



ESA–MOST China Dragon 4 Cooperation

→ **ADVANCED TRAINING COURSE IN OCEAN  
AND COASTAL REMOTE SENSING**

12 to 17 November 2018 | Shenzhen University | P.R. China

**BROADVIEW RADAR ALTIMETRY TOOLBOX**

**Marco Restano (SERCO c/o ESA-ESRIN), Marie-Hélène Rio & Jérôme Benveniste (ESA-ESRIN)**

Hosted by



- Notions of Waveforms acquisition & processing
- The Broadview Radar Altimetry Toolbox
- Using the Graphical User Interface (GUI)
  
- Practical on Altimetry
- Practical on Oceanography



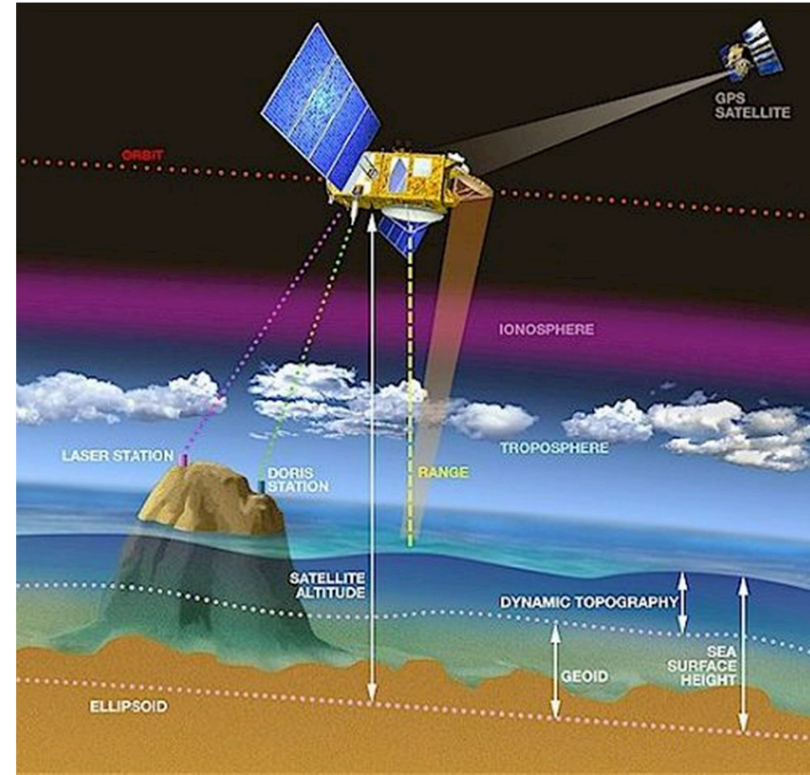
# Notions of Waveforms acquisition & processing



- Altimeters measure the **range** between the **satellite and the sea surface** observed at nadir.
- 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 NRT STC L2 products.).
- Geoids (i.e. the ocean surface excluding the influence of wind and tides) are obtained from other missions (e.g. GRACE, GOCE).
- A reference ellipsoid shall be considered as baseline Datum (e.g. WGS84).
- The range measurement shall be **corrected** for a series of effects related to both the propagation into the Ionosphere/Troposphere and other effects.

**Sea Surface Height (SSH):**  $\text{Satellite\_Altitude} - \text{Corrected\_Range}$ .

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



Pulse limited acquisition.

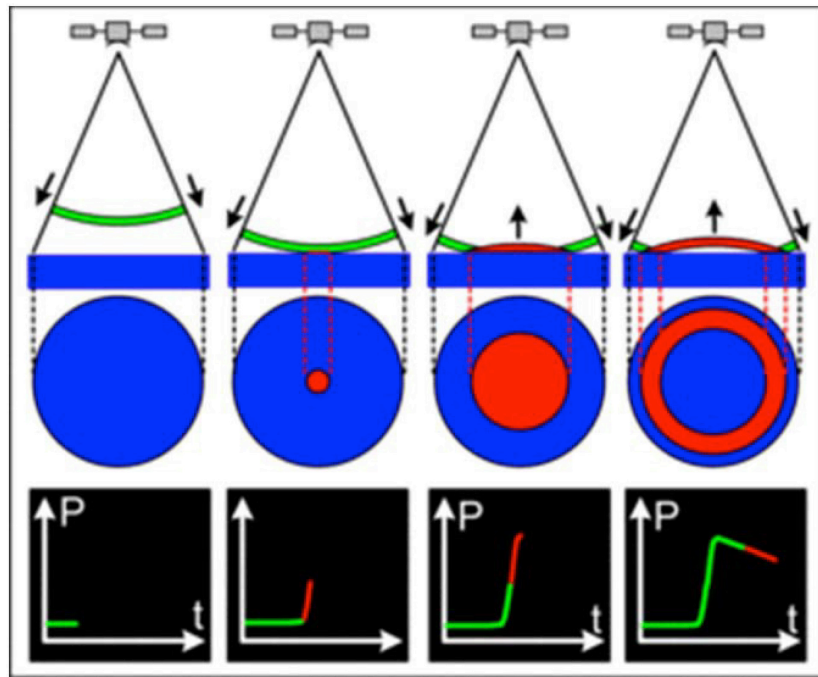
The time on target dictated by the beam illumination is not exploited.

- **Observed parameters:**

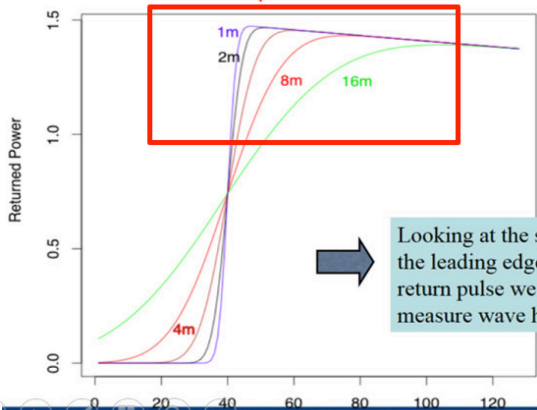
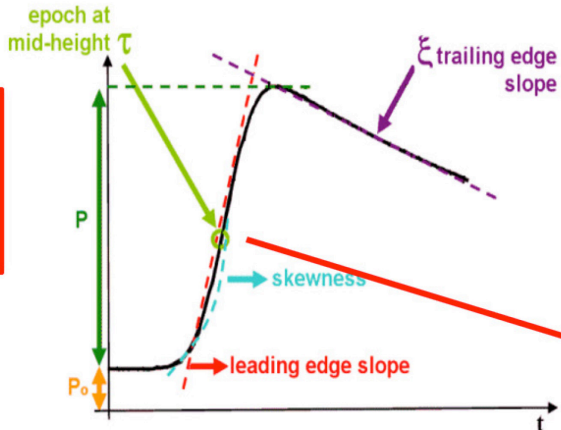
- 1-Significant Wave Height (SWH)
- 2-Wind Speed
- 3-Range (altimeter to mid height of sea level)

- **Typical specs:**

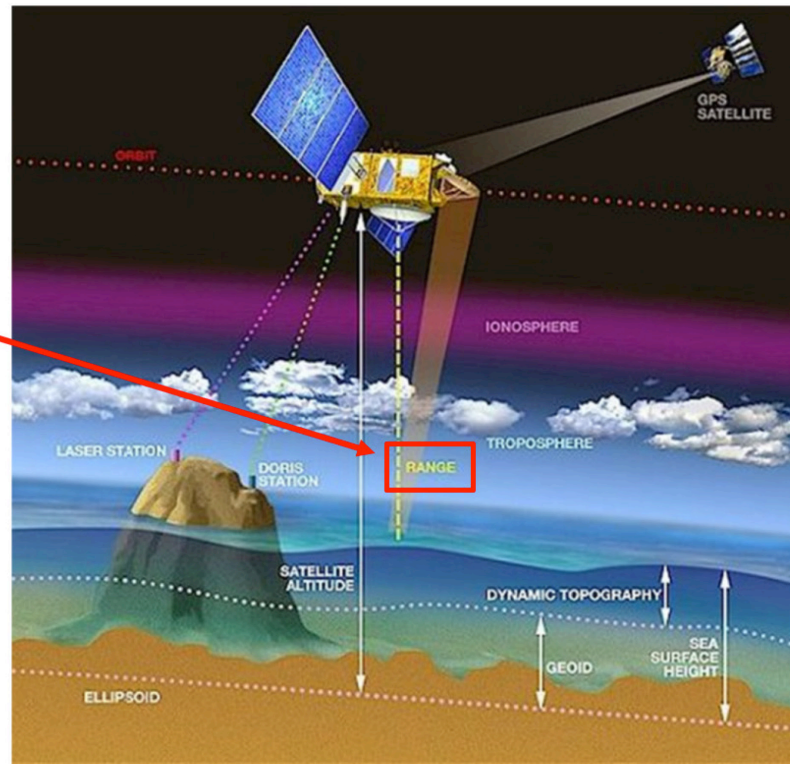
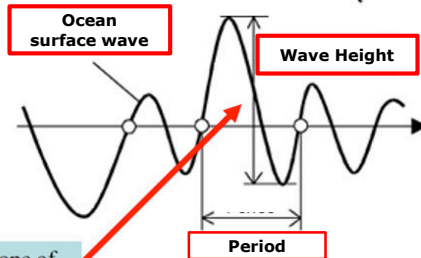
Along/Across track resolution: several km depending on SWH.



The Power amplitude ( $\sigma_0$ ) of the signal can be related to the wind speed.



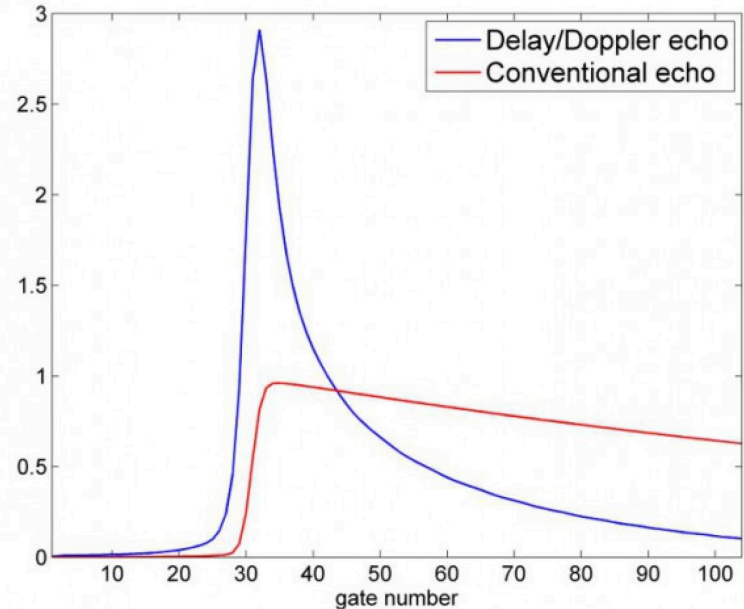
Looking at the slope of the leading edge of the return pulse we can measure wave height!



# L1b waveforms (1)

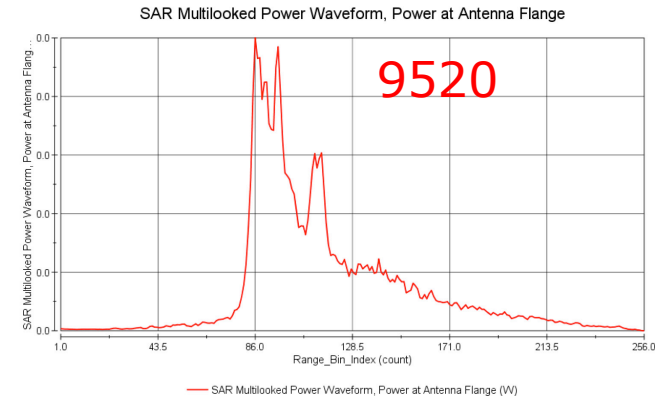
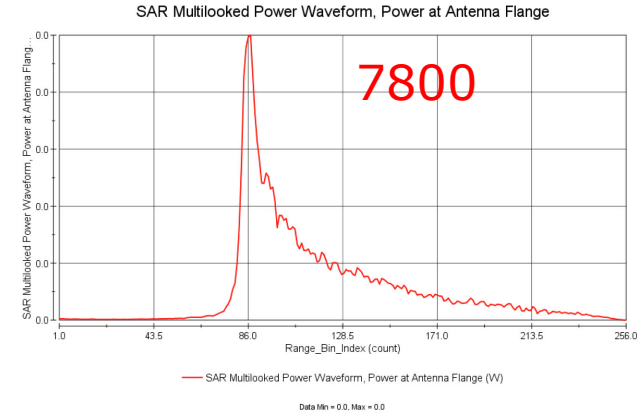
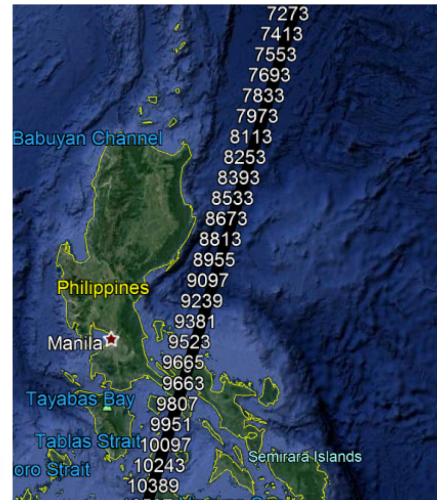
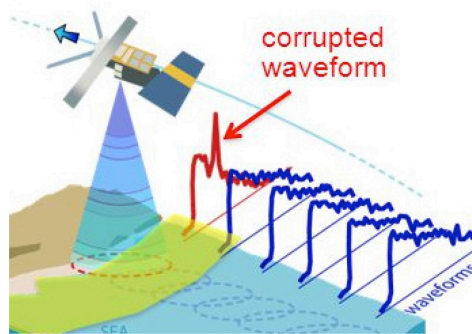


- Available in L1b products (the Jason-2 SIGDR products include these waveforms)
- The shape of L1b waveforms acquired in open ocean depends on the operative mode (LRM/Conventional or SAR/Delay-Doppler).
- LRM and SAR L1b waveforms are different and require different retracers to correctly estimate the quantities of interest (range, SWH, sigma0).
- Different scenarios (open ocean, coastal zone and inland water) require different retrackers.



# L1b waveforms (2)

- Waveforms acquired in the coastal zone can be significantly distorted due to the presence of the coast in the radar footprint.
- The WTC correction from the onboard radiometer are contaminated (models required).
- The estimates from these waveforms are not reliable and shall not be used without a proper selection.
- 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.





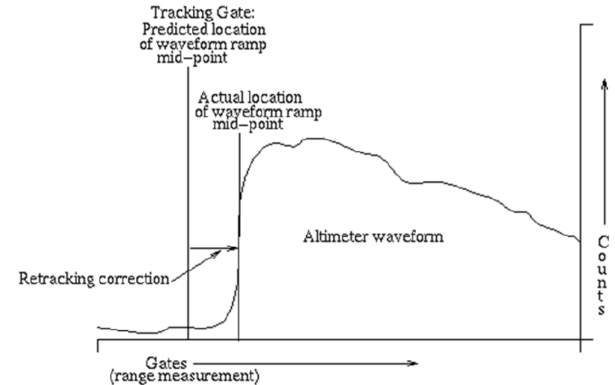
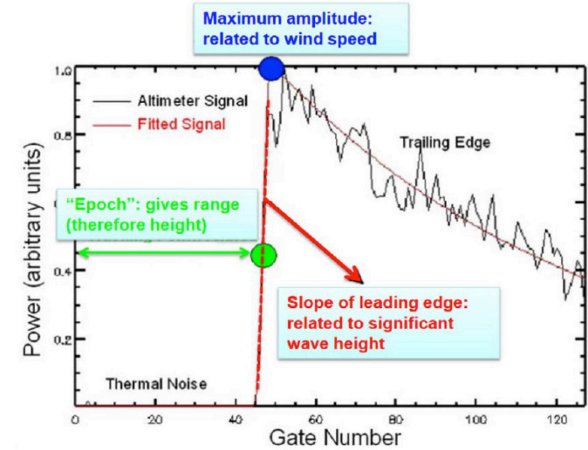
# Retracking & L2 Products

- The retracking process is required for improving the range precision of existing measurements guaranteeing a very accurate post-retracking Sea Surface Height (SSH). Waveform retracking is defined as an algorithm which:

- finds the mid-gate of leading slope in the return L1b waveform,
- fits the returned echo to a waveform model corresponding to the observed target (e.g. the Brown model for rough ocean: As several models will be tested and fitted to the altimeter signal, by varying **SWH**, **range** and **amplitude**, the best fit will minimize the error according to some criteria, e.g. the Normalised Residual Error (NRE)).

- corrects the range measurements from the on satellite tracking algorithm according to the departure between the mid-gate and original measurement.

- **L2 products** are created after the retracking process and include the estimated **SWH**, **range & amplitude ( $\sigma_0$ )**. Geophysical corrections are also included



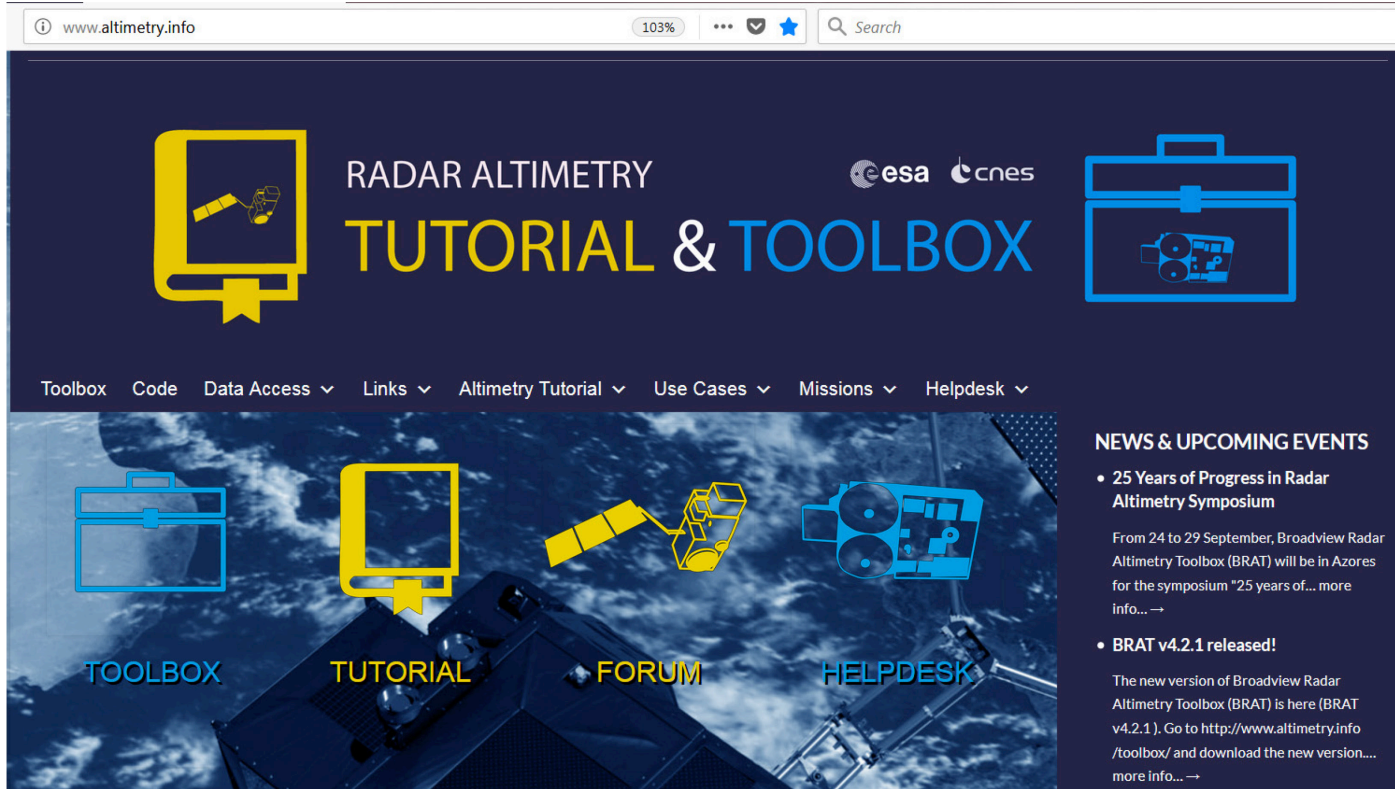


# The Broadview Radar Altimetry Toolbox





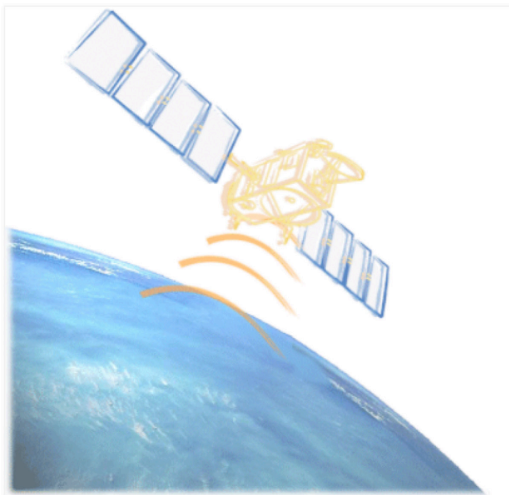
- The **Broadview Radar Altimetry Tutorial and Toolbox** is a joint project between **ESA** and **CNES** to develop an open source tool freely available to all the altimetry community.
- The Broadview Radar Altimetry Toolbox is a tool designed to use radar altimetry data.
- It is available in 32-bit and 64-bit versions for Windows, Mac OS X and Linux.



The screenshot shows the website [www.altimetry.info](http://www.altimetry.info) in a browser. The page features a dark blue background with a satellite in orbit. The main header includes the text "RADAR ALTIMETRY" and "TUTORIAL & TOOLBOX" in yellow and blue. Logos for ESA and CNES are present. A navigation menu lists: Toolbox, Code, Data Access, Links, Altimetry Tutorial, Use Cases, Missions, and Helpdesk. Below the menu are four icons: a toolbox, a book, a satellite, and a camera, labeled "TOOLBOX", "TUTORIAL", "FORUM", and "HELPDESK" respectively. On the right, a "NEWS & UPCOMING EVENTS" section lists two items: "25 Years of Progress in Radar Altimetry Symposium" and "BRAT v4.2.1 released!".

## 5. Radar Altimetry Tutorial

[Radar Altimetry Tutorial and Toolbox](#) > [5. Radar Altimetry Tutorial](#)



Altimetry is basically a technique for measuring height. Satellite radar altimetry measures the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Moreover, this measurement yields a wealth of other information that can be used for a wide range of applications.

- [How it works](#)
- [Data flow](#)
- [Future technology improvements](#)
- [SAR Tutorial](#)
- [Training Material](#)

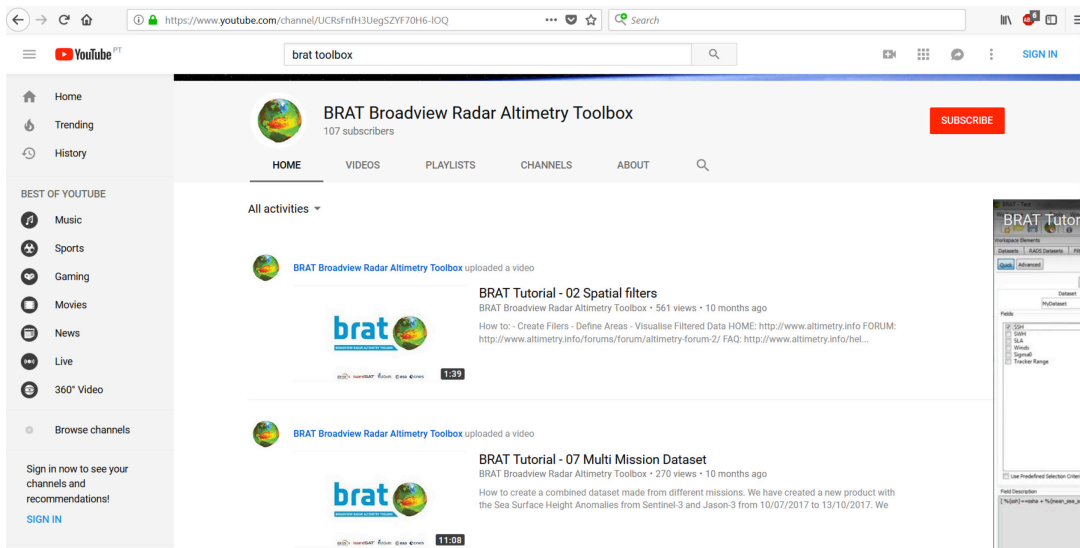
[Download this tutorial in pdf \(12 MB\)](#)

### 5. Altimetry Tutorial

- [5.1 How altimetry works](#)
- [5.2 Data Flow](#)
- [5.3 Future technology improvements](#)
- [5.4. SAR Tutorial](#)
- [5.5 Training Material](#)

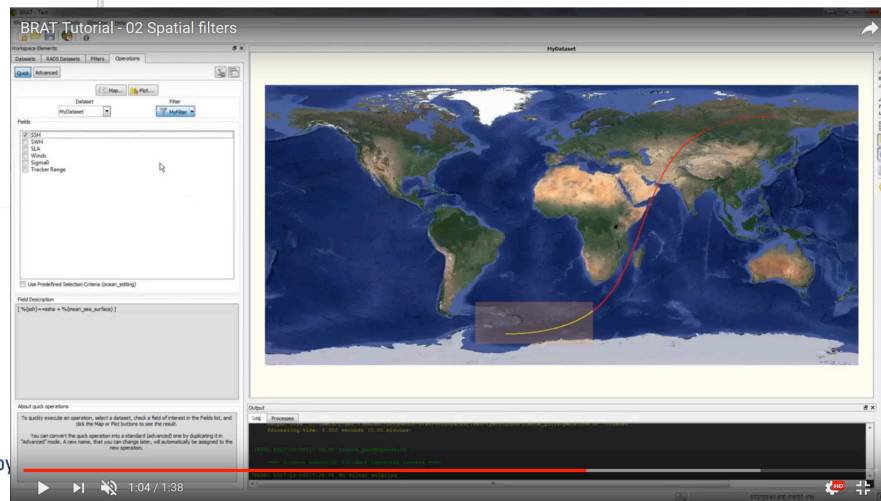
## Search for: **BRAT Broadview Radar Altimetry Toolbox**

**Many video tutorials are available!**



The screenshot shows the YouTube channel page for "BRAT Broadview Radar Altimetry Toolbox". The channel has 107 subscribers and a "SUBSCRIBE" button. The page displays two video uploads:

- BRAT Tutorial - 02 Spatial filters**: 561 views, 10 months ago. Description: "How to: Create Filters - Define Areas - Visualise Filtered Data HOME: <http://www.altimetry.info FORUM: http://www.altimetry.info/forums/forum/altimetry-forum-2/> FAQ: <http://www.altimetry.info/hel...>"
- BRAT Tutorial - 07 Multi Mission Dataset**: 270 views, 10 months ago. Description: "How to create a combined dataset made from different missions. We have created a new product with the Sea Surface Height Anomalies from Sentinel-3 and Jason-3 from 10/07/2017 to 13/10/2017. We"



The screenshot shows a video player displaying a tutorial titled "BRAT Tutorial - 02 Spatial filters". The interface includes a "Help" list with items like "SST", "SLA", "Signall", and "Tracker Range". A world map is shown with a red line indicating a track. The video player controls at the bottom show a progress bar at 1:04 / 1:38.



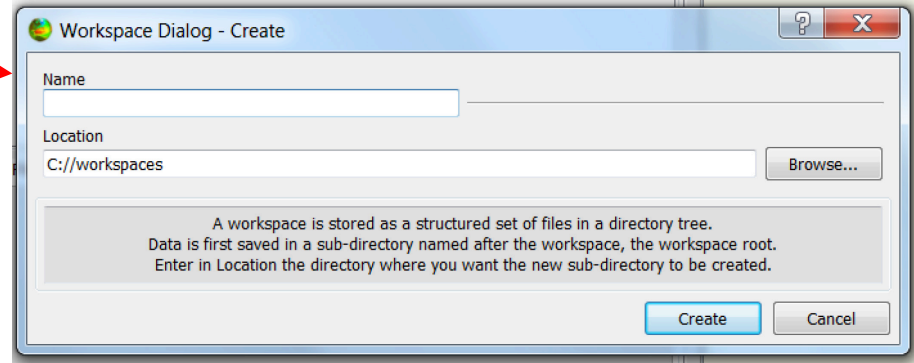
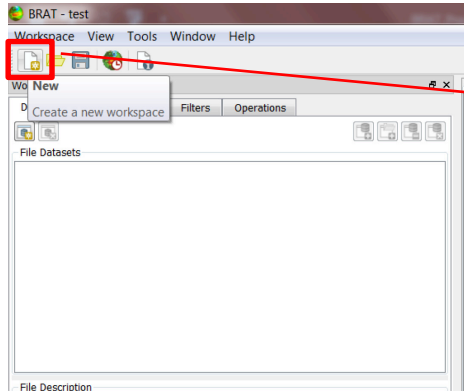
# Using the Graphical User Interface (GUI)



# Create a Workspace



- When you open the BRAT GUI, click on “ New” to name and locate the **‘Workspace’** you will use:



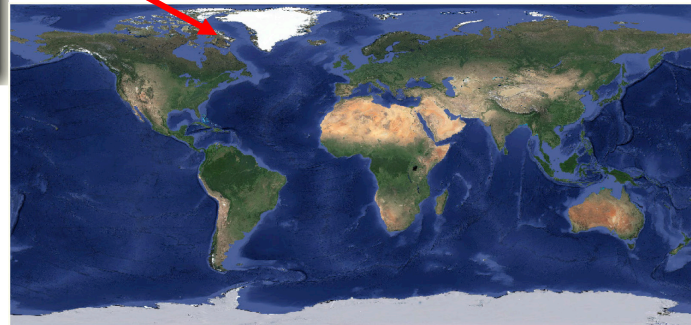
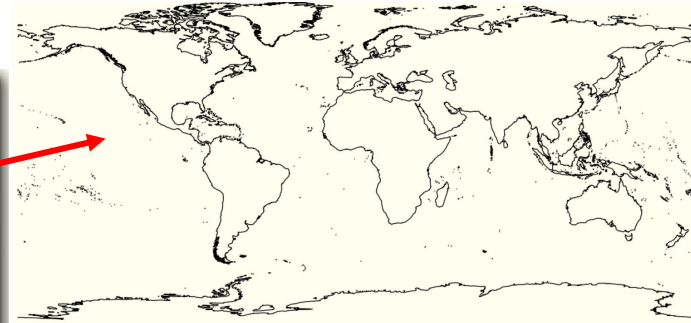
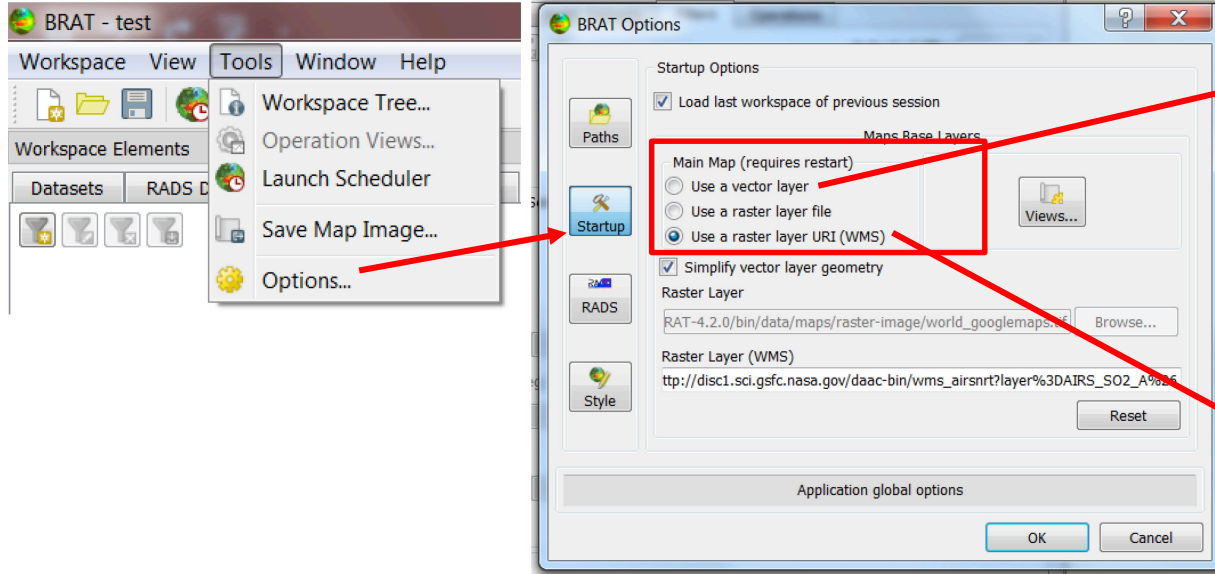
- A **‘Workspace’** is a way of saving your preferences, computations and generally the work done with BRAT GUI. Some or all elements of a workspace can be imported into another workspace. The “Workspace” menu (and also the main toolbar) allow the user to create, open, close, save, import, rename or 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 that if you answer “no” and have not saved anything previously, none of your work can be recalled later. BRAT GUI recalls the last used Workspace by default.





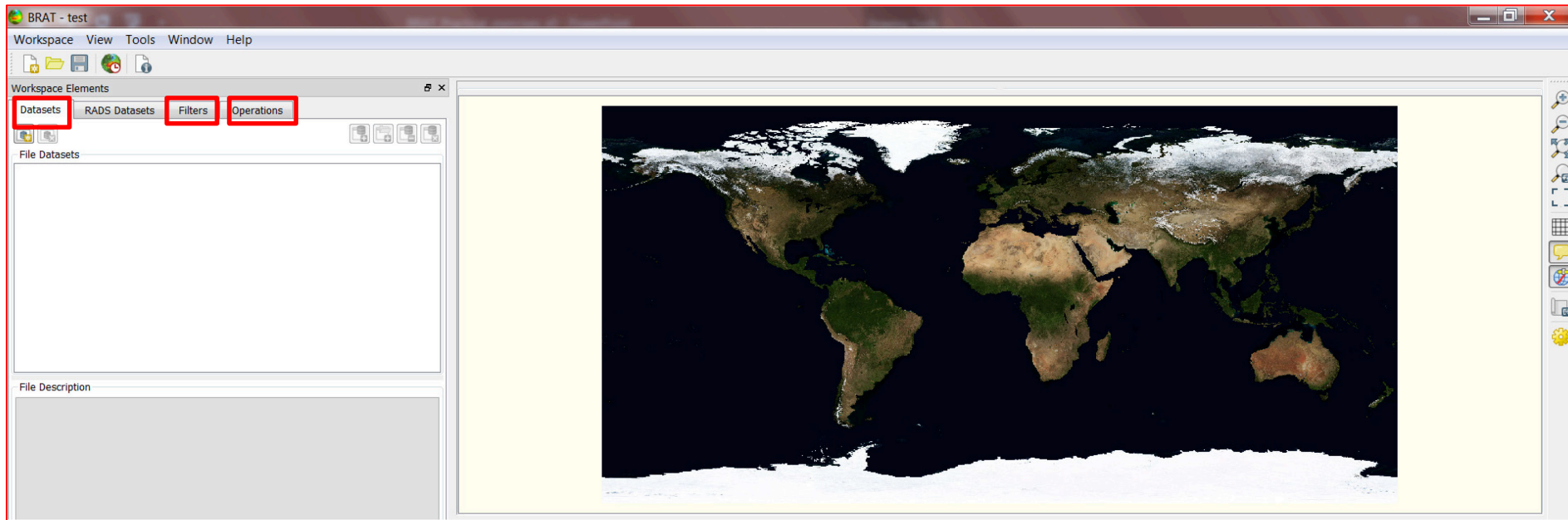
# Select the Map Layer

- BRAT offers 3 Map Layers accessible from **Tools-> Options -> Startup**



- Select **“Use a raster layer URI (WMS)”** and press **OK**.
- Close & Restart** BRAT to display the selected map layer.

Using BRAT GUI is basically a 3-step process.



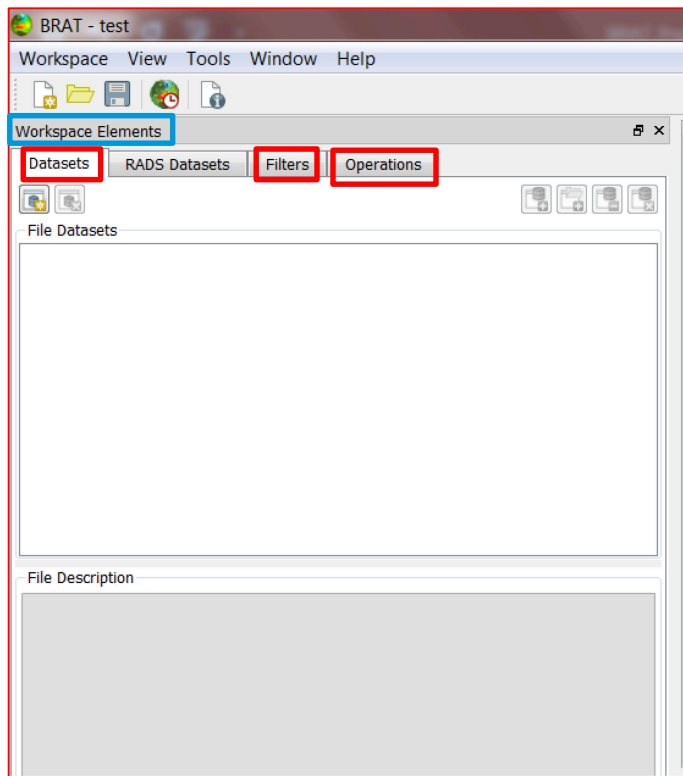
# The BRAT GUI (2)



1. 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).
2. 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.
3. 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'll have to use all of them ('Filters' in optional) one after the other.



# Practical on Radar Altimetry

(Use data provided in the “[Practical\\_Altimetry](#)” folder)

- Jason-2 products (L2 & SGDR) to show L1b waveforms & variables in BRAT.
- One cycle of L2 ENVISAT Data (Cycle 25, March 2004) to investigate SWH with and without Loess Filtering (low-pass filter mostly used for smoothing). Data can be accessed here: <https://earth.esa.int/web/guest/home>
- Single Sentinel-3A SRAL track acquired on July 10th co-located with an OLCI optical image (processed in SNAP) to investigate Typhoon Maria.
- L3 Multi-mission products (RADS & CMEMS).
- Mean Sea Level variation in China using multi-mission SLCCI products.

# Practical n.1: Evaluating L1b waveforms



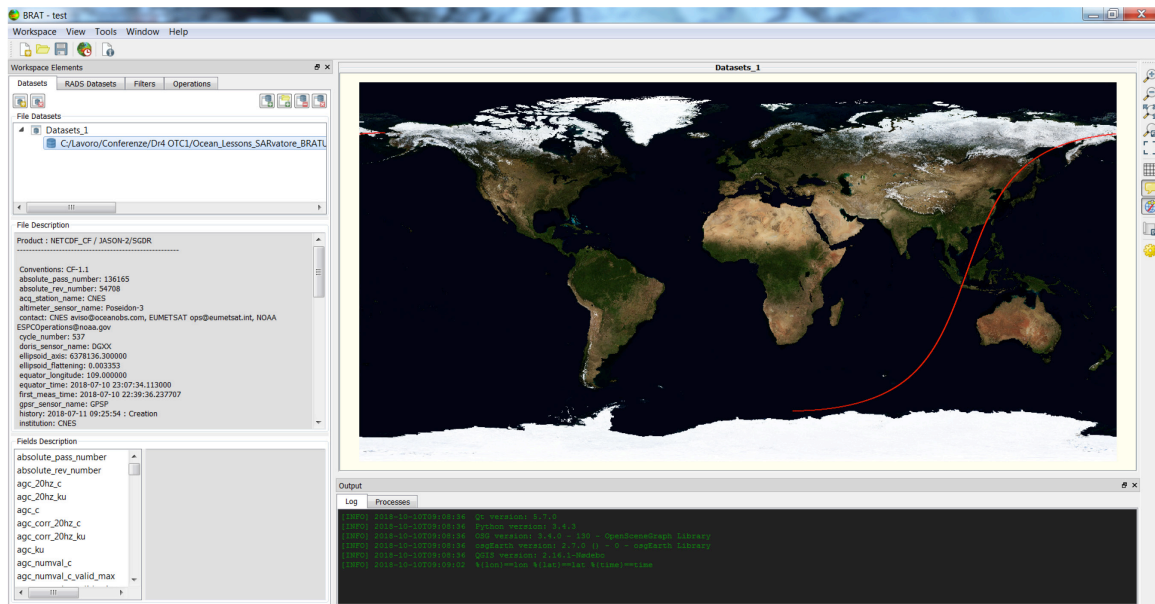
Track used: **Jason-2 SIGDR** track  
(Sensor Interim Geophysical Data Record). '**Sensor**' indicates that it includes the waveforms

Folder: **J2\_SGDR**

File: **JA2\_IPS\_2PdP537\_021\_20180710\_223936\_20180710\_233531.nc**

## Source:

<https://www.avisio.altimetry.fr/en/data/products/sea-surface-height-products/global/waveforms.html>



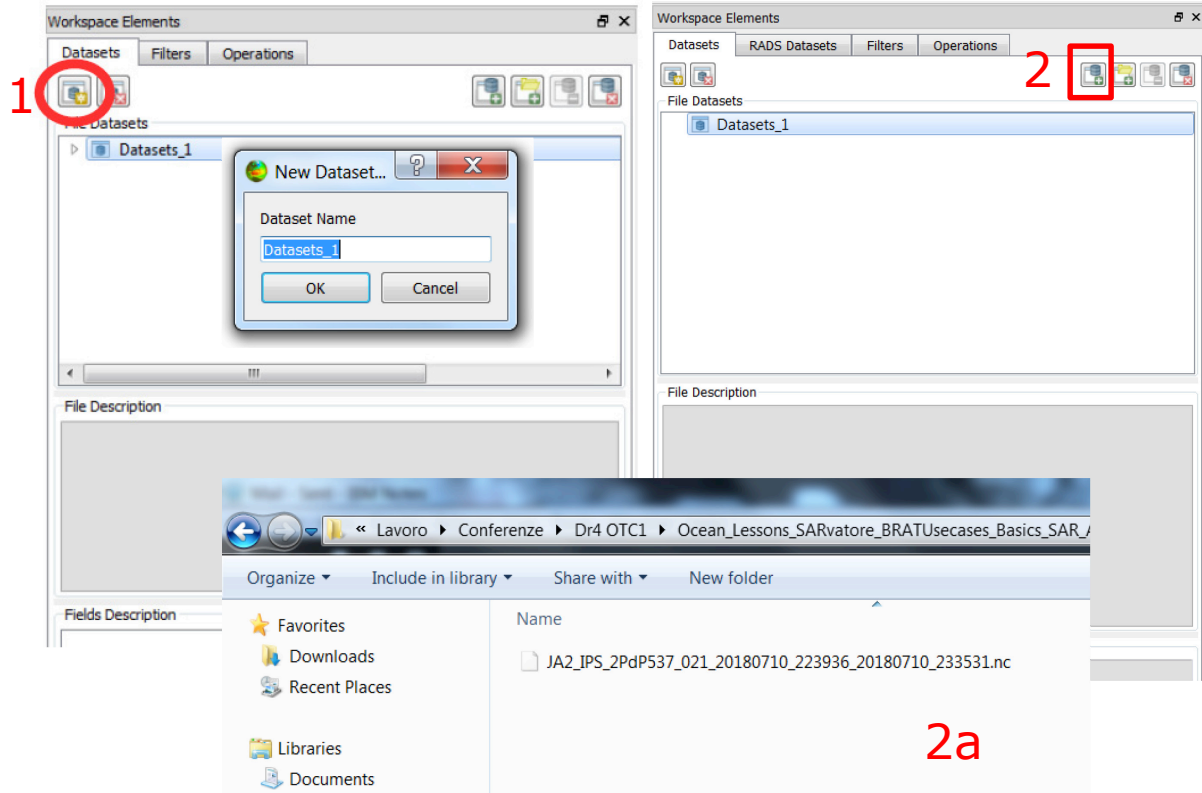
The first tab opened if you have never used BRAT is **'Datasets'** .

This 'Datasets' tab is dedicated to the definition and selection of the data you want to use.

You must define **at least one** dataset to be able to further use BRAT.

1: To create and name a dataset, click on the **'new'** button in the Datasets tab.

2-2a: To import the data, click on the **'add files'** button in the Datasets tab.



# Filters (optional)

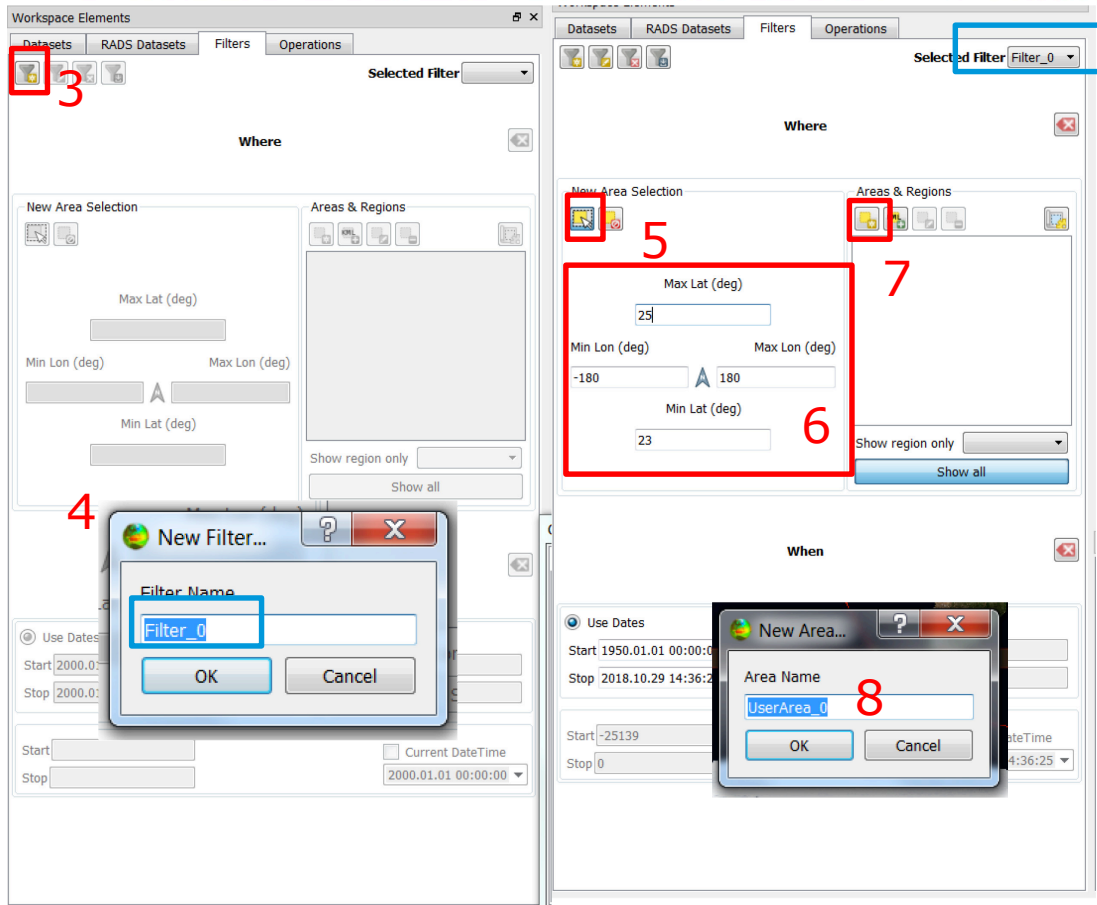
3: To create a filter press on the **“Create Filter”** icon.

4: Name the filter.

5-6: Click on **“Selection tool”** icon in the **“New Area selection”** menu and define the filtering box.

7-8 Click on **“Create Area”** in the **“Areas and Region”** menu, name the area and tick the corresponding box associated with the created Area (see the red box in the next slide).

(Delete any other Area, if needed)





# Filters (2)



The screenshot shows the BRAT (Brower Remote Access Tool) software interface. The main window displays a world map with a red curved line indicating a filter path. The left sidebar contains configuration options for filters, including 'Where' and 'When' sections. The 'Where' section includes 'New Area Selection' and 'Areas & Regions' panels. The 'When' section includes 'Use Dates' and 'Use Relative Time (days)' options. The 'Output' panel at the bottom right shows a log of system information.

**Workspace Elements**

Selected Filter: Filter\_0

**Where**

New Area Selection

Areas & Regions

- UserArea\_0

Max Lat (deg): 25

Min Lon (deg): -180

Max Lon (deg): 180

Min Lat (deg): 23

Show region only

Show all

**When**

Use Dates  Use Cycle/Pass (4 values required)

Start: 1950.01.01 09:14:14

Start Cycle:

Start Pass:

Stop: 2018.10.10 09:14:14

Stop Cycle:

Stop Pass:

Use Relative Time (days)

Start: 25119

Stop: 0

Current DateTime

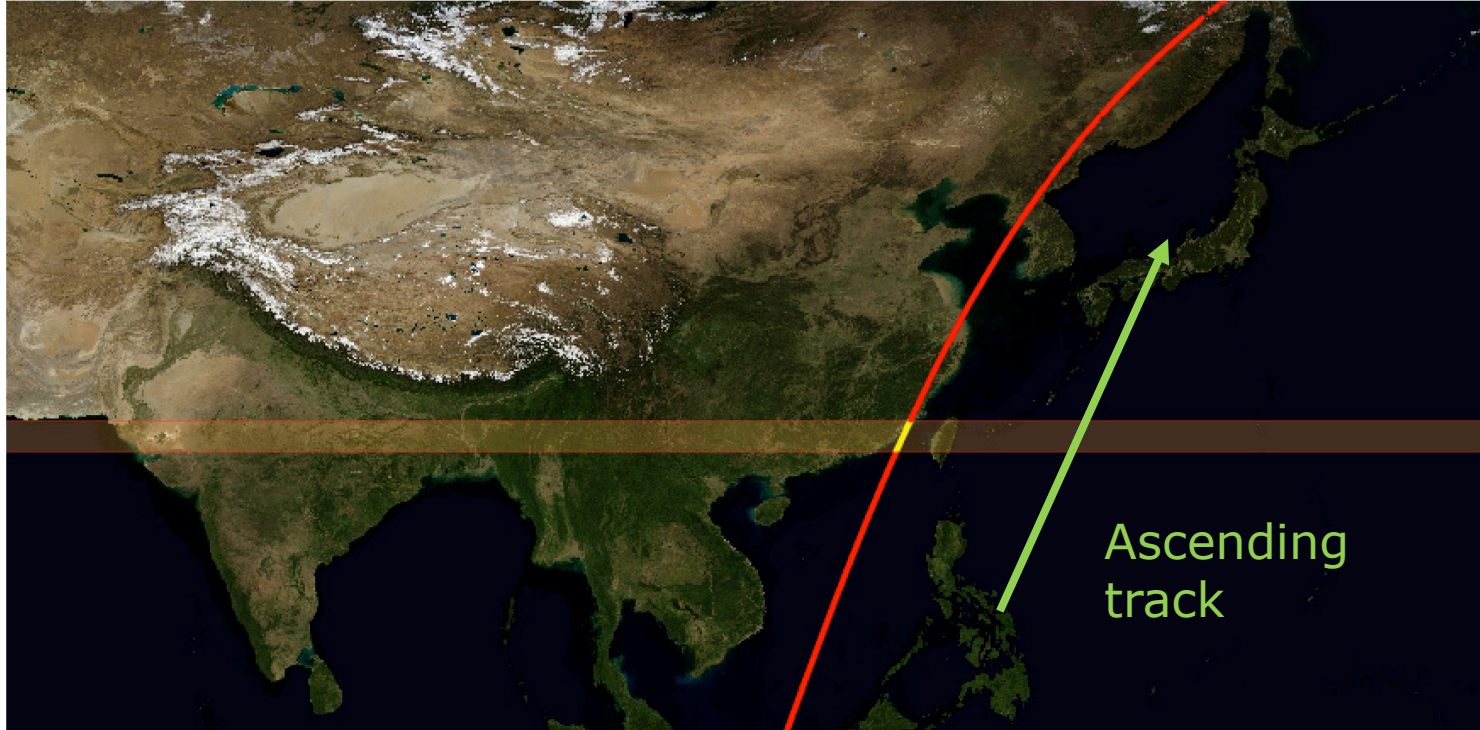
2018.10.10 09:14:14

**Output**

```
Log Processes
[INFO] 2018-10-10T09:08:36 Qt version: 5.7.0
[INFO] 2018-10-10T09:08:36 Python version: 3.4.3
[INFO] 2018-10-10T09:08:36 OS version: 4.4.0 - 32 - OpenSceneGraph Library
[INFO] 2018-10-10T09:08:36 osgEarth version: 2.7.0 (1) - 6 - osgEarth Library
[INFO] 2018-10-10T09:08:36 GDAL version: 2.14.1-Nodebe
[INFO] 2018-10-10T09:08:02 %lon%%lon %lat%%lat %time%%time
```

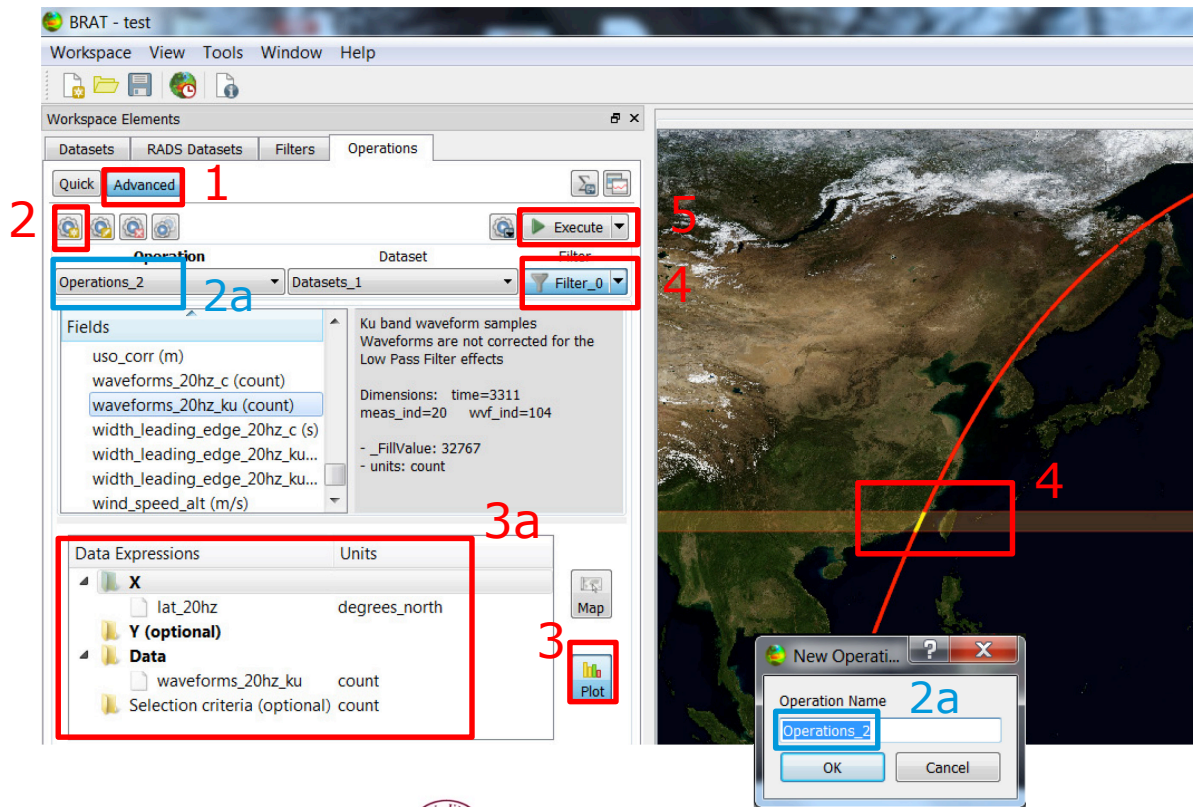


- Evaluating the quality of L1b waveforms in approaching the coast



# L1b waveforms in J2 SGDR products

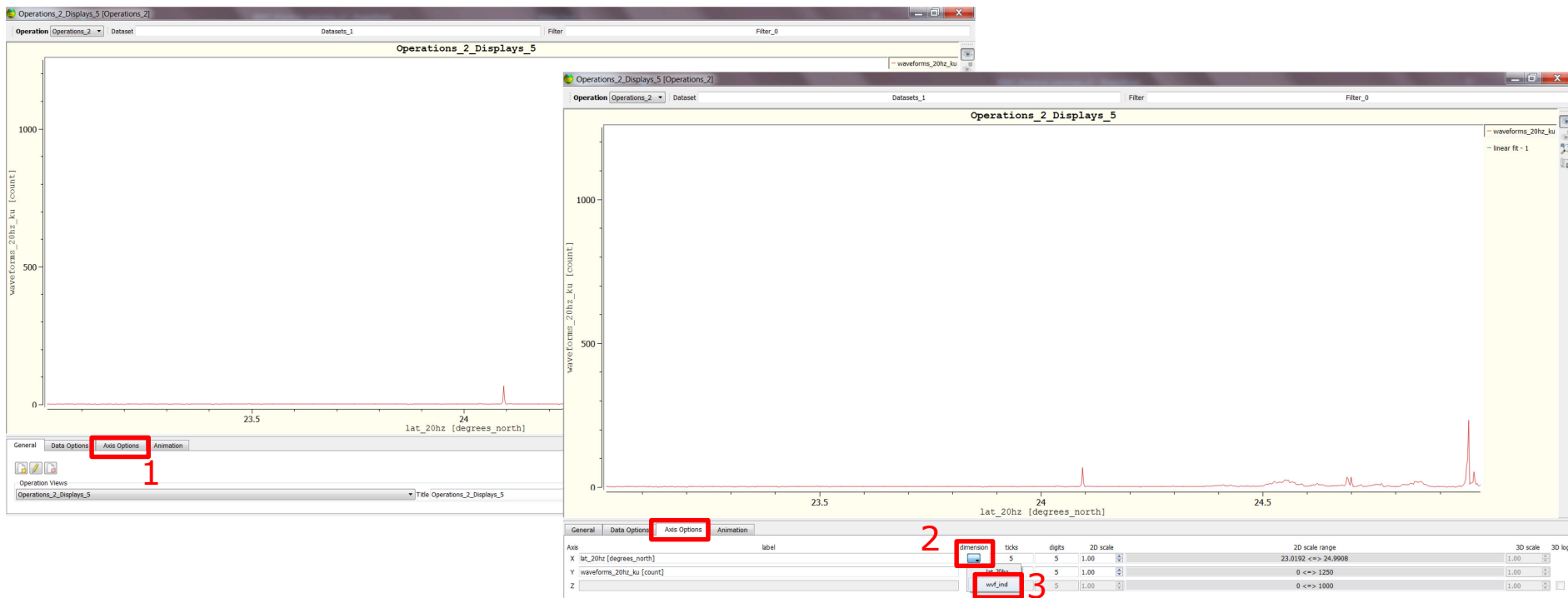
- 1-2a: In the '**Operations**' tab, create an Advanced operation by clicking on '**Advanced**' (1) and on the '**Create Operation**' icon (2). Name the operation (2a).
- 3-3a: Create a plot by selecting the plot icon (3) and **drag and drop** the needed variables from '**Fields**' to '**X**' and '**Data**' of the '**Data Expressions**' section (3a).
- 4: Select '**Filter\_0**' (see the available filters by pressing ↓). The part of the track selected will be evidenced in yellow.
- 5: Click on '**Execute**' to visualize the selected 'waveforms\_20Hz\_ku' field .



# L1b waveforms in J2 SIGDR products (2)



- Follow step 1-3 to correctly set the axis and the 2D scale

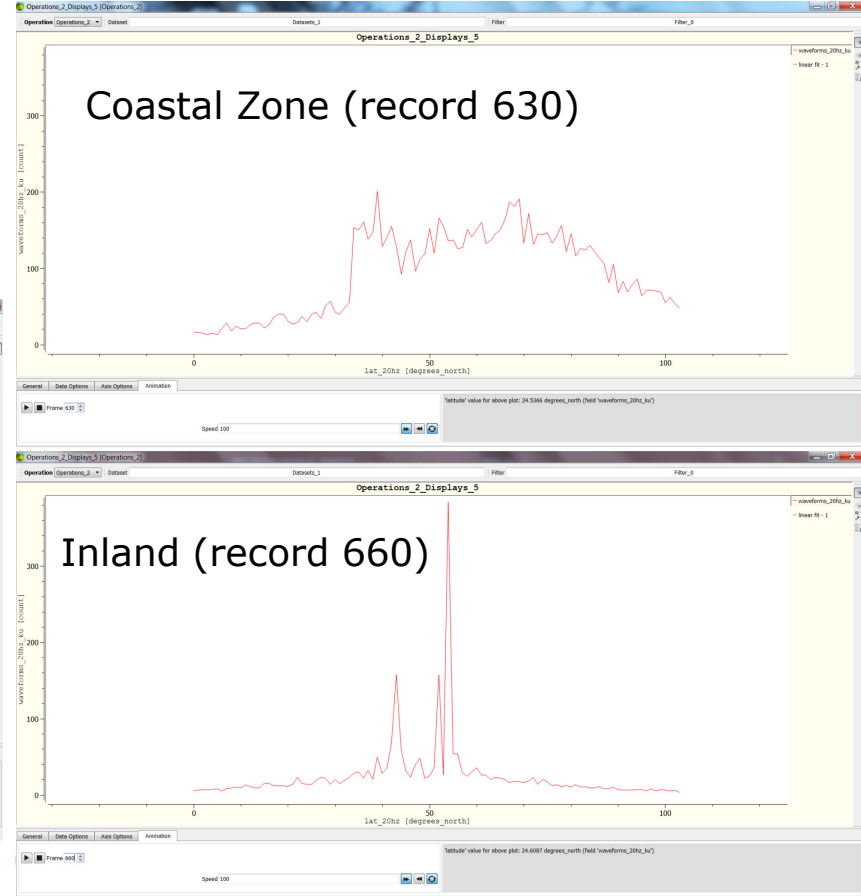
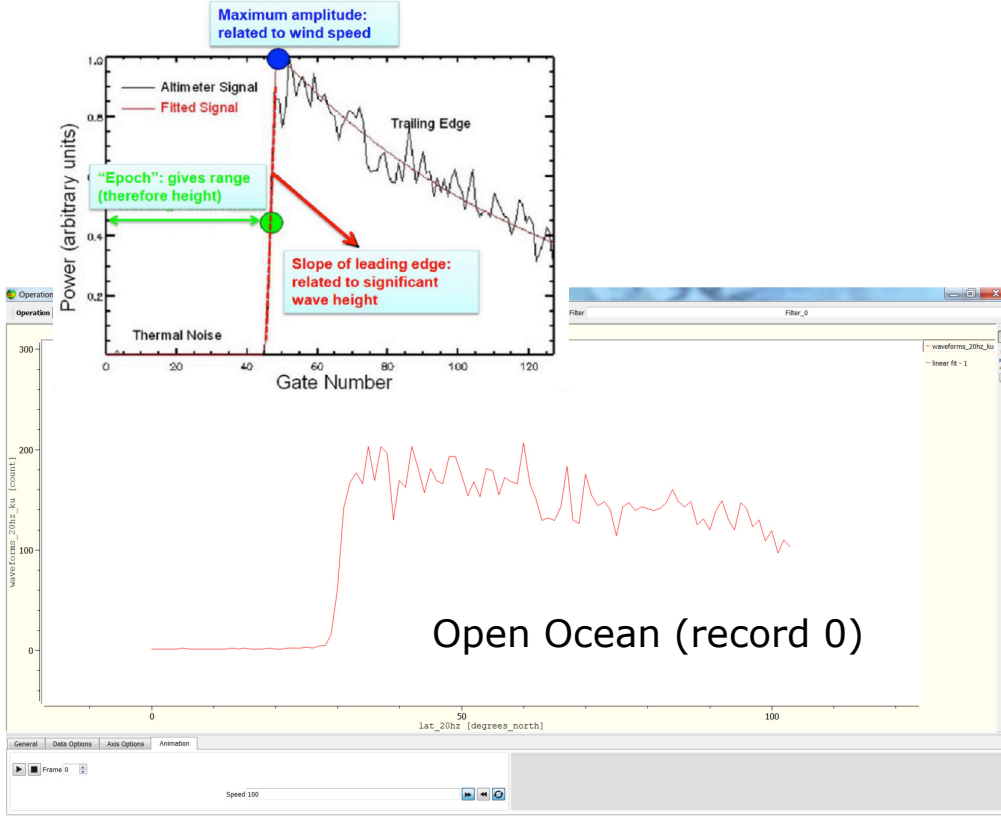


# Animation of L1b waveforms while approaching the coast

- Follow steps 1-4 to correctly display the dynamic of the waveform and start the animation showing the L1b waveforms in approaching the coast.
- Use the mouse (wheel & right button to centre the waveform & zoom in/out)



# Comparing L1b waveforms

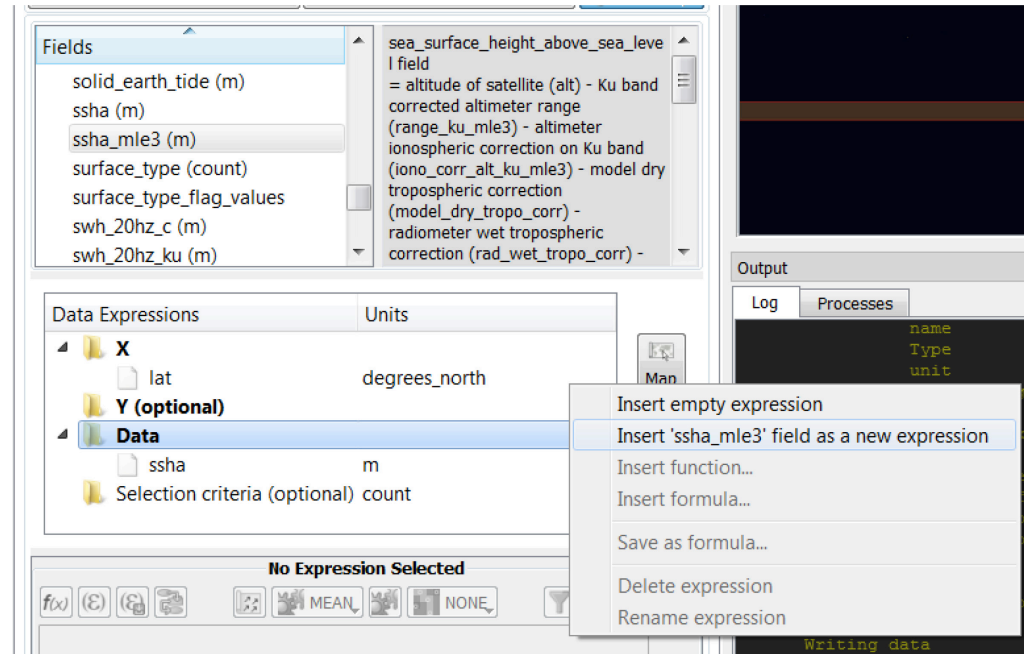


- Using the same operation close the current plot and delete (right click on the name) the '**X**' & '**Data**' fields (`lat_20hz` & `waveforms_20hz_ku`).
- Drag and drop '**lat**' in '**X**' insert the following '**Data**' fields:

1. **ssha**: by drag and drop the field

2. **ssha\_mle3**: by creating a new expression (right click on '**Data**'), two options appear.

Then carefully follow the instructions on the next slide to finalize the creation of the new expression.



The screenshot shows a software interface with several panels. On the left, a 'Fields' list contains items like 'solid\_earth\_tide (m)', 'ssha (m)', and 'ssha\_mle3 (m)'. Below it, a 'Data Expressions' panel shows a tree structure with 'X' (containing 'lat' in degrees\_north) and 'Data' (containing 'ssha' in m). A context menu is open over the 'Data' folder, with options: 'Insert empty expression', 'Insert 'ssha\_mle3' field as a new expression', 'Insert function...', 'Insert formula...', 'Save as formula...', 'Delete expression', and 'Rename expression'. On the right, an 'Output' panel shows a table with columns 'name', 'Type', and 'unit'. At the bottom, a toolbar includes icons for 'f(x)', 'E', and 'NONE', along with a 'No Expression Selected' status bar.

# Case 1: Empty Expression (used later for Formulas)



- 1-3: Modify (by double click on the name) 'Expression\_3', its associated box and 'count' to match the Field 'ssha\_mle3(m)'
- 4: Before proceeding check the correctness of the name/formula in the box by clicking on ✓
- 5: The save the expression be pressing <math>\epsilon</math>
- **If the expression is not saved an error occurs!**

start

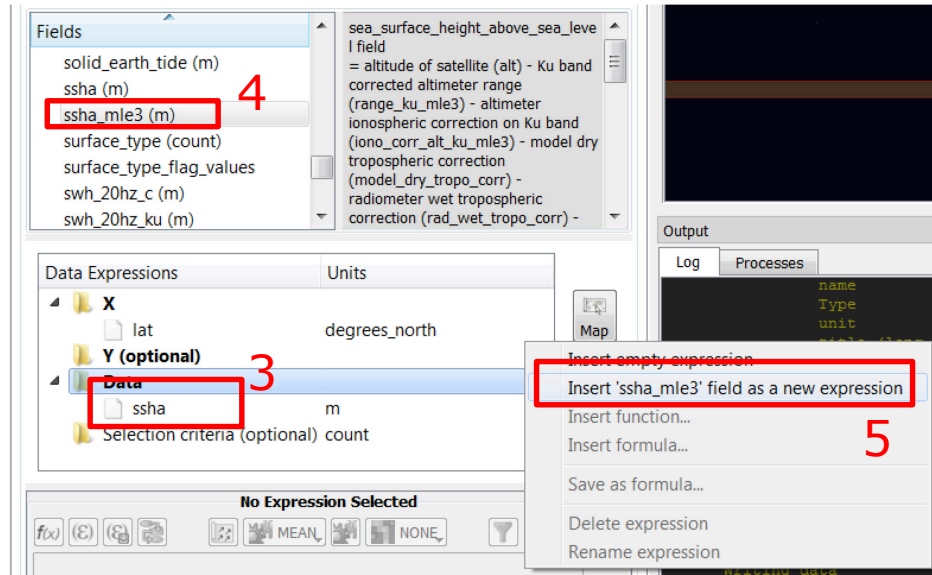
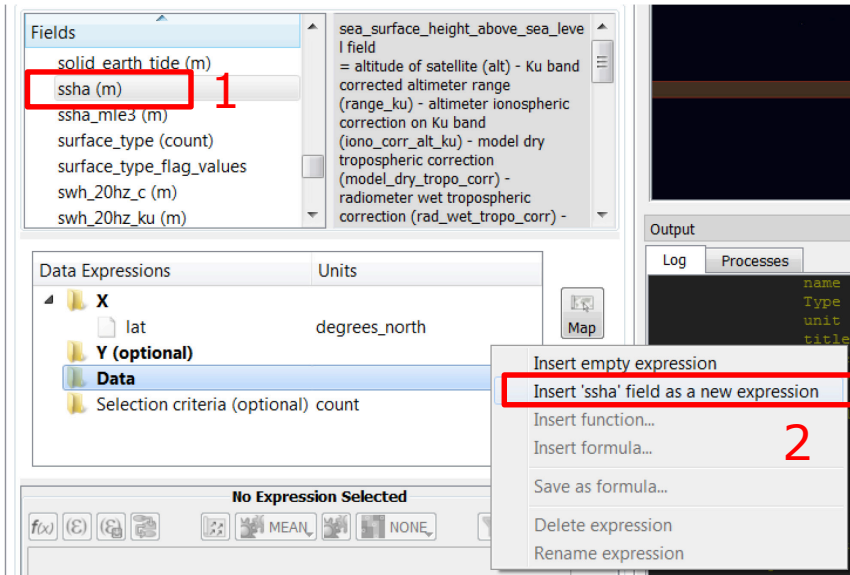
end



# Case 2: Automatic Drag & Drop



- It is possible to write the Data variables by simply highlight the desired field (1) and right click on 'Data' to import the field with the second option of the menu (2-3).



- This method can only be applied when no formulas (using more data fields) are considered!!!**



## 2 Runs: **Execute** (plot) & $\Sigma$ icon (to calculate statistics)

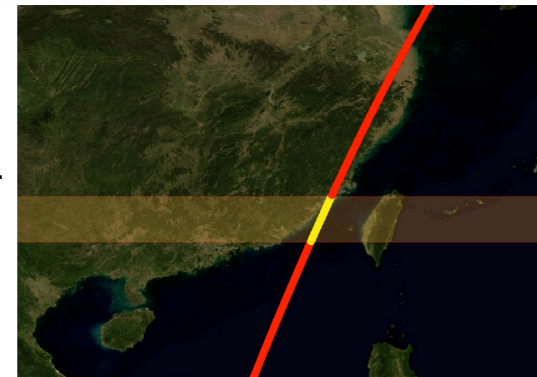
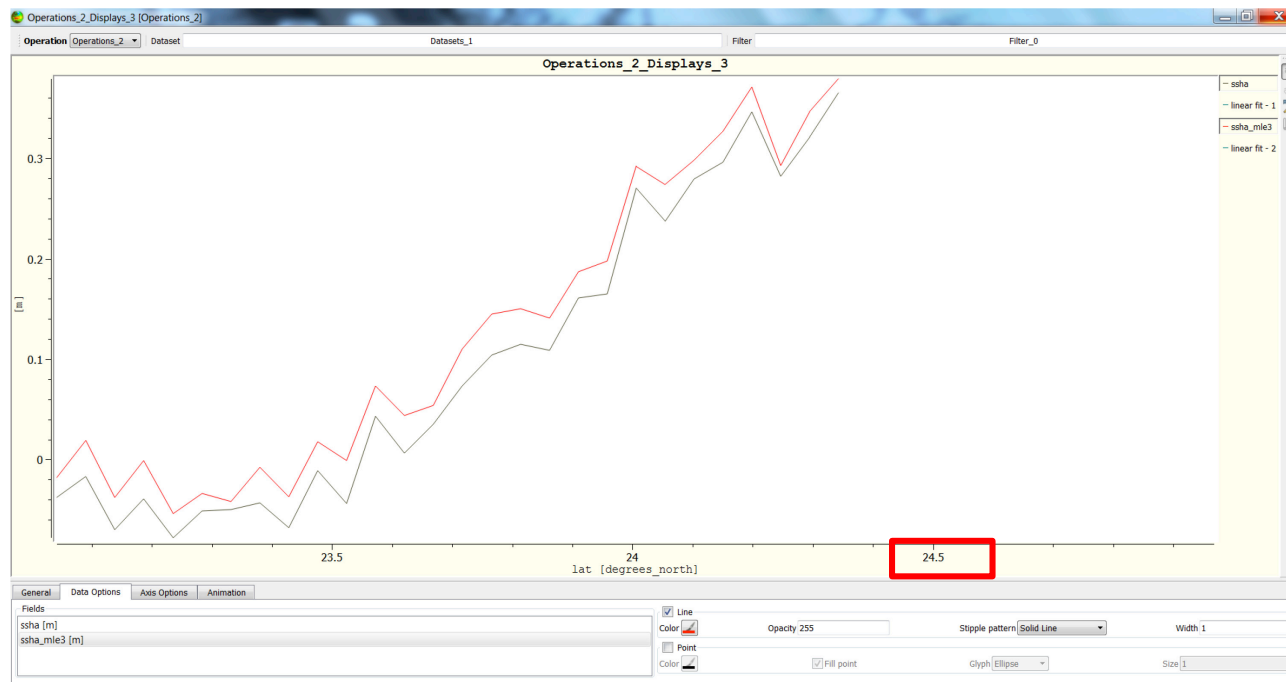
The screenshot shows the BRAT software interface. The main window displays a world map with a red satellite track. The interface includes several panels:

- Workspace Elements:** Contains tabs for Datasets, RADS Datasets, Filters, and Operations. The 'Execute' button is highlighted with a red box.
- Operations:** Shows the current operation 'Operations\_2' and the dataset 'Datasets\_1'. A 'Filter\_0' is applied.
- Fields:** Lists various satellite data fields such as 'sea\_surface\_height\_above\_sea\_level', 'solid\_earth\_tide (m)', 'ssha (m)', 'ssha\_mle3 (m)', 'surface\_type (count)', 'surface\_type\_flag\_values', 'swh\_20hz\_c (m)', and 'swh\_20hz\_ku (m)'. Descriptions for some fields are provided.
- Data Expressions:** Shows the current data expressions, including 'X' (lat) in degrees\_north and 'Data' (ssha, ssha\_mle3) in meters.
- Data:** Displays the current data set, 'ssha\_mle3'.
- Output:** Shows a log of system messages, including warnings about deprecated QPixmap::grabWidget methods.

# Practical n.2: Results from different Retrackerers



- SSHA estimates from the two retrackers are in good agreement.
- Tide gauges are needed as an independent reference for validation.
- No estimates are given inland (**lat > 24.5**) as waveforms do not respect the retracking model.



New Area Selection

**Max Lat (deg)**  
25

Min Lon (deg)      Max Lon (deg)  
-180      180

**Min Lat (deg)**  
23

- The results of the statistics are the following



```
[WARN] 2018-10-10T10:02:12 Stats_Operations_2 :
=====
Result for 'ssha'
=====

[WARN] 2018-10-10T10:02:12 Stats_Operations_2 :
Number of valid data = 28.000000
Mean = 0.096357

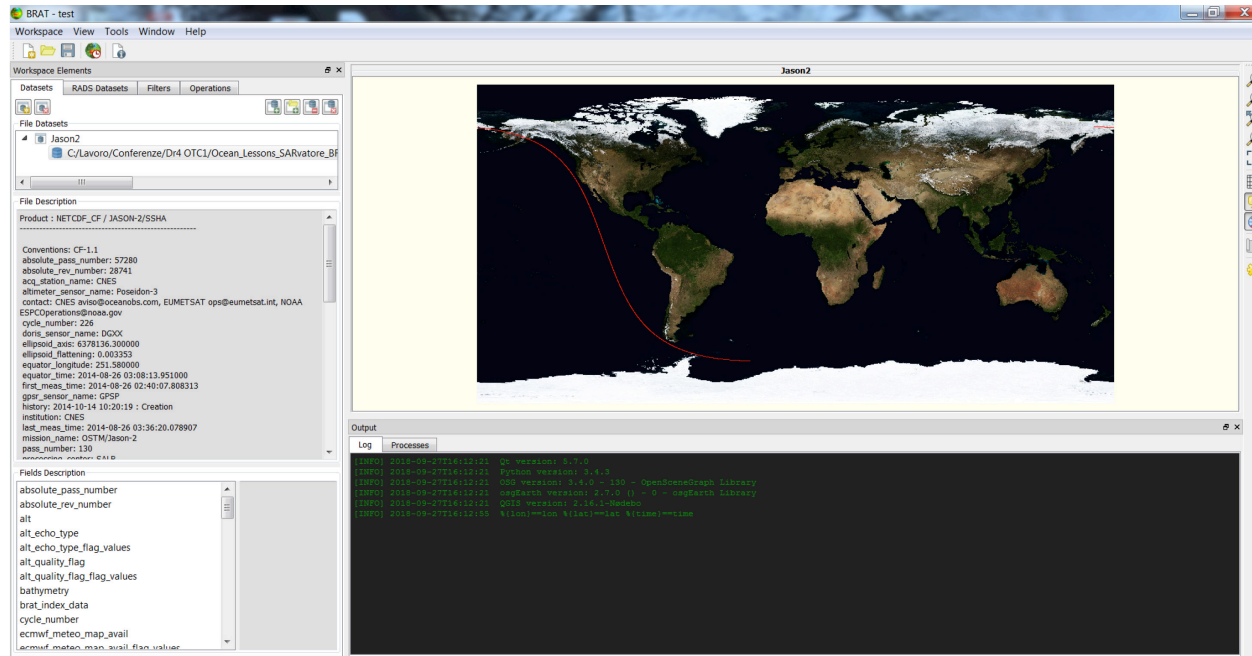
[WARN] 2018-10-10T10:02:12 Stats_Operations_2 :
Standard deviation = 0.145827
Minimum = -0.078000
Maximum = 0.365000
=====
Result for 'ssha_mle3'
=====
Number of valid data = 28.000000
Mean = 0.124500
Standard deviation = 0.143738
Minimum = -0.054000
Maximum = 0.379000

=====> Result is also saved into C:/workspaces/test/Operations/Stats_Operations_2.txt
```

**IMPORTANT:** **Execute** (plot) &  $\Sigma$  icon produce netCDF and txt files as output products.

Folder: **J2** (also in the BRAT DEMO Folder)

Track used: **JA2\_GPR\_2PdP226\_130\_20140826\_024007\_20140826\_033620.nc**



The screenshot shows the BRAT (Browse Remote Access Tool) interface. The main window displays a satellite track (red line) over a map of the ocean, labeled "Jason2". The track starts in the North Atlantic and moves southwards. On the left, there is a "File Description" panel for the file "C:\Lavoro\Conferenze\Dr4\OTC1\Ocean\_Lessons\_SARivatore\_Bf". The description includes the following details:

- Product: NETCDF\_CF / JASON2/SSHA
- Conventions: CF-1.1
- absolute\_pass\_number: 57280
- absolute\_rev\_number: 28741
- acq\_station\_name: CHES
- altimeter\_sensor\_name: Poseidon-3
- contact: CHES\_sviso@oceanobs.com, EUMETSAT\_ops@eumetsat.int, NOAA\_ESOC\_operations@noaa.gov
- cycle\_number: 228
- doris\_sensor\_name: DQX
- ellipsoid\_name: GRS80
- ellipsoid\_semi\_major\_axis: 6378136.300000
- ellipsoid\_flattening: 0.003353
- equator\_longitude: 251.580000
- equator\_time: 2014-08-26 03:08:13.951000
- first\_meas\_time: 2014-08-26 02:40:07.808313
- gprf\_sensor\_name: GPRF
- history: 2014-10-14 10:20:19 : Creation
- institution: CHES
- last\_meas\_time: 2014-08-26 03:36:20.078907
- mission\_name: OSTM/Jason-2
- pass\_number: 130

Below the description is a "Fields Description" list:

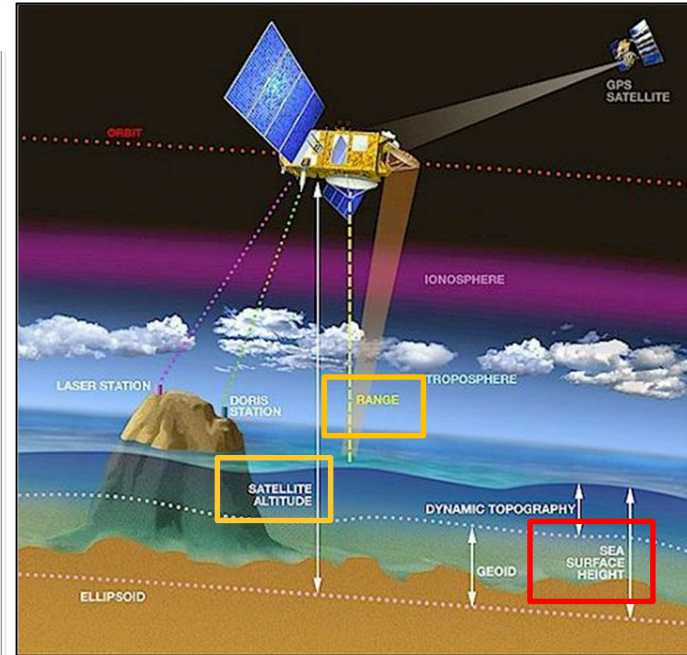
- absolute\_pass\_number
- absolute\_rev\_number
- alt
- alt\_echo\_type
- alt\_echo\_type\_flag\_values
- alt\_quality\_flag
- alt\_quality\_flag\_flag\_values
- bathymetry
- brat\_index\_data
- cycle\_number
- ecmwf\_meteo\_map\_avail
- acsmwf\_meteo\_map\_avail\_flag\_value

The bottom panel shows the "Output" window with a log of processes:

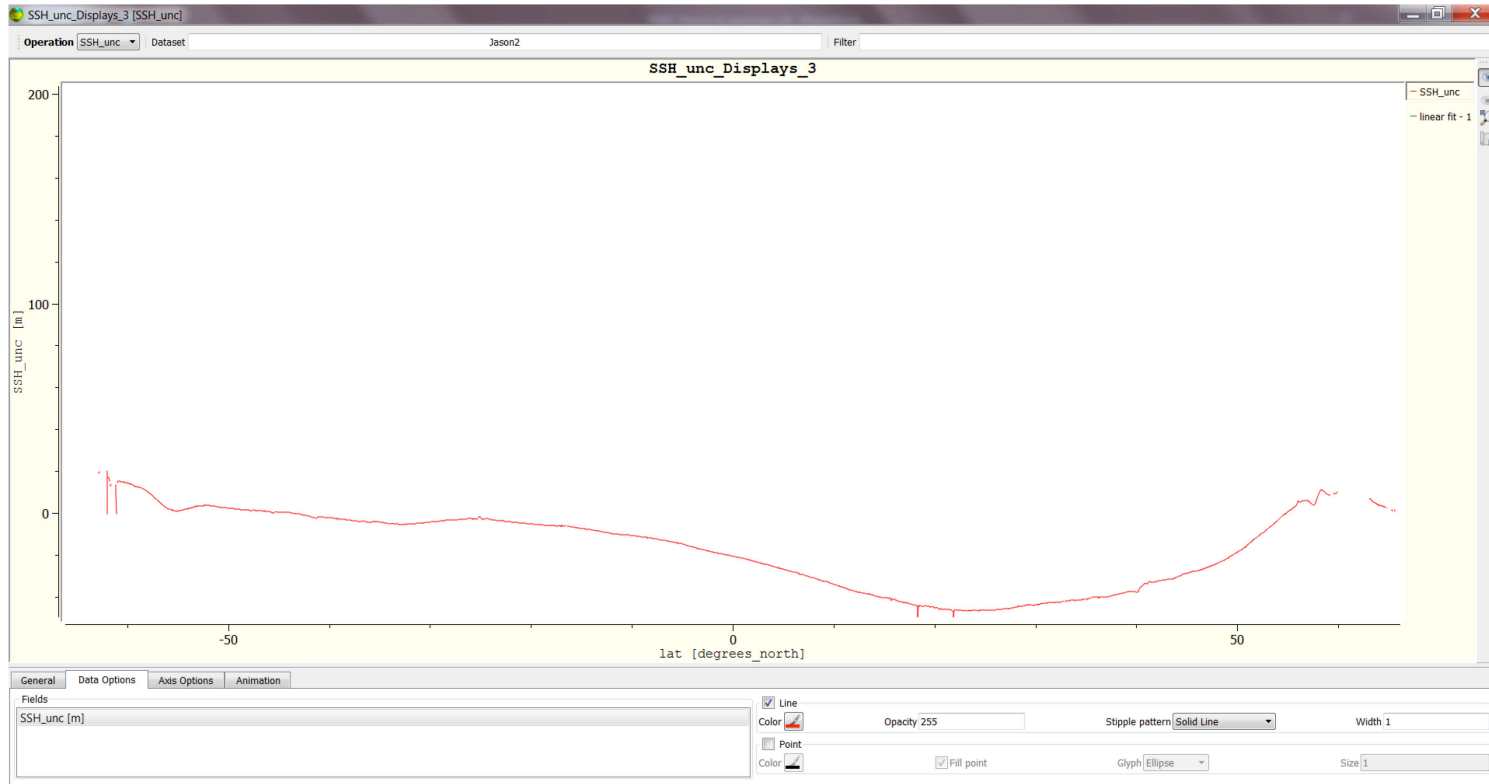
```
Log Processes
[INFO] 2018-09-27T18:12:00.000000000 [D:\brat\bin] C:\brat\bin\brat.exe
[INFO] 2018-09-27T18:12:01.000000000 [D:\brat\bin] C:\brat\bin\brat.exe
[INFO] 2018-09-27T18:12:02.000000000 [D:\brat\bin] C:\brat\bin\brat.exe
[INFO] 2018-09-27T18:12:03.000000000 [D:\brat\bin] C:\brat\bin\brat.exe
[INFO] 2018-09-27T18:12:04.000000000 [D:\brat\bin] C:\brat\bin\brat.exe
```

- Quantity derived from the altitude and the range **not including the geophysical corrections**.
- Create an **"Empty expression"** (right click on 'Data'). We name it **'SSH\_unc'** and put **'m'** as Units.
- The **formula** to be inserted is **'alt - range\_ku'** [m].
- Check the correctness of the formula with **✓** and save it with **<ε** before executing the operation and plotting.

The screenshot shows two windows from the QGIS interface. The top window, 'Data Expressions', lists variables: 'X' (lat, degrees\_north), 'Y (optional)', 'Data 1' (SSH\_unc, m), and 'Selection criteria (optional) count'. The bottom window, 'Data Expression Editor', shows the formula 'alt - range\_ku' entered in the expression field. The 'Units' field is empty. The 'OK' button is checked, and the 'Save' button is highlighted.



# The Uncorrected Sea Surface Height (SSH) (2)



# Filtering in Latitude (using Selection Criteria)



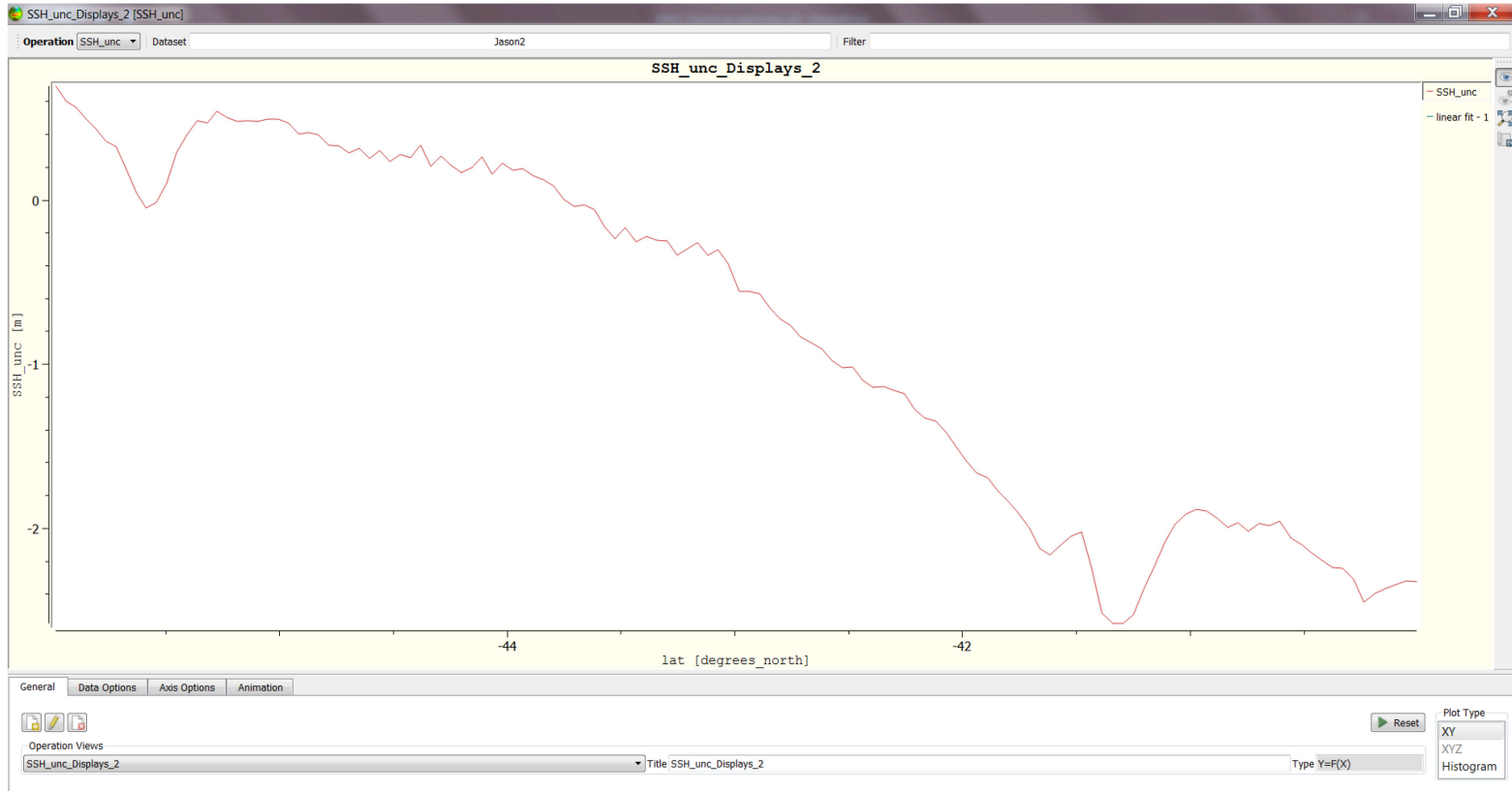
- This alternative way of filtering the data is useful when the time vector is not present in the input product. In such cases, the 'Filters' tab cannot be used (see MDT & ADT in the Practical on Oceanography).
- To insert the selection criteria, left click on "**Selection criteria (optional)**", the correspondent box will be activated.
- Insert in the box the filtering in latitude:  $(lat > -46) \& (lat < -40)$ .
- As for formulas, please check with ✓ and save the criteria with **⊗**.
- Click on "**Execute**" to plot the filtered trend.

The screenshot shows the 'Filters' tab in a software interface. The 'Fields' list on the left includes: rad\_wet\_tropo\_corr (m), rain\_flag (count), rain\_flag\_flag\_values, range\_ku (m), range\_ku\_mle3 (m), sea\_state\_bias\_ku (m), sea\_state\_bias\_ku\_mle3 (m), sig0\_ku (dB), sig0\_ku\_mle3 (dB), and solid\_earth\_tide (m). The 'Data Expressions' table shows: X (lat, degrees\_north), Y (optional) (lat, degrees), and Data (CSH\_unc, m). The 'Selection criteria (optional)' input box contains the formula:  $(lat > -46) \& (lat < -40)$ . The 'Execute' button is highlighted with a red box and the number 5. Other red boxes and numbers highlight the 'Selection criteria (optional)' label (1), the formula input box (2), the checkmark icon (3), and the save icon (4).





# Filtering in Latitude (using Selection Criteria)



# Comparing outputs from 2 Retrackerers



- Again, we could compare the output of 2 retrackers adding a new expression.

Data Expressions

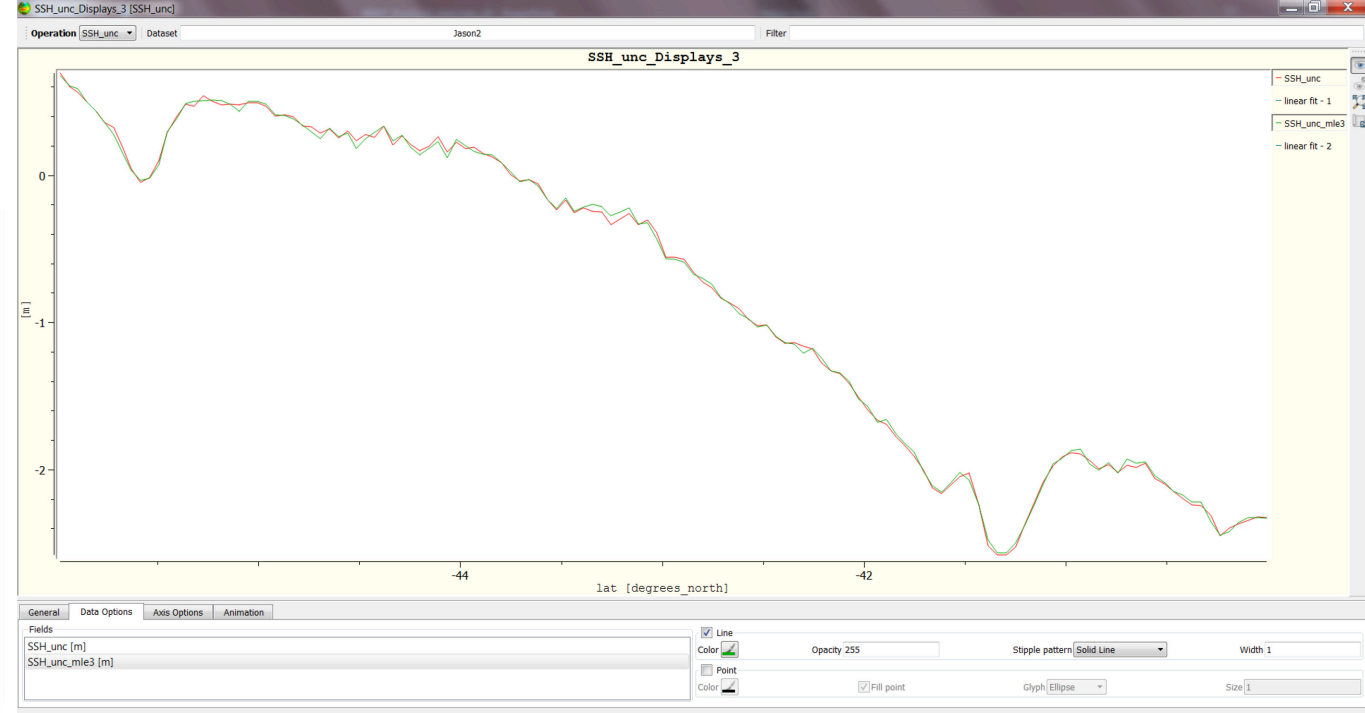
Data Expressions	Units
✖ X	
lat	degrees_north
✖ Y (optional)	
Data	
SSH_unc	m
SSH_unc_mle3	m
Selection criteria (optio...	count

Map Plot

Data

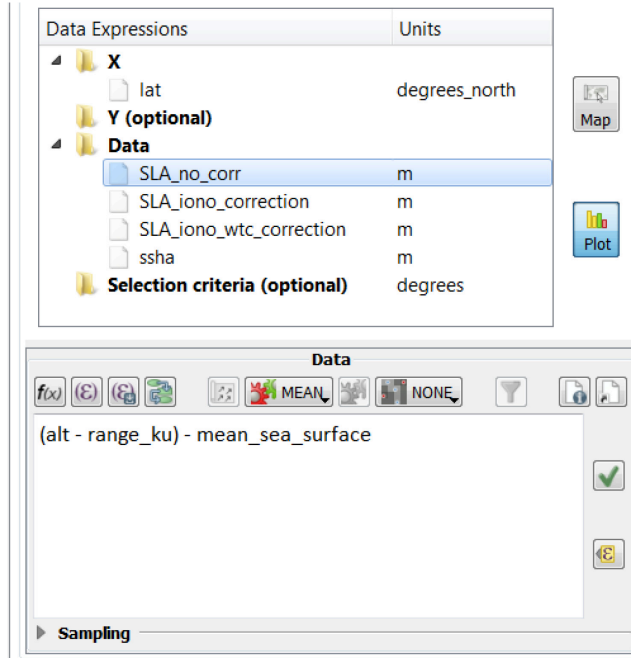
alt - range\_ku\_mle3

Sampling

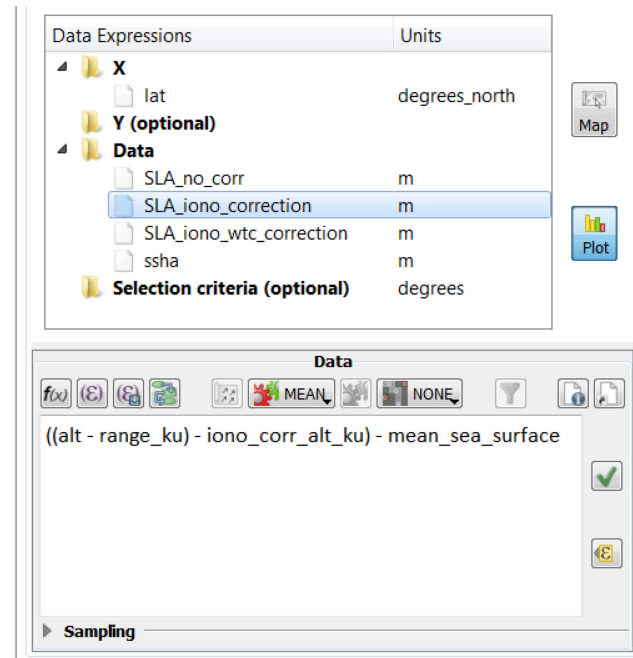


- Using the same input file, we evaluate the impact of geophysical corrections on SLA (= SSH-MSS).
- We compare the SLA obtained with the uncorrected SSH (no geo corrections applied) to the SLA obtained with: 1) a few corrections (ionosphere and WTC) and 2) all corrections applied.
- The altimetry community is constantly working on the production of improved geophysical corrections to allow the precise determination on SLA from which instantaneous geostrophic currents are derived.

- By using the same product, we create the following plot composed of 4 expressions named and formulated as follows:

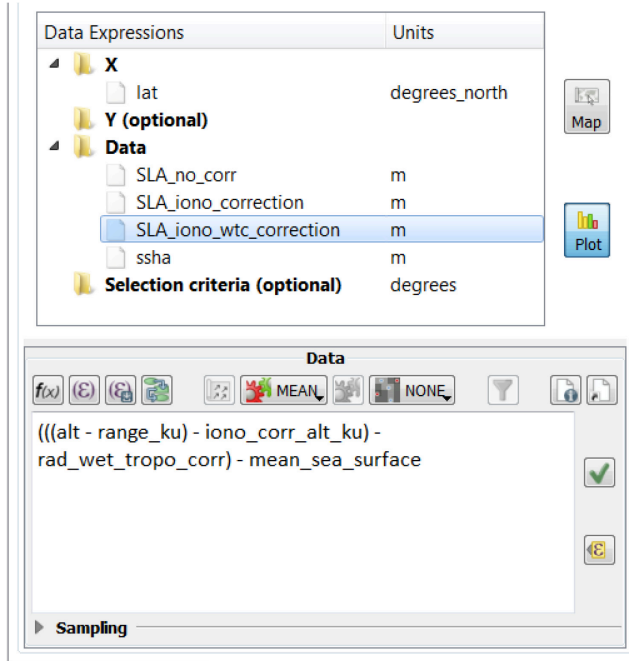


The screenshot shows the QGIS interface with the Data Expressions panel and the Data panel. The Data Expressions panel lists variables: X (lat, degrees\_north), Y (optional), Data (SLA\_no\_corr, SLA\_iono\_correction, SLA\_iono\_wtc\_correction, ssha, m), and Selection criteria (optional) (degrees). The Data panel shows the expression:  $(alt - range\_ku) - mean\_sea\_surface$ .



The screenshot shows the QGIS interface with the Data Expressions panel and the Data panel. The Data Expressions panel lists variables: X (lat, degrees\_north), Y (optional), Data (SLA\_no\_corr, SLA\_iono\_correction, SLA\_iono\_wtc\_correction, ssha, m), and Selection criteria (optional) (degrees). The Data panel shows the expression:  $((alt - range\_ku) - iono\_corr\_alt\_ku) - mean\_sea\_surface$ .

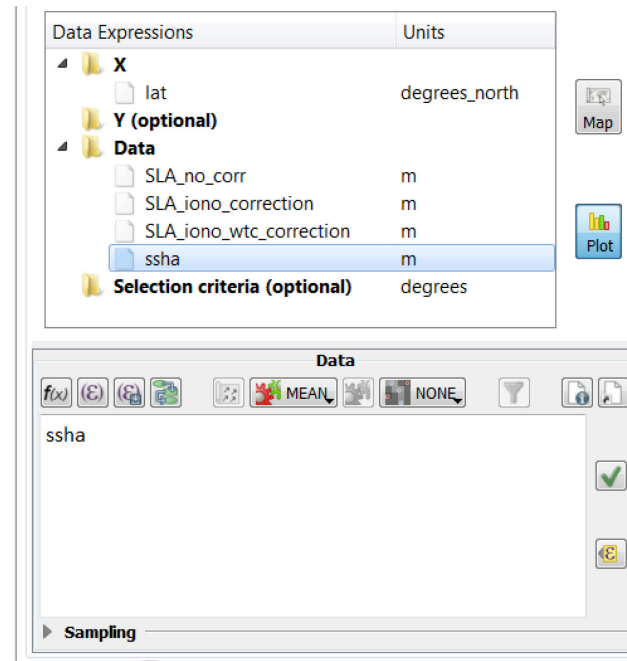
- By using the same product, we create the following plot composed of 4 expressions named and formulated as follows:



The screenshot shows a software interface with a table of data expressions and a formula editor. The table lists the following expressions and units:

Data Expressions	Units
<b>X</b>	
lat	degrees_north
<b>Y (optional)</b>	
<b>Data</b>	
SLA_no_corr	m
SLA_iono_correction	m
SLA_iono_wtc_correction	m
ssha	m
<b>Selection criteria (optional)</b>	degrees

The formula editor below the table contains the following expression:

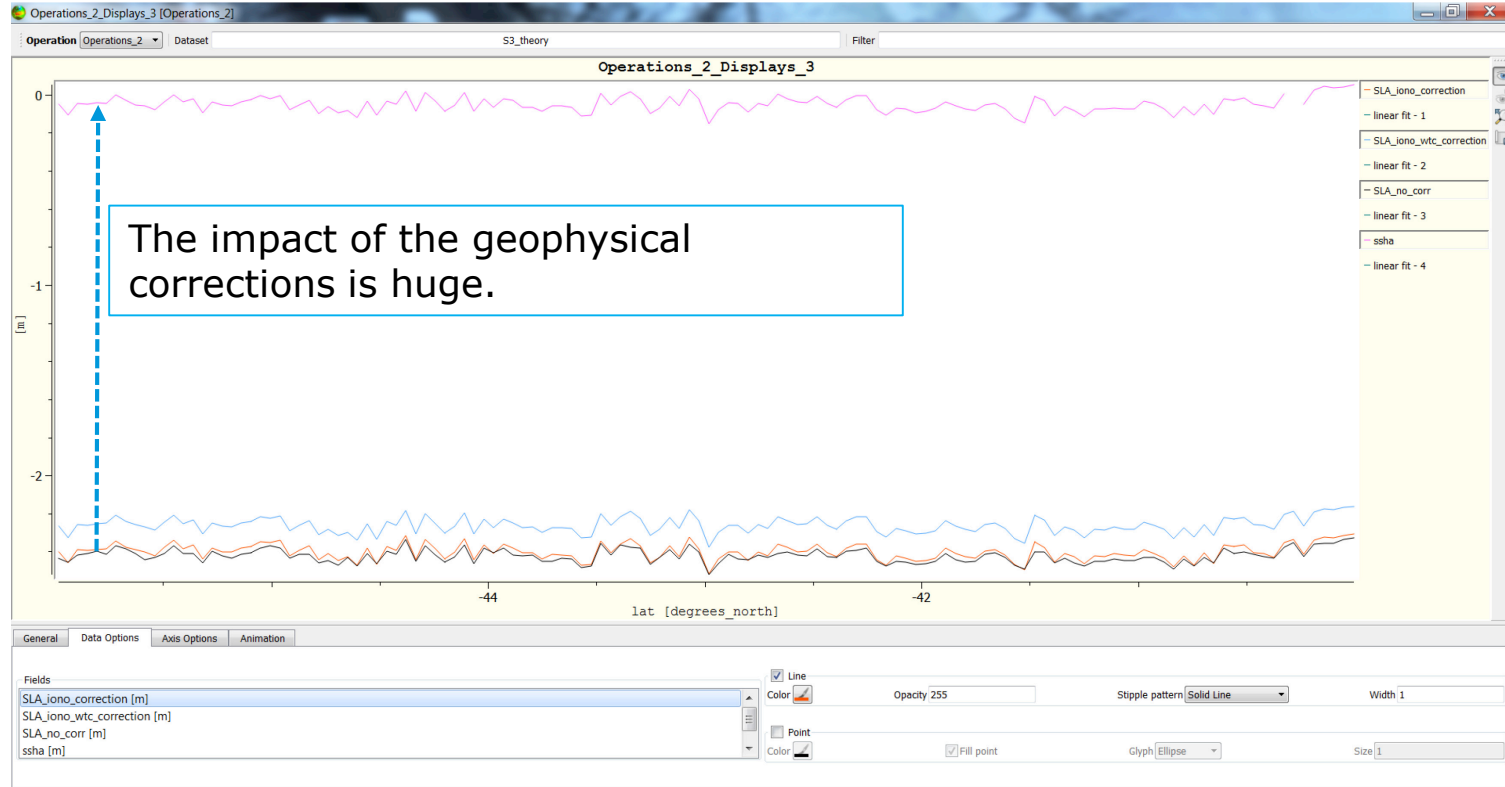
$$(((alt - range\_ku) - iono\_corr\_alt\_ku) - rad\_wet\_tropo\_corr) - mean\_sea\_surface$$


The screenshot shows a software interface with a table of data expressions and a formula editor. The table lists the following expressions and units:

Data Expressions	Units
<b>X</b>	
lat	degrees_north
<b>Y (optional)</b>	
<b>Data</b>	
SLA_no_corr	m
SLA_iono_correction	m
SLA_iono_wtc_correction	m
ssha	m
<b>Selection criteria (optional)</b>	degrees

The formula editor below the table contains the following expression:

$$ssha$$

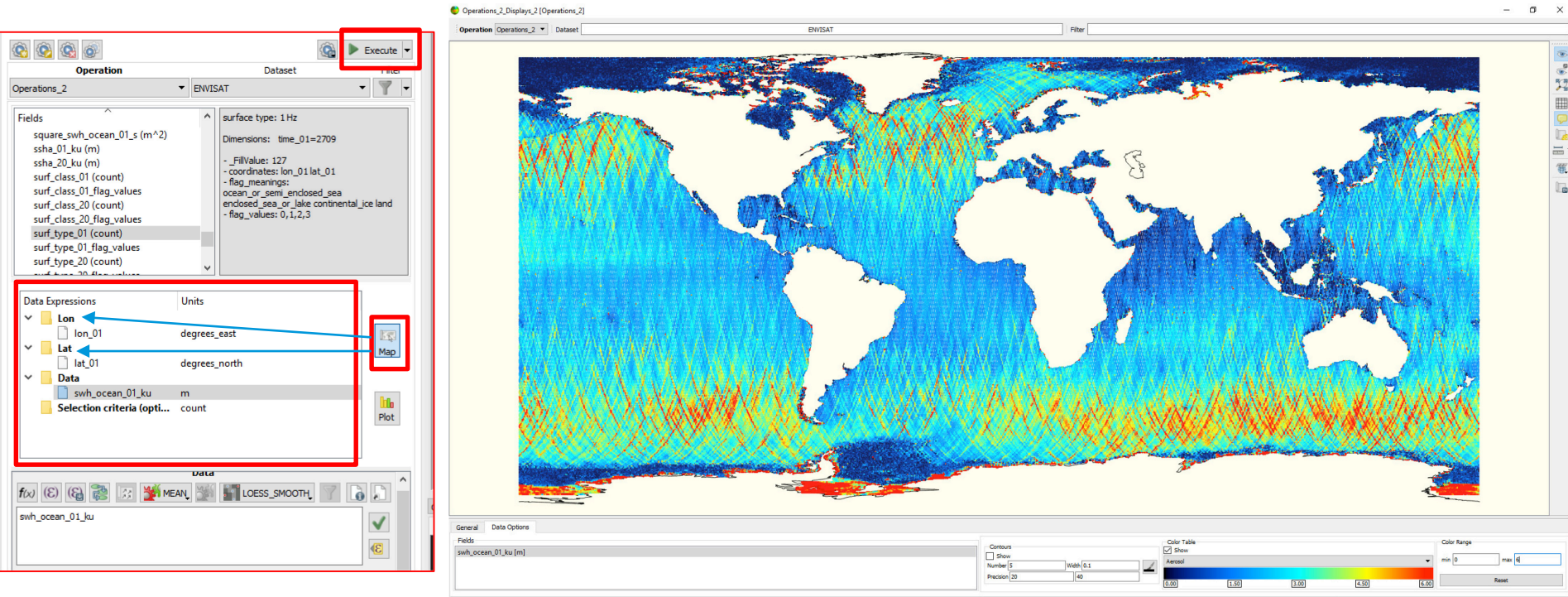


# Impact of Geophysical Corrections on SLA (4)



# Global SWH (no filtering)

- Input data: ENVISAT (Cycle 25). Plot data using the MAP (lat, lon) option.
- All fields are at 1 Hz (lon\_01, lat\_01 & swh\_ocean\_01\_ku)





# Global SWH (Loess Smooth Filtering)



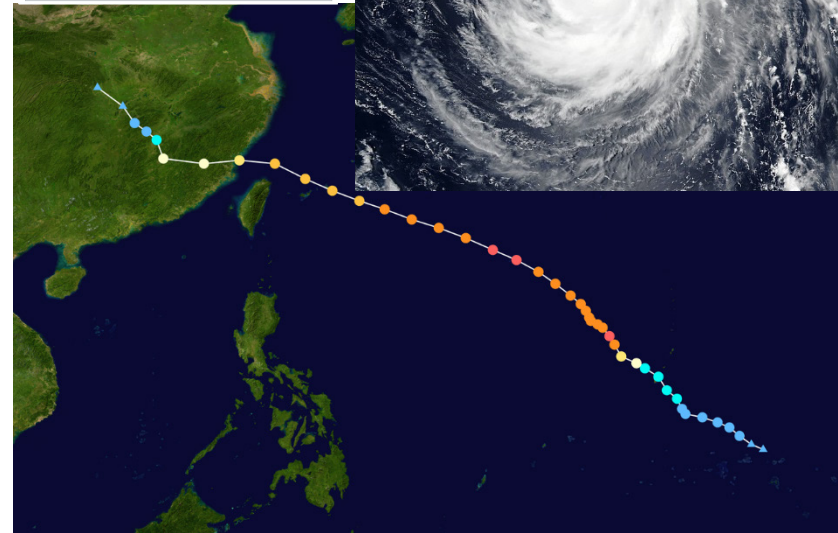
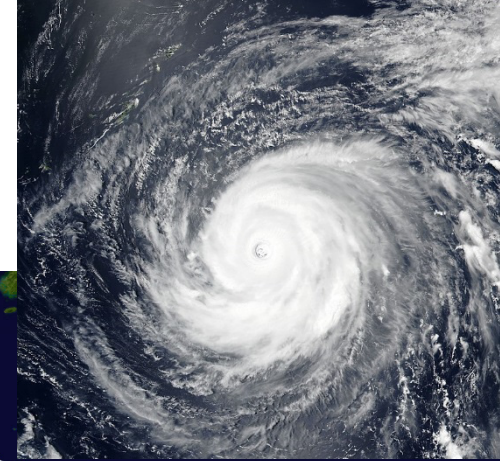
A Loess filter is a low-pass filter mostly used for smoothing. Loess cut-off values are discussed in the BRAT user manual. Here an example with the LOESS\_SMOOTH filter:

The screenshot displays the ENVI software interface. On the left, the 'Operations\_2' panel shows the 'LOESS\_SMOOTH' filter selected. The 'Sampling' section is configured with 'Lon Resolution' (expression: 'lon\_01', units: 'degrees\_east', value: 180) and 'Lat Resolution' (expression: 'lat\_01', units: 'degrees\_north', value: 90). The 'Loess Cut-Off' is set to 31. The 'Execute' button is highlighted with a red box. The main window shows a global map of Significant Wave Height (SWH) with a color scale from 0.05 to 6.00. The 'Color Table' is set to 'Aerocol' and 'Show' is checked. The 'Color Range' is set to 'min 0.048203' and 'max 6'.



- **Typhoon Maria** was a powerful tropical cyclone that affected Taiwan & China.
- The typhoon reached its first peak intensity on July 6; 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.

Formed	July 3, 2018
Dissipated	July 12, 2018
Highest winds	10-minute sustained: 195 km/h (120 mph) 1-minute sustained: 260 km/h (160 mph)
Lowest pressure	915 hPa (mbar); 27.02 inHg
Fatalities	2 total
Damage	\$491 million (2018 USD)
Areas affected	Mariana Islands, Ryukyu Islands, Taiwan, China
Part of the 2018 Pacific typhoon season	



Text and images credit: [https://en.wikipedia.org/wiki/Typhoon\\_Maria\\_\(2018\)](https://en.wikipedia.org/wiki/Typhoon_Maria_(2018))

# Practical n.4: Typhoon Maria (OLCI & S3-A) (2)



The co-located Sentinel-3A and OLCI data products have been acquired on July 10<sup>th</sup> near Taiwan:

`S3A_SR_2_WAT___20180710T013336_20180710T021747_20180804T173801_2651_033_174_____MAR_O_NT_003.SEN3`  
(also available in SARvatore with a useful .kml track file).

`S3A_OL_1_EFR___20180710T015012_20180710T015312_20180711T060534_0179_033_174_2520_LN1_O_NT_002`.

**Exercise Folder:** Typhoon\_Maria\GPOD\Typhoon\_detected

**Open in BRAT the SARvatore file:**  
`RES_S3A_SR_1_SRA_A_20180710T013336_20180710T022406_20180804T230236_3029_033_174_GPOD_SAR_O_NT_003.nc`

Please note that BRAT was not conceived to read **SARvatore** data, so the track will not be displayed on the map of the BRAT GUI.

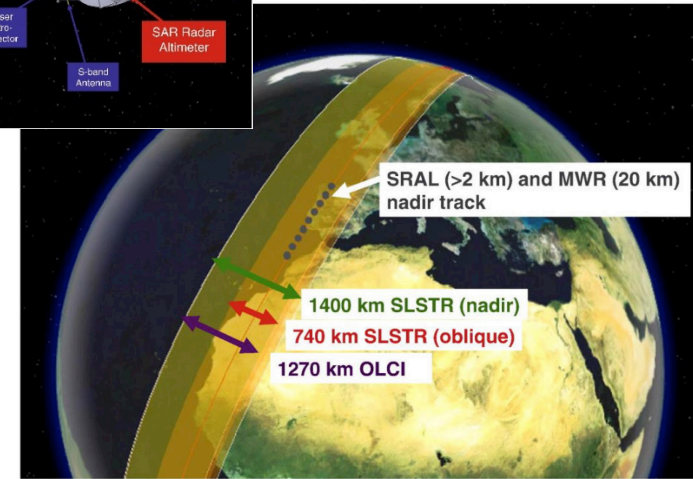
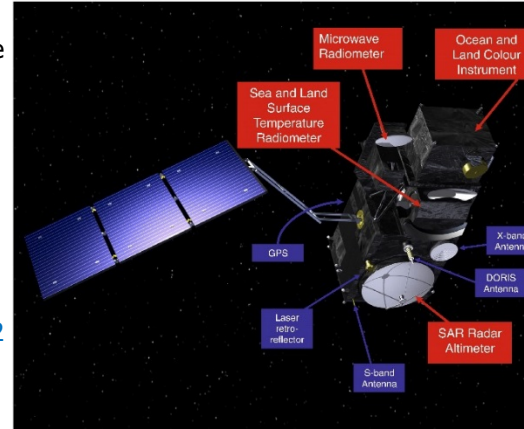


Figure 1-3: SENTINEL-3 Ground Track Resolution (Credit: ESA)



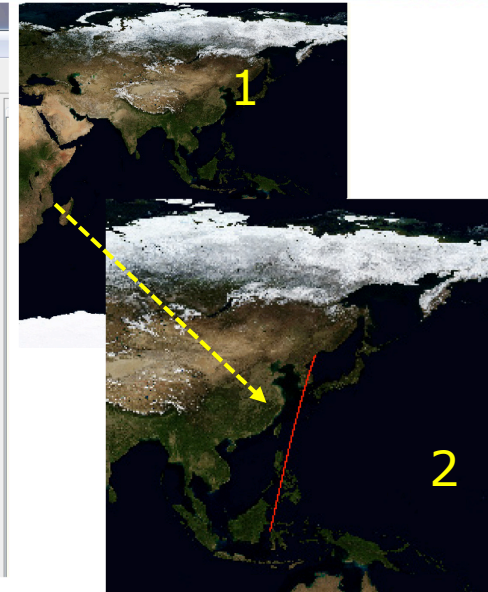
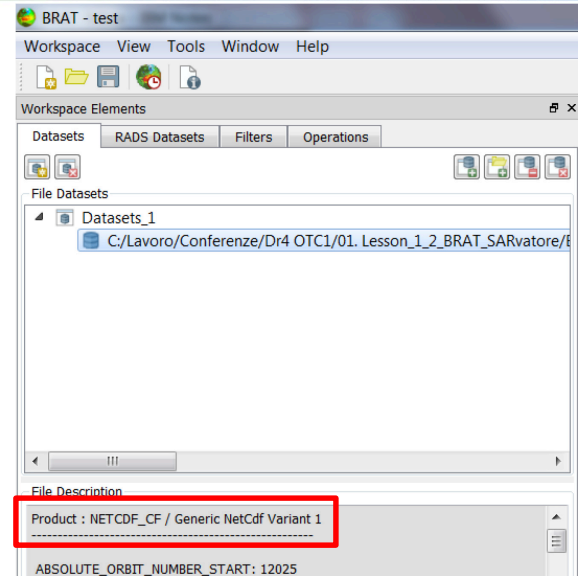
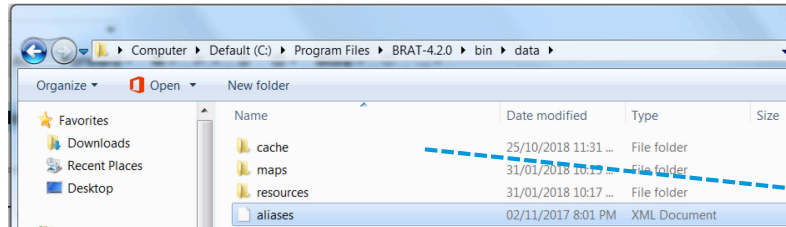
# Work-around to display SARvatore tracks in BRAT



- **1** - Please note that BRAT was not conceived to read **SARvatore** data, so the track will not be displayed on the map of the BRAT GUI. However, there is a work-around:
- In opening the product in BRAT, the netCDF file is associated with the **NETCDF\_CF / Generic NetCdf Variant 1** format.

## Work-around:

- Open the **aliases.xml** from **bratXX/bin/data**:



```
<aliases productType="Generic NetCdf Variant 1" description="Generic Netcdf Dataset - Aliases Variant 1">  
<alias name="lat">latitude</alias>  
<alias name="lon">longitude</alias>  
<alias name="time">time</alias>  
</aliases>
```

```
<aliases productType="Generic NetCdf Variant 1" description="Generic Netcdf Dataset - Aliases Variant 1">  
<alias name="lat">latitude_1Hz</alias>  
<alias name="lon">longitude_1Hz</alias>  
<alias name="time">time_counter_1Hz</alias>  
</aliases>
```

- **2** - Change the **latitude** by **latitude\_1Hz**, **longitude** by **longitude\_1Hz**, and **time** by **time\_counter\_1Hz** (or those at 20Hz) in the **Generic NetCdf Variant 1** section.



# Sentinel-3 Data Access

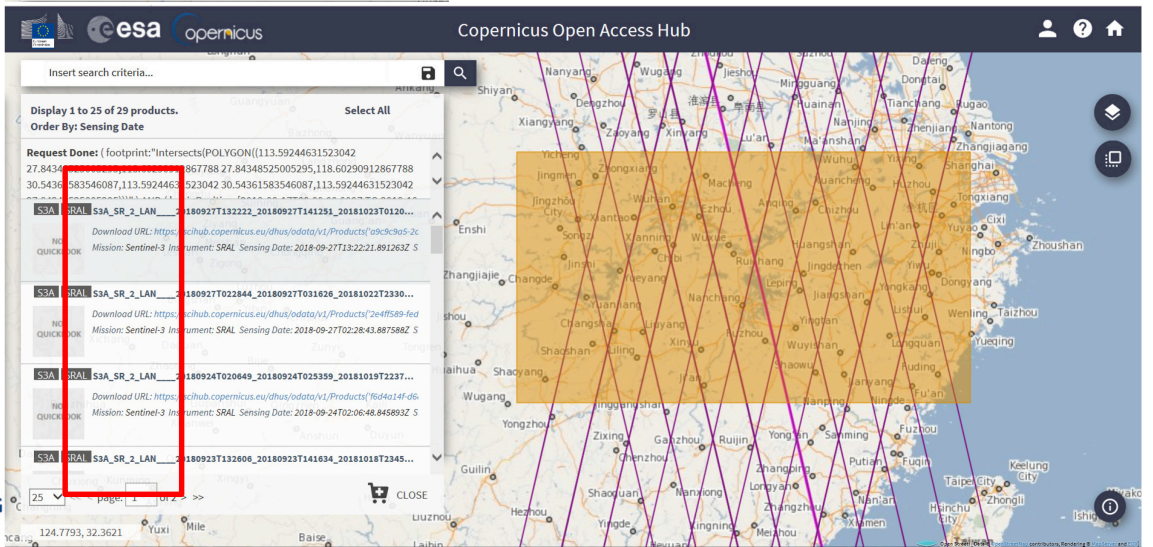
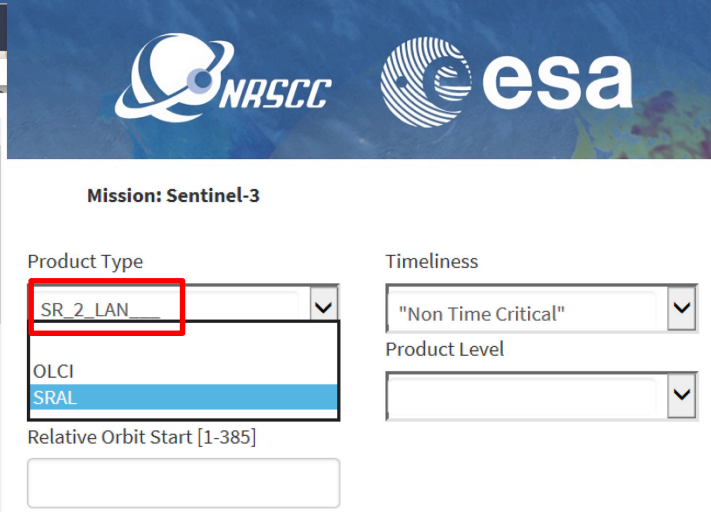
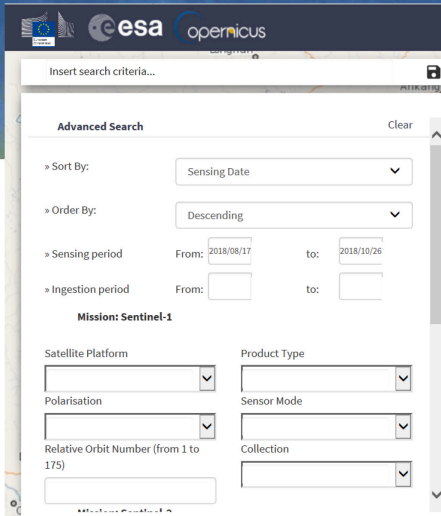
- **L2 Sentinel-3 altimetry data** from SRAL are available in two flavors:

- Land Products **"S3A\_SR\_2\_LAN\_XXX"** (distributed by ESA at <https://scihub.copernicus.eu/dhus/#/home>) including inland water areas & coastal zone.

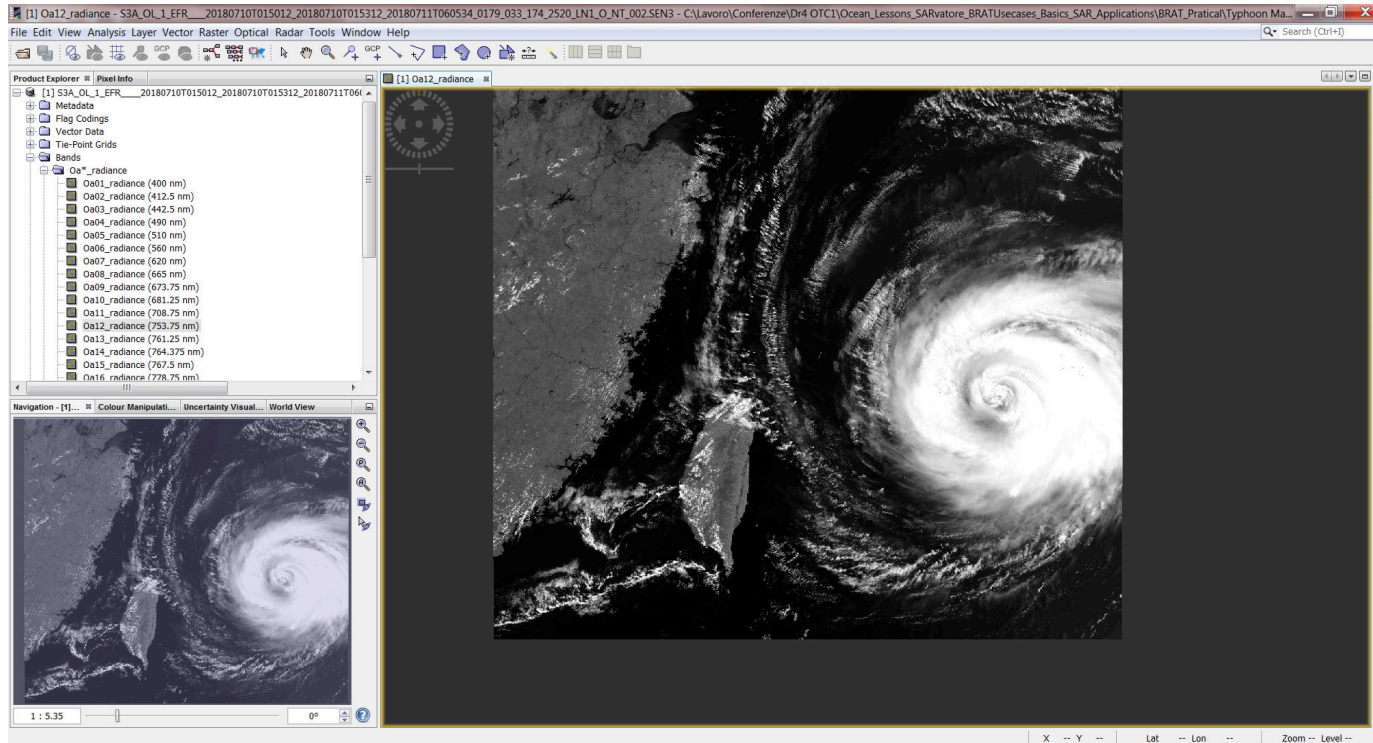
- Water Products **"S3A\_SR\_2\_WAT\_XXX"** (distributed by EUMETSAT at <https://codas.eumetsat.int/#/home>) including coastal zone & open ocean.

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

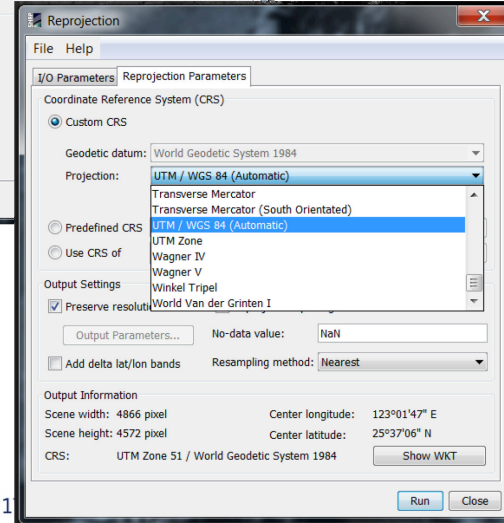
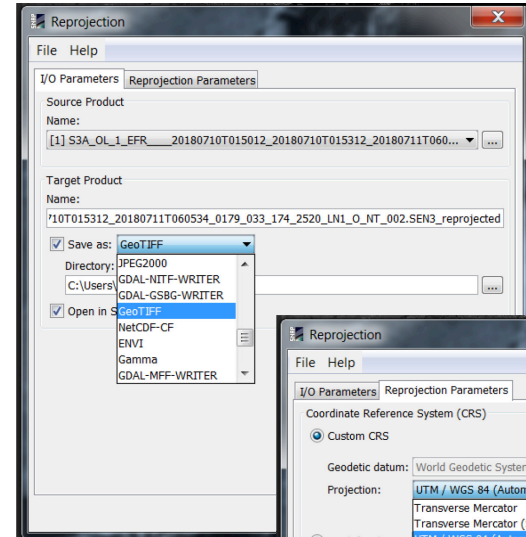
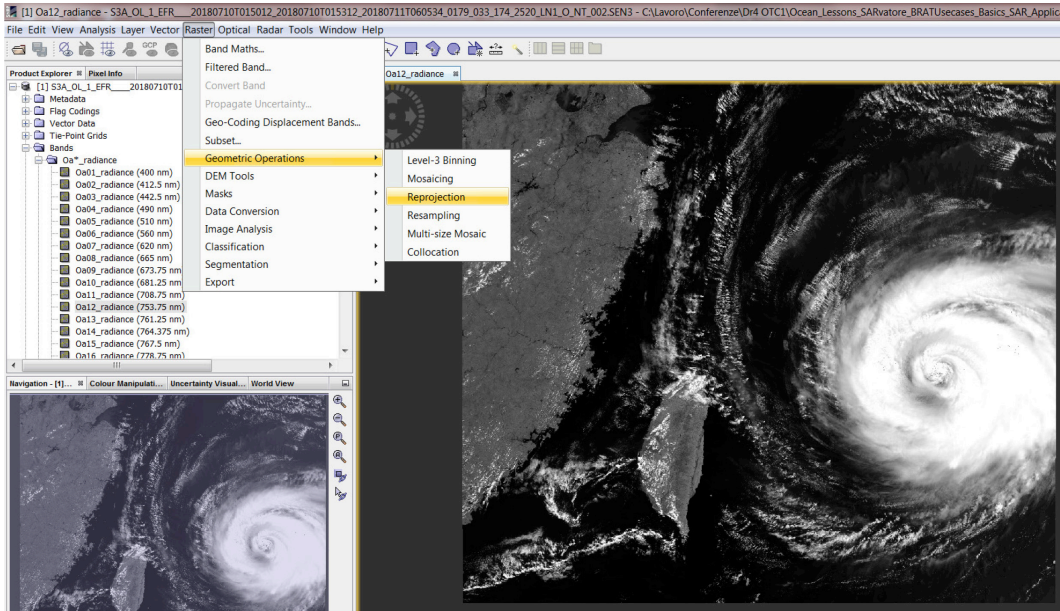
➔ **ADVANCED TRAINING COURSE IN OCEAN AND COASTAL REMOTE SENSING**



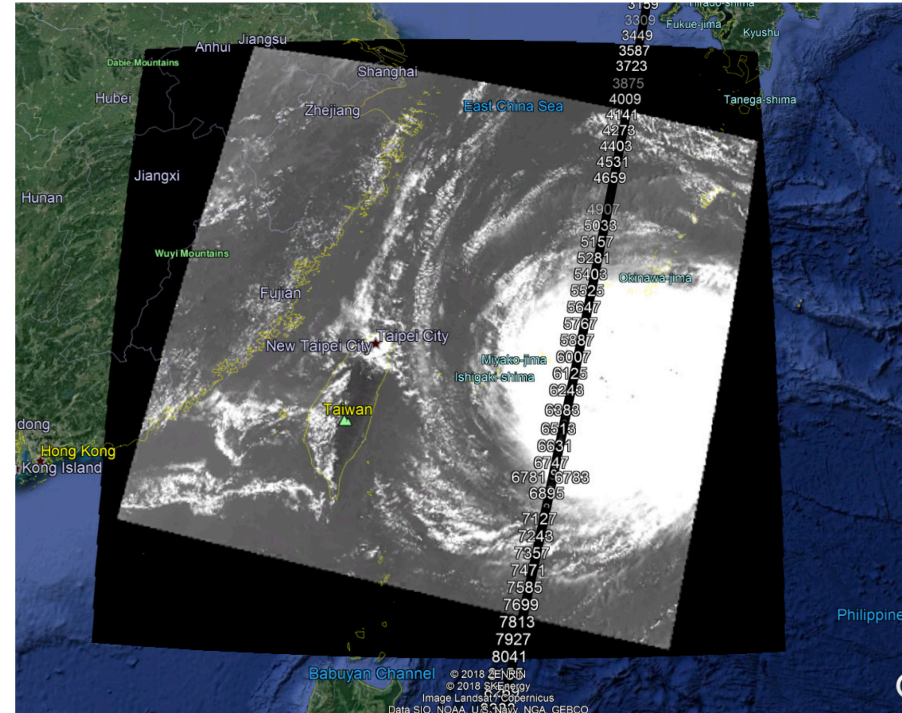
- The OLCI product can be opened in SNAP (open the **xfdumanifest.xml** file).



- Then re-projected in UTM/WGS 84 and saved in GeoTIFF



- Once the GeoTiff is created, it can be opened in Google Earth along with the **.kml of the S3A track available in SARvatore (folder: Typhoon\_Maria\GPOD\Typhoon\_detected)**.
- The track intersects the typhoon at **a latitude of around 25 degrees** (not crossing the eye of the storm).
- Variation in SWH, SLA, wind speed and Sigma0 are expected in comparison to the typical case (no typhoon).
- We compare with a track acquired one month before the event:
- RES\_S3A\_SR\_1\_SRA\_A\_20180609T013721\_20180609T022751\_20180704T225338\_3029\_032\_117\_GPOD\_SAR\_O\_NT\_003





# Plotting on BRAT



BRAT - test

Workspace View Tools Window Help

Workspace Elements

Datasets RADS Datasets Filters Operations

Quick Advanced

Execute

Operation Dataset Filter

Operations\_2 Datasets\_1

Fields

- Iterations\_Count\_20Hz (count)
- L2\_PROCESSOR\_RELEASE\_VERSION (sec...
- Land\_Alt\_1Hz (meters)
- Land\_Alt\_20Hz (meters)
- latitude\_1Hz (degree\_north)
- latitude\_20Hz (degree\_north)
- Leap\_Second (second)

Geodetic Latitude at 20 Hz

Dimensions: Meas\_Index\_20Hz=14908

- units: degree\_north

Data Expressions Units

- X
  - latitude\_20Hz degree\_north
- Y (optional)
- Data
  - SWH\_20Hz meters
  - Selection criteria (optional) count

Map Plot

X

latitude\_20Hz

MEAN NONE

Sampling

BRAT - test

Workspace View Tools Window Help

Workspace Elements

Datasets RADS Datasets Filters Operations

Quick Advanced

Execute

Operation Dataset Filter

Operations\_2 Datasets\_1

Fields

- Time\_Tag\_Bias (seconds)
- TPXO\_Ocean\_Tide\_1Hz (meters)
- TPXO\_Ocean\_Tide\_20Hz (meters)
- U10\_1Hz (meters/seconds)
- U10\_20Hz (meters/seconds)
- USO\_20Hz (meters)
- Wet\_Corr\_1Hz (meters)

10 meter Wind Speed over sea at 20 Hz

Dimensions: Meas\_Index\_20Hz=14908

- units: meters/seconds

Data Expressions Units

- X
  - latitude\_20Hz degree\_north
- Y (optional)
- Data
  - U10\_20Hz meters/seconds
  - Selection criteria (optional) count

Map Plot

Data

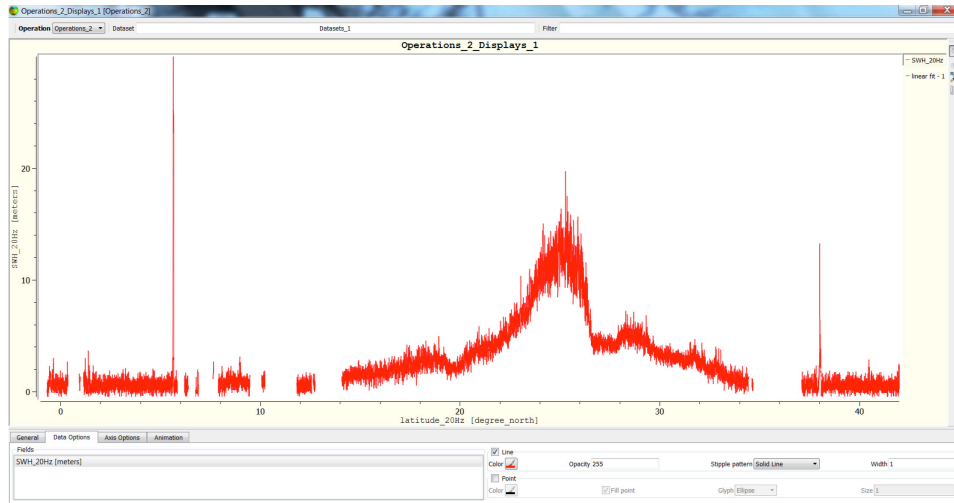
U10\_20Hz

MEAN NONE

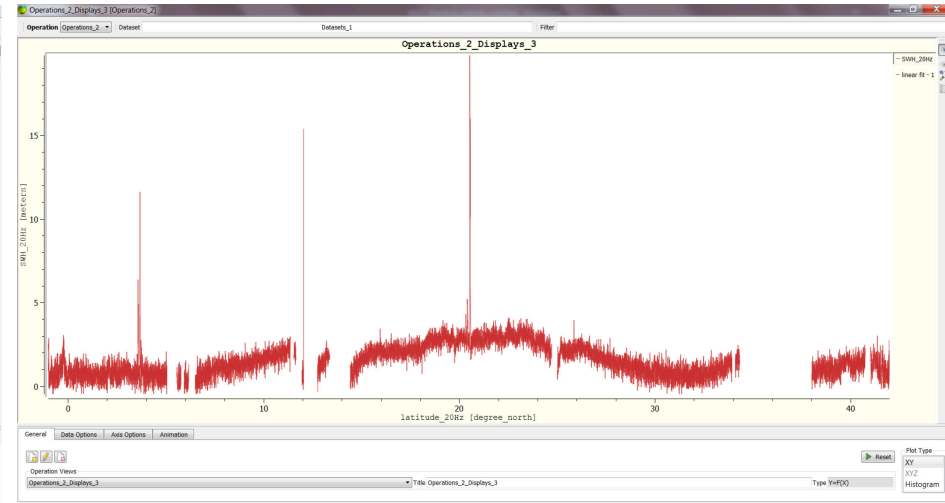
Sampling



# Impact of Typhoon Maria on SWH\_20Hz estimates



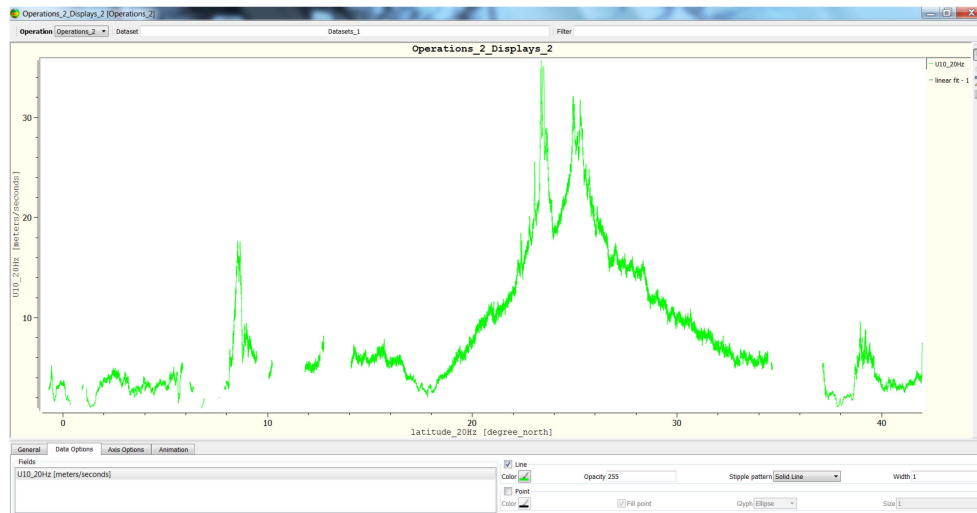
TYPHOON



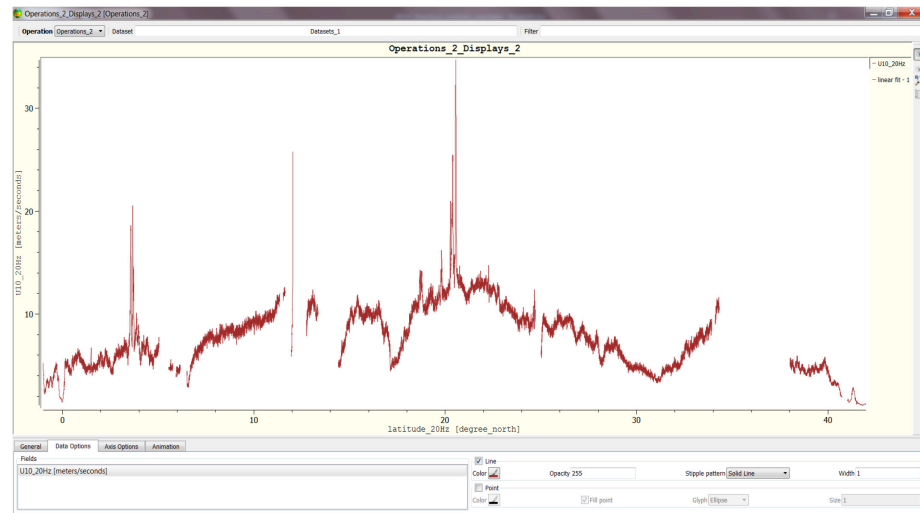
NO TYPHOON



# Impact of Typhoon Maria on Wind-speed (U10\_20Hz) estimates



TYPHOON



NO TYPHOON



# Plotting on BRAT



BRAT - test

Workspace View Tools Window Help

Workspace Elements

Datasets RADS Datasets Filters Operations

Quick: Advanced

Execute

Operation Dataset Filter

Operations\_2 Datasets\_1

Fields

- SET\_Corr\_1Hz (meters)
- Sigma0\_1Hz (dB)
- Sigma0\_20Hz (dB)
- SLA\_1Hz (meters)
- SLA\_20Hz (meters)
- SSB\_1Hz (meters)
- SSB\_20Hz (meters)

Sigma Nought at 20 Hz (corrected for atmospheric attenuation)

Dimensions: Meas\_Index\_20Hz=14908

- units: dB

Data Expressions Units

- X latitude\_20Hz degree\_north
- Y (optional)
- Data
  - Sigma0\_20Hz dB
  - Selection criteria (optional) count

Map Plot

Data

MEAN NONE

Sigma0\_20Hz

Sampling

BRAT - test

Workspace View Tools Window Help

Workspace Elements

Datasets RADS Datasets Filters Operations

Quick: Advanced

Execute

Operation Dataset Filter

Operations\_2 Datasets\_1

Fields

- SET\_Corr\_1Hz (meters)
- Sigma0\_1Hz (dB)
- Sigma0\_20Hz (dB)
- SLA\_1Hz (meters)
- SLA\_20Hz (meters)
- SSB\_1Hz (meters)
- SSB\_20Hz (meters)

Sea Level Anomaly at 20 Hz (no sea state bias applied)

Dimensions: Meas\_Index\_20Hz=14908

- units: meters

Data Expressions Units

- X latitude\_20Hz degree\_north
- Y (optional)
- Data
  - SLA\_20Hz meters
  - Selection criteria (optional) count

Map Plot

Data

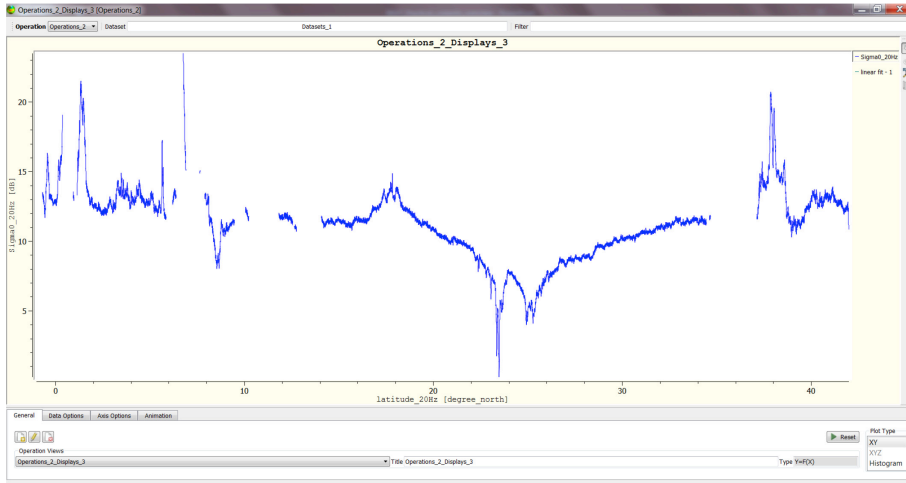
MEAN NONE

SLA\_20Hz

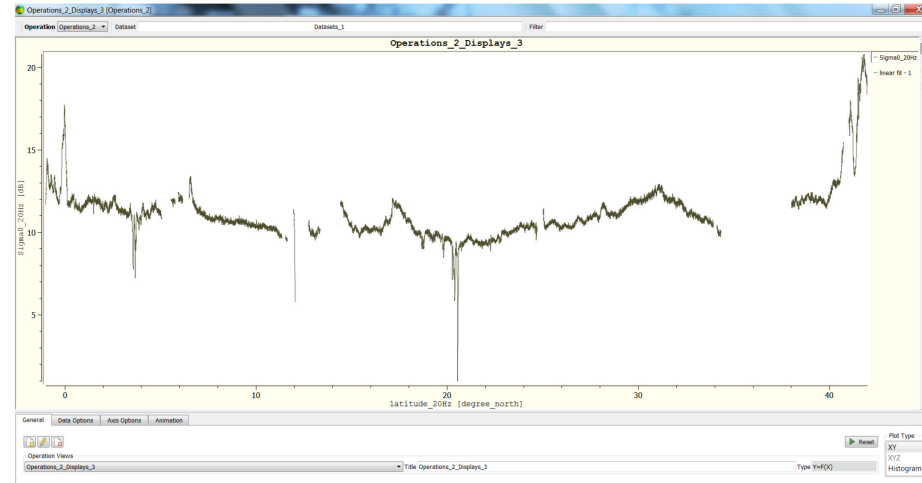
Sampling



# Impact of Typhoon Maria on Sigma0 (Sigma0\_20Hz) estimates



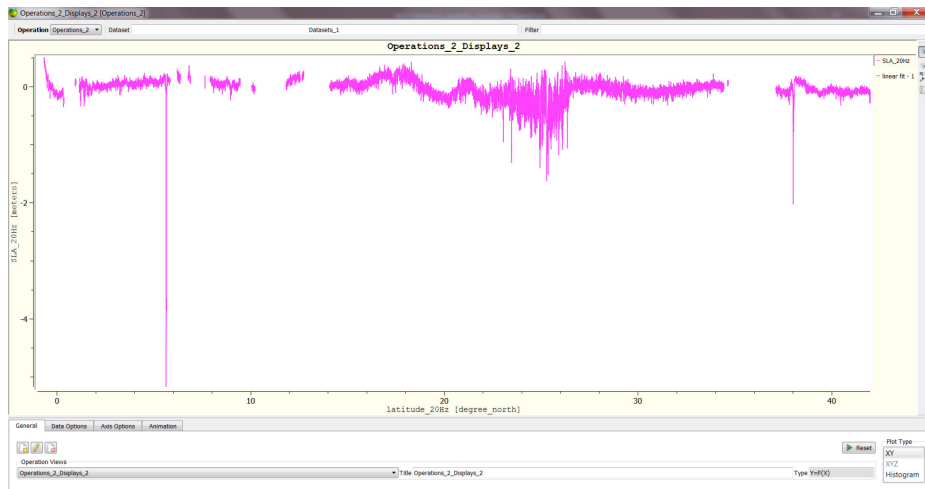
TYPHOON



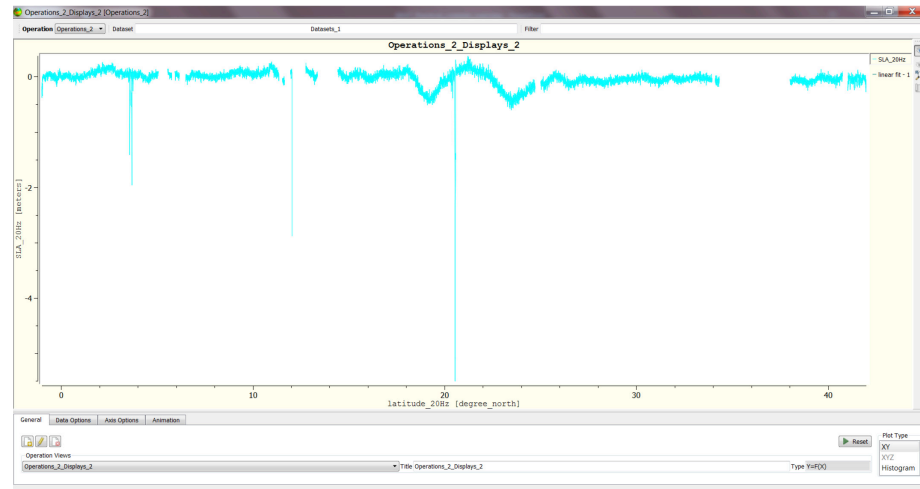
NO TYPHOON



# Impact of Typhoon Maria on SLA (SLA\_20Hz) estimates



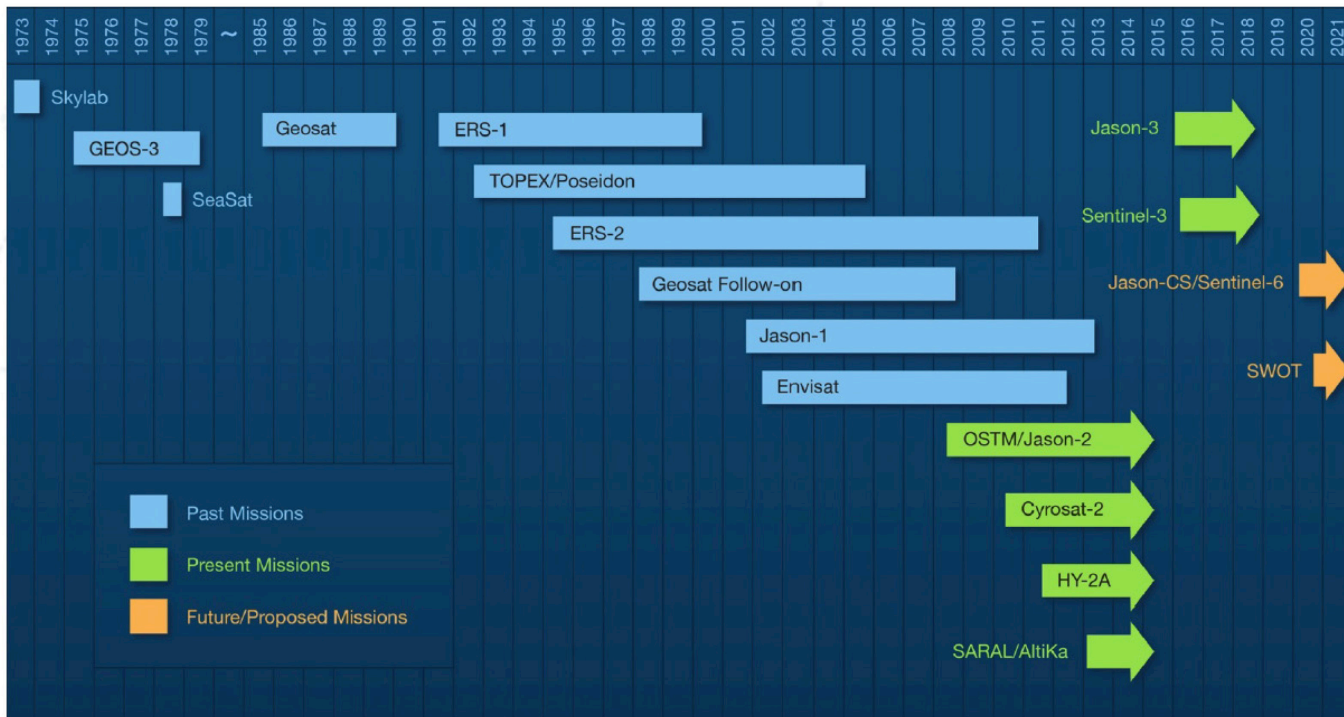
TYPHOON



NO TYPHOON



## Altimetry Missions (1973-2017)



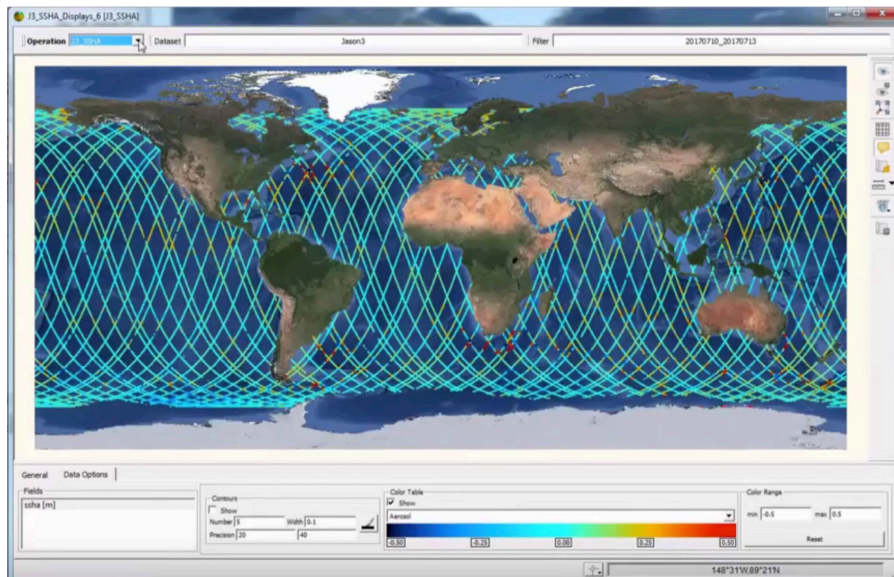
- The Sentinel-3 constellation includes 4 satellites.
- Sentinel-3 A & B have been successfully launched.
- Sentinel-3 C & D will be launched in 2021.

# Multi\_Mission Products (1)

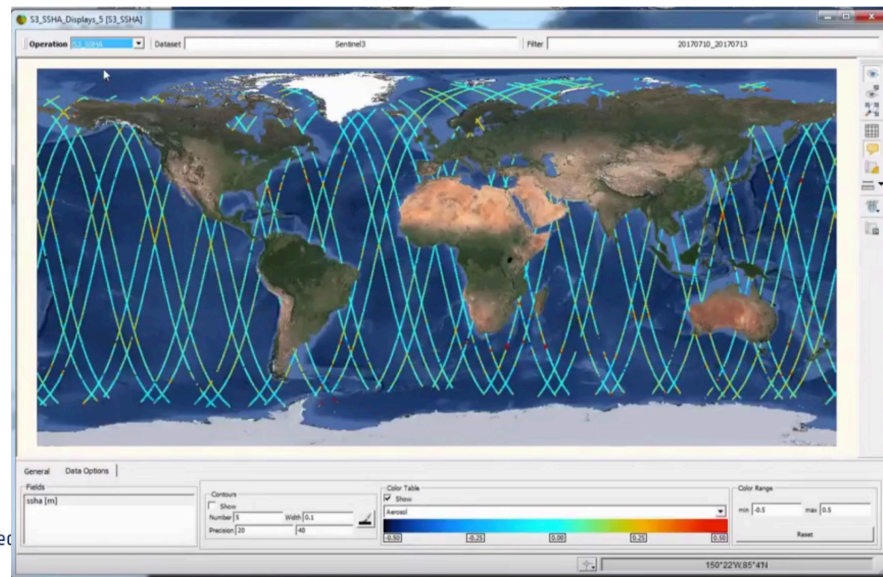


- BRAT offers the possibility to combine data from different altimetry missions using data stored on the Radar Altimeter Database (RADS) .
- A video tutorial is available here: <https://www.youtube.com/watch?v=4TXAU6CFaaM>

## Jason-3 (LRM mission)

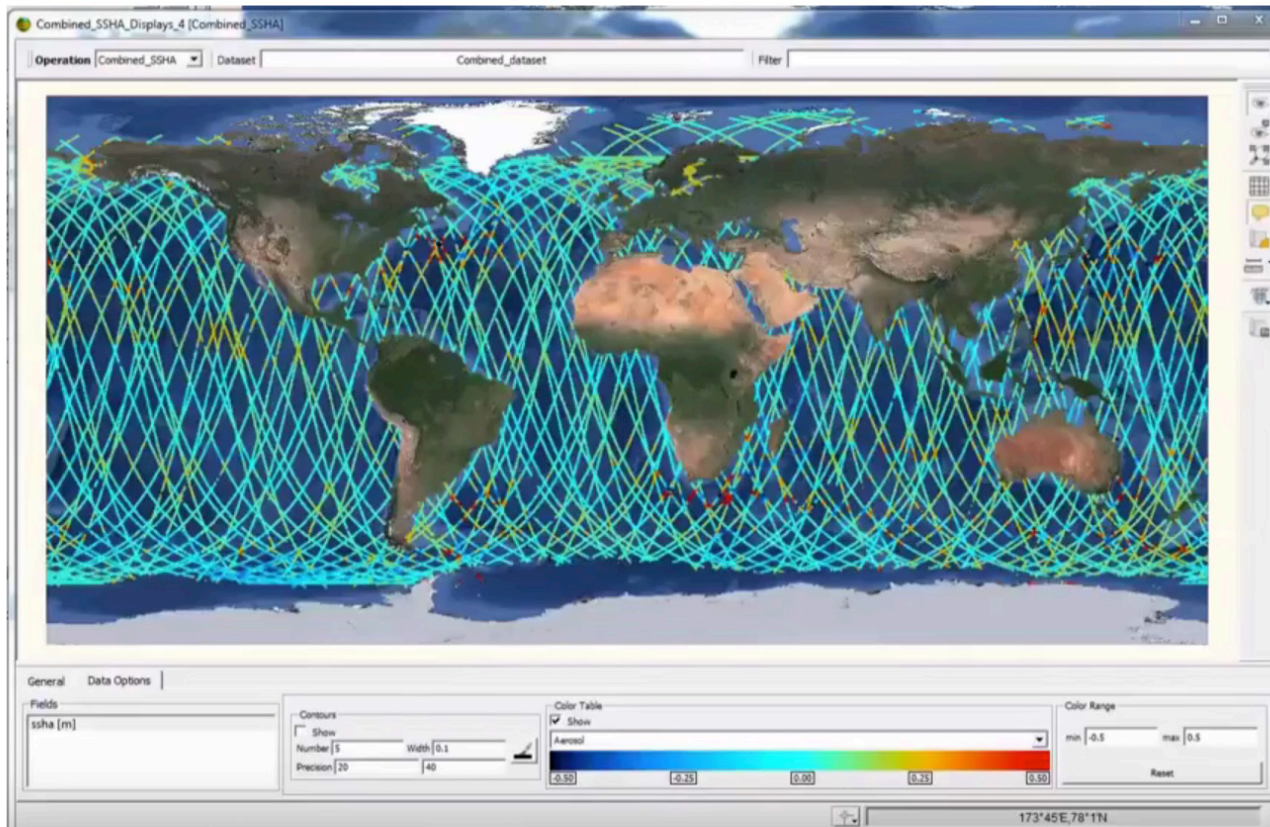


## Sentinel-3 (SAR mission)

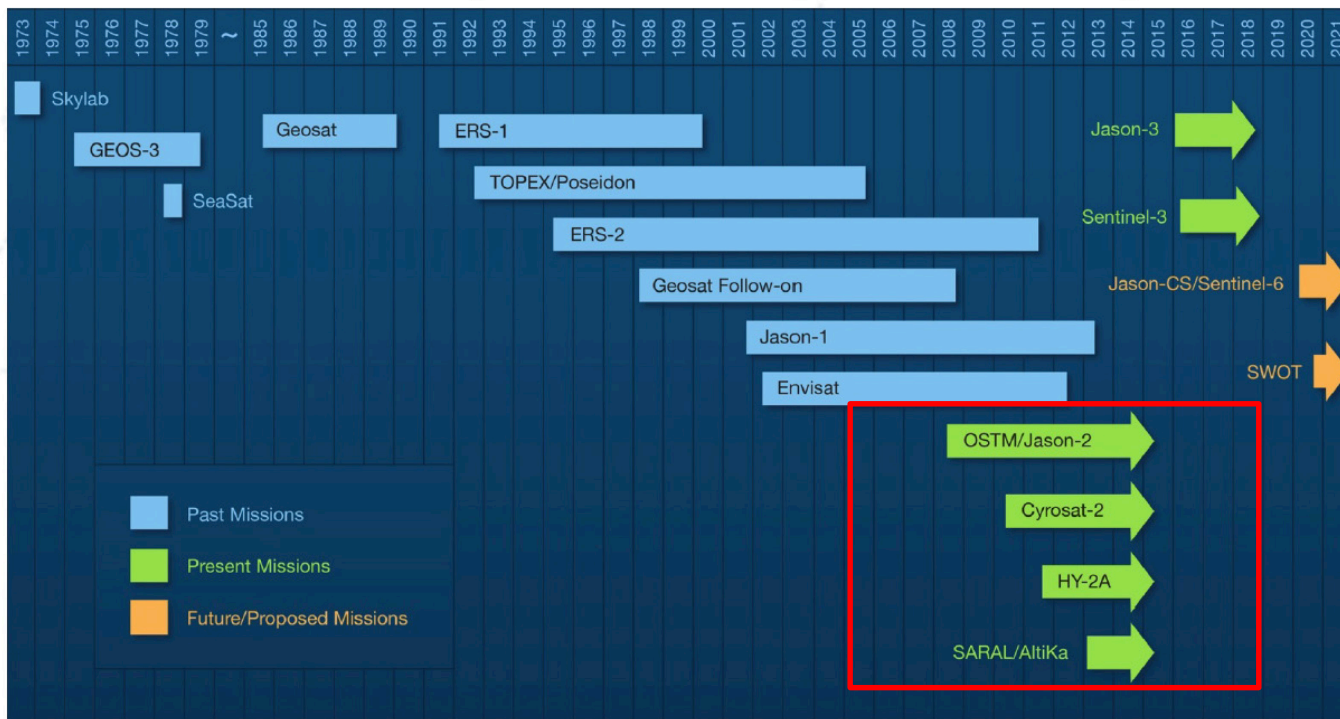




# Multi\_Mission Products (2) – Combined SSHA Map

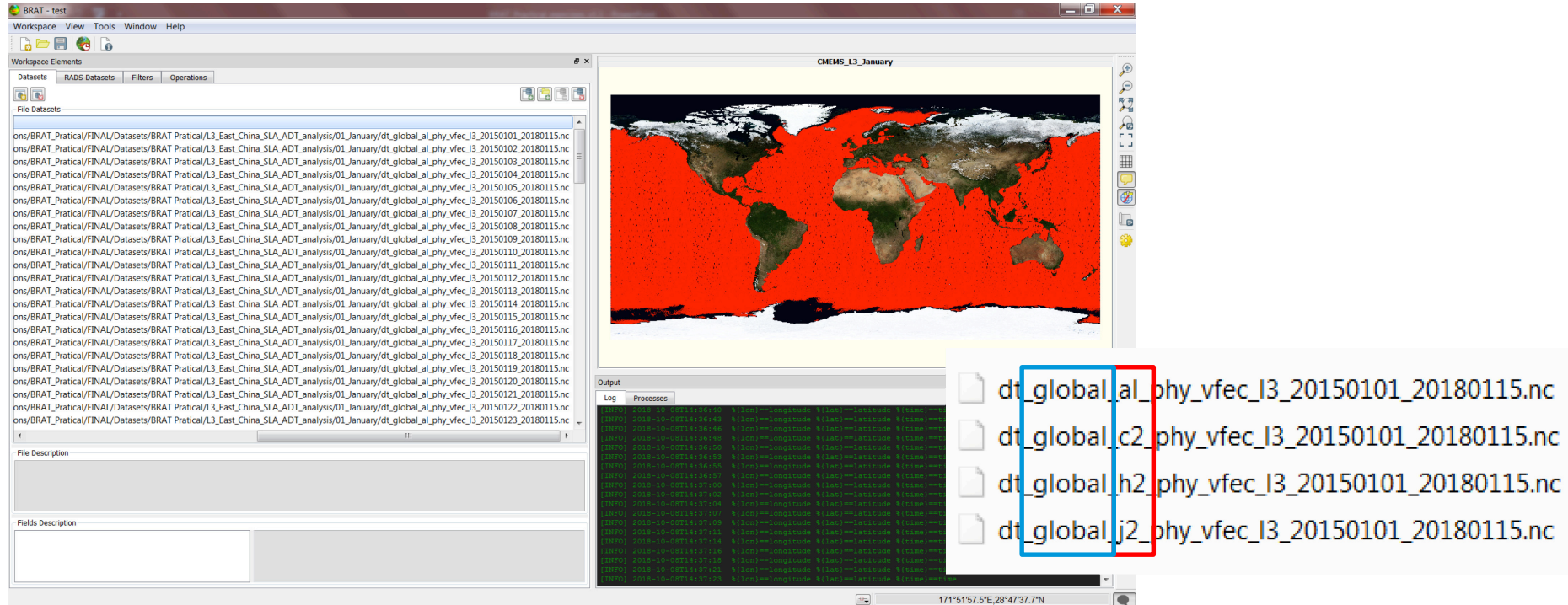


## Altimetry Missions (1973-2017)



- BRAT is able to read CMEMS L3 data from various missions including **HY-2A**.
- **L3 data (SLA, ADT)** are along-track data including all corrections. Data are provided filtered or unfiltered (horizontal resolution is 14km for filtered and 7km for unfiltered)
- Products can be downloaded from the website (**1 month of data is available in the Dataset provided along with figures & stats**):  
<http://marine.copernicus.eu/>
- Here we show how to combine 2015 L3 data from 4 satellites (HY-2A, CryoSat-2 Jason-2 & AltiKa)
- We derive monthly maps (SLA & ADT) and monthly time series.

- Each monthly dataset is composed of monthly data from the 4 satellites (indicated in file naming as: a1,c2,h2, j2) offering global coverage. Data from the month of January are available in the folder **L3\_SLA\_ADT**.



The screenshot displays the BRAT (BathyRemote Analysis Tool) interface. The main window shows a global map of sea level anomalies (SLA) for January, with a color scale ranging from -0.1 to 0.1. The map is overlaid with a red color, indicating a positive anomaly. The interface includes a workspace with datasets, a file list on the left, and an output window at the bottom right. The output window shows a list of files, with the following files highlighted by a blue and red box:

- dt\_global\_a1\_phy\_vfec\_l3\_20150101\_20180115.nc
- dt\_global\_c2\_phy\_vfec\_l3\_20150101\_20180115.nc
- dt\_global\_h2\_phy\_vfec\_l3\_20150101\_20180115.nc
- dt\_global\_j2\_phy\_vfec\_l3\_20150101\_20180115.nc



# Split plots function for SLA and ADT



BRAT - ENVISAT

Workspace View Tools Window Help

Workspace Elements

Datasets RADS Datasets Filters Operations

Quick Advanced

Operation Dataset

Operations\_2 Jan

Fields

- adt\_filtered (m)
- brat\_index\_data (count)
- cycle (1)
- date\_created (seconds since 1950-01-01)
- date\_isused (seconds since 1950-01-01)
- date\_modified (seconds since 1950-01-01)
- geospatial\_lat\_max
- geospatial\_lat\_min
- geospatial\_lat\_resolution
- geospatial\_lon\_max
- geospatial\_lon\_min

sea\_surface\_height\_above\_geoid field  
The absolute dynamic topography is the sea surface height above geoid; it is obtained as follows: adt=sla+mdt where mdt is the mean dynamic topography; see the product user manual for details

Dimensions: time=23483

- FillValue: 32767
- add\_offset: 0.000000
- coordinates: longitude latitude
- scale\_factor: 0.001000
- standard\_name: sea\_surface\_height\_above\_geoid

Data Expressions Units

- Lon
  - longitude degrees\_east
- Lat
  - latitude degrees\_north
- Data
  - sla\_filtered m
  - adt\_filtered m
  - Selection criteria (optional) count

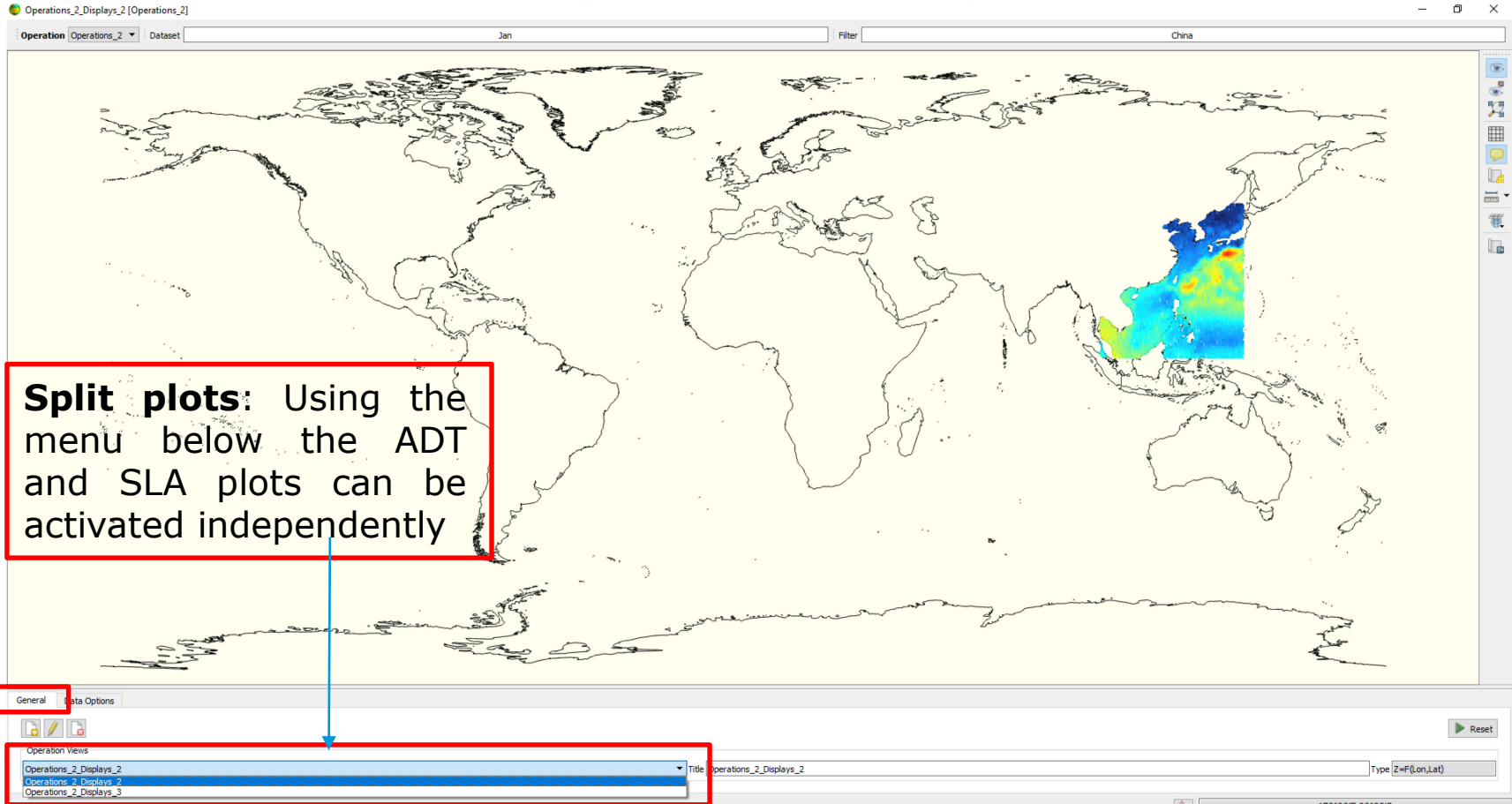
Map Plot

Output

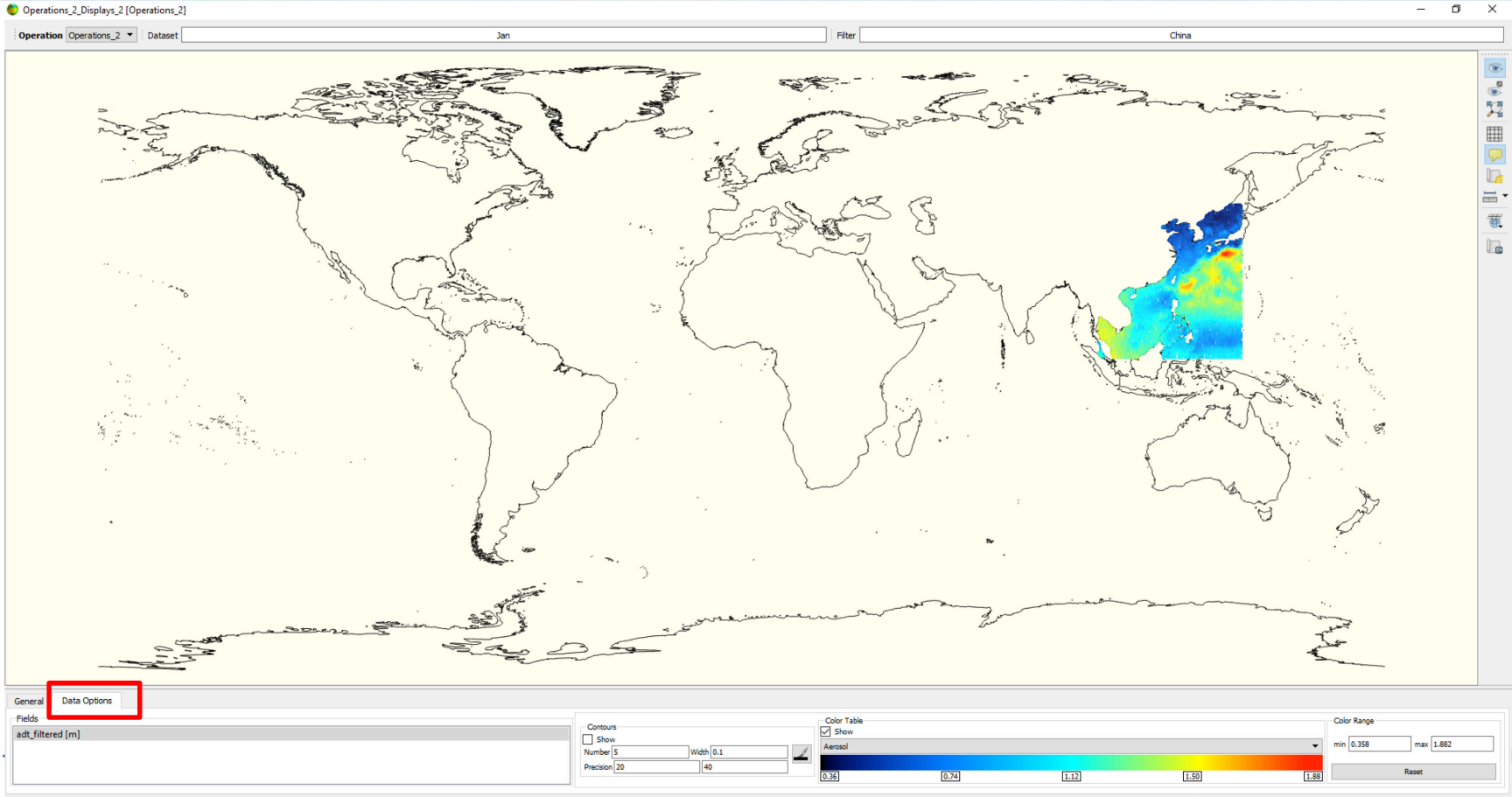
Log	Processes
[INFO]	2018-10-05T09:33:47 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:33:48 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:33:50 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:33:51 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:33:54 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:33:55 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:33:57 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:34:00 [lon]====longitude [lat]====latitude [time]====time
[INFO]	2018-10-05T09:34:02 [lon]====longitude [lat]====latitude [time]====time
[WARN]	2018-10-05T09:34:59 Data expression OK.
[WARN]	2018-10-05T09:34:59 Data expression OK.
[WARN]	2018-10-05T09:37:00 Data expression OK.

Sampling

# Map Selection



# Filtered ADT Map

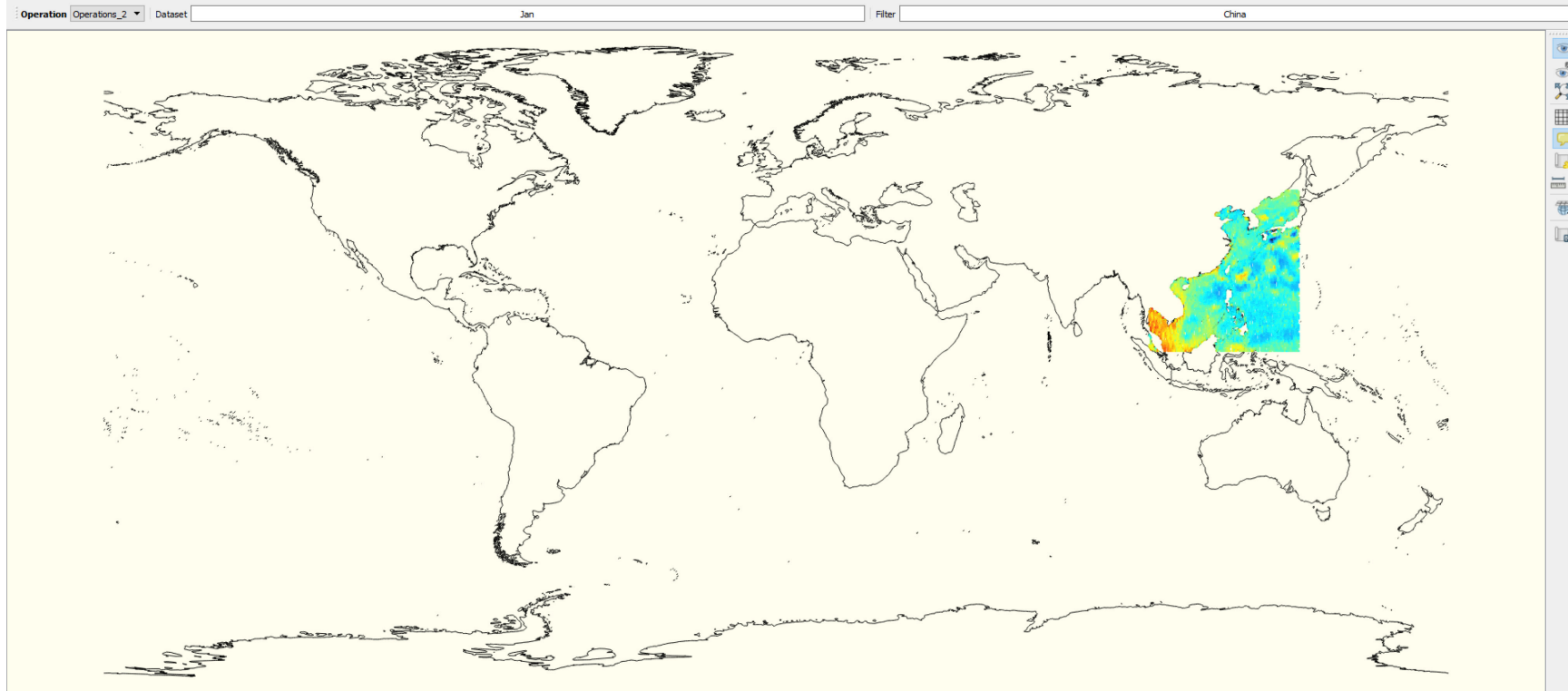




# Filtered SLA Map



Operations\_2\_Displays\_3 [Operations\_2]



General Data Options

Fields  
sla\_filtered [m]

Contours  
 Show  
Number 5 Width 0.1  
Precision 20 40

Color Table  
 Show  
Aerosol  
Color Range  
min -0.47475 max 0.401  
Reset

Color Table Legend: -0.47, -0.35, -0.04, 0.18, 0.40

# Exporting the images



Operations\_2\_Displays\_2 [Operations\_2]

Operation: Operations\_2    Dataset:    Jan    Filter:    China

**Export to Image** ? X

**Image and File Type**

tif  2D  3D

**2D Output File**

ents/BRAT/user-data/Operations\_2\_Displays\_2\_2D.tif

**3D Output File**

ents/BRAT/user-data/Operations\_2\_Displays\_2\_3D.tif

Select a file name and location. The extension will automatically be assigned according to the chosen image type.

General    Data Options

Fields

adt\_filtered [m]

Contours

Show    Width: 0.1    Precision: 20    40

Color Table

Show

Aerocol

Color Range

min: 0.358    max: 1.882

na

# Calculating Monthly Statistics



BRAT - ENVISAT

Workspace View Tools Window Help

Workspace Elements

Datasets RADS Datasets Filters Operations

Quick: Advanced

Operations\_2 Dataset: Jan Filter: China

Fields

- adt\_filtered (m)
- brat\_index\_data (count)
- cycle (1)
- date\_created (seconds since 1950-01-01)
- date\_issued (seconds since 1950-01-01)
- date\_modified (seconds since 1950-01-01)
- geospatial\_lat\_max
- geospatial\_lat\_min
- geospatial\_lat\_resolution
- geospatial\_lon\_max
- geospatial\_lon\_min

sea\_surface\_height\_above\_geoid field  
The absolute dynamic topography is the sea surface height above geoid; it is obtained as follows:  $adt=sa+mdt$  where  $mdt$  is the mean dynamic topography; see the product user manual for details

Dimensions:  $tme=23483$

- FillValue: 32767
- add\_offset: 0.000000
- coordinates: longitude latitude
- scale\_factor: 0.001000
- standard\_name: sea\_surface\_height\_above\_geoid

Data Expressions

- Lon
  - longitude degrees\_east
- Lat
  - latitude degrees\_north
- Data
  - sla\_filtered m
  - adt\_filtered m
  - Selection criteria (optional) count

Map Plot

Output

```
[WARN] 2018-10-08T09:48:52 State_Operations_2 :
Process record 19595 of 26661

[WARN] 2018-10-08T09:48:53 State_Operations_2 :
Process record 26660 of 26661

[WARN] 2018-10-08T09:48:53 State_Operations_2 :
Result for 'adt_filtered'
-----
Number of valid data = 79767.000000
Mean = 1.063071
Standard deviation = 0.287364
Minimum = 0.840000
Maximum = 1.544000
-----
Result for 'sla_filtered'
-----
Number of valid data = 79777.000000
Mean = 0.016590
Standard deviation = 0.104691
Minimum = -0.627000
Maximum = 0.473000
-----
====> Result is also saved into C:/Users/Administrator/Documents/BR
[WARN] 2018-10-08T09:48:53 State_Operations_2 :
AT/workspaces/ENVISAT/Operations/Stats_Operations_2.txt
[INFO] 2018-10-08T09:48:53 State_Operations_2 :
====> Process execution finished reporting success <<====
[INFO] 2018-10-08T09:48:53 State_Operations_2 :
====> Process execution finished reporting success <<====
```

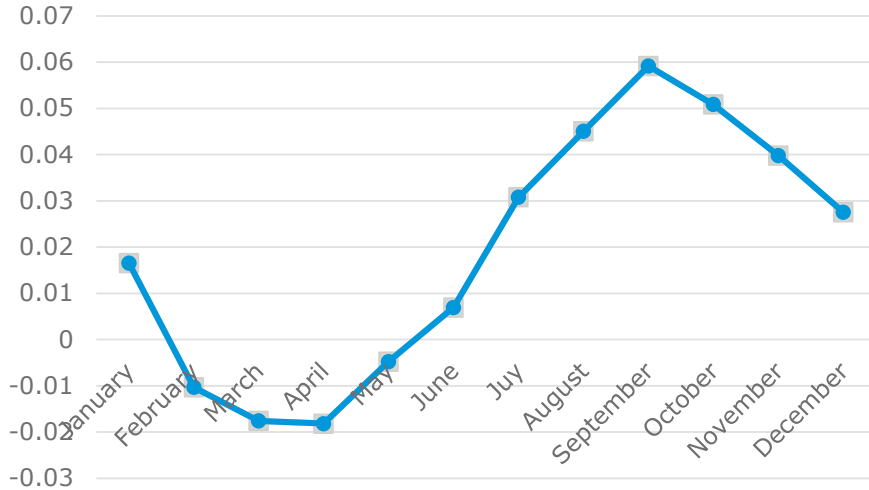
# Calculating Monthly Statistics (2)



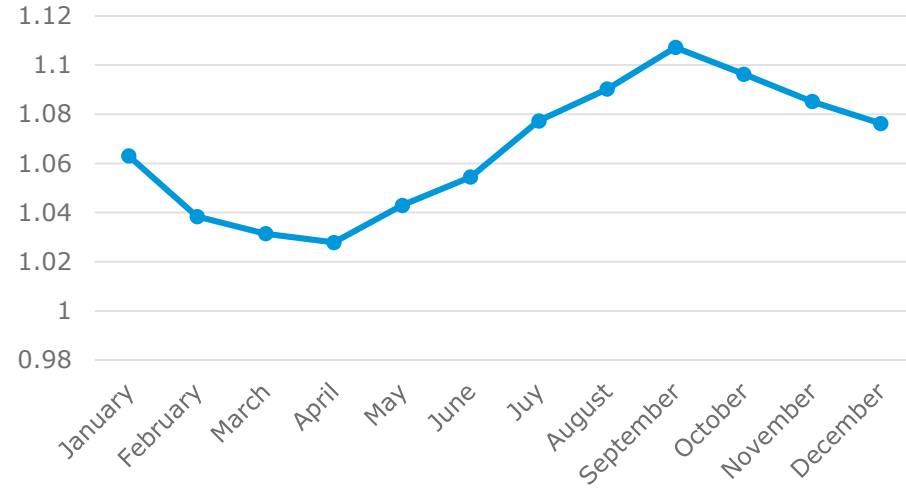
		January	February	March	April	May	June	July	August	September	October	November	December
SLA [m]	<b>valid data points</b>	79777	73242	81313	76344	75378	74243	76700	73737	76384	77741	77737	79808
	<b>mean</b>	0.01658	-0.01031	-0.01758	-0.01816	-0.00475	0.00696	0.0308	0.04503	0.059176	0.05086	0.039829	0.02756
	<b>std</b>	0.10489	0.09468	0.09052	0.0956	0.10338	0.11441	0.12632	0.14008	0.144755	0.14975	0.154872	0.154263
	<b>min</b>	-0.627	-0.679	-0.851	-0.886	-0.681	-0.724	-0.646	-0.801	-0.739	-0.611	-0.532	-0.634
	<b>max</b>	0.473	0.466	0.428	0.359	0.429	0.512	0.63	0.606	0.627	0.614	0.546	0.523
ADT [m]	<b>valid data points</b>	79767	73230	81303	76332	75367	74226	76689	73723	76371	77721	77725	79793
	<b>mean</b>	1.06307	1.03841	1.03145	1.02784	1.04295	1.05447	1.07731	1.09023	1.107174	1.09632	1.08516	1.076235
	<b>std</b>	0.28736	0.28232	0.29692	0.307	0.30555	0.31318	0.31018	0.29877	0.30596	0.303	0.295889	0.305641
	<b>min</b>	0.34	0.18	0.232	0.206	0.248	-0.029	0.204	0.237	0.352	0.274	0.339	0.2
	<b>man</b>	1.944	1.989	1.98	1.949	1.948	1.917	2.039	2.194	2.127	2.117	2.109	2.096



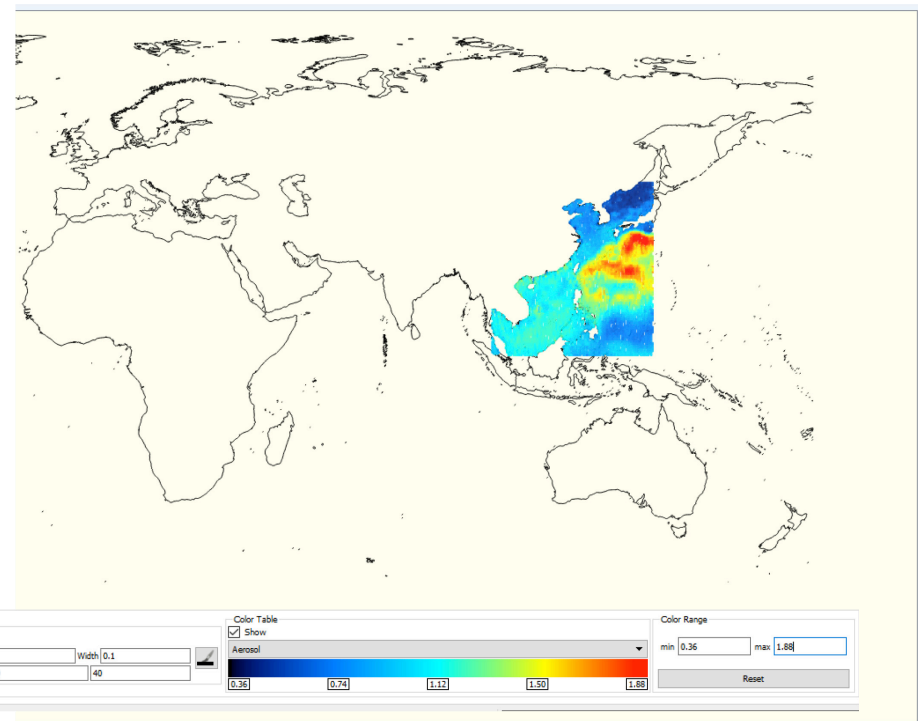
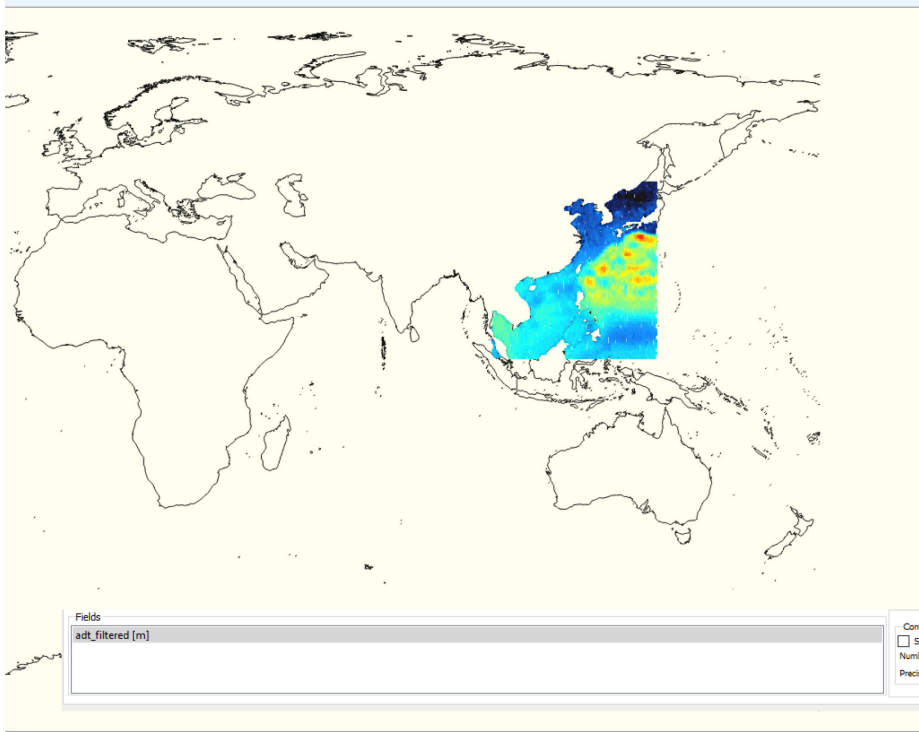
### SLA [m]



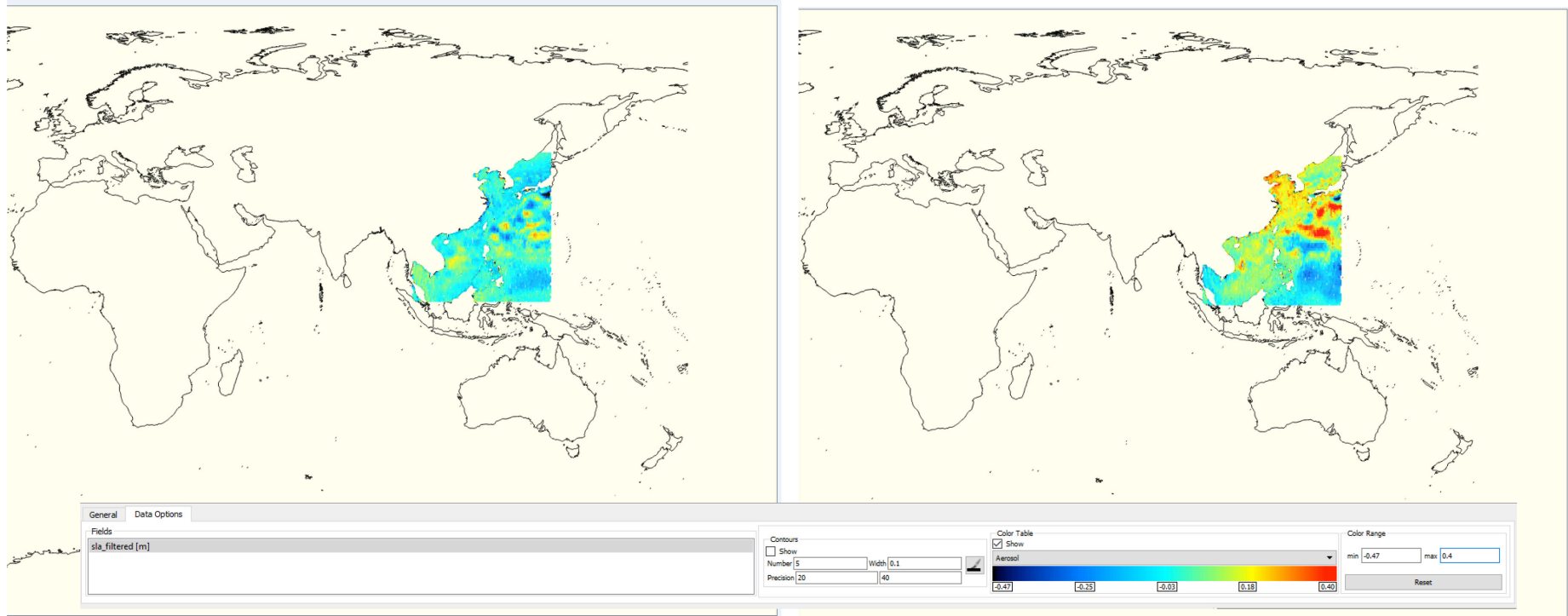
### ADT [m]



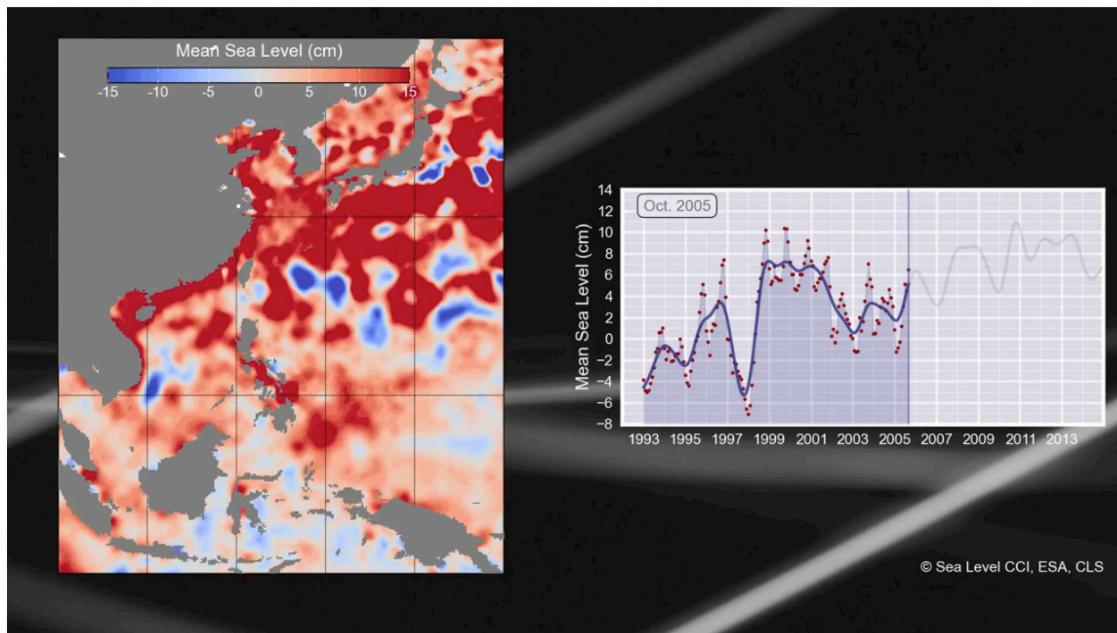
# ADT (April vs September) ->



# SLA (April vs September)



The Mean Sea Level for China calculated using the SLCCI v2 dataset is available at:  
<https://www.youtube.com/watch?v=iocJiY47KN0&feature=youtu.be>



Mean Sea Level China





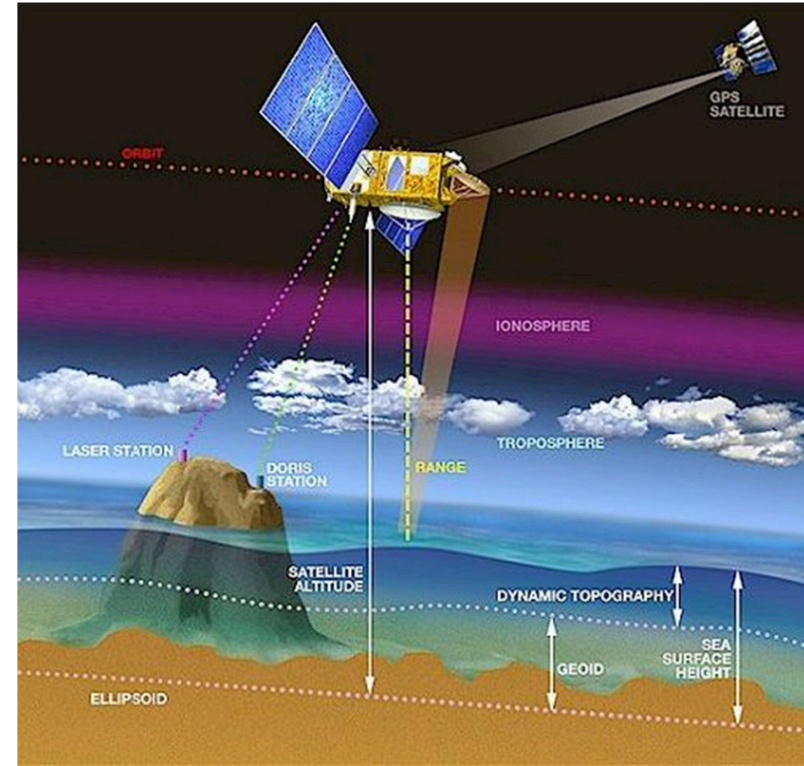
# Practical on Oceanography

(Use data provided in the “[Practical\\_Oceanography](#)” folder)

- Altimeters measure the **range** between the **satellite and the sea surface** observed at nadir.
- 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 NRT STC L2 products.).
- Geoids (i.e. the ocean surface excluding the influence of wind and tides) are obtained from other missions (e.g. GRACE, GOCE).
- A reference ellipsoid shall be considered as baseline Datum (e.g. WGS84).
- The range measurement shall be corrected for a series of effects related to both the propagation into the Ionosphere/Troposphere and other effects.

**Sea Surface Height (SSH):**  $\text{Satellite\_Altitude} - \text{Corrected\_Range}$ .

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



- MDT: [MDT\\_CNES\\_CLS\\_09\\_15M.nc](#)  
[from GUT apriori data: <https://earth.esa.int/web/guest/software-tools/gut/about-gut/overview>]  
Estimates of the ocean MDT for the 1993-1999 period  
CNES-CLS 2009 MDT at 15min resolution  
Coverage = Global  
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.
- SLA: [ESACCI-SEALEVEL-L4-MSLA-MERGED-19930115000000-fv02.nc](#)  
The SLA grids are calculated after merging data from altimetry missions (TOPEX/Poseidon, Jason-1/2, GFO, ERS-1/2, Envisat, CryoSat-2 and SARAL/Altika) into monthly grids with a spatial resolution of 1/4 of degree.

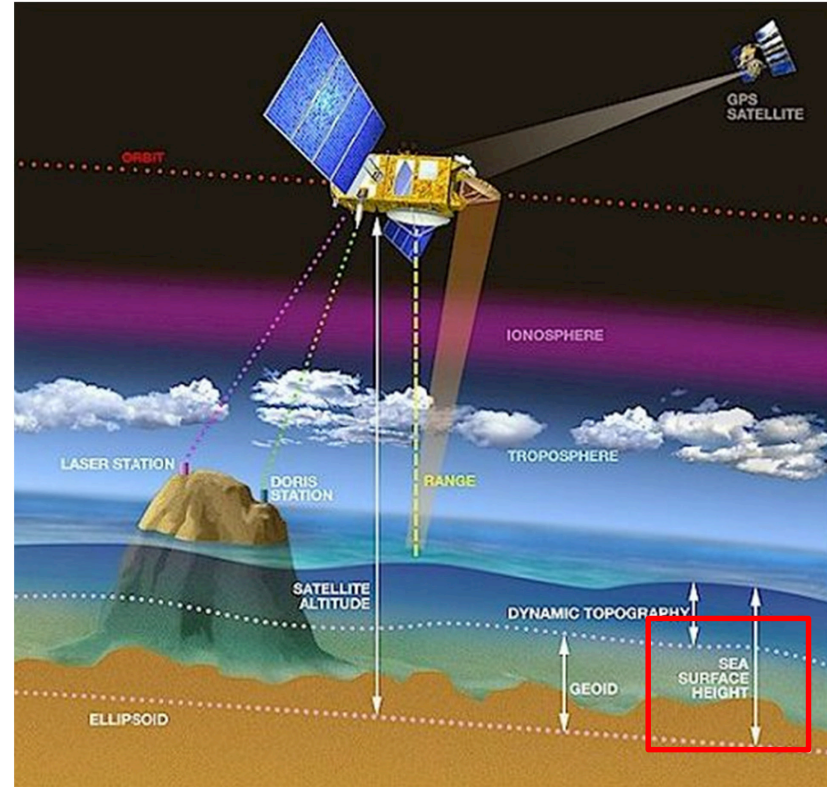
The MSS DTU15 (mean reference period: 1993–2012) has been used.

**The v2.0 dataset covers the period Jan. 1993 to Dec. 2015.**

# 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. **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).

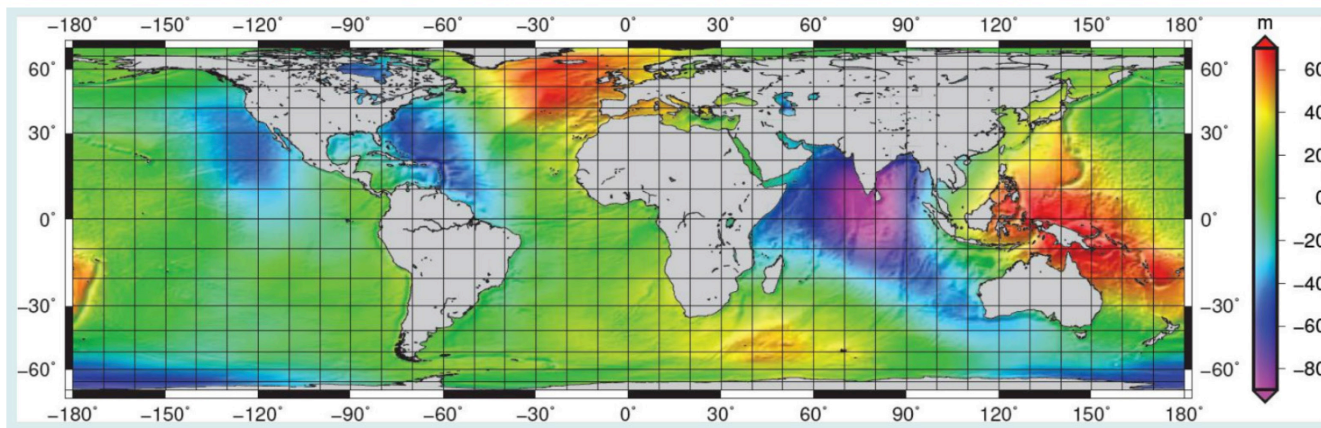


# Mean Sea Surface – Comparison

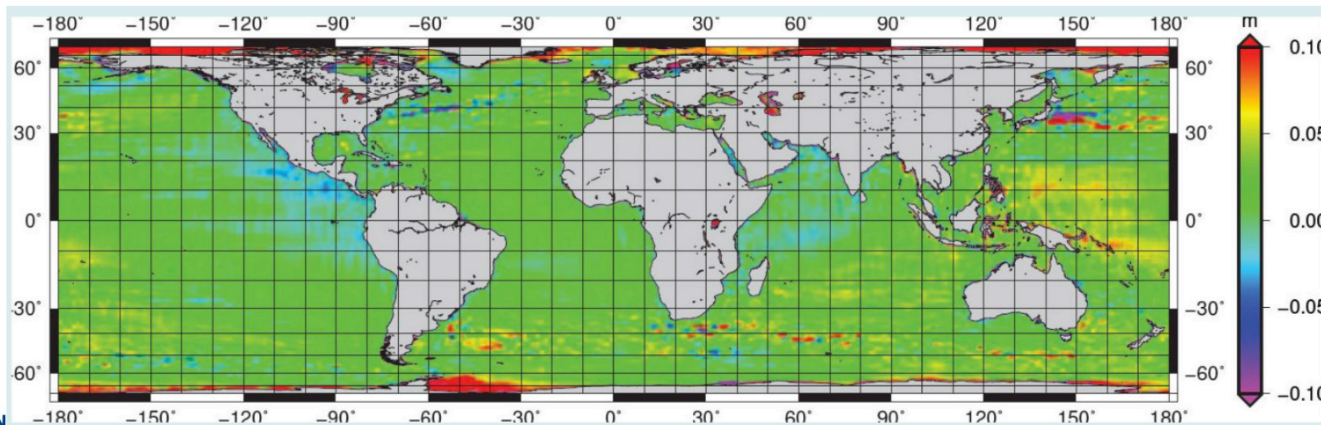


Andersen et al., The DTU15 MSS (Mean Sea Surface) and DTU15LAT (Lowest Astronomical Tide) reference surface

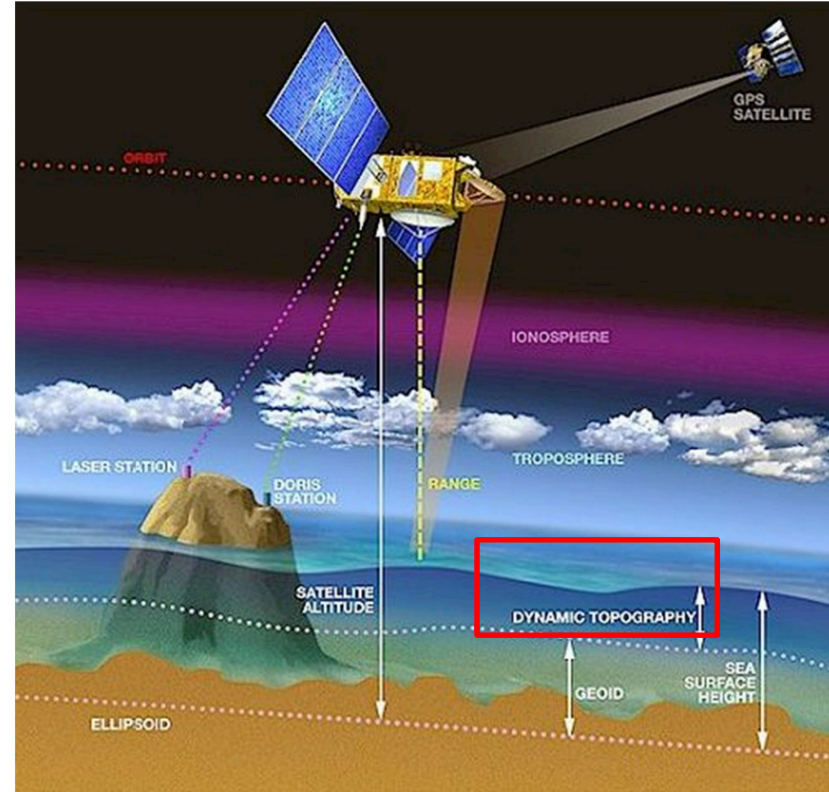
- DTU15MSS



- DTU15-DTU13



- **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.



# Eddies detection with SLA data



- SSALTO/DUACS - DT MSLA - Merged Product

Folder: **SLA** (also in the BRAT DEMO folder)

File: **dt\_upd\_global\_merged\_msla\_h\_20060705\_20060705\_20070110.nc**

The screenshot shows the software interface with the following components:

- Operations Panel:** Shows 'Operations\_2' selected with dataset 'J2'. Fields include Longitude (degrees\_east), Latitude (degrees\_north), GridDepth (count), Grid\_0001\_Date\_CNES\_JD, Grid\_0001\_date (seconds since 1...), and Grid\_0001 (cm). Dimensions are Longitude=1080 and Latitude=915. Metadata includes Date\_CNES\_ID: 20639.000000, \_FillValue: 18446744073709551616.000000, date: 2006-07-05 00:00:00.000000, UTC, and units: cm.
- Data Expressions Panel:** Lists variables: Lon (Longitude, degrees\_east), Lat (Latitude, degrees\_north), and Data (Grid\_0001, cm). It also shows 'Selection criteria (optional) count'.
- Data Panel:** Shows 'Grid\_0001' with a 'MEAN' operation selected. A 'Sampling' section is visible at the bottom.

The screenshot shows a map display of sea level anomaly data. The map is color-coded from blue (low) to red (high). A blue arrow points to the 'Contours' checkbox in the 'Data Options' panel, which is checked. The 'Data Options' panel is highlighted with a red box and labeled '1'. The 'Contours' panel is also highlighted with a red box and labeled '2'. The 'Color Table' panel shows a color scale from -100 to 100 cm.

Operations\_2\_Displays\_1 [Operations\_2]  
Operation (Operations\_2) Dataset J2 Filter

Fields: Grid\_0001 [cm]

1

2

Contours  
 Show  
Number 5 Width 0.1  
Precision 20 40

Color Table  
 Show  
Aerosol  
Color Range: min -100 max 100  
[-100.00] [-50.00] [0.00] [50.00] [100.00] Reset

Tick the box to activate contours

# Eddies detection with SLA data (2D/3D view)



The screenshot displays a software interface for eddy detection using Sea Level Anomaly (SLA) data. The interface is divided into several panels:

- Left Panel:** Contains configuration options for "Where" (geographic area) and "When" (time period).
  - Where:** Includes "New Area Selection" with input fields for Max Lat (45), Min Lon (100), Max Lon (140), and Min Lat (2). It also has "Areas & Regions" with a checked "UserArea\_1" and a "Show all" button.
  - When:** Offers "Use Dates" (selected) or "Use Cycle/Pass" options. It includes fields for Start (1950.01.01 00:00:00), Stop (2018.10.08 15:19:27), and "Use Relative Time (days)".
- Top Center Panel:** Shows a 3D view of the map of China with a color-coded eddy detection overlay. A blue arrow points from the 3D view to the 2D view below.
- Bottom Center Panel:** Shows a 2D view of the map of China with a color-coded eddy detection overlay. A blue arrow points from the 2D view to the color bar on the right.
- Right Panel:** Contains a "Color Range" control with a color bar and input fields for "min -50" and "max 50". A red box highlights these fields, and a blue arrow points from the text "The interval of the colour bar can be modified here" to this area.
- Bottom Left Panel:** Contains a "General" section with "Fields" (Grid\_0001 [cm]), "Contours" (Number: 5, Precision: 20), and "Color Table" (Aerosol, min: -50.00, max: 50.00).

Click on the icon for the 3D View

The interval of the colour bar can be modified here



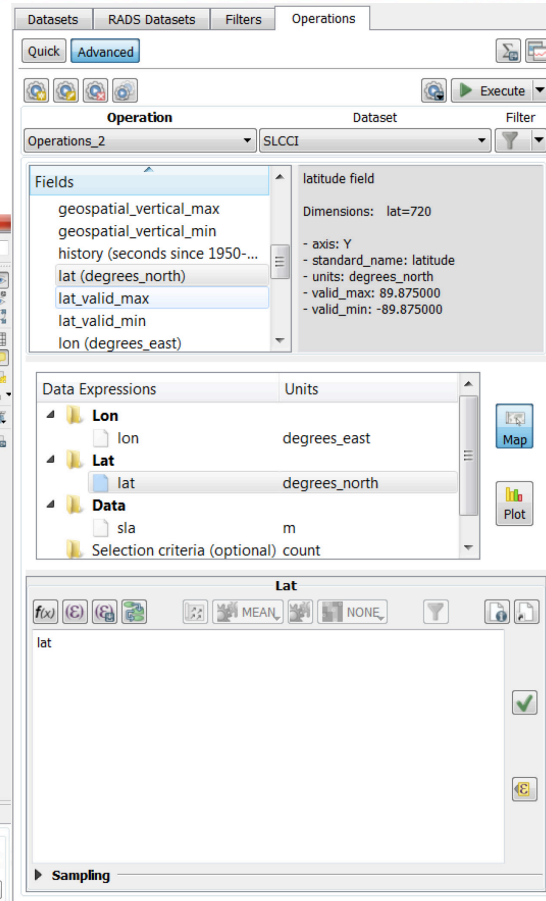
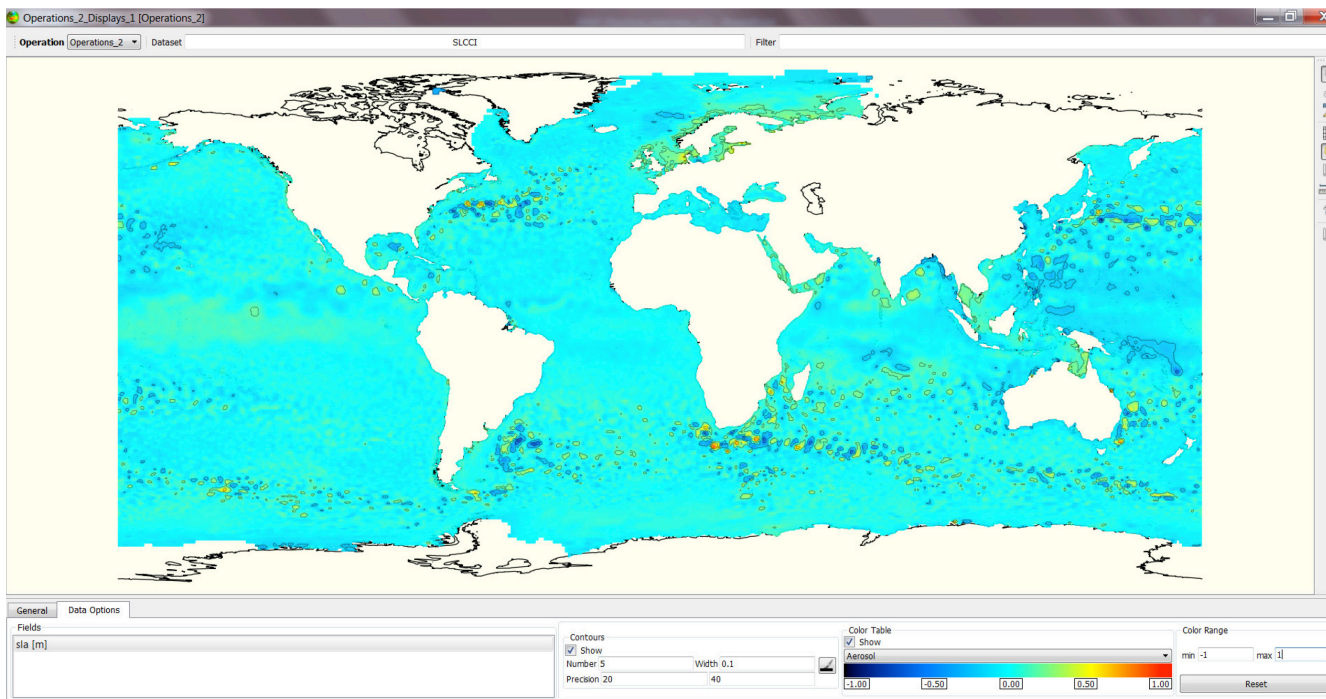


# Eddies detection with SLA data

- SLCCI Product for comparison

Folder: **SLA**

File: **ESACCI-SEALEVEL-L4-MSLA-MERGED-1993011500000-fv02.nc**

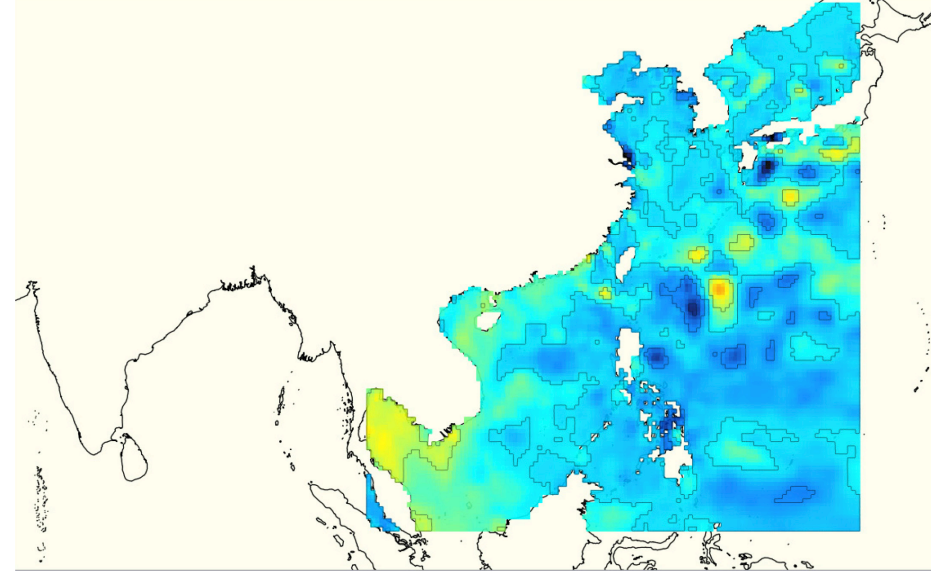
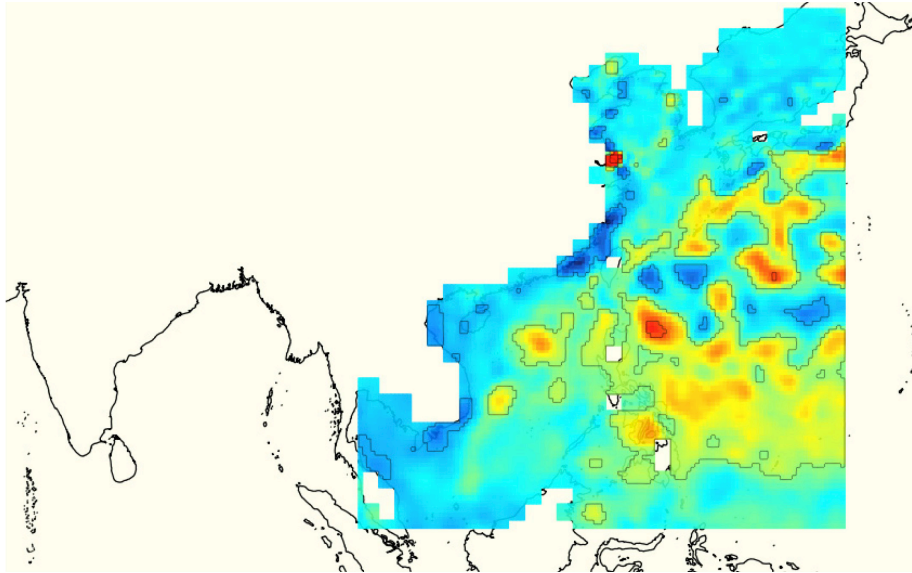


The screenshot shows the QGIS interface with the 'Operations' panel open. The 'Operation' is set to 'Operations\_2' and the 'Dataset' is 'SLCCI'. The 'Fields' list includes 'geospatial\_vertical\_max', 'geospatial\_vertical\_min', 'history (seconds since 1950-...', 'lat (degrees\_north)', 'lat\_valid\_max', 'lat\_valid\_min', and 'lon (degrees\_east)'. The 'Data Expressions' section shows 'Lon' (lon, degrees\_east), 'Lat' (lat, degrees\_north), and 'Data' (sla, m). The 'Units' section shows 'lon' (degrees\_east), 'lat' (degrees\_north), and 'sla' (m). The 'Sampling' section is also visible.

# SLA data (SSALTO/DUACS vs. SLCCI)



- **SSALTO/DUACS (right)** Monthly Map: 2006 07 05. The **MSS\_CNES\_CLS11** (mean reference period: 1993–2012) has been used.
- **SLCCI (left)** Monthly Map: 1993 01 15. The **MSS DTU15** (mean reference period: 1993–2012) has been used.



General Data Options

Fields  
sla [m]

Contours  
 Show  
Number 5 Width 0.1  
Precision 20 40

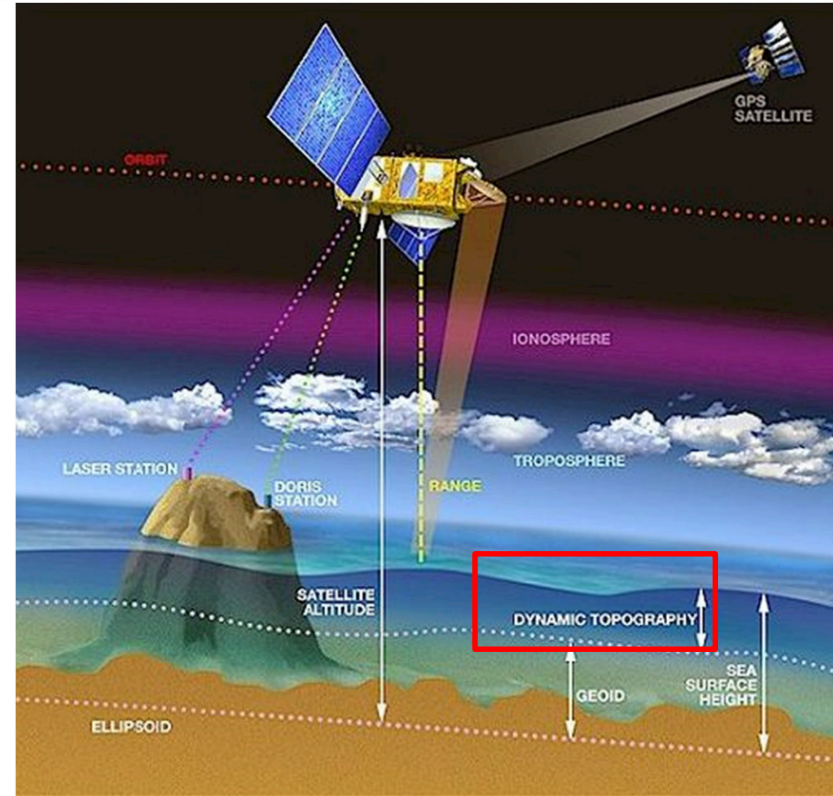
Color Table  
 Show  
Aerosol  
-0.50 -0.25 0.00 0.25 0.50

Color Range  
min -0.5 max 0.5  
Reset

# Mean Dynamic Topography



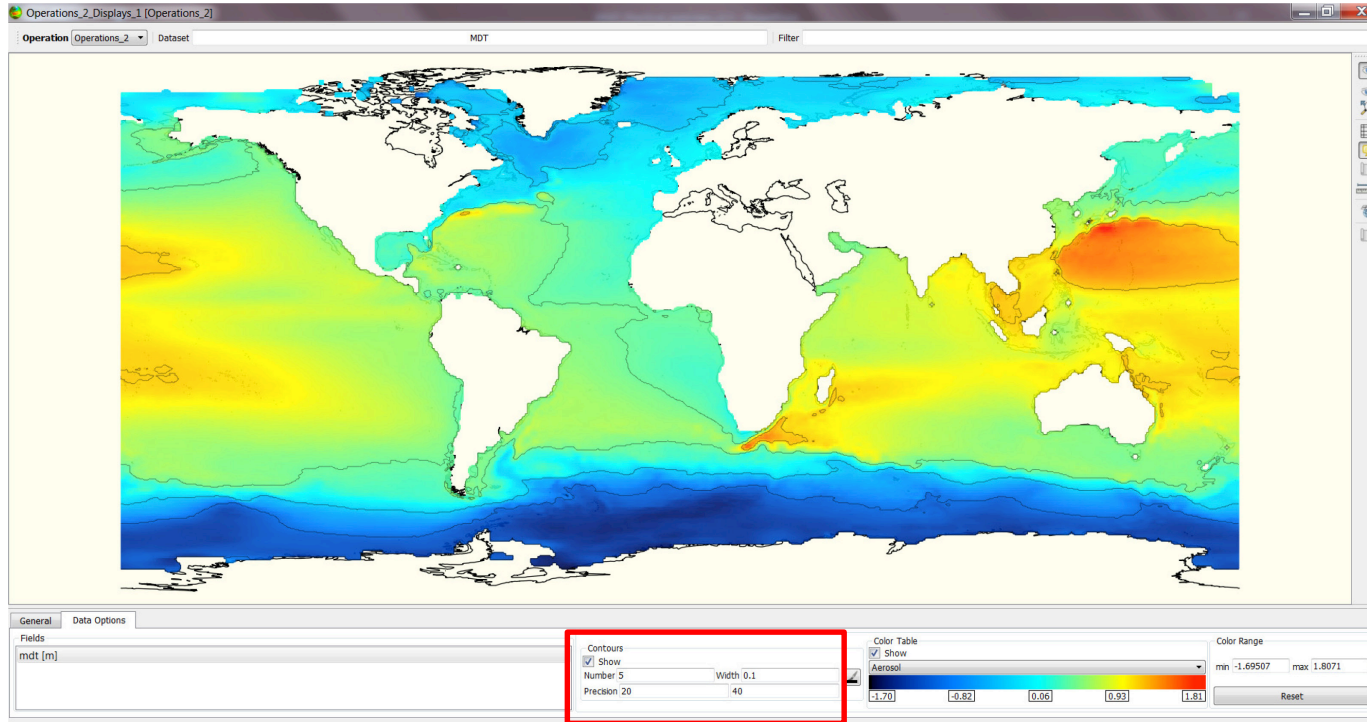
- A **Mean Dynamic Topography** (MDT = MSS – geoid) is required to estimate mean (time-invariant) transport in the ocean.
- It contributes to the calculation of the **absolute dynamic topography (ADT)**, which is given by the sum of **sea level anomaly (SLA)** and **mean dynamic topography (MDT)**.
- The MSS and the geoid shall be referenced to the same ellipsoid.



# Mean Dynamic Topography (2)



•Input File: **MDT\_CNES\_CLS\_09\_15M**



Datasets RADS Datasets Filters Operations

Quick: Advanced

Operation: Operations\_2 Dataset: MDT Filter:

Fields

- crs\_earth\_rotation\_rate
- crs\_inverse\_flattening
- crs\_semi\_major\_axis
- lat (degrees\_north)
- lon (degrees\_east)
- mdt (m)

longitude field

Dimensions: lon=1440

- standard\_name: longitude

- units: degrees\_east

Data Expressions

Units

- Lon lon degrees\_east
- Lat lat degrees\_north
- Data mdt m

Selection criteria (optional): count

Map

Plot

Lon

lon

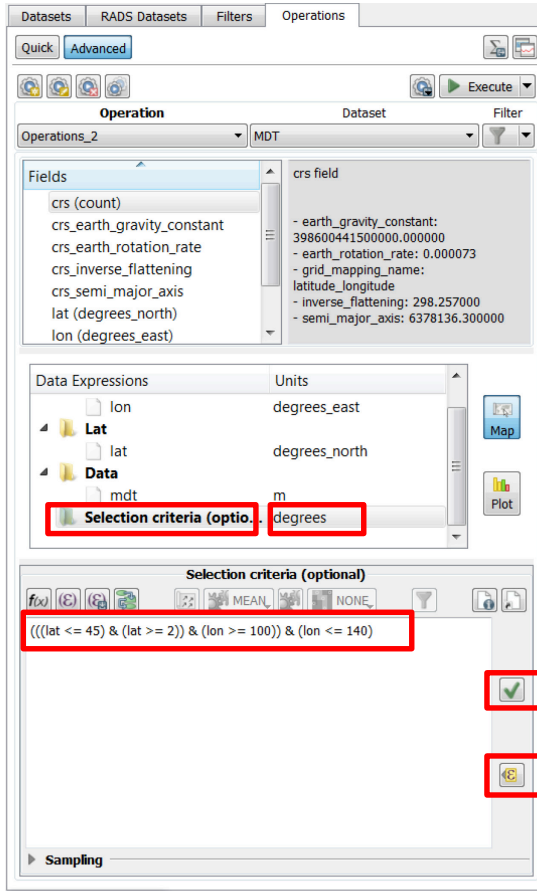
MEAN NONE

Sampling



# Mean Dynamic Topography (3)

- In this case the geographical filtering shall be made using the selection criteria box (the 'Filters' tab requires the presence of a time vector, which is absent in the adopted MDT product).



Operations\_2

Fields

- crs (count)
- crs\_earth\_gravity\_constant
- crs\_earth\_rotation\_rate
- crs\_inverse\_flattening
- crs\_semi\_major\_axis
- lat (degrees\_north)
- lon (degrees\_east)

crs field

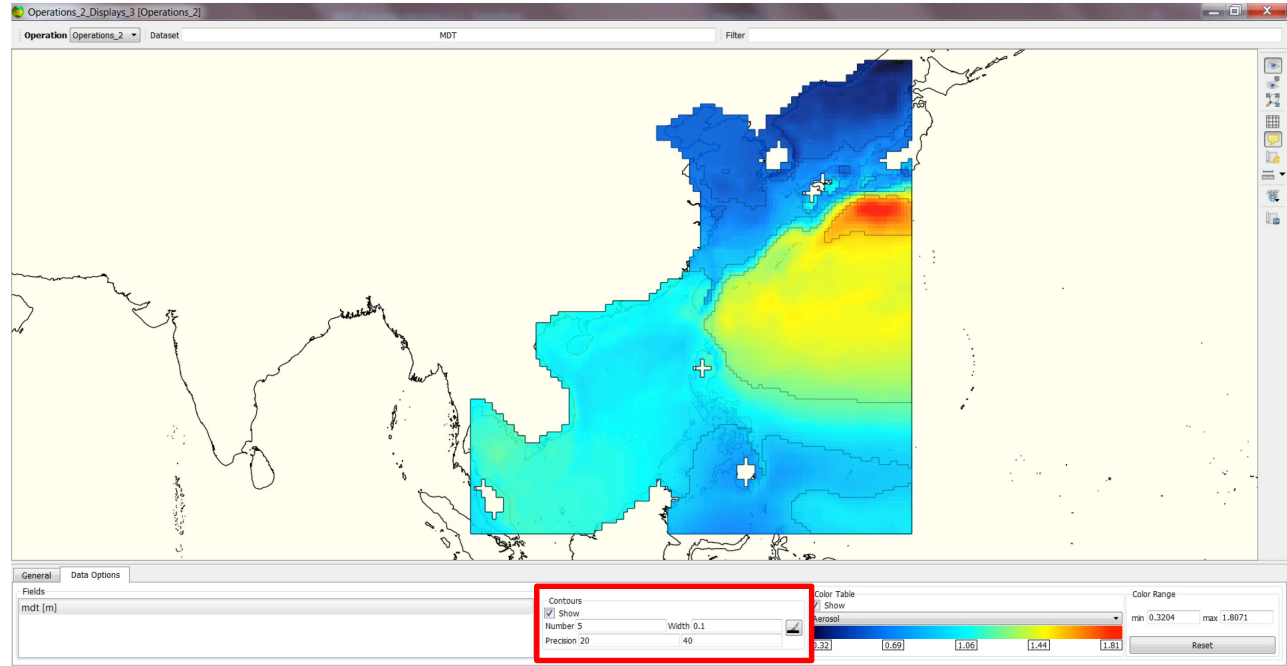
- earth\_gravity\_constant: 398600441500000.000000
- earth\_rotation\_rate: 0.000073
- grid\_mapping\_name: latitude\_longitude
- inverse\_flattening: 298.257000
- semi\_major\_axis: 6378136.300000

Data Expressions

- lon: degrees\_east
- Lat: degrees\_north
- Data: mdt: m

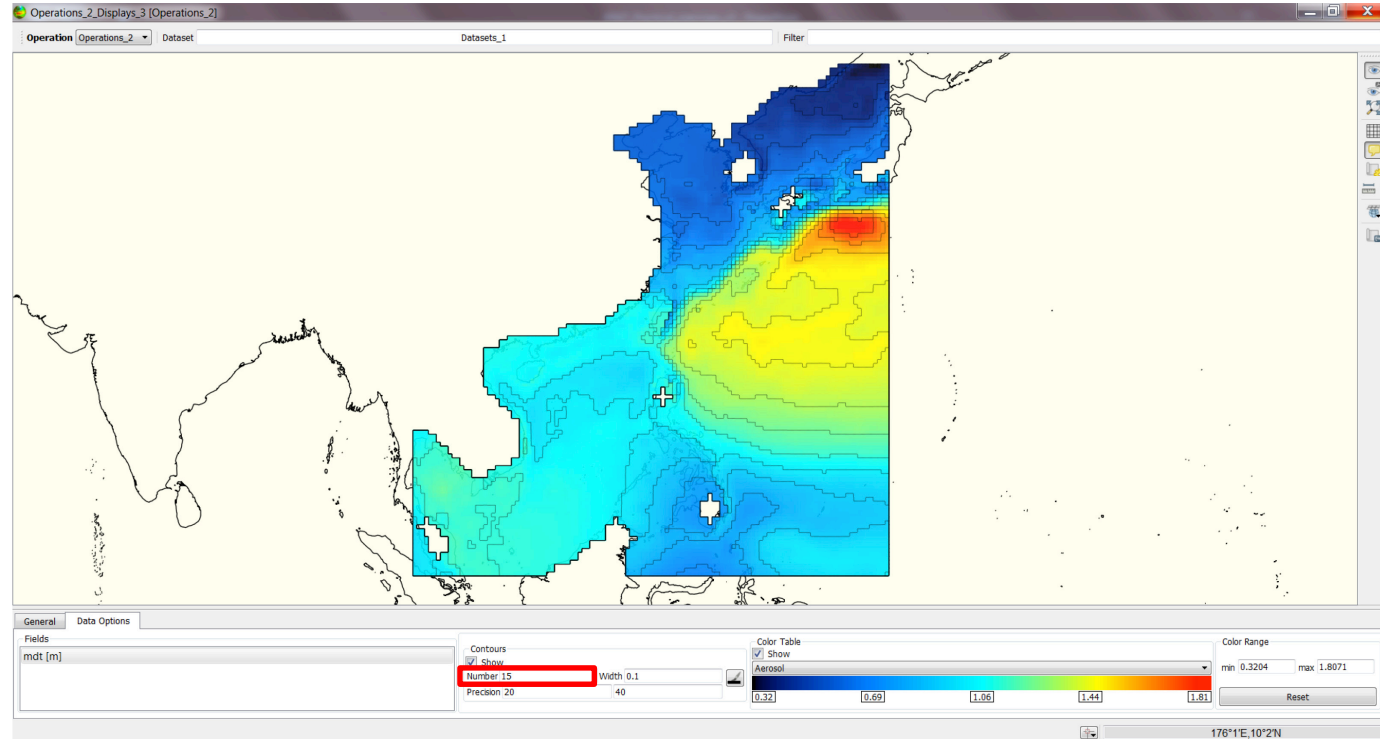
Selection criteria (optional)

$(((lat \leq 45) \& (lat \geq 2)) \& (lon \geq 100)) \& (lon \leq 140)$



# Mean Dynamic Topography (4)

- To show more contours, the “**Number**” attribute (default = 5) shall be increased.
- To cover 0.1 m with each contour, we put “**Number = 15**”, as the colour bar ranges from 0.3 to 1.8 m.
- The contours detail improves for higher precision numbers but the processing time also increases.
- For more information see the **User Manual** (Documentation folder)



# Practical n.2: Absolute Dynamic Topography & Absolute 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):

$$ADT = MDT + SLA$$

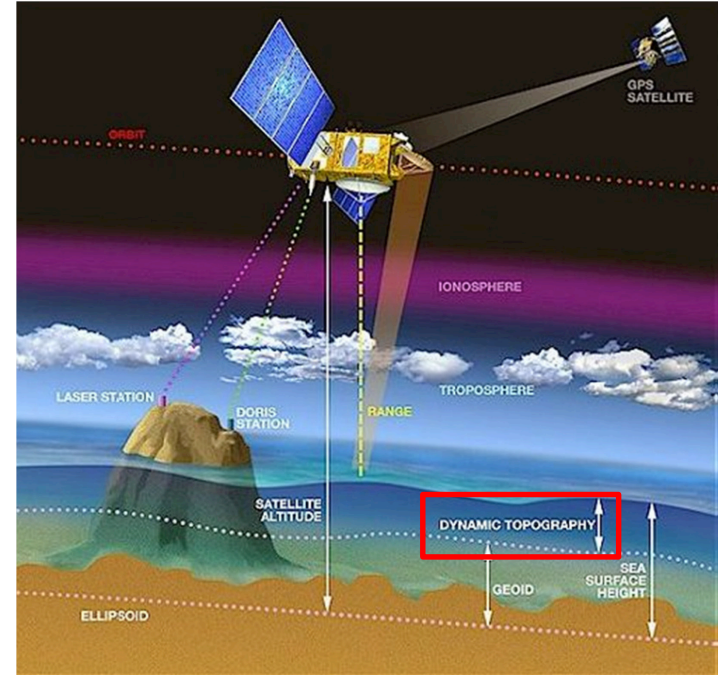
(MSS used to generate the SLAs must be defined over the same averaging period as the MDT!)

It 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.

Folder: **ADT**

Input File: **ADT\_from\_MDT\_AVISO\_CLS\_2009\_plus\_SLCCI\_v2.nc.**

It is given by the sum of

MDT: **mdt\_cnes\_cls2009\_global\_v1.1.nc [from AVISO]**

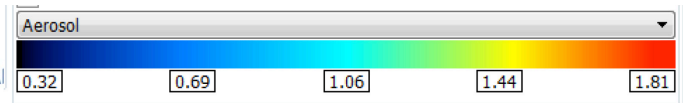
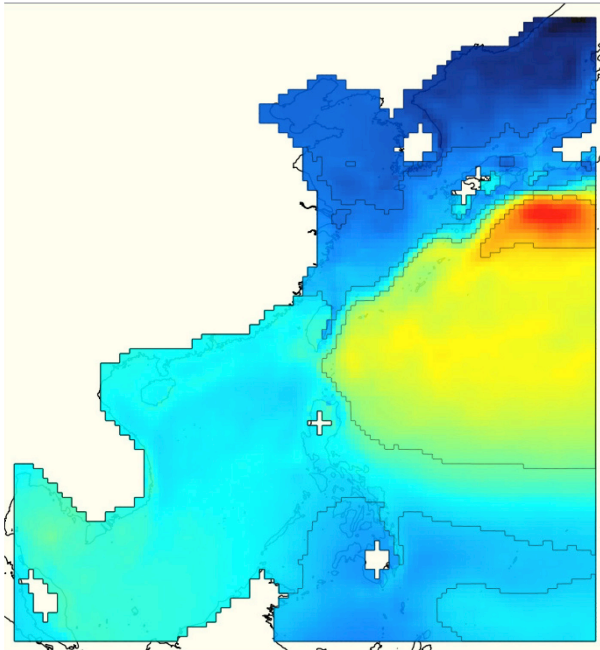
**+**

SLA: **ESACCI-SEALEVEL-L4-MSLA-MERGED-19930115000000-fv02.nc**

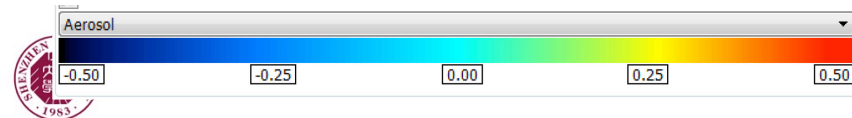
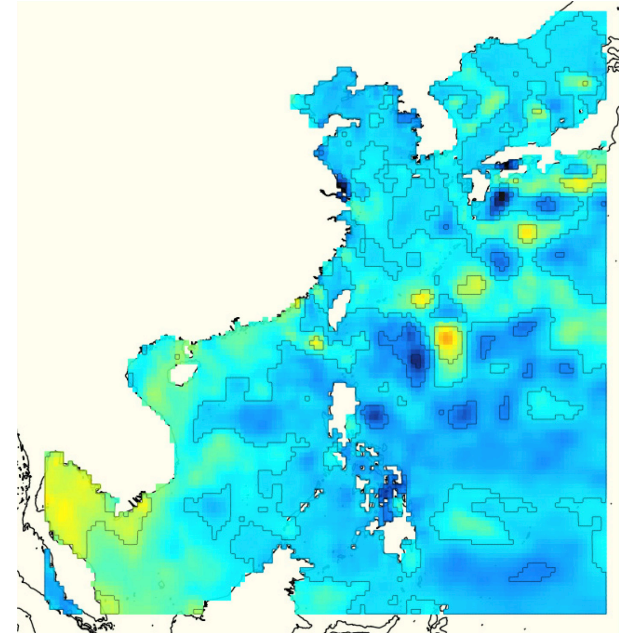
**The MSS used to generate the SLAs must be defined over the same averaging period as the MDT.**



MDT\_CNES\_CLS\_09\_15M [m]



SLA (SLCCI v2.0 data) [m]



# Absolute Dynamic Topography

dt = MDT [MDT\_CNES\_CLS\_09\_15M] + SLA [SLCCI data]



1-6: Apply the geographical filtering on the area of interest as made for the MTD and create a 'dt' Map with contours (7-8).

Operations

Fields

- crs\_earth\_rotation\_rate
- crs\_inverse\_flattening
- crs\_semi\_major\_axis
- dt (m)
- lat (degrees\_north)
- lon (degrees\_east)

longitude field

Dimensions: lon=1440

- standard\_name: longitude

- units: degrees\_east

Data Expressions

- lon (degrees\_east)
- Lat (degrees\_north)
- lat (degrees\_north)
- dt (m)
- Selection criteria (optional) degrees

Selection criteria (optional)

`((lat >= 2) & (lat <= 45)) & (lon >= 100) & (lon <= 140)`

Map

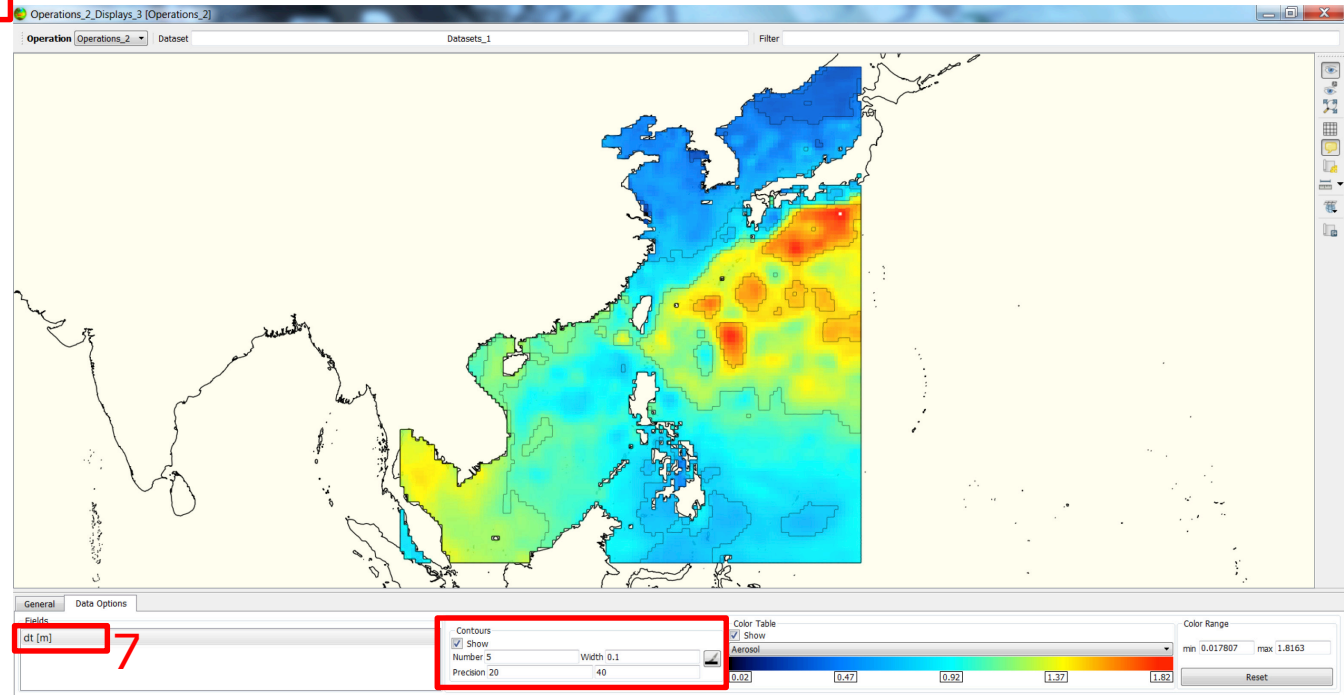
Plot

3

4

5

6



# Absolute Geostrophic Velocity (1)



1: **Map** the data Field 'dt' (=ADT) and create an expression named **U** [m/s].

2-5: Highlight **U** and select the algorithms icon (2) to insert the BRAT algorithm **BratAlgoGeosVelGridU**.

Modify the default expression to

`exec("BratAlgoGeosVelGridU", %{lat}, %{lon}, dt, 2)`

Equator\_Margin = 2 degrees (latitude North and South below which the computation won't be done, to take into account the lack of Coriolis force at the Equator).

6-7: Check the correctness of the formula with ✓ and save it with ⚡.



Name	Description	Format	Unit
1 % {lat}	Latitude field.	double	degrees_north
2 % {lon}	Longitude field.	double	degrees_east
	Height: sea surface height variable (or expression) used to derive the geostrophic velocity component.		

Output Unit: m/s

# Absolute Geostrophic Velocity (2)

- 1: Create another expression named **V [m/s]**
- 2-5: Highlight **V** and select the algorithms icon (2) to insert the BRAT algorithm **BratAlgoGeosVelGridV**.
- Modify the default expression to  
`exec("BratAlgoGeosVelGridV", %{lat}, %{lon}, dt, 2)`
- 6-7: Check the correctness of the formula with  and save it with **⌘E**.

The screenshot shows the BRAT software interface with several windows and components:

- Operations Window:** Shows a list of fields including 'crs (count)', 'crs\_earth\_gravity\_constant', 'crs\_earth\_rotation\_rate', 'crs\_inverse\_flattening', 'crs\_semi\_major\_axis', 'dt (m)', 'lat (degrees\_north)', and 'lon (degrees\_east)'. A 'Map' button is highlighted with a red box (1).
- Data Expressions Window:** Shows a tree view with 'Lon' (degrees\_east), 'Lat' (degrees\_north), and 'Data' (m/s). The 'V' expression is highlighted with a red box (1), and its unit 'm/s' is also highlighted (1).
- Algorithms Window:** Shows a list of algorithms. 'BratAlgoGeosVelGridV' is selected and highlighted with a red box (3).
- Insert Algorithm Dialog:** Shows the 'Input Parameters' table with columns for Name, Description, Format, and Unit. The 'OK' button is highlighted with a red box (4).
- Data Expressions Window (Bottom):** Shows the expression editor with the formula `exec("BratAlgoGeosVelGridV", %{lat}, %{lon}, dt, 2)` entered. The 'Data' window has a checkmark icon highlighted with a red box (6) and a save icon highlighted with a red box (7).

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

The screenshot shows the 'Data Expressions' panel with 'U' selected. Below it, the 'Data' toolbar has a red box around the vector plot icon. A blue arrow points to the 'U' Display Properties dialog, where 'Vector Plot Component' is checked and 'East Component' is selected. The 'OK' button is also highlighted with a red box.

Data Expressions	Units
Lon	
lon	degrees_east
Lat	
lat	degrees_north
Data	
dt	m
U	m/s
V	m/s
Selection criteria (optional)	count

exec("BratAlgoGeosVelGridU", %{lat}, %{lon}, dt, 2)

**'U' Display Properties**

Vector Plot Component  
 North Component  
 East Component

Edit the expression 'U' display properties.  
Vector box is available only if a map operation has more than 1 data field.

OK Cancel

The screenshot shows the 'Data Expressions' panel with 'V' selected. Below it, the 'Data' toolbar has a red box around the vector plot icon. A blue arrow points to the 'V' Display Properties dialog, where 'Vector Plot Component' is checked and 'North Component' is selected. The 'OK' button is also highlighted with a red box.

Data Expressions	Units
Lon	
lon	degrees_east
Lat	
lat	degrees_north
Data	
dt	m
U	m/s
V	m/s
Selection criteria (optional)	count

exec("BratAlgoGeosVelGridV", %{lat}, %{lon}, dt, 2)

**'V' Display Properties**

Vector Plot Component  
 North Component  
 East Component

Edit the expression 'V' display properties.  
Vector box is available only if a map operation has more than 1 data field.

OK Cancel

# Absolute Geostrophic Topography and Velocities



1-6: As made before but including **U & V expressions**.

7-8: Two maps are selectable now: **dt [m]**, as before, and **U/V [m/s]**.

Operations

Quick **Advanced**

**6** Execute

Operation: Operations\_2 Dataset: ADT Filter: Filter

Fields

- longitude field
- Dimensions: lon=1440
- standard\_name: longitude
- units: degrees\_east

Data Expressions

Data Expressions	Units
lat	degrees_north
<b>1</b> dt	m
U	m/s
V	m/s
<b>2</b> Selection criteria (optional)	degrees

**3** Selection criteria (optional)

**4**

**5**

(((lat >= 2) & (lat <= 45)) & (lon >= 100) & (lon <= 140))

Sampling

Operations\_2\_Displays\_1 (Operations\_2)

Operation: Operations\_2 Dataset: ADT Filter: Filter

**7** dt [m] U/V [m/s]

**8** Contours

Show  Width 0.1 Precision 20

Color Table

Show  Aerosol

Color Range

mn 0.017807 max 1.8163

0.02 0.47 0.92 1.37 1.82

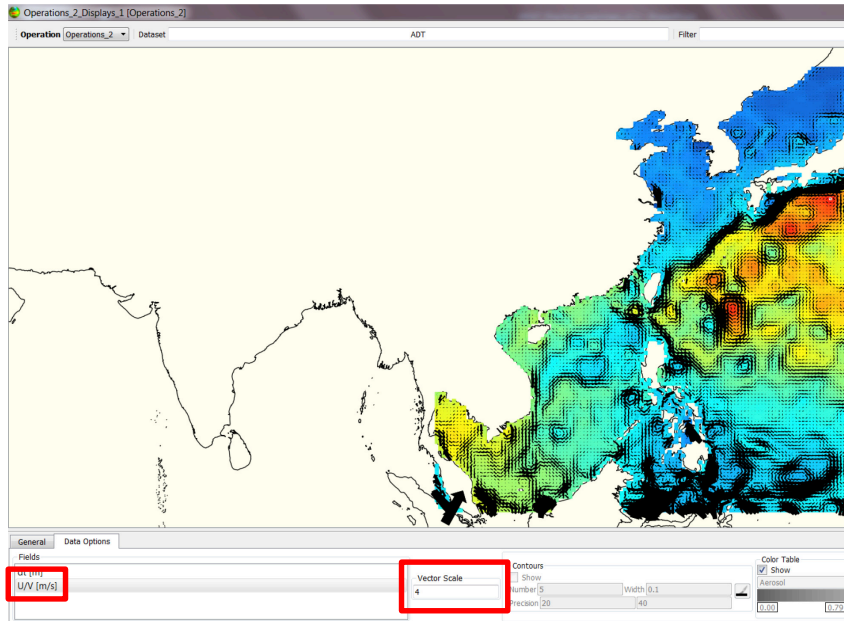
Reset



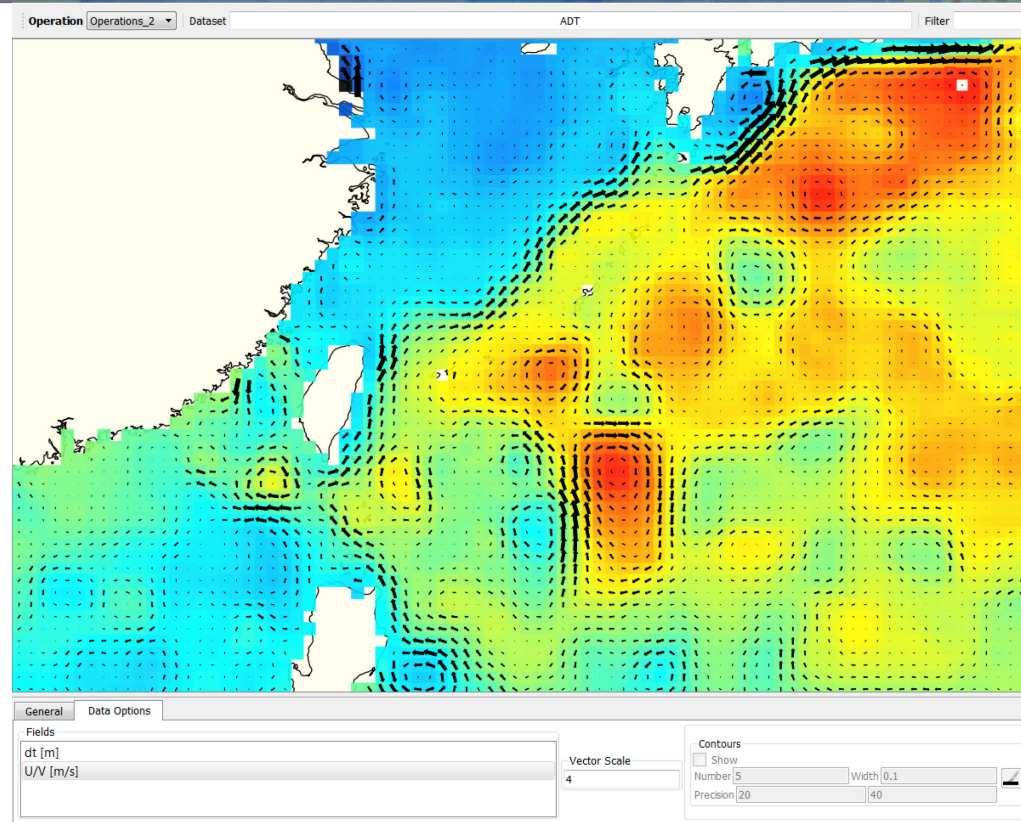
# Absolute Geostrophic Velocities



Switch to the **U/V Map** and put Vector scale = 4

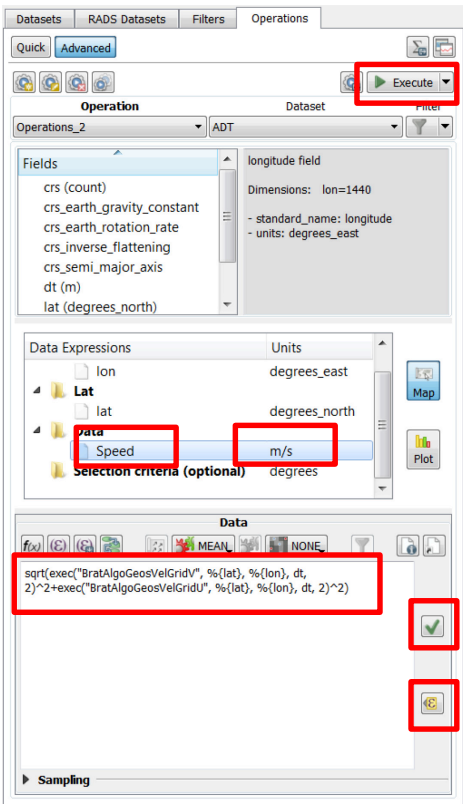


Zoom-in to see the currents



# Current Speed derived from ATD

Copy and paste **U** and **V** formulas into a new expression to be named '**Speed**' [m/s] and rework as shown to obtain '**Wadt**' (delete the previous expressions U, V & dt and close the previous Maps before clicking on 'Execute')



Operations\_2 Displays\_2 (Operations\_2)

Operation Operations\_2 Dataset ADT Filter

Fields

- longitude field
- Dimensions: lon=1440
- standard\_name: longitude
- units: degrees\_east

Data Expressions

- lon degrees\_east
- Lat lat degrees\_north
- Speed m/s

Data

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

Execution buttons: [Execute] [Map] [Plot] [Data] [MEAN] [NONE]

