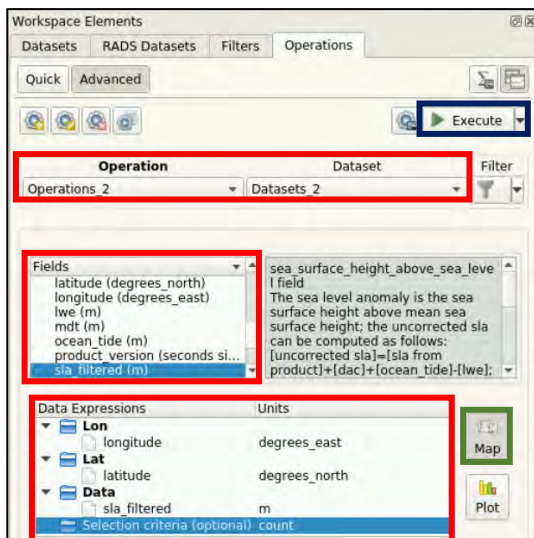
To run this exercise, please delete the current workspace, create a new one, name it **Webinar_2_sla** and then create a new dataset including all the data tracks from the folder: **/shared/Training/OCEA07_Oceanography_TutorialKit/Original/CMEMS_data/Sentinel-3_GLO**

Name it “**Datasets_2**” and click on the arrow at its left to view all the loaded data tracks.



As the CMEMS data template is not memorised in BRAT, the imported tracks will not be displayed on the BRAT map. However, products can be processed.

Go to **Operations** tab → **Advanced**, click on the **Map** icon  and run the following operation to create a map. Drag from the “**Fields**” field the variables and drop them in the “**Data Expressions**” field. Use:

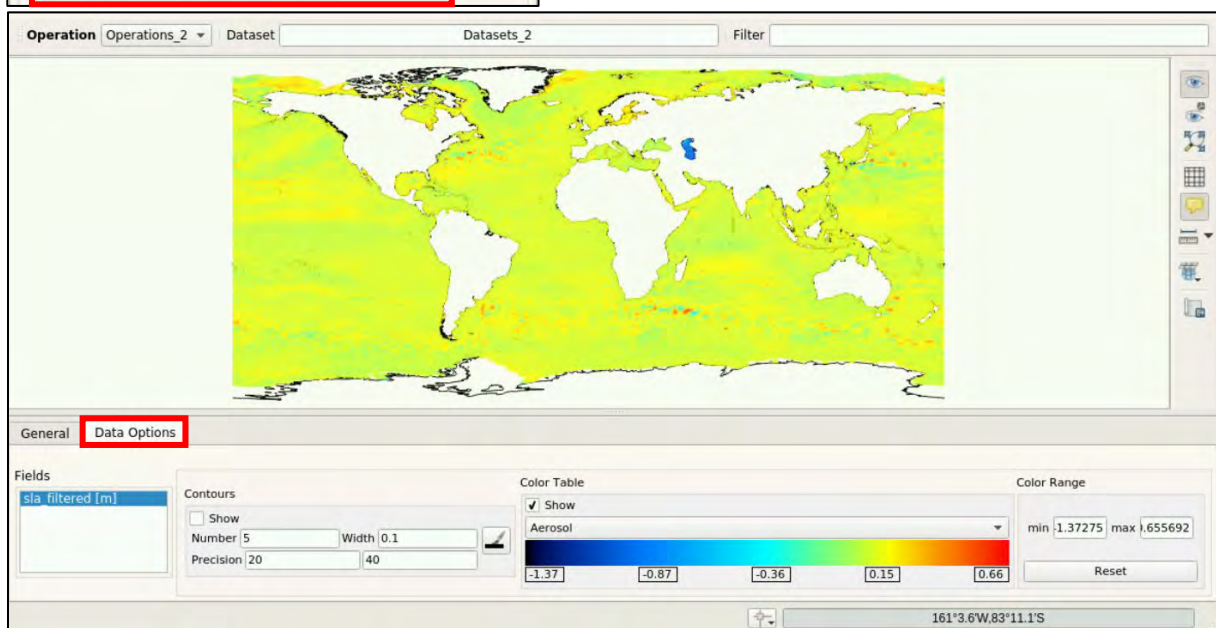


- in **Lon**: **longitude (degrees_east)**
- in **Lat**: **latitude (degrees_north)**
- in **Data**: **sla_filtered (m)**

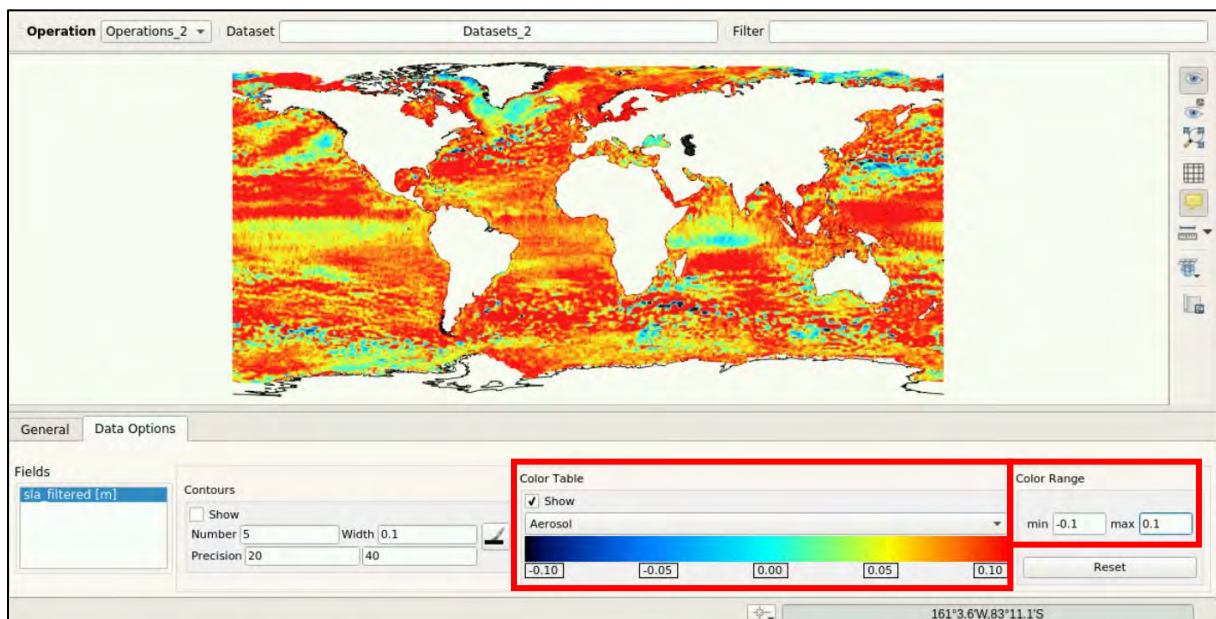
Make sure that under “**Operation**” and “**Dataset**” you have selected the proper ones that refer to the data you are working with.

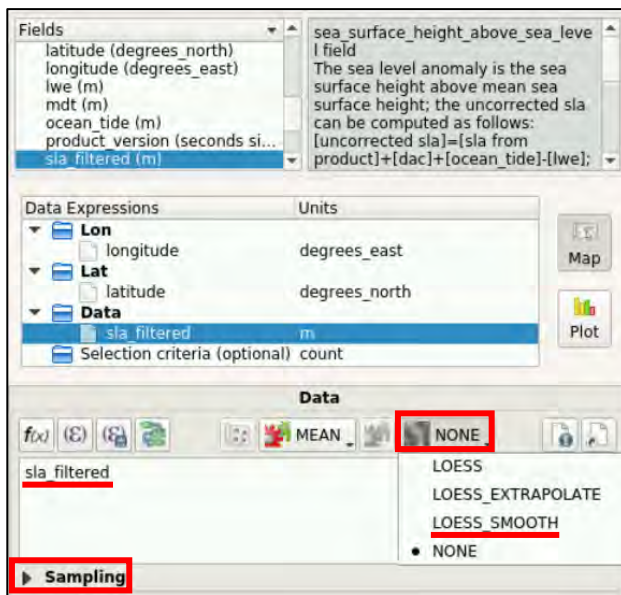
Click on **Execute** and then on “Yes” at the pop-up window.

It will take a few minutes and once the processing is completed, the following resulting Map will appear (go to “**Data Options**” tab):



At “**Colour Range**”, set as **min**: **-0.1** and **max**: **0.1** (double click in each field, write the value and press **Enter** so that the value will be accepted). You can **Reset** the values or change the **Colour Table**/ramp.



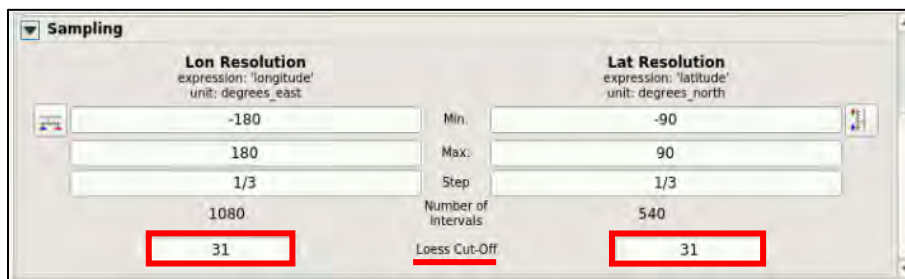


BRAT allows users to apply filters for smoothing (to filter out high frequency features by reducing the resolution of the native product).

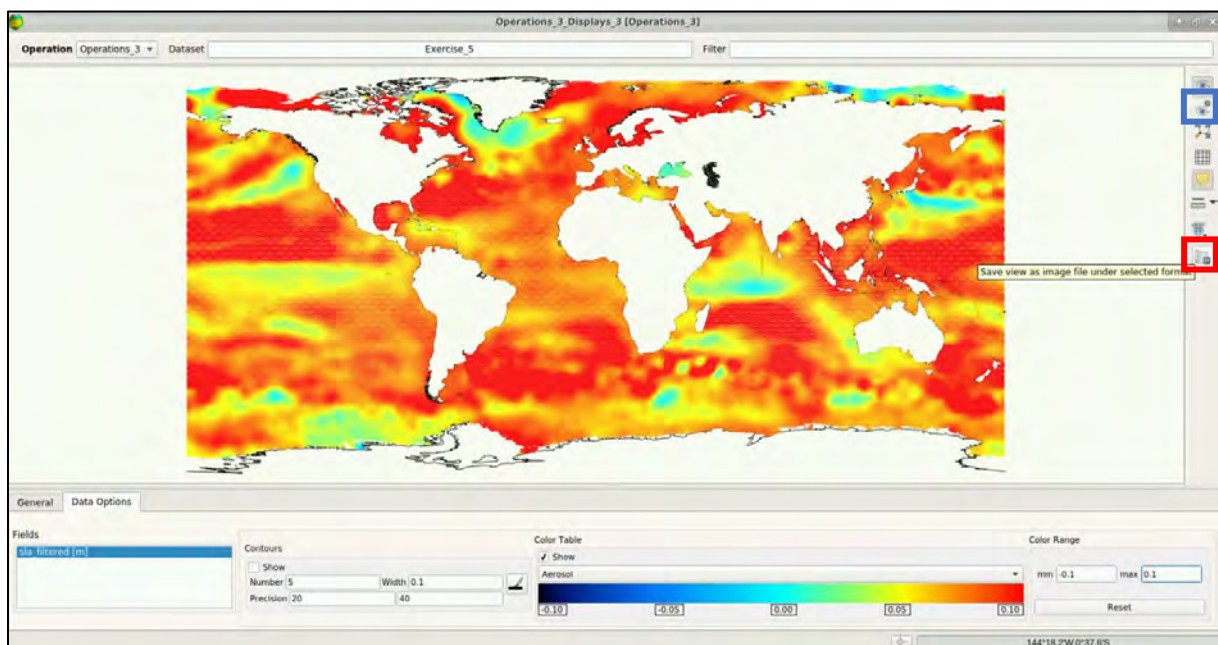
A **Loess filter** is a low-pass filter mostly used for smoothing. Loess cut-off values are discussed in the BRAT user manual.



Here is an example with the **LOESS_SMOOTH** filter selected as reported below after having highlighted the **sla_filtered** and it is evident under **Data**.

Click on **NONE** and once **LOESS_SMOOTH** has been selected, click on **Sampling** and modify the fields as the figure below:



Execute again the operation and the following Map will be produced (set **min** and **max** values again):




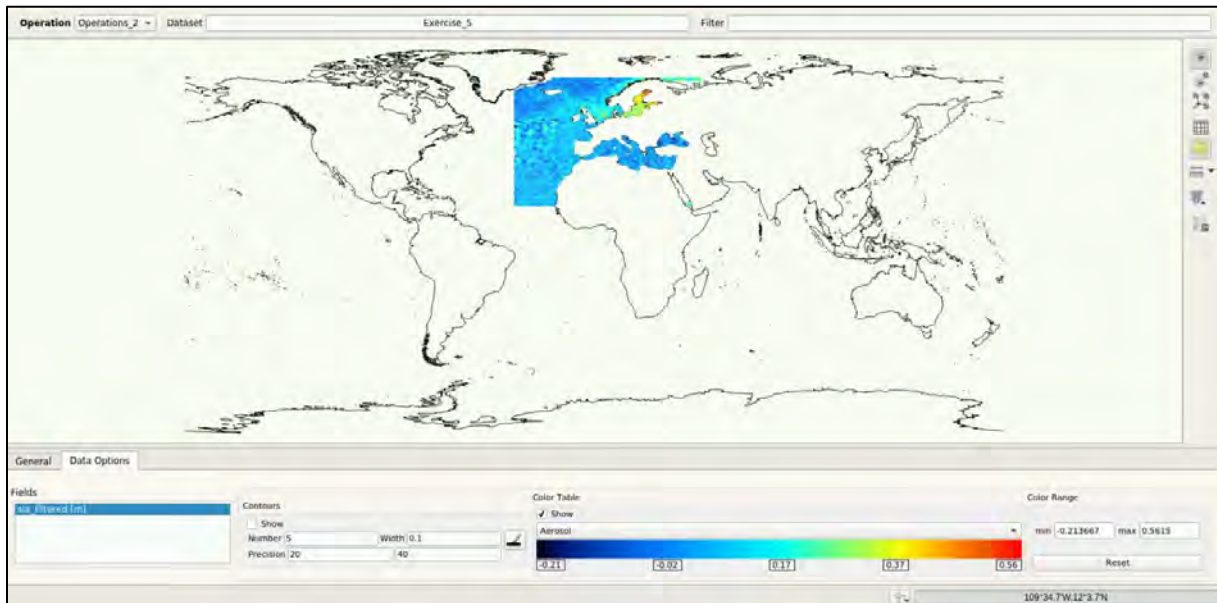
The smooth version is available and can be saved using the button  at the **Processing** folder. You can also visualize the result in 3D view by clicking on the **"3D Display 3D view"** icon .


7.5.3 Monthly mean Sea Level Anomaly

The same exercise can be repeated with the CMEMS dataset available in the folder **@/shared/Training/OCEA07_Oceanography_TutorialKit/Original/CMEMS_data/Sentinel-3/Data**.

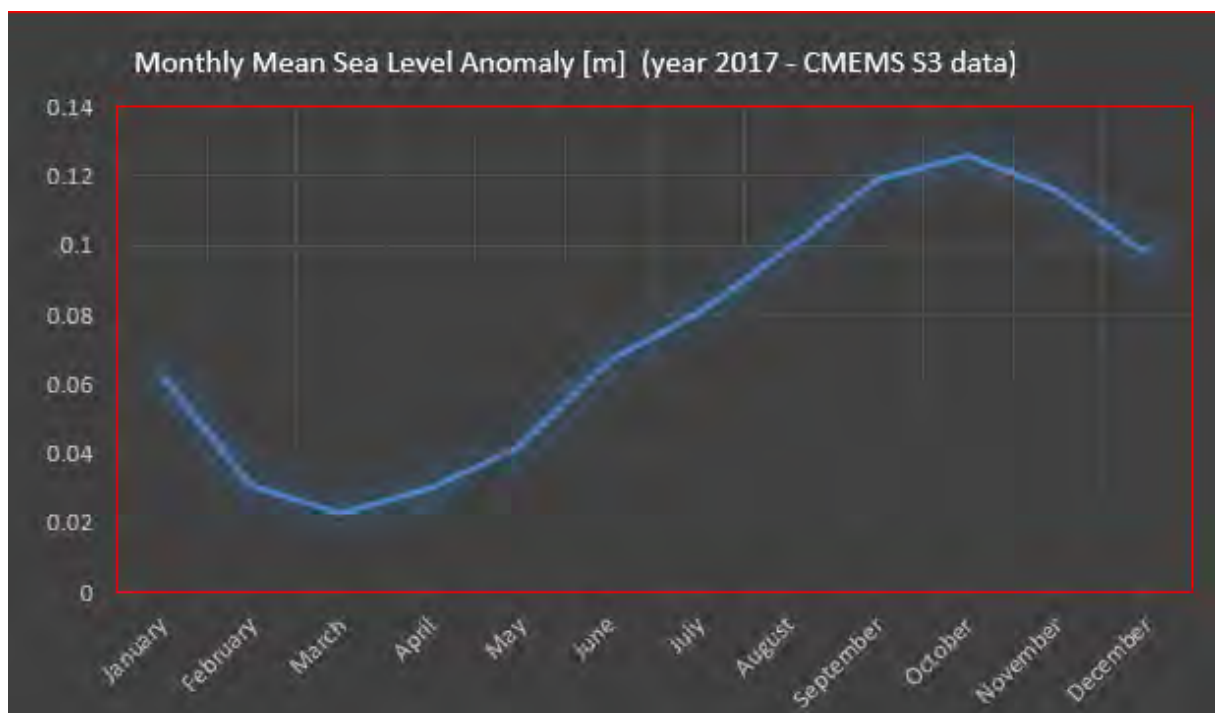
In this case, data are grouped per month. By importing one month of data at a time, the SLA can be


calculated for the Mediterranean CMEMS dataset and the **statistics evaluated** . It follows that it is possible to create an animation by using the 12 figures obtained as outputs of the 12 operations (one per month maintaining the same colour bar interval, see the video of the Webinar). As an example, for January 2017 data:



By calculating the statistics  we can evaluate the mean sea level anomaly variation month by month:

	January	February	March	April	May	June	July	August	September	October	November	December
Number of valid data	83109	74416	77243	78187	81342	77920	80021	81296	79256	83458	79177	82774
Mean	0.6255	0.30815	0.022681	0.29932	0.041732	0.066822	0.080526	0.09915	0.118942	0.125794	0.115792	0.097546
Standard Deviation	0.82444	0.06894	0.061728	0.060739	0.059023	0.056505	0.057874	0.057414	0.061969	0.069672	0.071395	0.067417
Minimum	-0.251	-0.497	-0.317	-0.302	-0.263	-0.204	-0.374	-0.403	-0.292	-0.301	-0.288	-0.211
Maximum	0.573	0.437	0.345	0.341	0.551	0.515	0.422	0.365	0.434	0.495	0.527	0.546



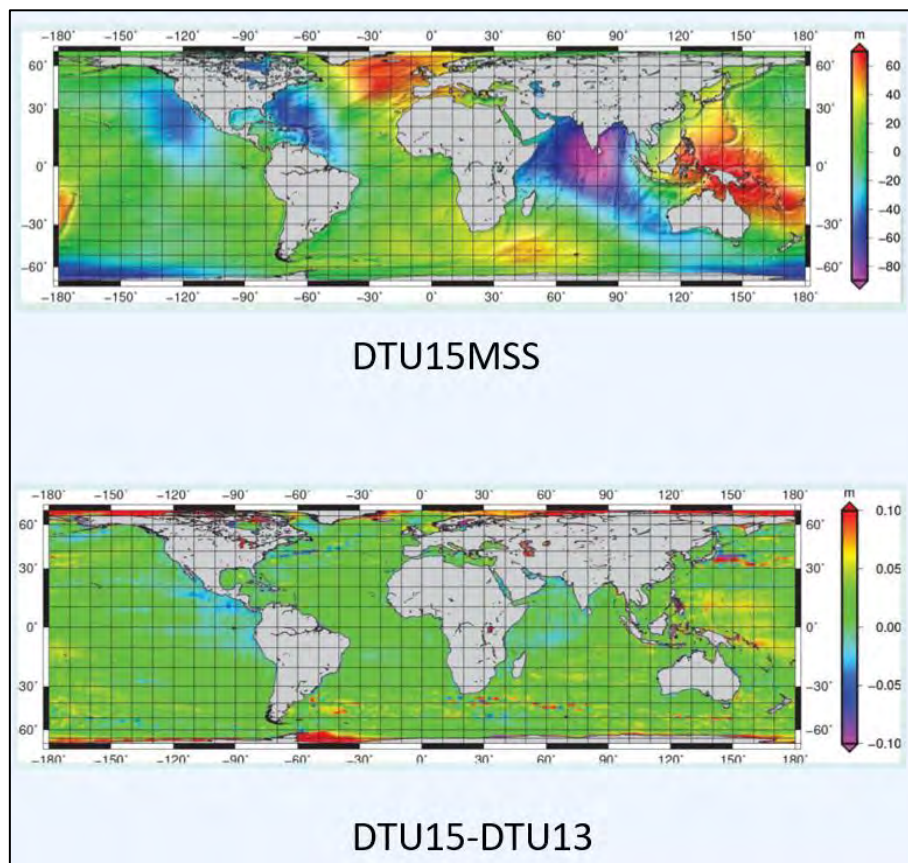
 **NOTE 8:** BRAT statistics can be used to evaluate the average values of points in one track (e.g. over rivers/lakes or in the coastal zone) or in a dataset (gridded products or datasets composed many along track files as the CMEMS ones).

7.6 Exercise n. 6 – Geostrophic currents & Current Speed

7.6.1 Mean Sea Surface

Mean Sea Surfaces (MSS) are essentially satellite altimetry by-products. MSS are used to obtain the sea level anomalies by subtracting SSH-MSS. The mean sea surface is the displacement of the sea surface relative to a mathematical model of the earth and it closely follows the geoid.

MSS amplitudes ranges between +/- 100 meters. To produce them, along-track mean profiles from different inter-calibrated missions are merged using optimal interpolation techniques. The resulting gridded field is the so-called altimetric Mean Sea Surface (MSS). Two examples of MSS are reported below:

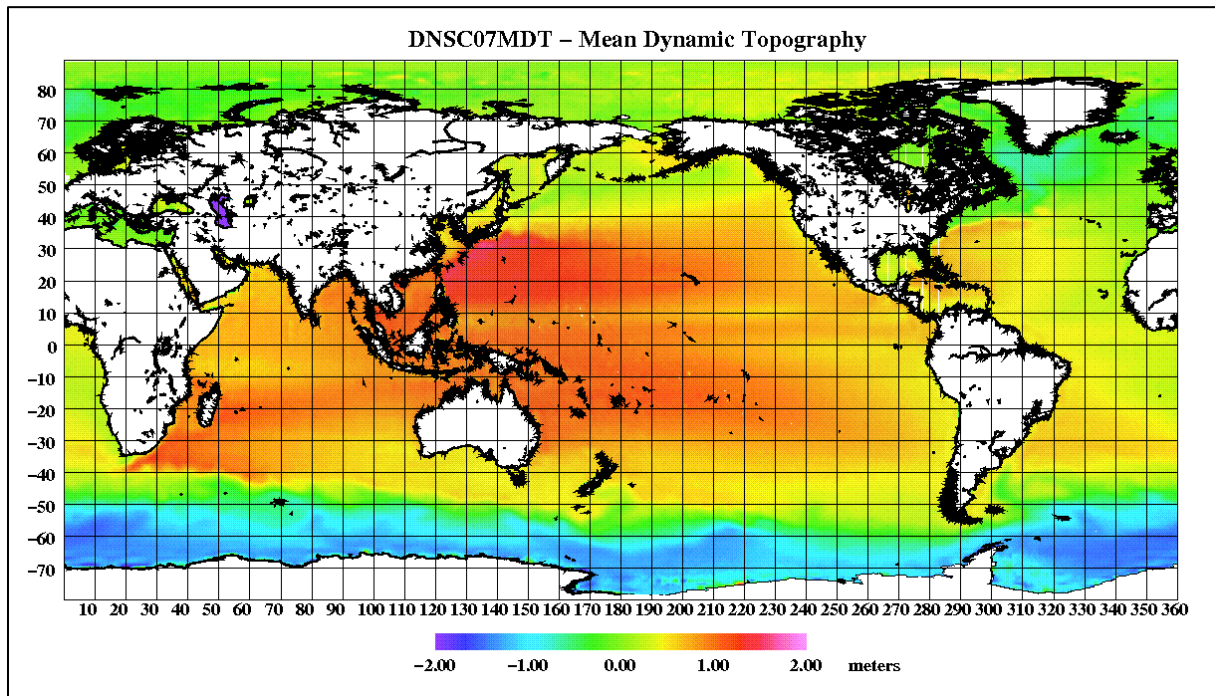


7.6.2 Mean Dynamic Topography

If the oceans were static and not affected by external influence as for example wind, temperature and air pressure, then Mean Sea Surface (MSS) and the Geoid would be the same surfaces. However, there are steady currents in the ocean, driven by winds and atmospheric heating and cooling, which give rise to differences in sea level around the world. These local differences between the Geoid and MSS are described by the Dynamic Ocean Topography (DOT). The DOT values range between (approximately) - 2.5m and +1.2 m. Recent MDTs and MSS are calculated using 20 years of altimetry data.

A **Mean Dynamic Topography (MDT = MSS – geoid)** is required to estimate the mean (time-invariant) transport in the ocean.

From the MDT scientists calculate the components and speed of time-invariant ocean geostrophic currents.

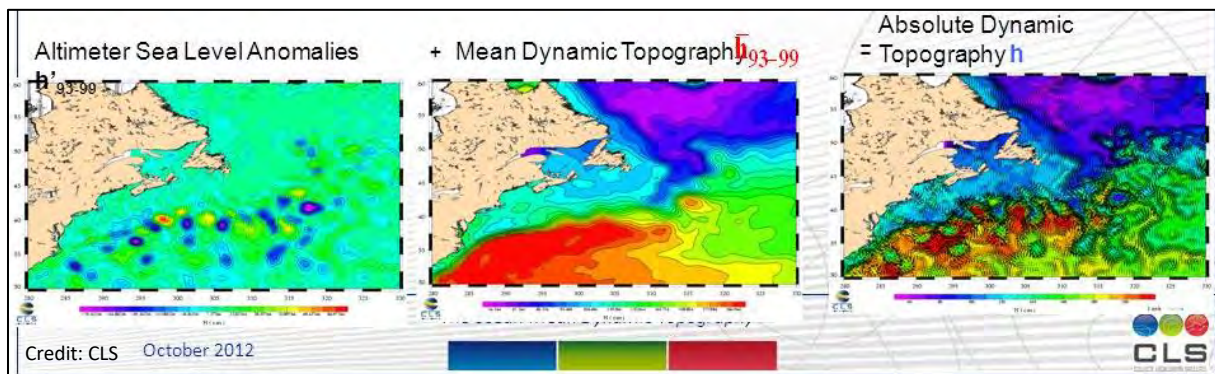


7.6.3 Geostrophic currents

Definition: The absolute dynamic topography is defined as the sea surface height above the geoid and is obtained by summing sea level anomaly (SLA) and mean dynamic topography (MDT):

$$ADT = MDT + SLA$$

The MSS used to generate the SLAs must be defined over the same averaging period as the MDT.



For this exercise use the **ADT_from_MDT_AVIS0_CLS_2009_plus_SLCCI_v2.nc** in the folder: **/shared/Training/OCEA07_Oceanography_TutorialKit/Original/SLCCI_Data**

The provided ADT is used to evaluate the **instantaneous total surface geostrophic currents** using the typical geostrophic equations:

$$u_s = \frac{-g}{f} \frac{\partial h}{\partial y} \quad v_s = \frac{g}{f} \frac{\partial h}{\partial x}$$

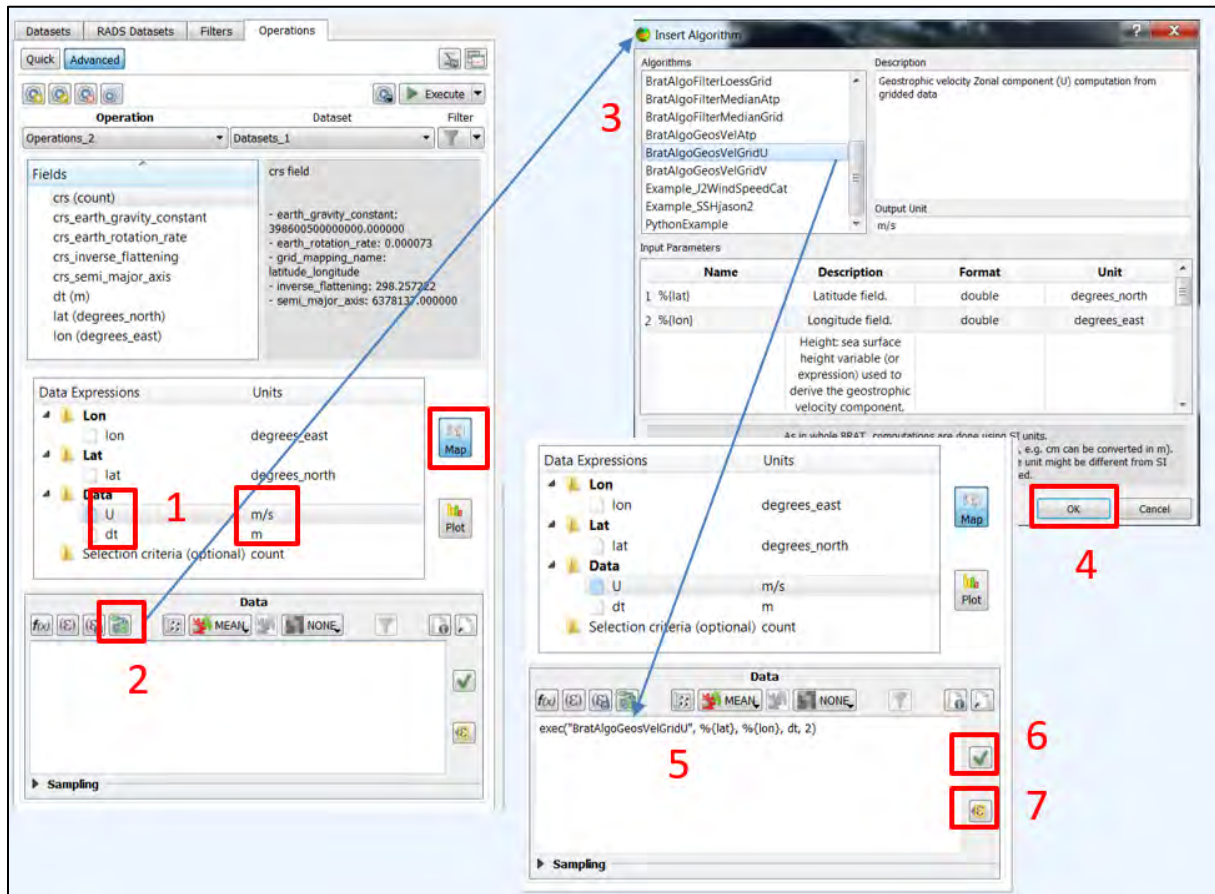
and allows the calculation of the corresponding **total surface geostrophic speed**:

$$W_{adt} = \sqrt{U_{adt}^2 + V_{adt}^2}$$

→ where u_s and v_s are the components of the surface geostrophic velocity, f is the Coriolis parameter, g is the acceleration due to gravity, h is the ADT and x and y are distances along zonal and meridional directions, respectively.

The principle of geostrophy is useful to oceanographers because it allows them to infer ocean currents from measurements of the sea surface height.

In BRAT, please create a **New Workspace**, go to **Datasets** tab and create a **New Dataset**, Add the product mentioned above, then go to **Operations** tab → **Advanced** → **Create operation** and create the following **Map** operation:



- 1: Select **Map** in order to map the data Field '**dt**' (=ADT) as in the previous exercises and create an empty expression named **U [m/s]**.
- 2-5: Highlight **U** and select the algorithms icon (2) to insert the BRAT algorithm **BratAlgoGeosVelGridU** (3) and click **OK** (4). The algorithm will appear under the **Data** field.
- Modify the default expression to `exec("BratAlgoGeosVelGridU", %{lat}, %{lon}, dt, 2)` (5).
- Equator_Margin = 2 degrees (latitude North and South below which the computation will not be done, to take into account the lack of Coriolis force at the Equator).
- 6-7: Check the correctness of the formula with ✓ (if it is correct, you will see at the **Output** → **Log** → "**Data expression OK**", if not, an invalid expression **warning** window will pop-up). Then save it with **ε**.


Then repeat the same steps (1-7) and create another expression where you will set the parameters as following:

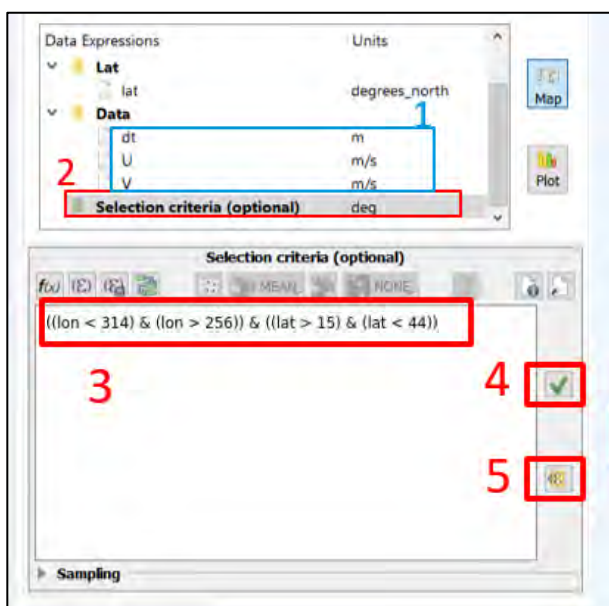
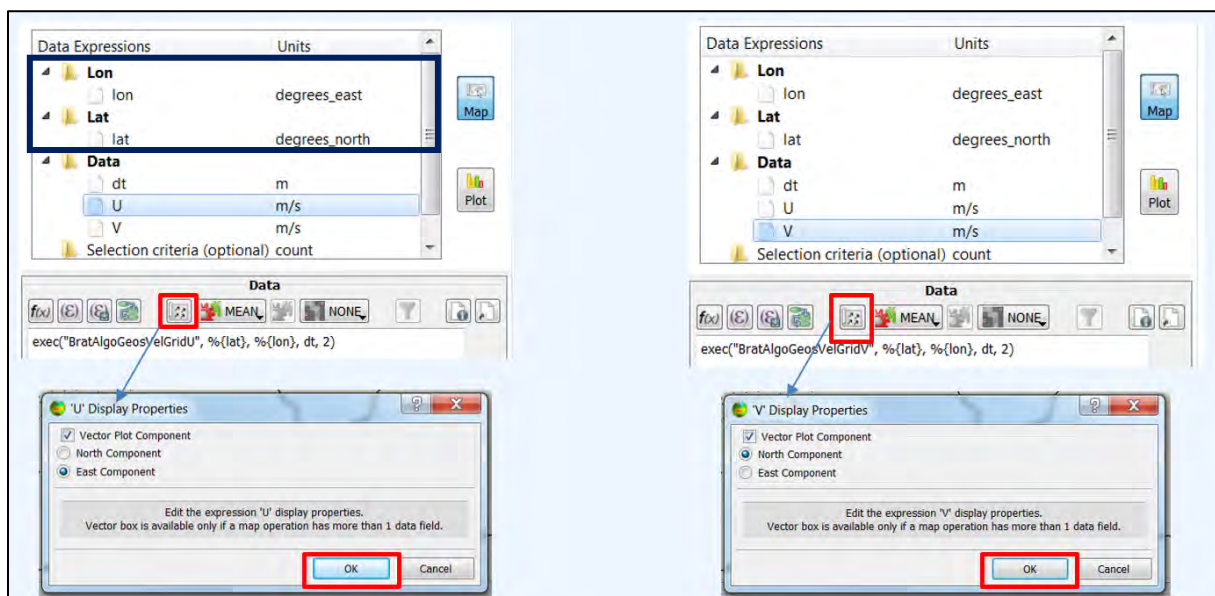
- 1: Select **Map** in order to map the data Field '**dt**' (=ADT) as in the previous exercises and create another empty expression named **V [m/s]**.
- 2-5: Highlight **V** and select the algorithms icon (2) to insert the BRAT algorithm **BratAlgoGeosVelGridV** (3) and click **OK** (4). The algorithm will appear under the **Data** field.
- Modify the default expression to **exec("BratAlgoGeosVelGridV", %{lat}, %{lon}, dt, 2)** (5).
- 6-7: Check the correctness of the formula with ✓ and save it with ε.

To conclude, set the vector plot components for **U** & **V** as follows:

"U" Display properties: Select "Vector Plot Component" and "East Component"

"V" Display properties: Select "Vector Plot Component" and "North Component"

 **NOTE 9:** If the "Display properties" window is inactive, make sure that you have inserted in the **Lon** and **Lat** the values as indicated below in the blue rectangle.




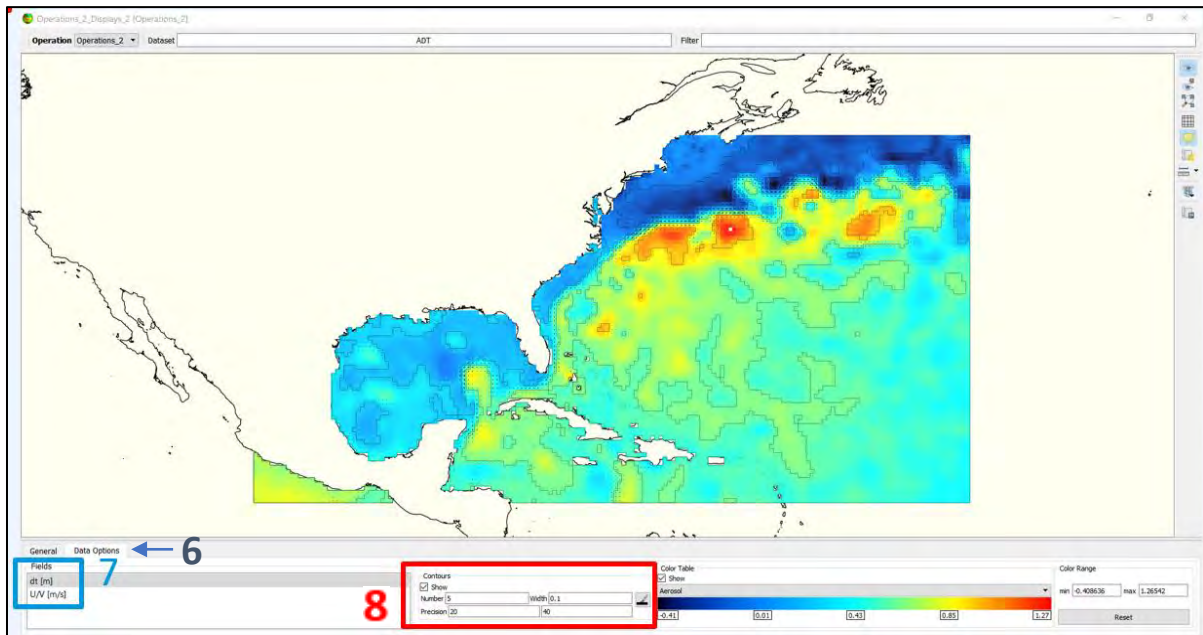
Please keep under **Data** the **dt**, **U** and **V** (1) and add the following selecting criteria (optional):

- 2: Selection criteria (optional): Set **Units = deg**
- 3: Write the following expression: **((lon < 314) & (lon > 256)) & ((lat > 15) & (lat < 44))**
- 4-5: Check the correctness of the formula with ✓ and save it with ε

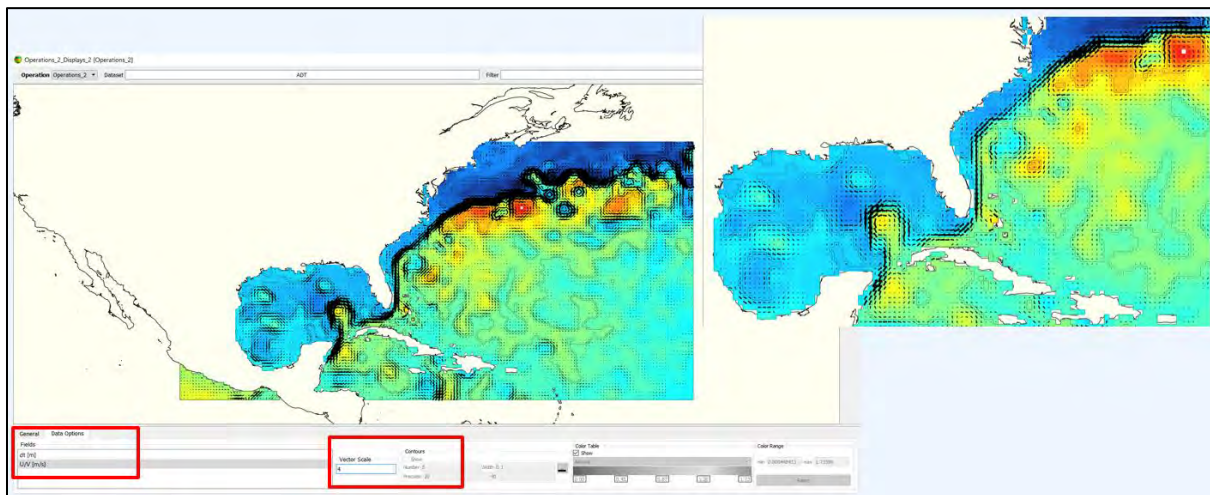
Then execute the operation by clicking on **Execute** and then on "Yes" at the pop-up window.

The following window-map will appear. Go to **Data Options** tab (6). Two maps are selectable now: **dt [m]**, as before, and **U/V [m/s]** (7).

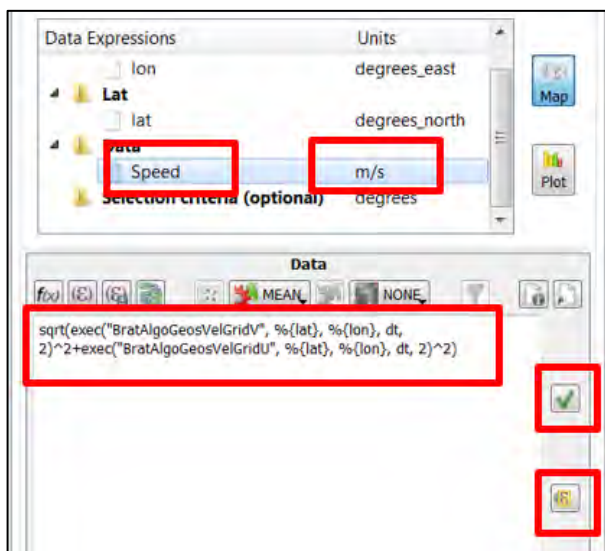
Select the **dt[m]** and check under **Contours** → "Show" , to show the contours (8):



Then, switch to the **U/V Map** and put e.g. **Vector Scale = 4**. You can try with 1 or 1.5 as well as with other values. Zoom in to better see the currents:



7.6.4 Current Speed



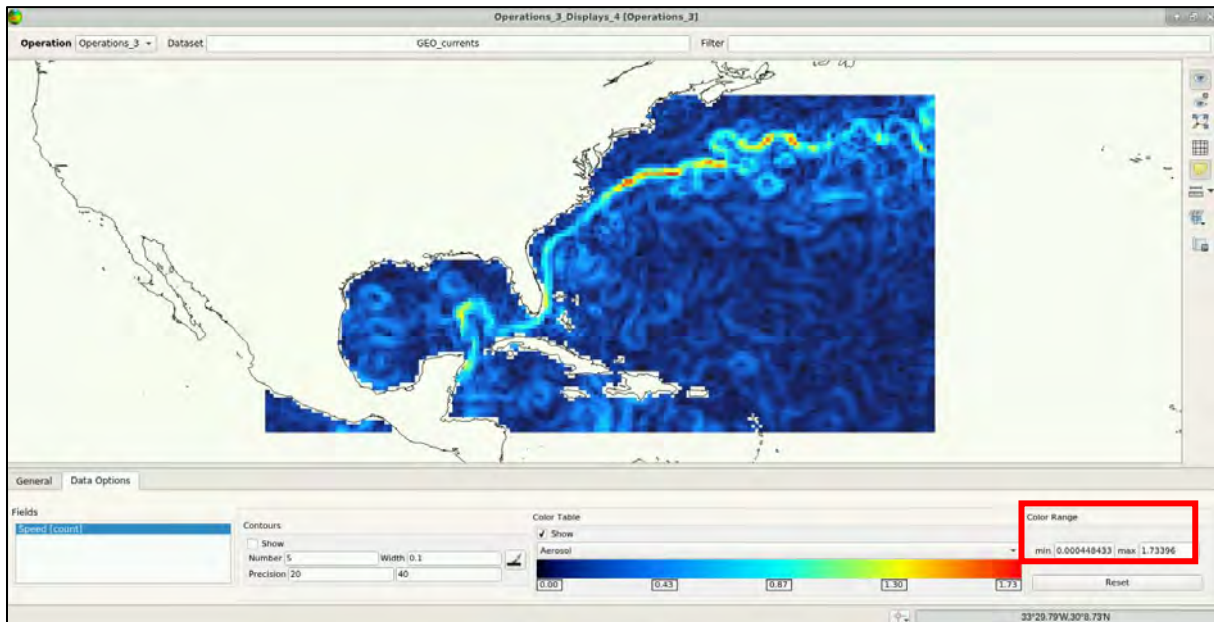
Delete the previous operation including expressions for **U**, **V** & **dt** and close the previous Maps before executing.

Create a **new operation** and copy and paste **U** and **V** formulas into a new expression to be named "**Speed**" [m/s] in order to obtain "**W_{adt}**":

$$W_{adt} = \sqrt{U_{adt}^2 + V_{adt}^2}$$

Data: `sqrt(exec("BratAlgoGeosVelGridV", %lat, %lon, dt, 2)^2+exec("BratAlgoGeosVelGridU", %lat, %lon, dt, 2)^2)`

Execute and repeat the last steps as before:



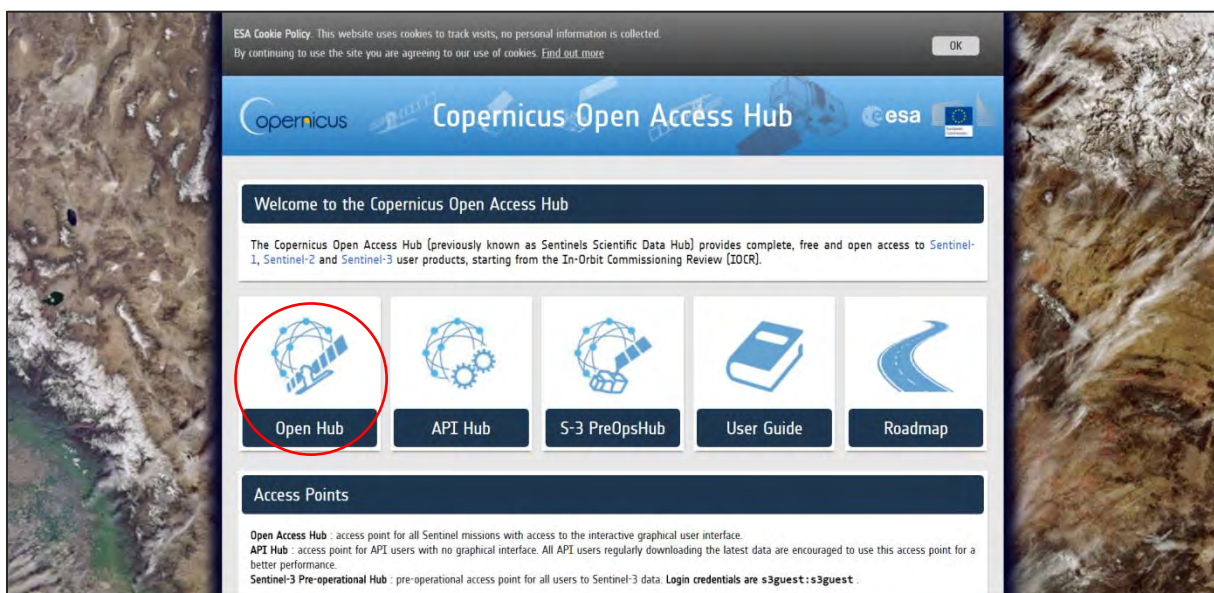
After having set the maximum colour bar value to 1.7m/s, the Gulf current is clearly revealed along with its speed.

8 Extra Steps

8.1 SNAP processing of Sentinel-3 products (see section 7.4) – Data download – ESA SciHUB

For those interested in using SNAP, the OLCI product can be downloaded from the Copernicus Open Access Hub using the online interface (**Applications** → **Network** → **Web Browser** or click the link below).

Go to <https://scihub.copernicus.eu/>



Go to **“Open Hub”**. If you do not have an account please sign up in the upper right corner, fill in the details and click register.

You will receive a confirmation email on the e-mail address you have specified: open the email and click on the link to finalize the registration.

Once your account is activated – or if you already have an account – log in.

- Switch the rectangle drawing mode to pan mode by clicking on the icon in the upper right corner of the map (**Green arrow**).
- Use the left mouse button to move over the globe and draw the rectangle shown below by holding the right 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 2018/07/10 to 2018/07/10 (1 day)


Check Mission: Sentinel-3

Product type: OL_1_EFR____

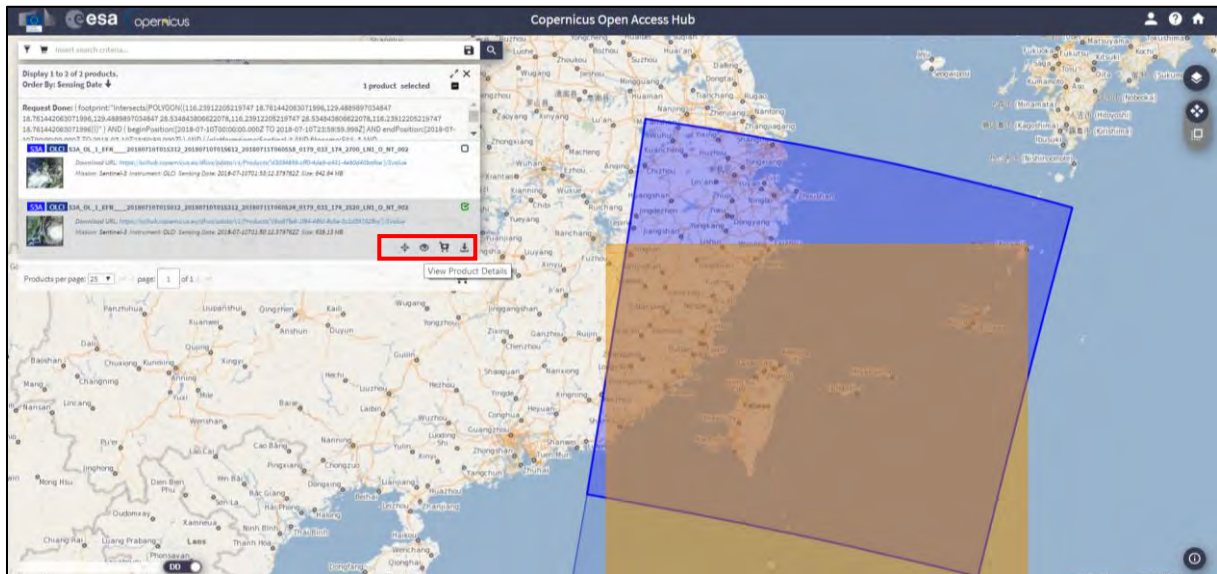
Timeliness: "Non Time Critical"


Instrument: OLCI

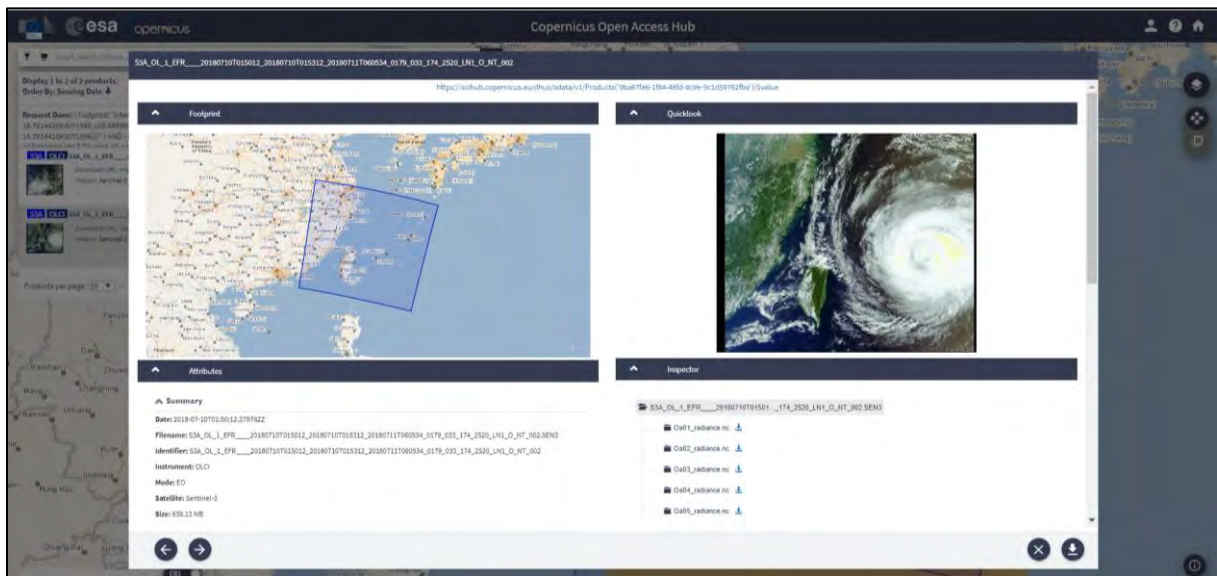
Product Level: "L1"

Download the following product by clicking the download icon .

S3A_OL_1_EFR___20180710T01512_20180710T015312_20180711T060534_0179_033_174_2520_LN1_O_NT_002





A quick look at the product, to verify the typhoon presence, is available by clicking on the icon .



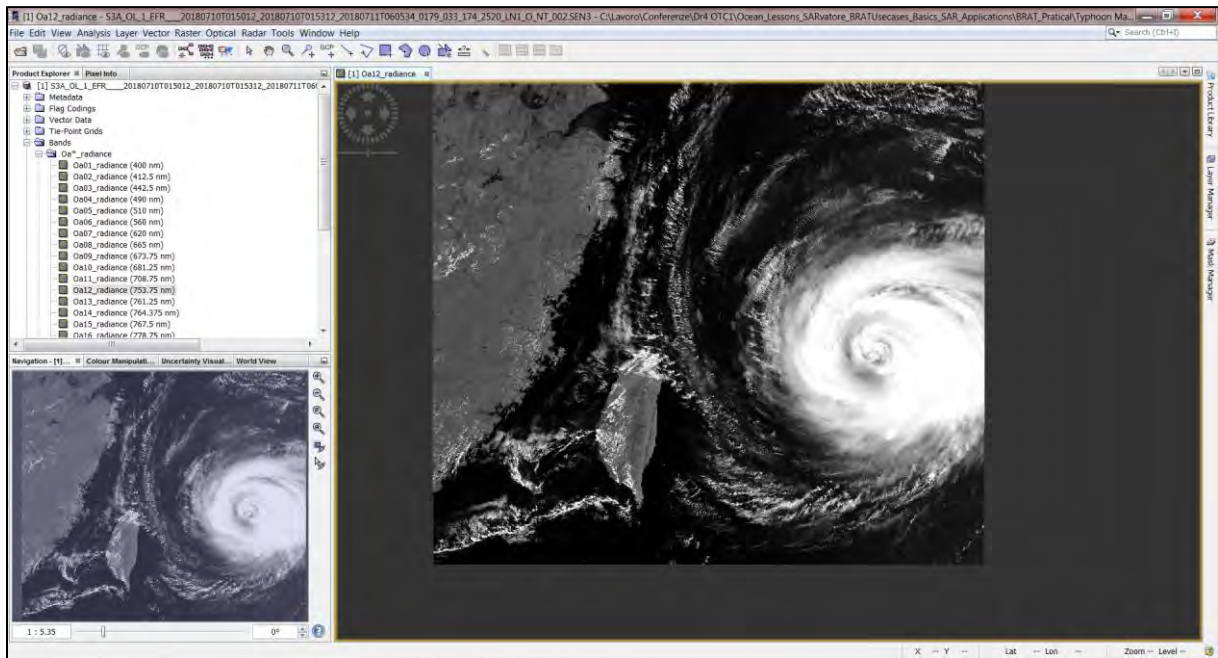
Once the product is downloaded (**@/home/rus/Downloads**), copy it to the following path and unzip it (**right click → Extract Here**)

Path: /shared/Training/OCEA07_Oceanography_TutorialKit/Original/OLCI

Later the product can be opened in SNAP (open the xfdumanifest.xml file).

Launch SNAP (icon on desktop ). When the SNAP window opens click Open product  and navigate to **/shared/Training/OCEA07_Oceanography_TutorialKit/Original/OLCI**, open the folder of the Sentinel-3 OLCI product and select the file **xfdumanifest.xml**. Then, click **OK**.

The product will appear as at the following window.



Then re-project in UTM/WGS 84 and save it in GeoTIFF format using the following command:

Go to **Raster** → **Geometric Operations** → **Reprojection**.

In the **I/O Parameters** tab set the following:

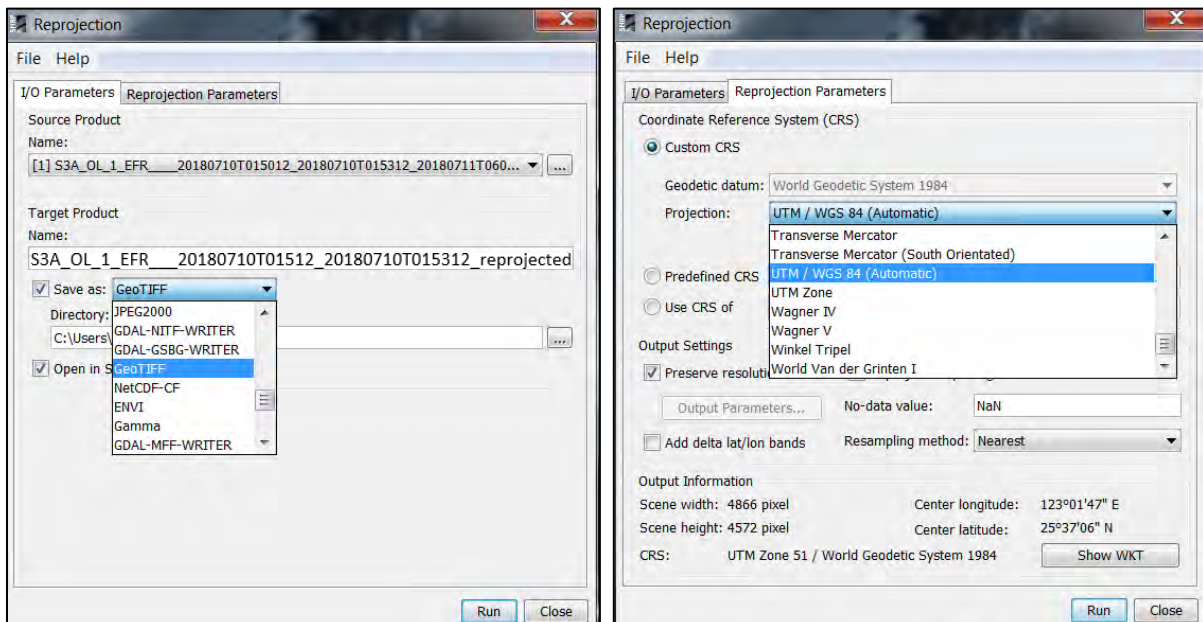
As **(Source)**: S3A_OL_1_EFR__20180710T01512_20180710T015312_20180711T060534_0179_033_174_2520_LN1_O_NT_002

As **(Target)**: S3A_OL_1_EFR__20180710T01512_20180710T015312_reprojected

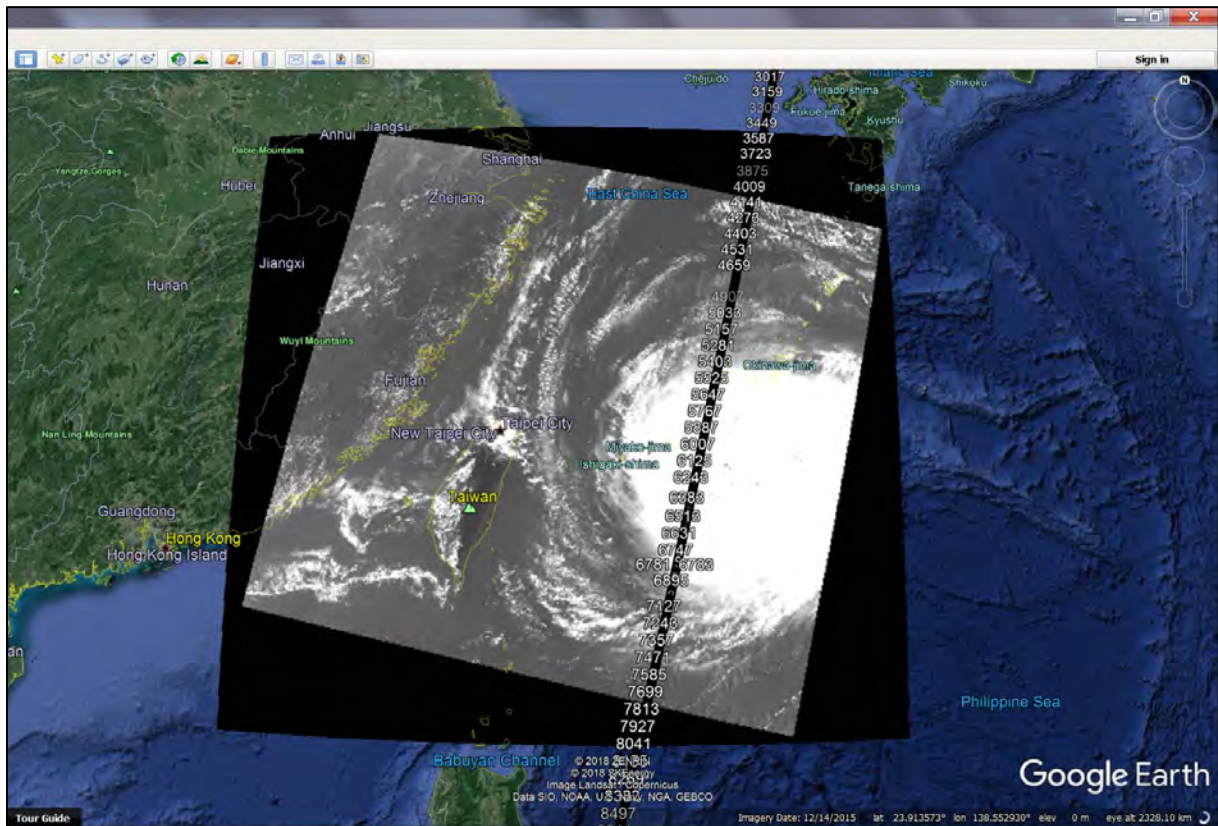
As **Directory**: /shared/Training/OCEA07_Oceanography_TutorialKit/Processing

In the **Processing Parameters** tab set the following:

Select **Custom CRS** and at **Projection**: **UTM / WGS 84 (Automatic)**.



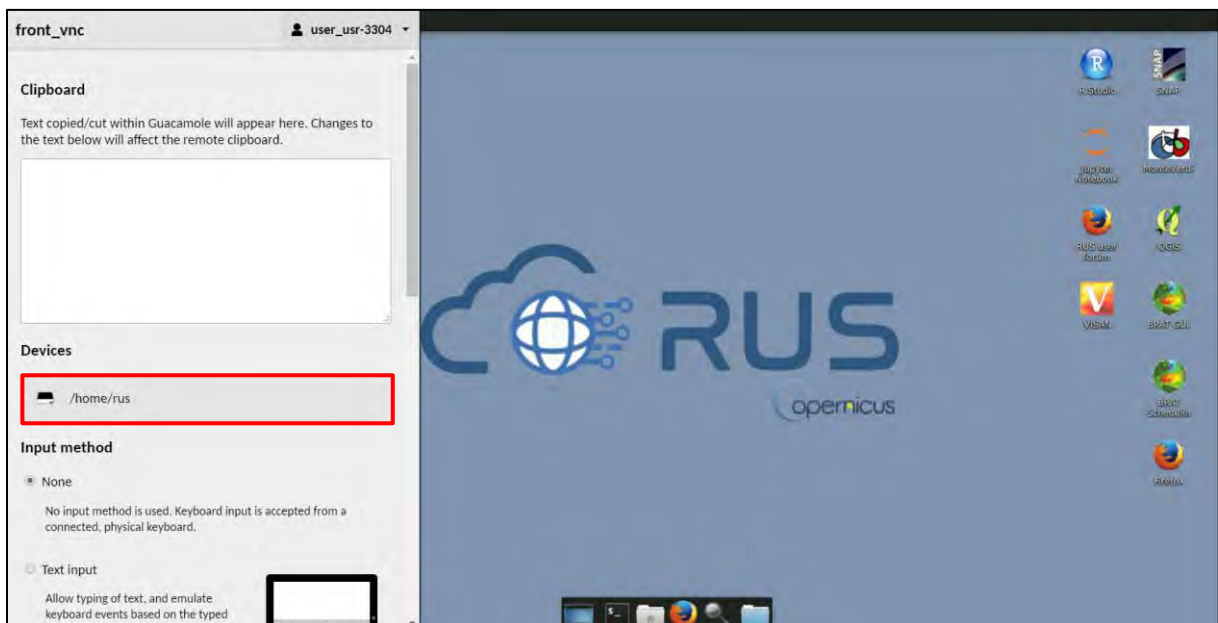
Click **Run**. Once the GeoTIFF is created, go to **File** → **Export** → **Other** → **View as Google Earth KMZ** so that it can be opened in Google Earth (a .kml including the position of the estimates in the L2 WAT product can be also prepared to support the combined analysis, or Sentinel-3 tracks in .kml format from: <https://sentinel.esa.int/web/sentinel/missions/sentinel-3/satellite-description/orbit> can be used).



8.2 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)
<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)
<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

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