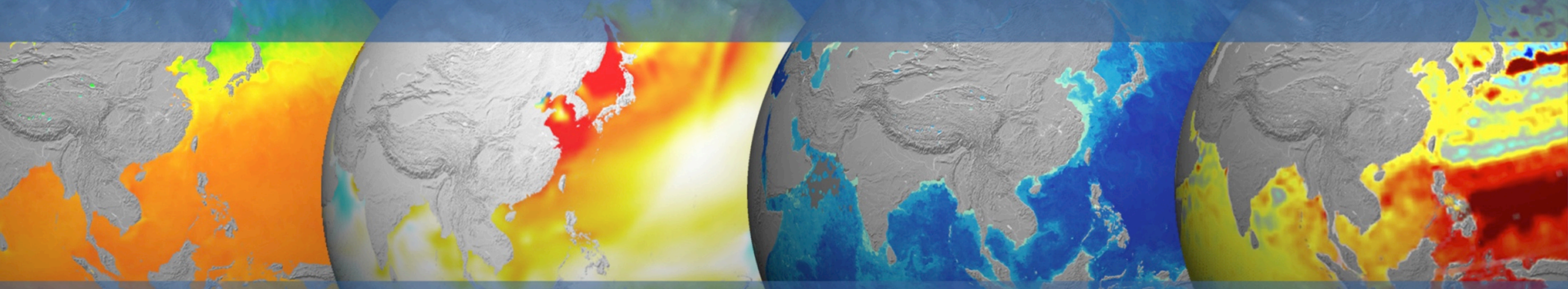
ESA–MOST China Dragon 4 Cooperation

→ ADVANCED TRAINING COURSE IN OCEAN AND COASTAL REMOTE SENSING



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

BROADVIEW RADAR ALTIMETRY TOOLBOX

Hosted by

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

Table of Contents

- 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

The Scenario

• 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.).

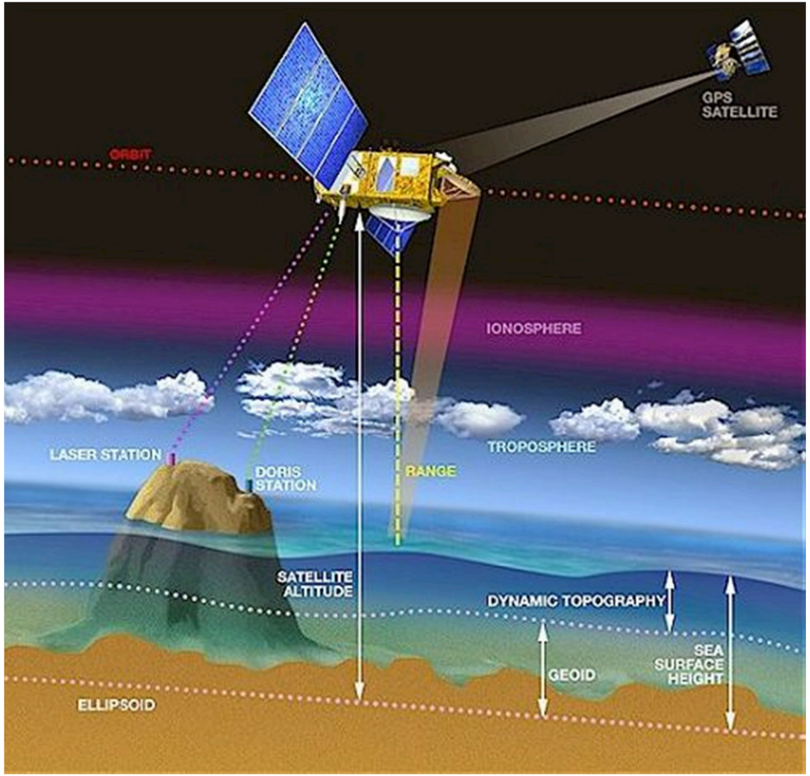
• Geoids (i.e. the ocean surface excluding the influence of wind and tides) are obtained from other missions (e.g. GRACE, GOCE).

• 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): Satellite_Altitude - Corrected_Range.

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



Processing schemes: Low Resolution Mode

Pulse limited acquisition.

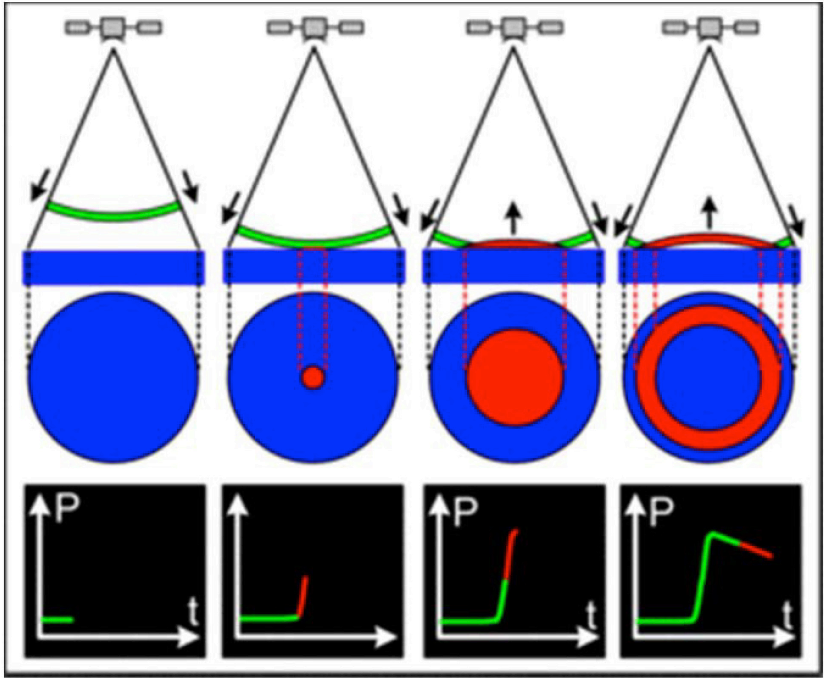
The time on target dictated by the beam illumination is not exploited.

- **Observed parameters:**

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

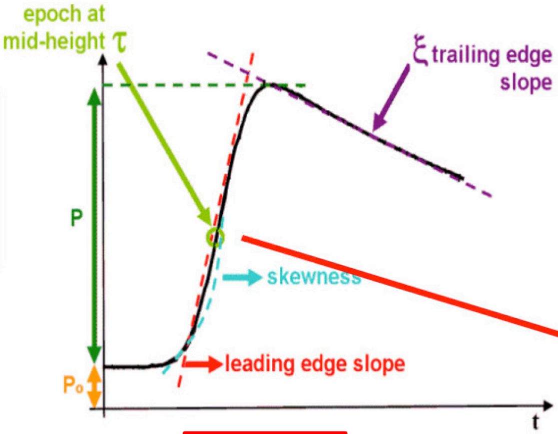
- **Typical specs:**

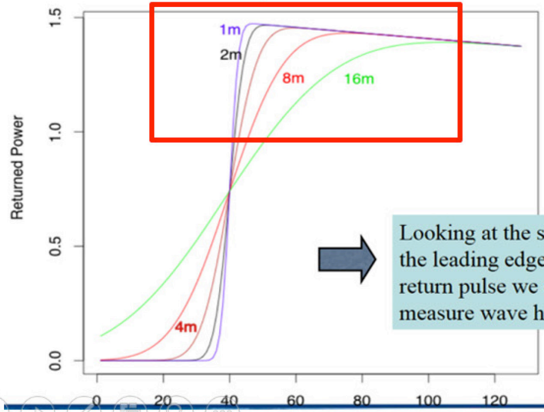
Along/Across track resolution: several km depending on SWH.



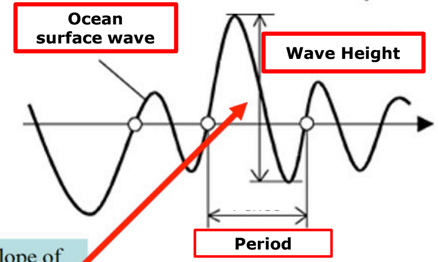
Processing schemes: Low Resolution Mode

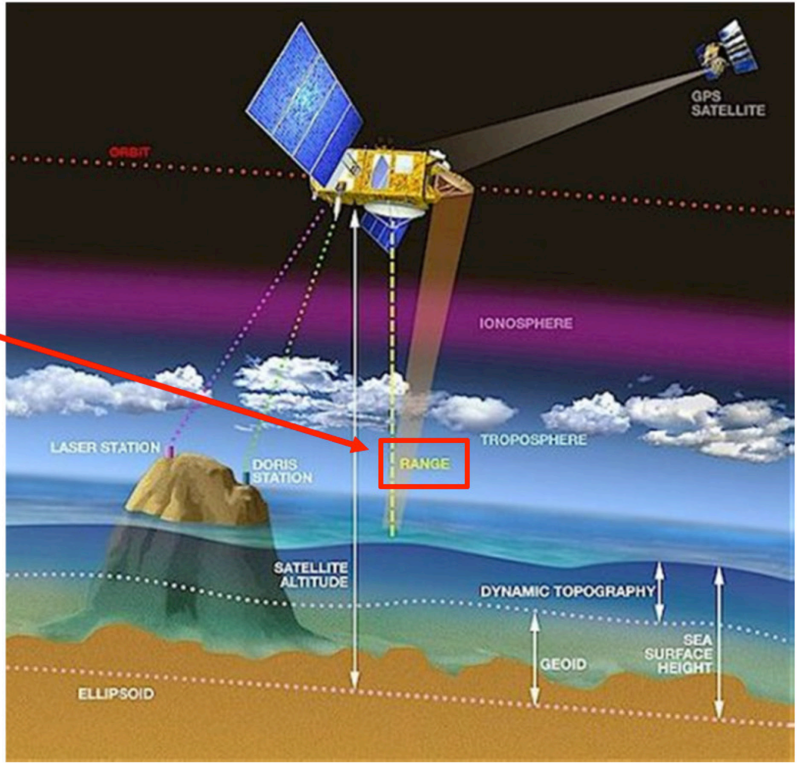
The Power amplitude (sigma0) of the signal can be related to the wind speed.





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





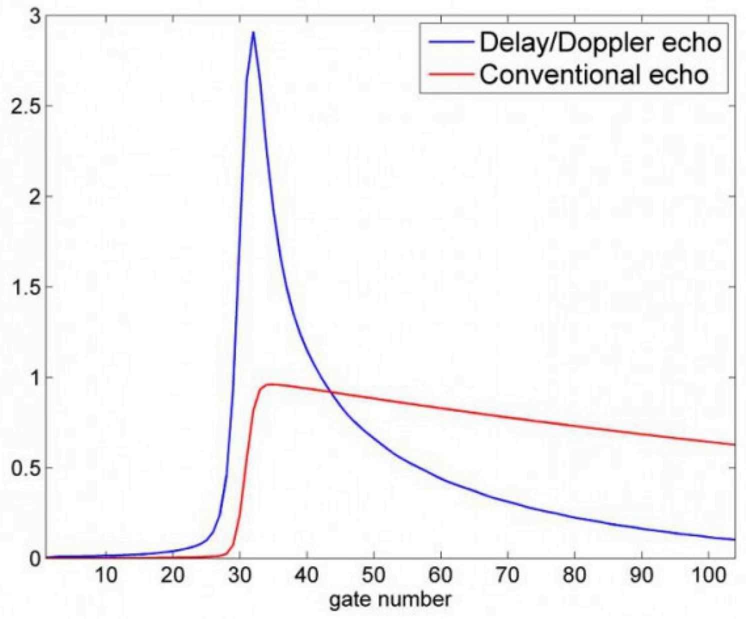
L1b waveforms (1)

- 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 retrackers 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)

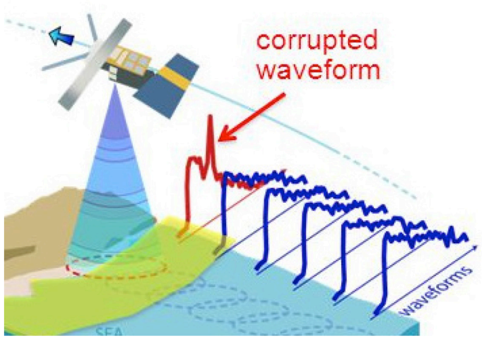
- Waveforms acquired in the coastal zone can be significantly distorted due to the presence of the coast in the radar footprint.

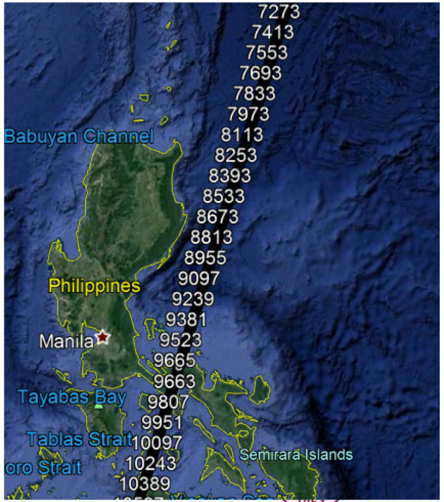
- The WTC correction from the onboard radiometer are contaminated (models required).

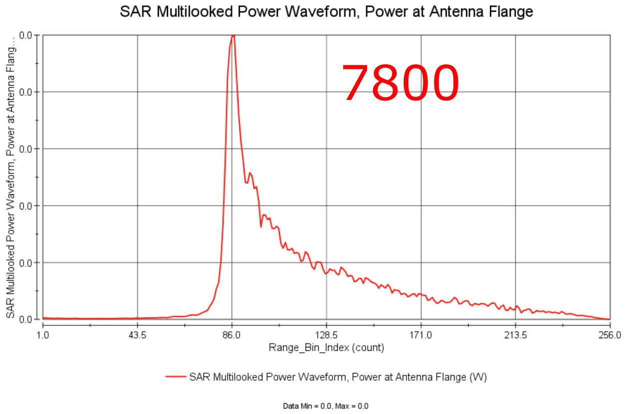
- The estimates from these waveforms are not reliable and shall not be used without a proper selection.

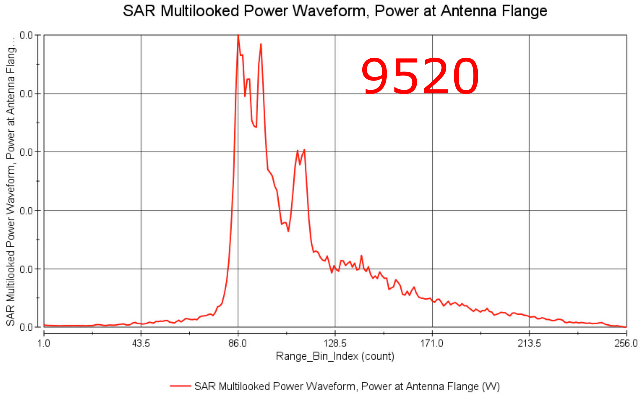
- The SAR operative mode (300 m resolution in along-track) allows to acquire more valid waveforms in approaching the coast than the LRM mode (7 km in along-track).

- The shape of the waveform can be checked for filtering purposes.









Retracking & L2 Products

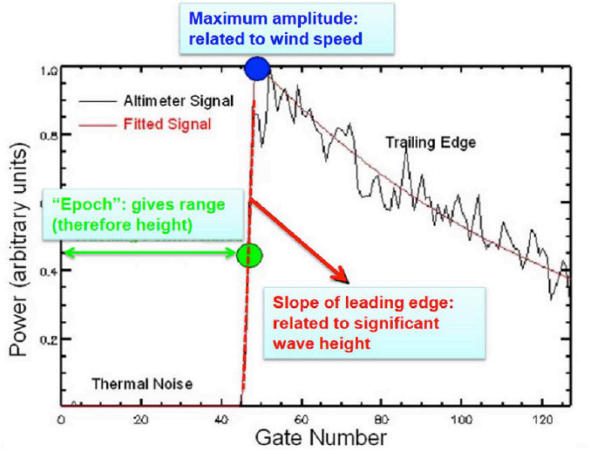
- **The retracking process is required for improving the range precision of existing measurements guaranteeing a very accurate post-retracking Sea Surface Height (SSH). Waveform retracking is defined as an algorithm which:**

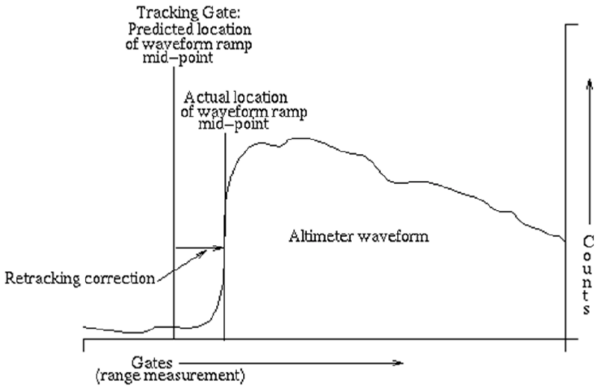
• finds the mid-gate of leading slope in the return L1b waveform,

• 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 (sigma0)**. Geophysical corrections are also included





The Broadview Radar Altimetry Toolbox

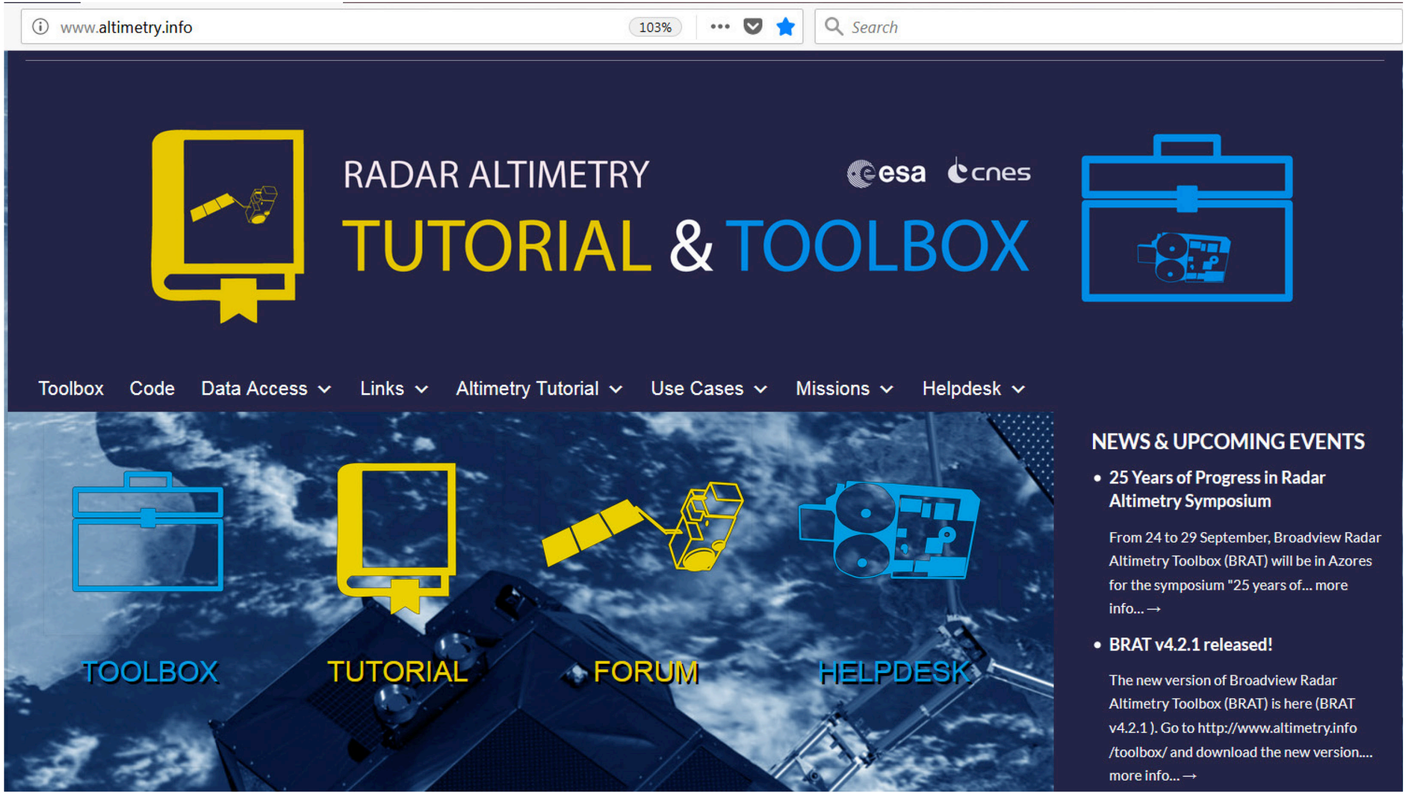
The Broadview Radar Altimetry Tutorial and Toolbox

- 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.

Website (http://www.altimetry.info/)

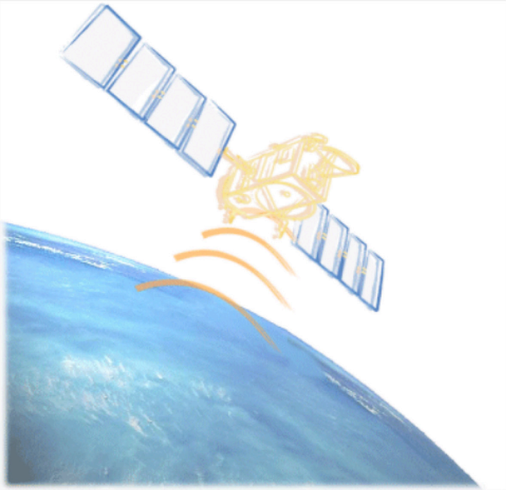


Radar Altimetry Tutorial

Toolbox | Code | Data Access | Links | Altimetry Tutorial | Use Cases | Missions | Helpdesk

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

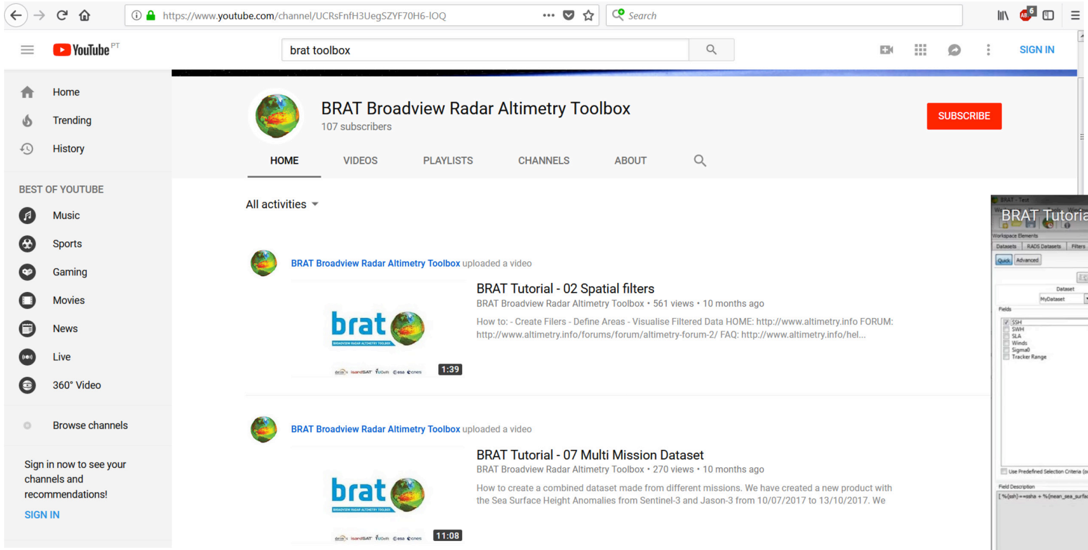
Download this tutorial in pdf (12 MB)

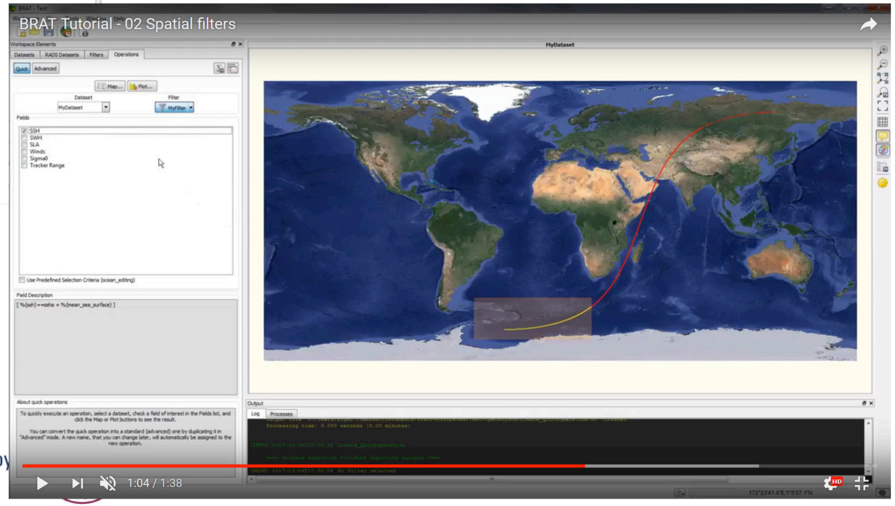
5. Altimetry Tutorial

BRAT YouTube Channel

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

Many video tutorials are available!

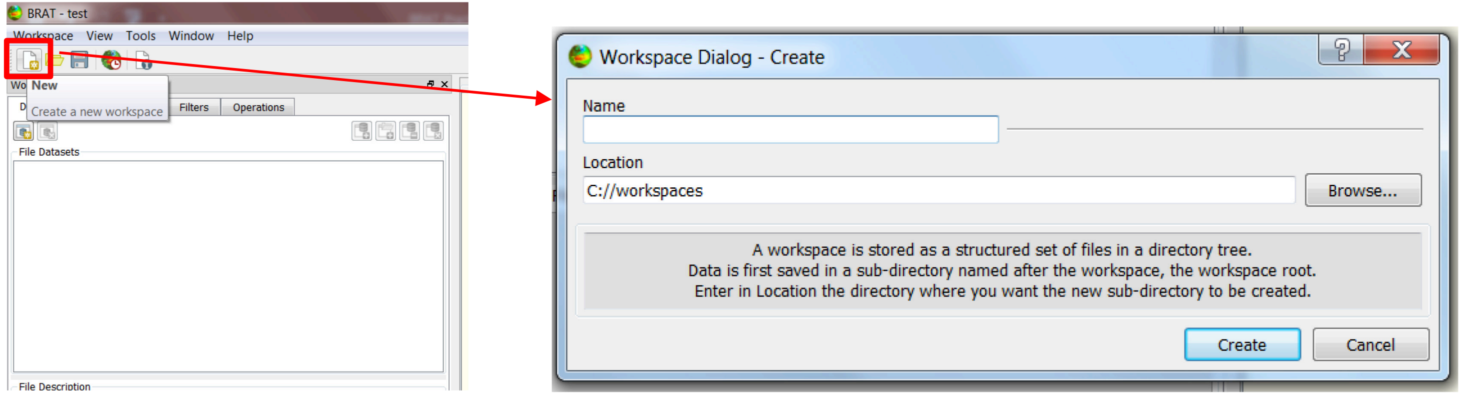




Using the Graphical User Interface (GUI)

Create a Workspace

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

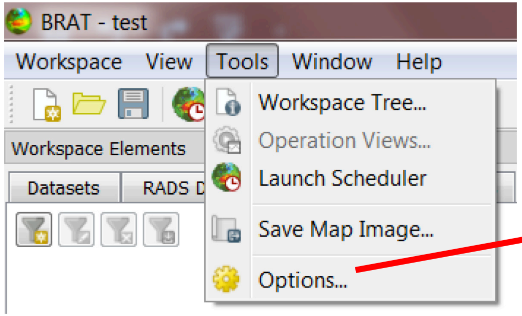


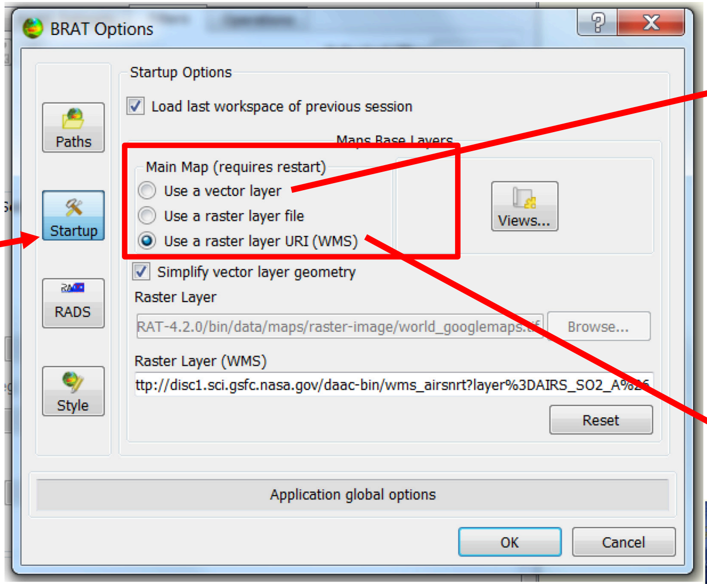
- A '**Workspace**' is a way of saving your preferences, computations and generally the work done with BRAT GUI. Some or all elements of a workspace can be imported into another workspace. The “Workspace” menu (and also the main toolbar) allow the user to create, open, close, save, import, rename or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

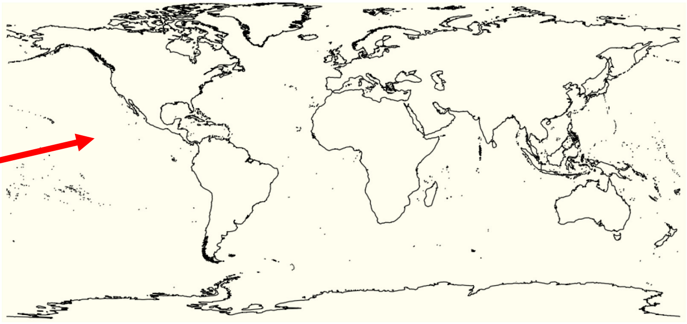
- **It is highly recommended to save your workspace** (ctrl+s, or ‘save’ in the “Workspace” menu) **while working**. You will be asked whether or not you wish to save the workspace when you quit BRAT GUI. Note that if you answer “no” and have not saved anything previously, none of your work can be recalled later. BRAT GUI recalls the last used Workspace by default.

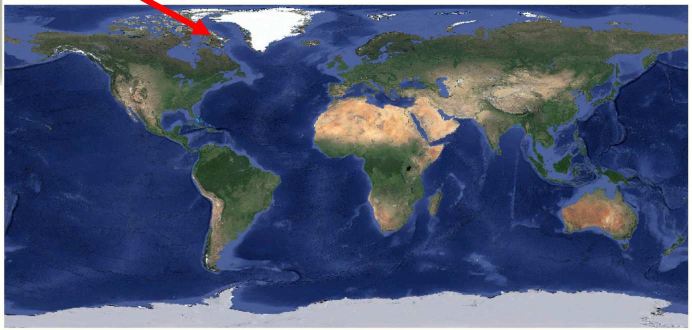
Select the Map Layer

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





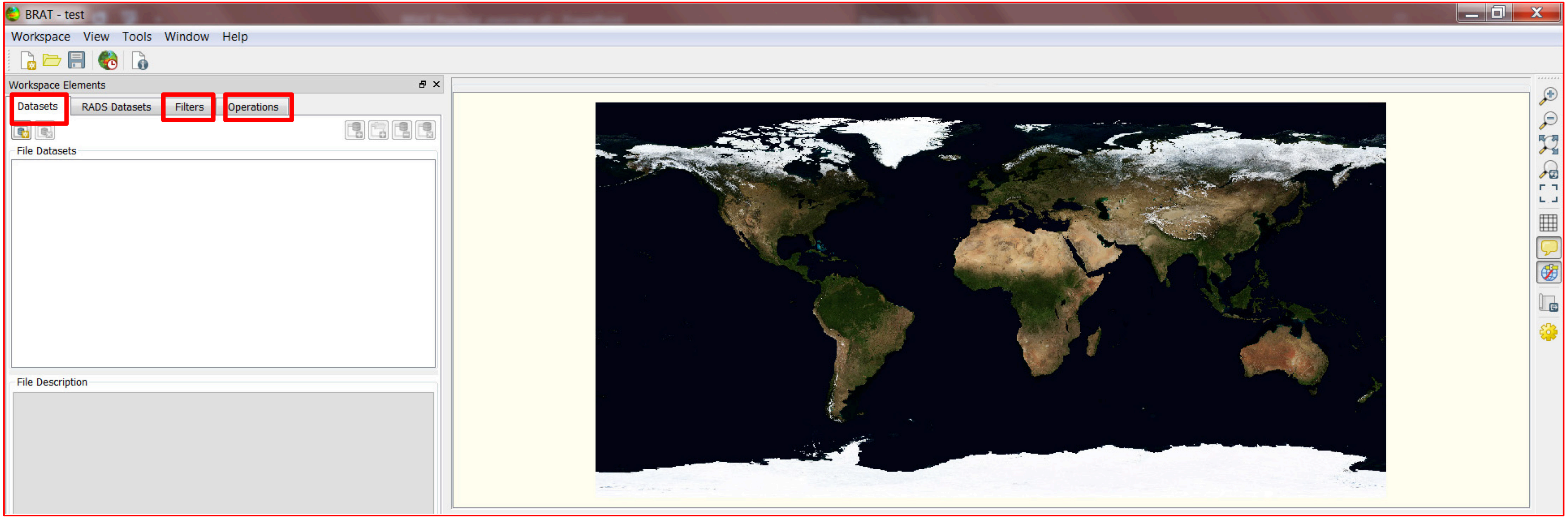




- Select "**Use a raster layer URI (WMS)**" and press **OK**.
- **Close** & **Restart** BRAT to display the selected map layer.

The BRAT GUI

Using BRAT GUI is basically a 3-step process.



The BRAT GUI (2)

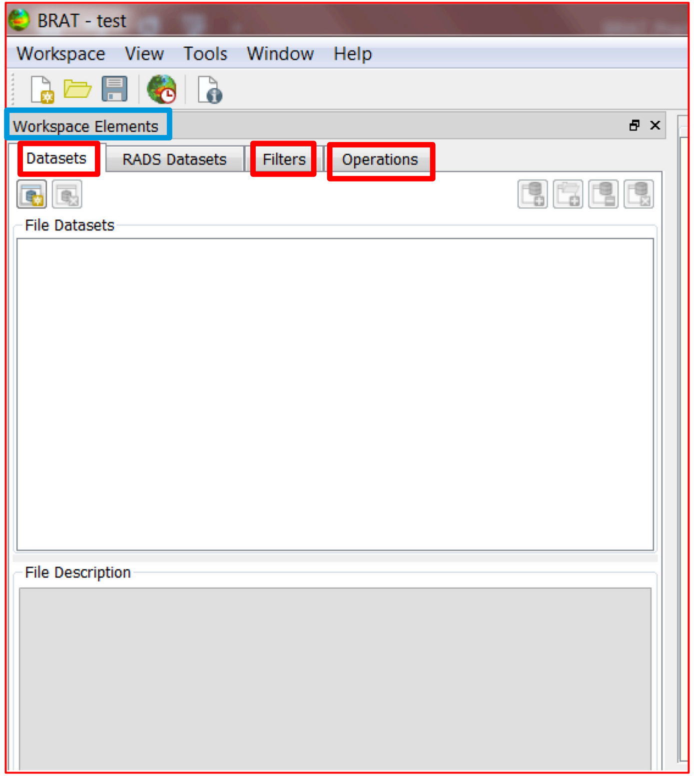
1. Define one or several '**Dataset(s)**': the product data you want to work on (see data required in each exercise, they will be imported from this tab).

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)

Datasets used in this Practical

- 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).

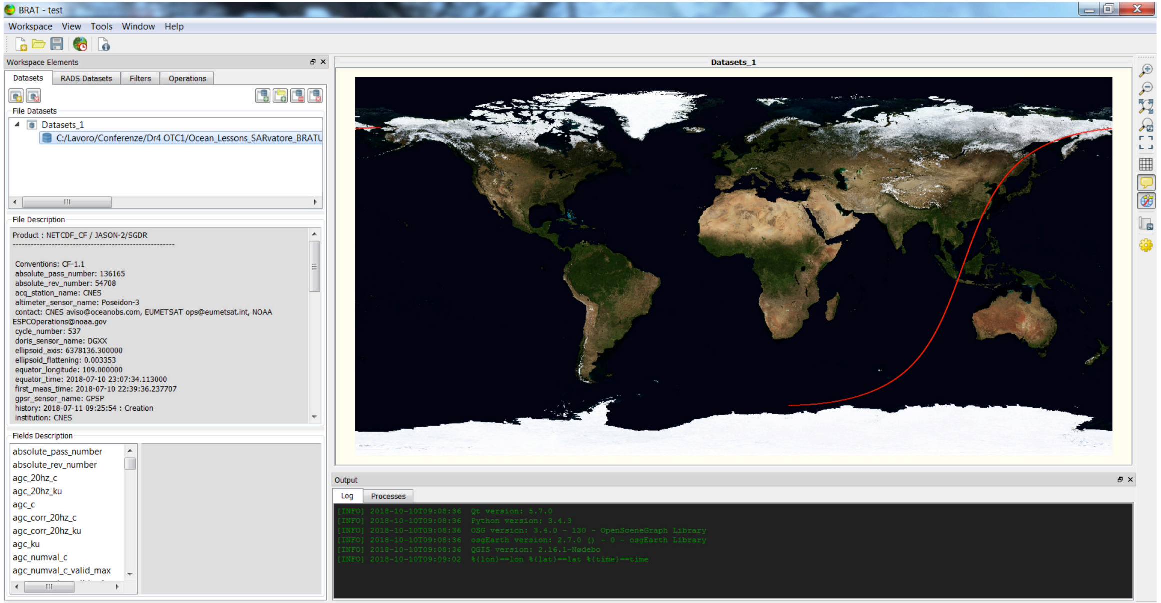
- Mean Sea Level variation in China using multi-mission SLCCI products.

Practical n.1: Evaluating L1b waveforms

Track used: **Jason-2 SIGDR** track (<u>Sensor</u> 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.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/waveforms.html

Datasets

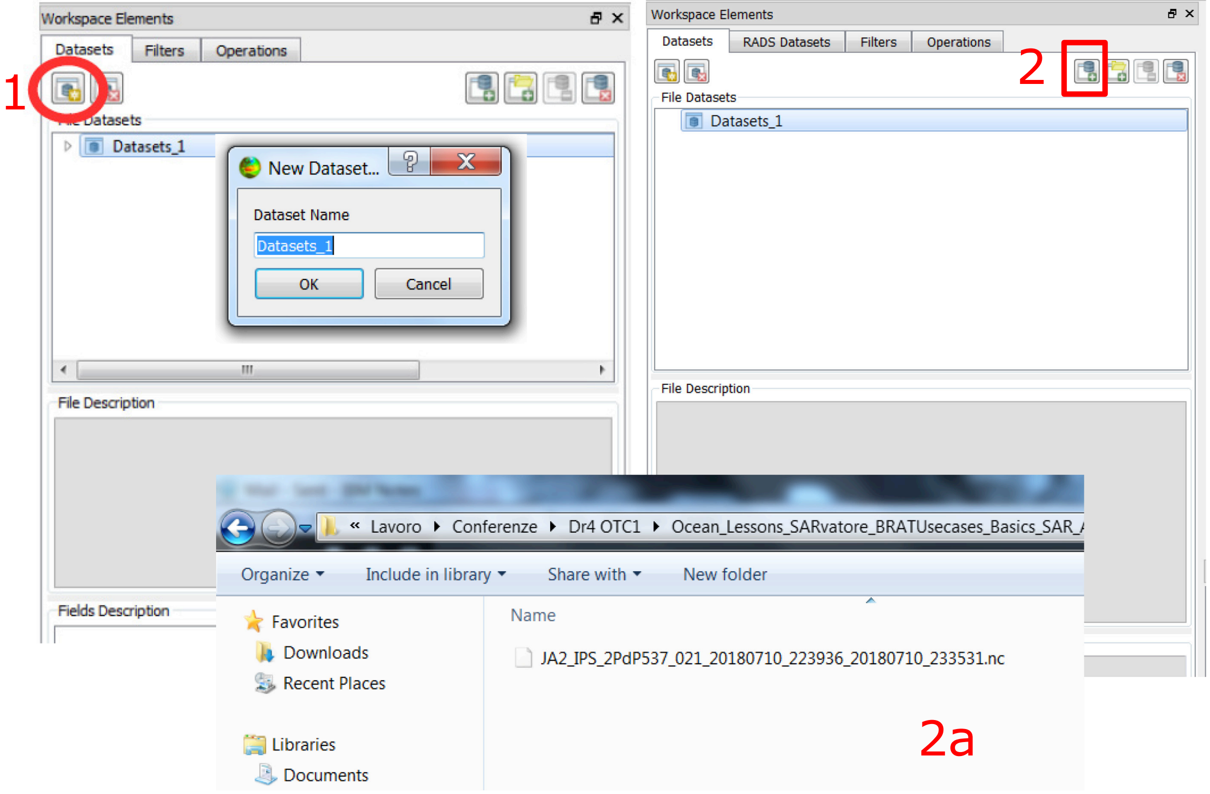
The first tab opened if you have never used BRAT is ‘**Datasets**’ .

This 'Datasets' tab is dedicated to the <u>definition and selection of the data</u> 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)

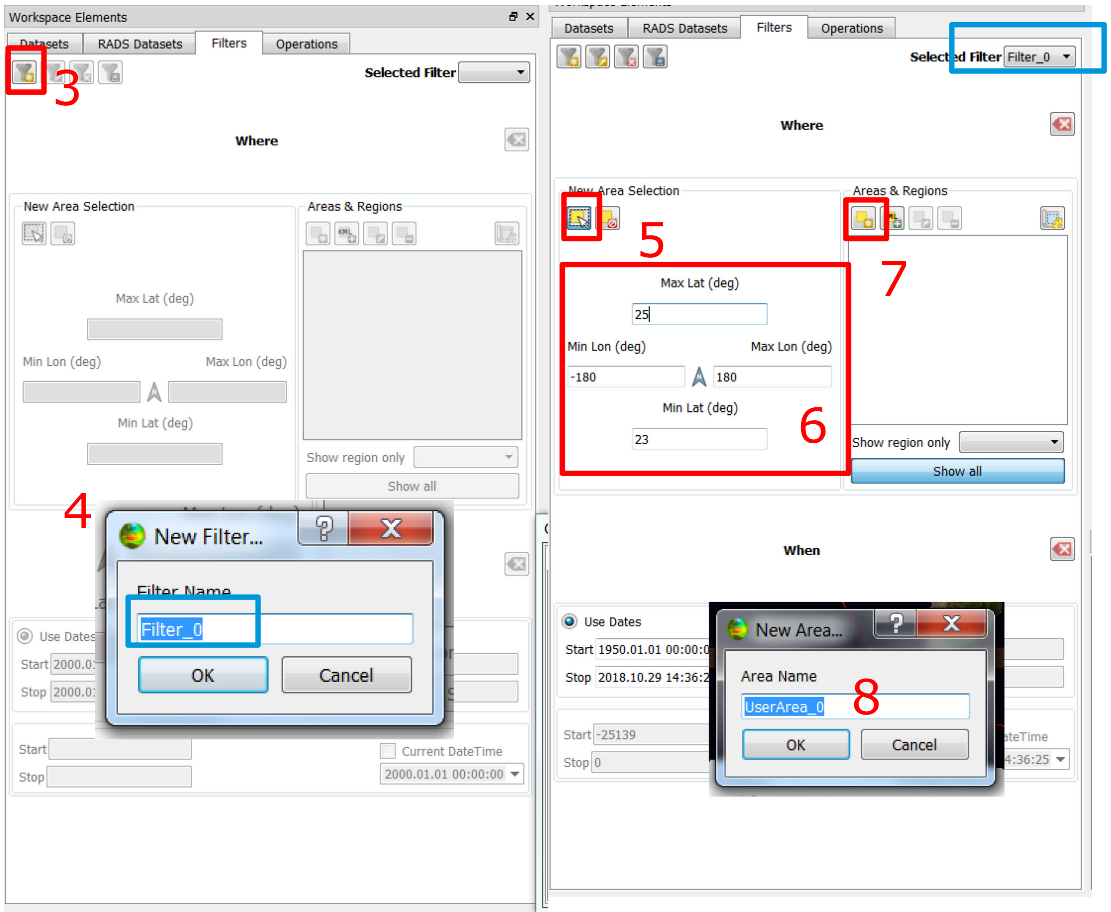
3: To create a filter press on the "**Create Filter**" icon.

4: Name the filter.

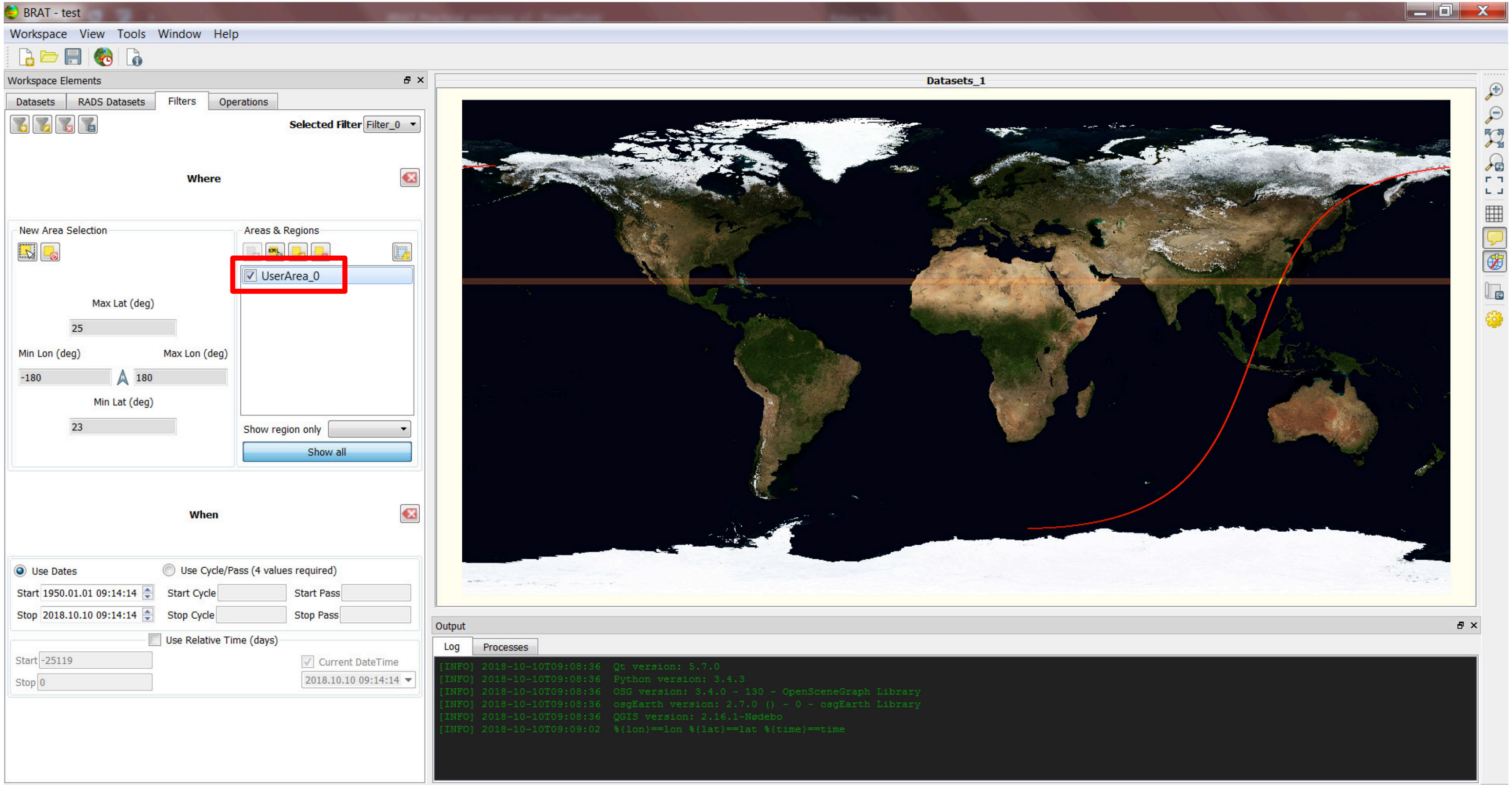
5-6: Click on "**Selection tool**" icon in the "**New Area selection**" menu and define the filtering box.

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)

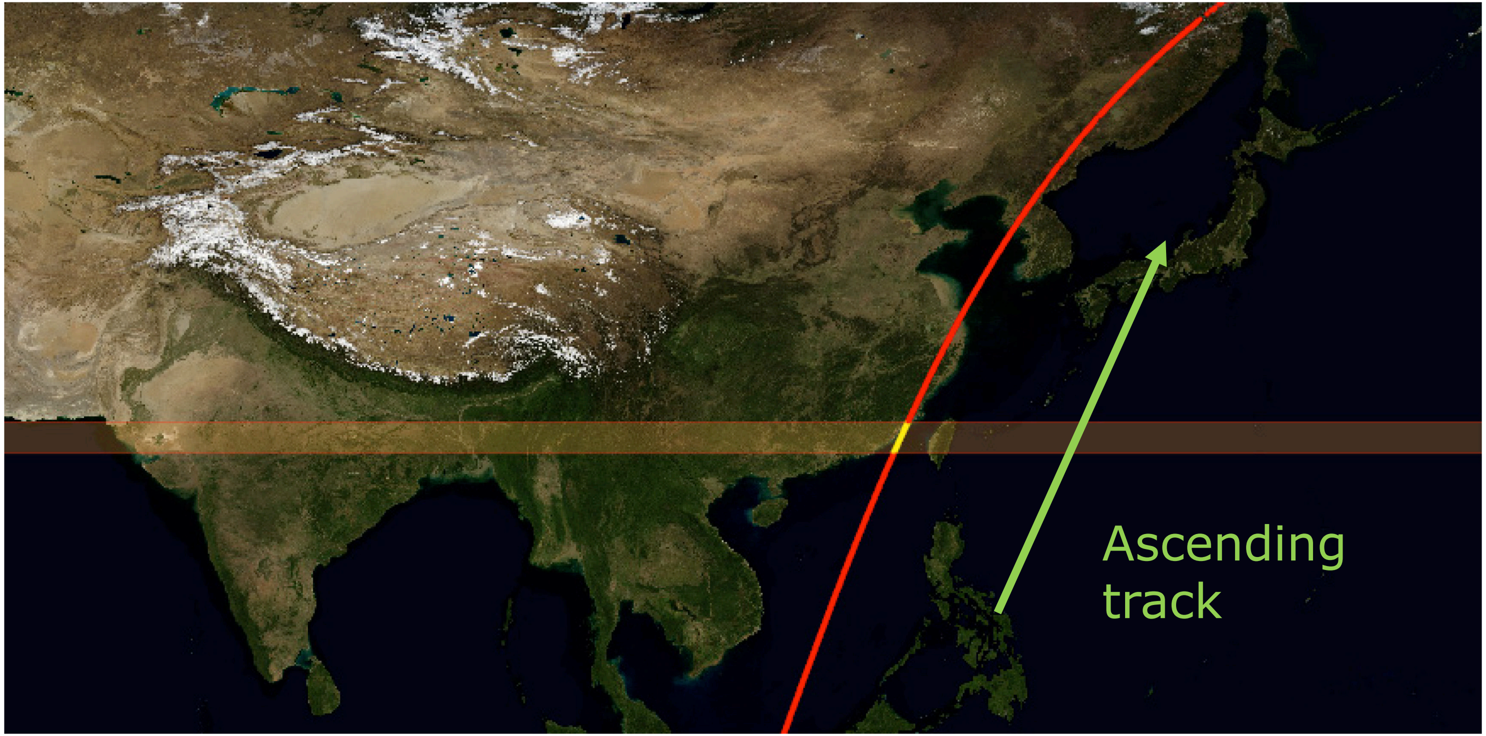


Filters (2)


BRAT - test
Workspace View Tools Window Help
Workspace Elements
Datasets RADS Datasets Filters Operations
Selected Filter Filter_0
Where
New Area Selection
Areas & Regions
UserArea_0
Max Lat (deg)
25
Min Lon (deg)
Max Lon (deg)
-180
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
Stop 2018.10.10 09:14:14
Start Cycle
Stop Cycle
Start Pass
Stop Pass
Use Relative Time (days)
Start -25119
Stop 0
Current DateTime
2018.10.10 09:14:14
Datasets_1
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 OSG version: 3.4.0 - 130 - OpenSceneGraph Library
[INFO] 2018-10-10T09:08:36 osgEarth version: 2.7.0 () - 0 - osgEarth Library
[INFO] 2018-10-10T09:08:36 QGIS version: 2.16.1-Nødebo
[INFO] 2018-10-10T09:09:02 %{lon}==lon %{lat}==lat %{time}==time

Goal

- Evaluating the quality of L1b waveforms in approaching the coast



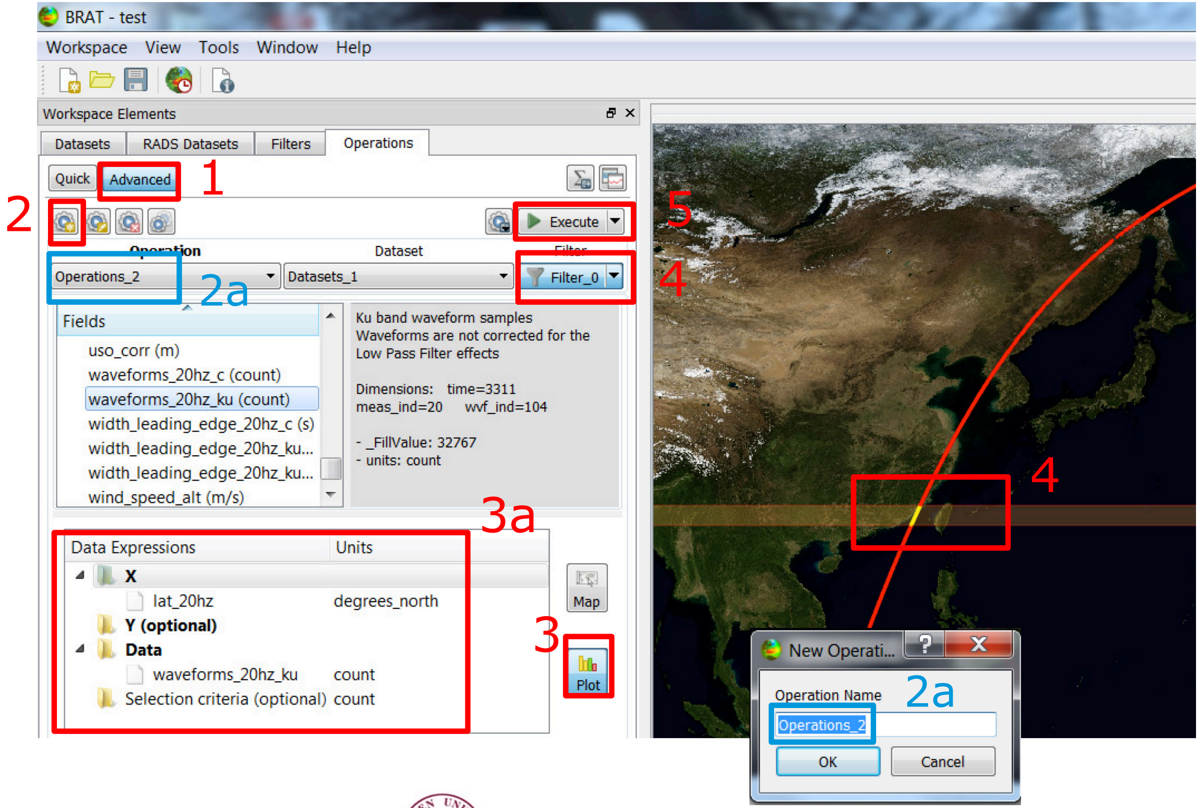
L1b waveforms in J2 SGDR products

- 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).

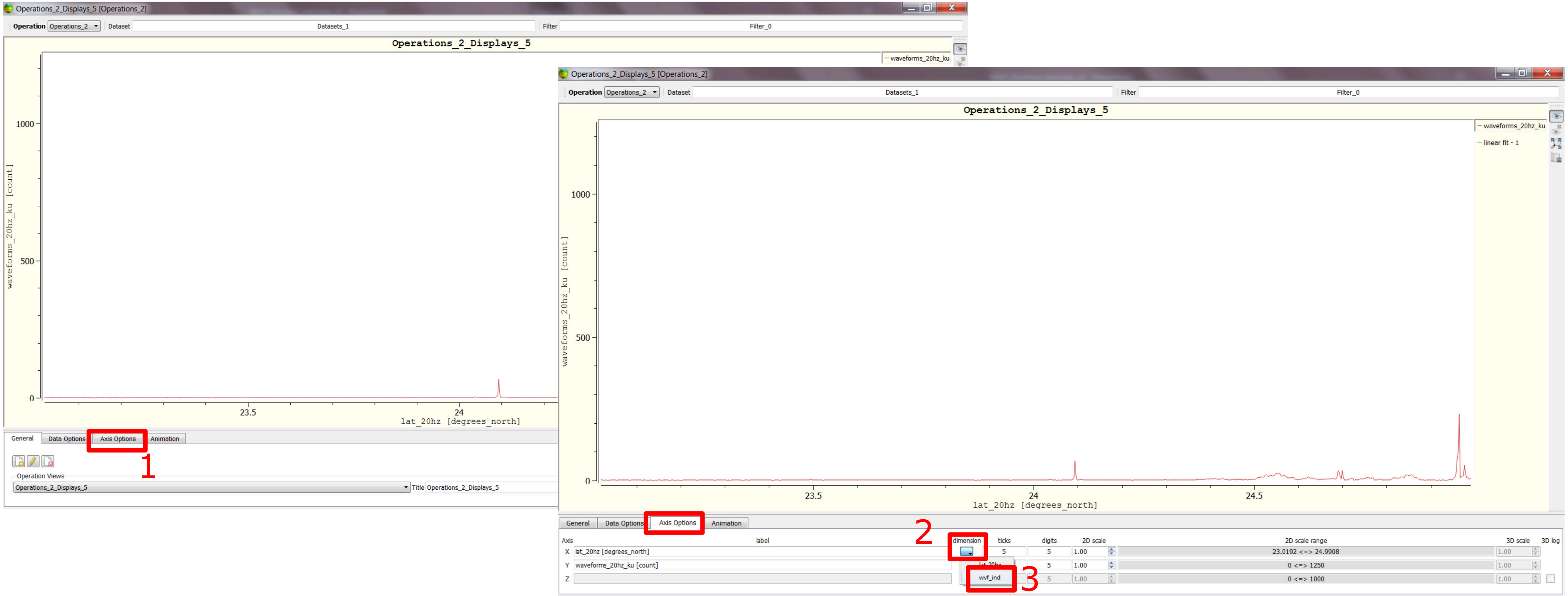
- 4: Select '**Filter_0**' (see the available filters by pressing ↓). The part of the track selected will be evidenced in yellow.

- 5: Click on '**Execute**' to visualize the selected 'waveforms_20Hz_ku' field .



L1b waveforms in J2 SIGDR products (2)

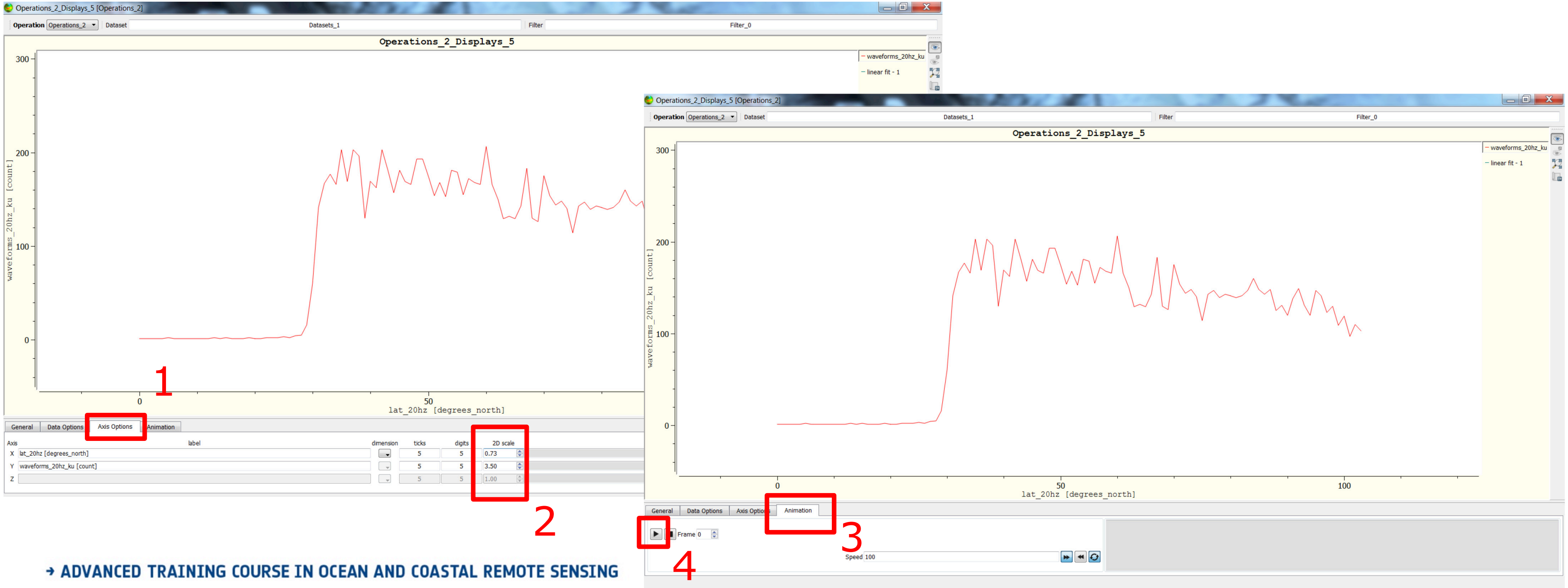
- Follow step 1-3 to correctly set the axis and the 2D scale



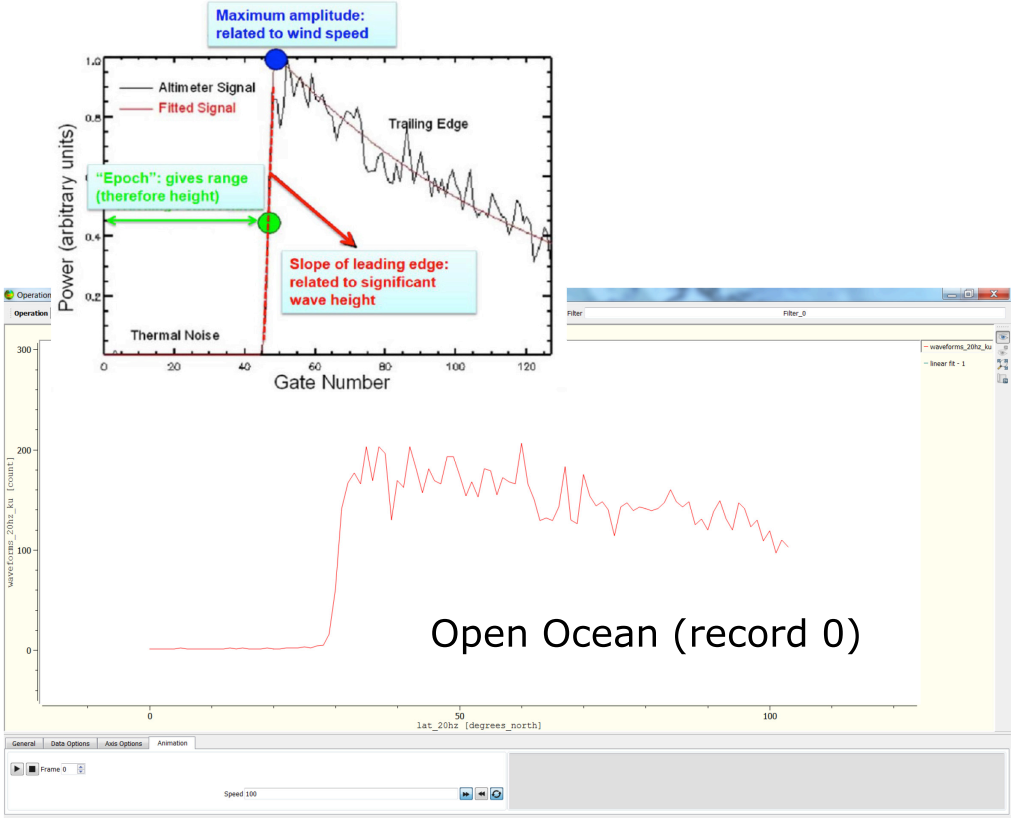
Animation of L1b waveforms while approaching the coast

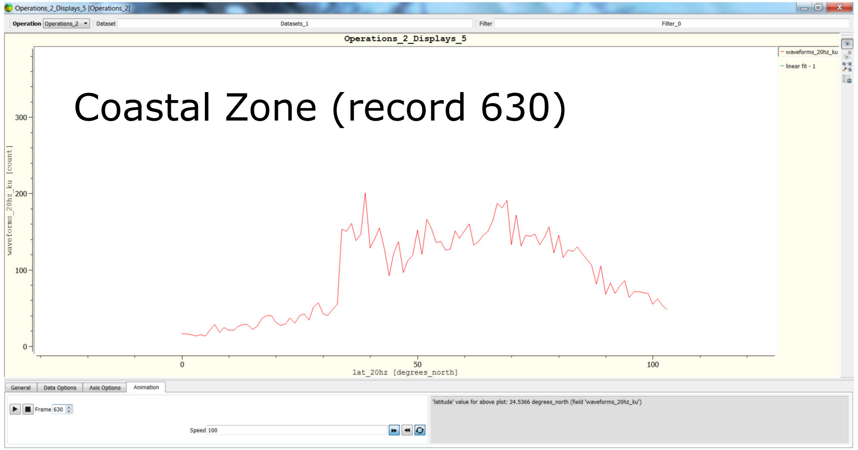
- Follow steps 1-4 to correctly display the dynamic of the waveform and start the animation showing the L1b waveforms in approaching the coast.

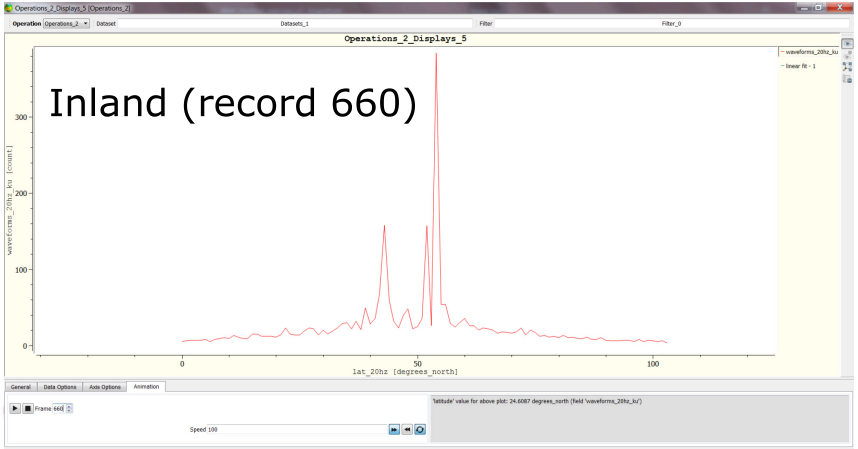
- Use the mouse (wheel & right button to centre the waveform & zoom in/out)



Comparing L1b waveforms







Practical n.2: Results from different Retrackers

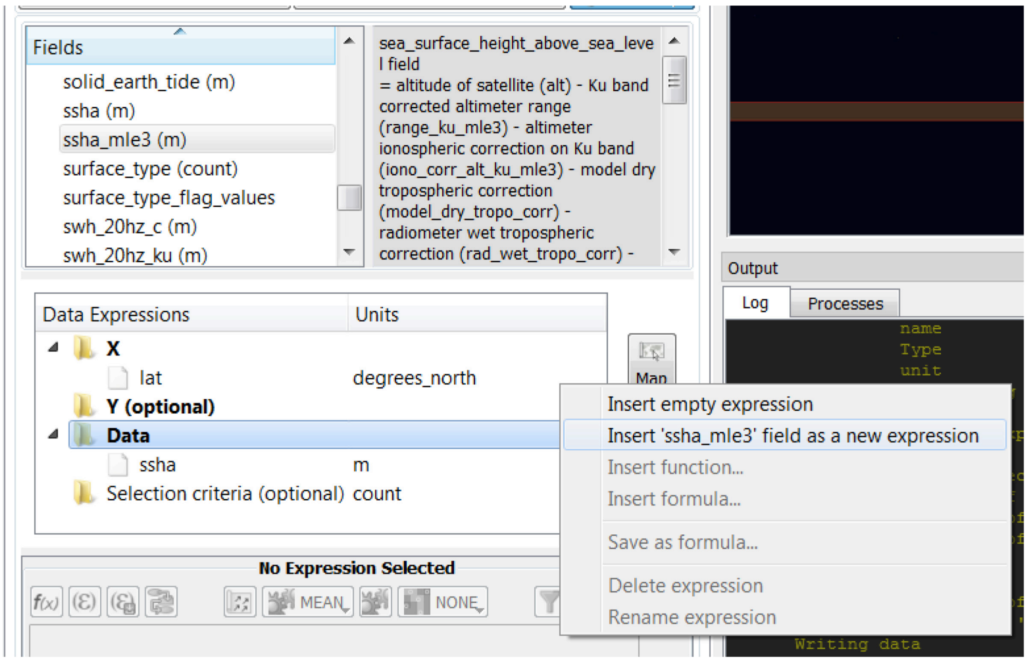
- Using the same operation close the current plot and delete (right click on the name) the 'X' & '**Data**' fields (lat_20hz & waveforms_20hz_ku).

- Drag and drop '**lat**' in '**X**' insert the following '**Data**' fields:

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

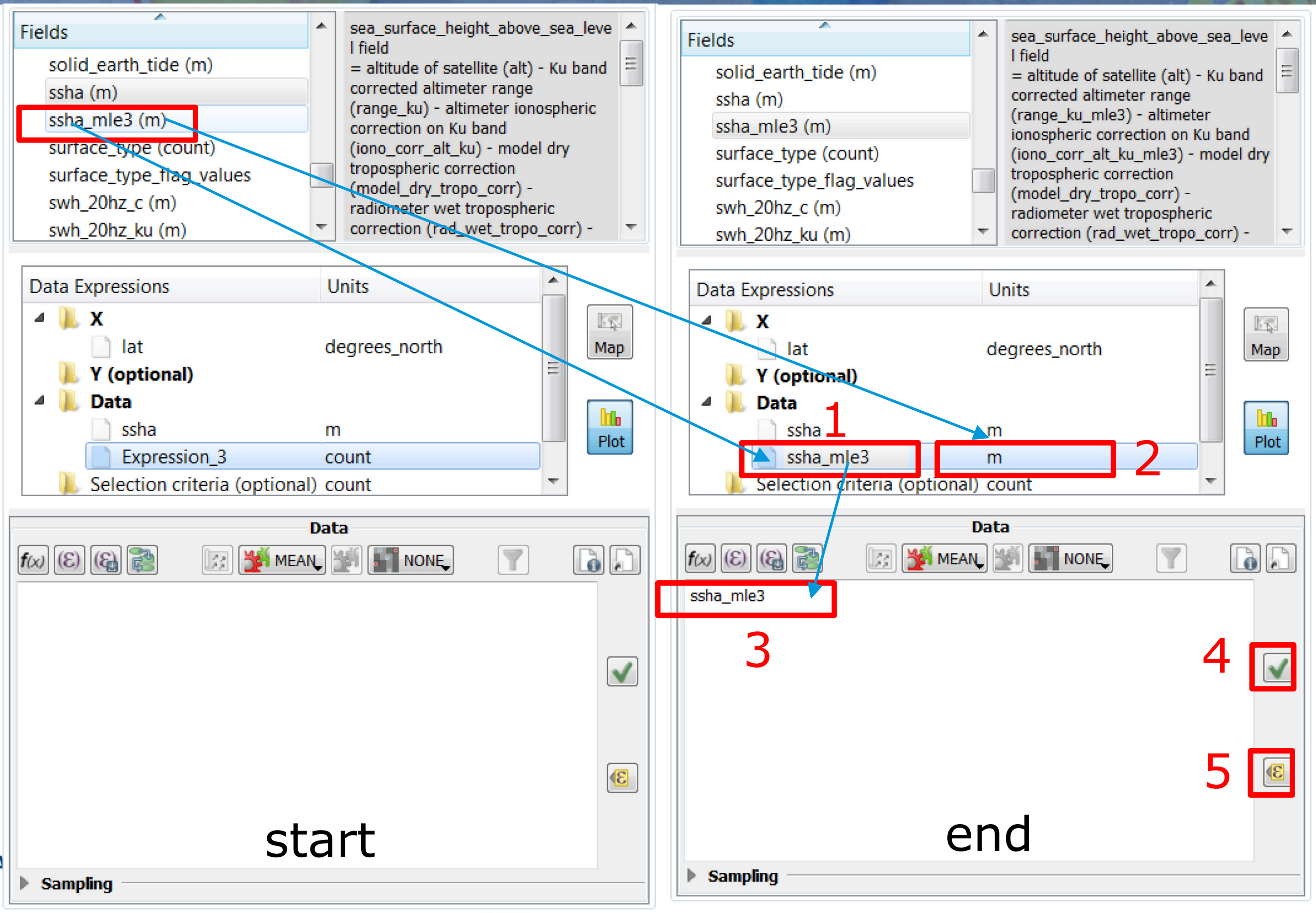
2. **ssha_mle3**: by creating a new expression (right click on '**Data**'), two options appear.

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



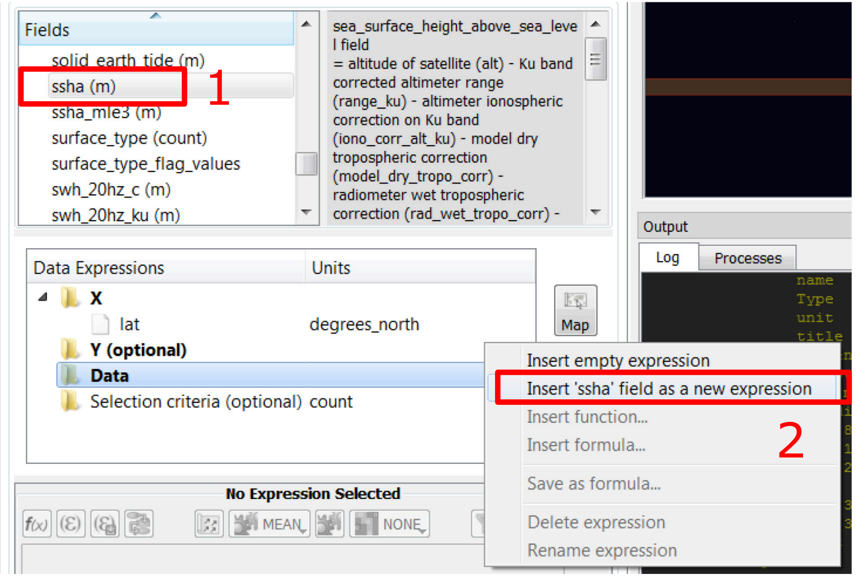
Case 1: Empty Expression (used later for Formulas)

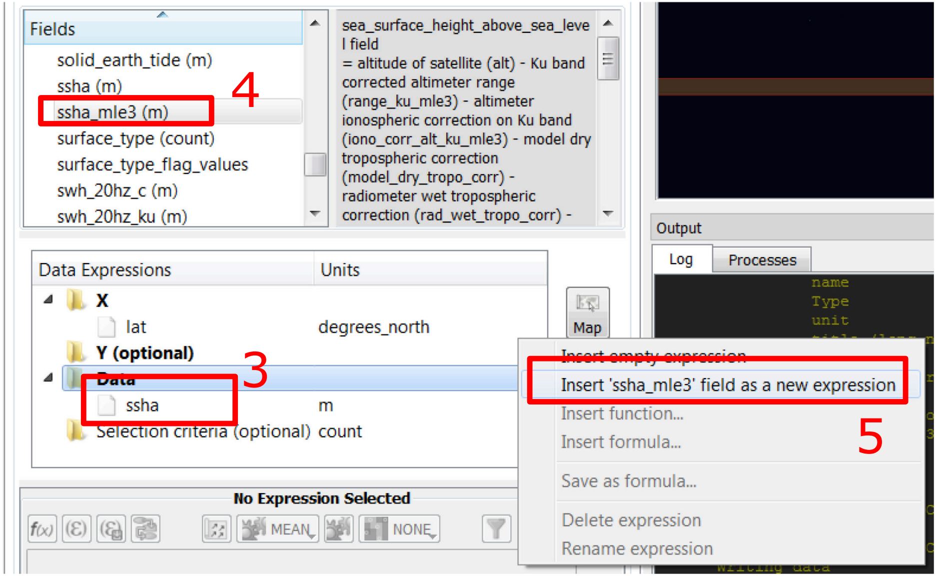
- 1-3: Modify (by double click on the name) ‘**Expression_3**’, its **associated box** and ‘**count**’ to match the Field ‘**ssha_mle3(m)**’
- 4: Before proceeding check the correctness of the name/formula in the box by clicking on ✓
- 5: The save the expression be pressing ◁ε
- **If the expression is not saved an error occurs!**



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).

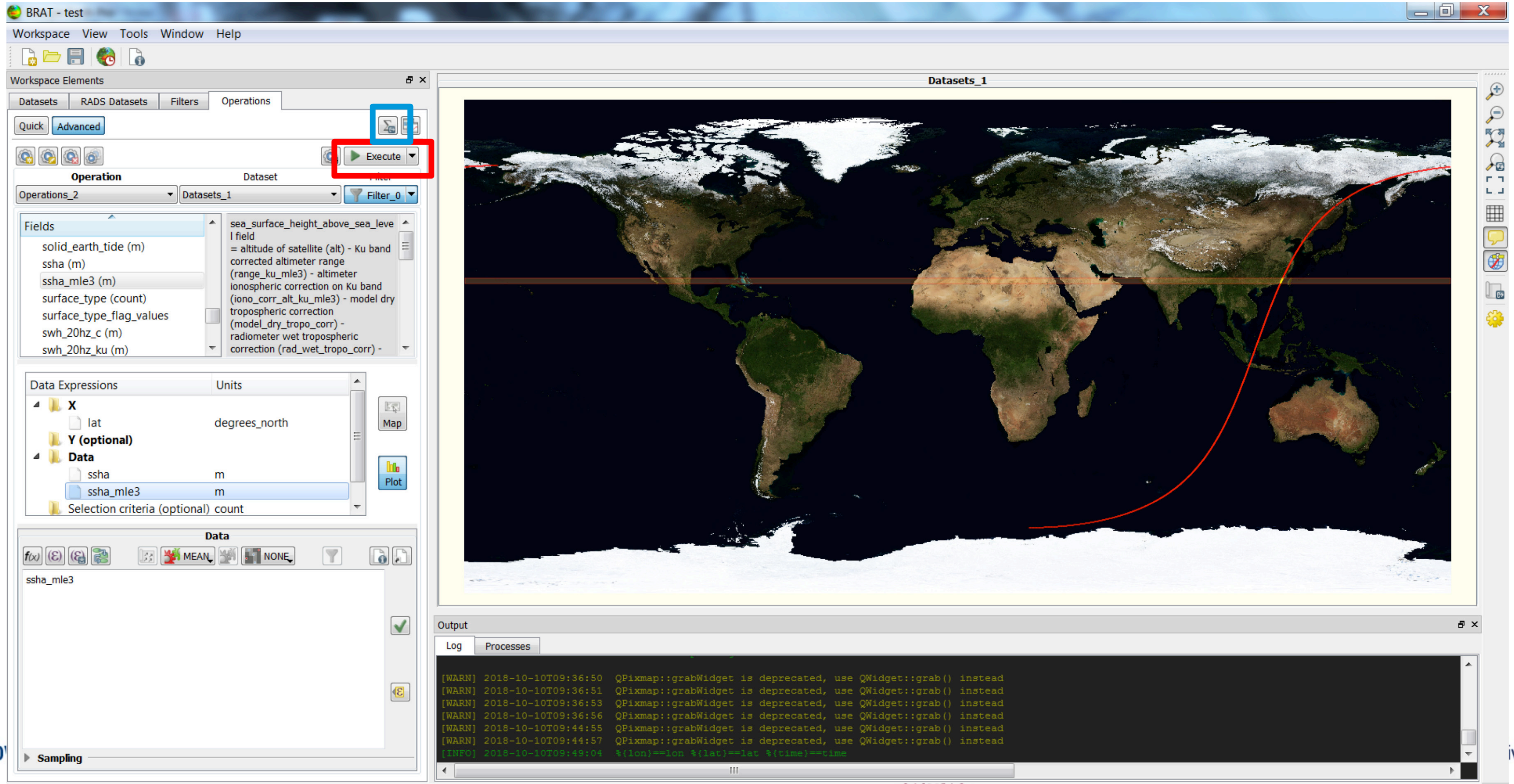




- **This method can only be applied when no formulas (using more data fields) are considered!!!**

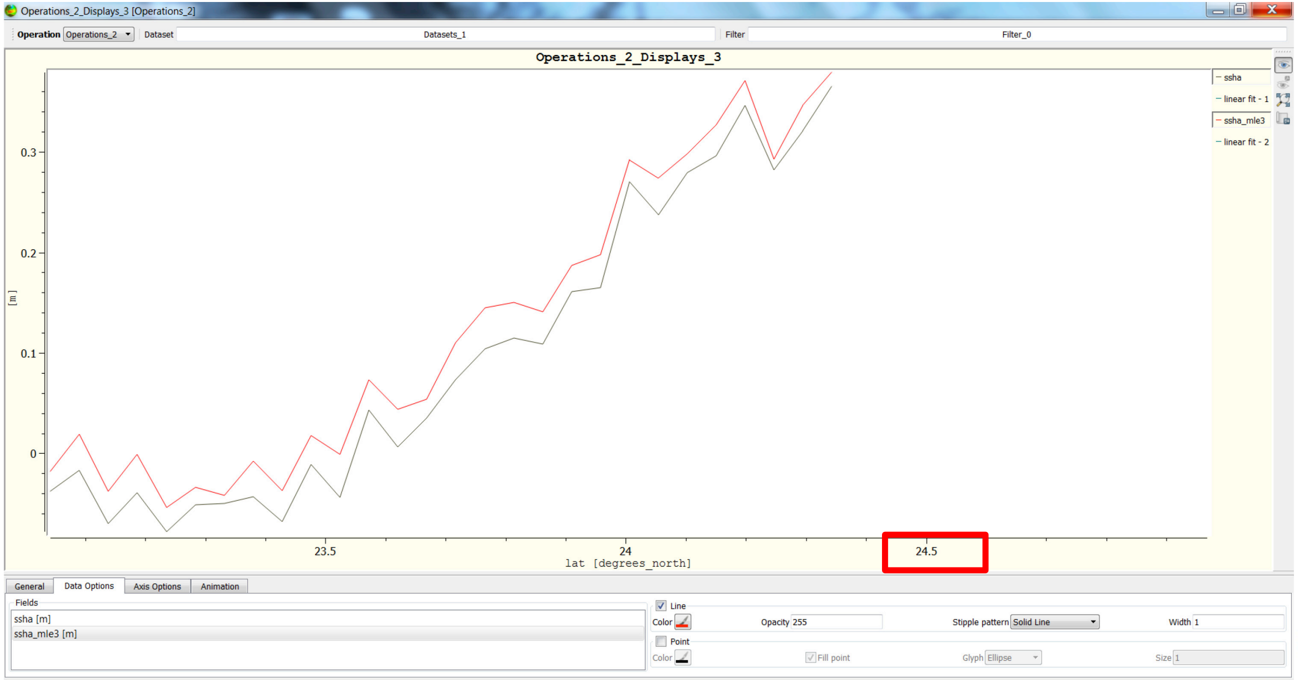
Practical n.2: Results from different Retrackers (3)

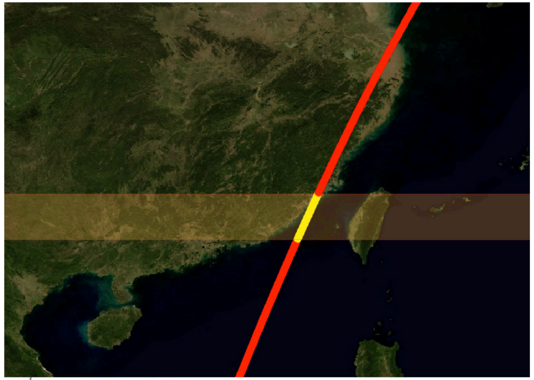
2 Runs: Execute (plot) & Σ icon (to calculate statistics)

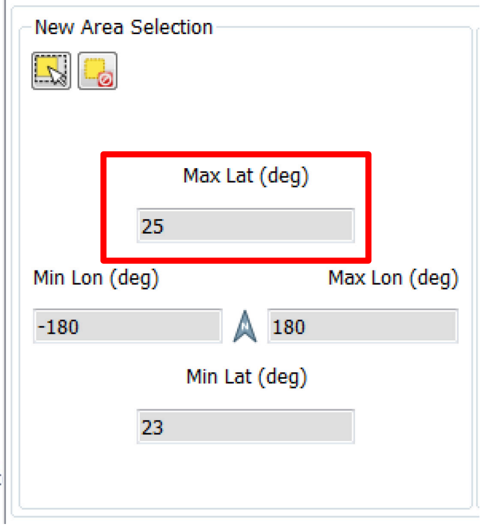


Practical n.2: Results from different Retrackers

- 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.



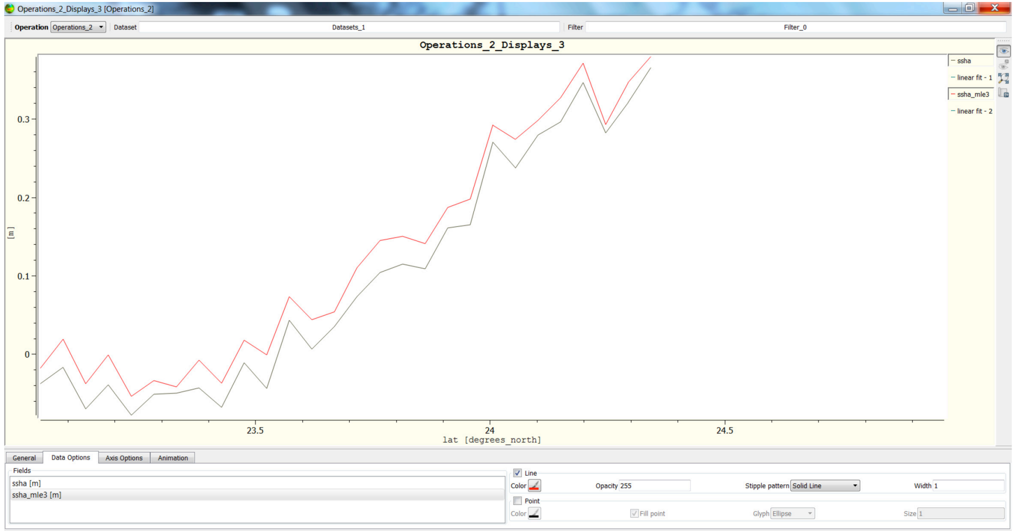




12 t

Practical n.2: Results from different Retrackers (4)

- The results of the statistics are the following



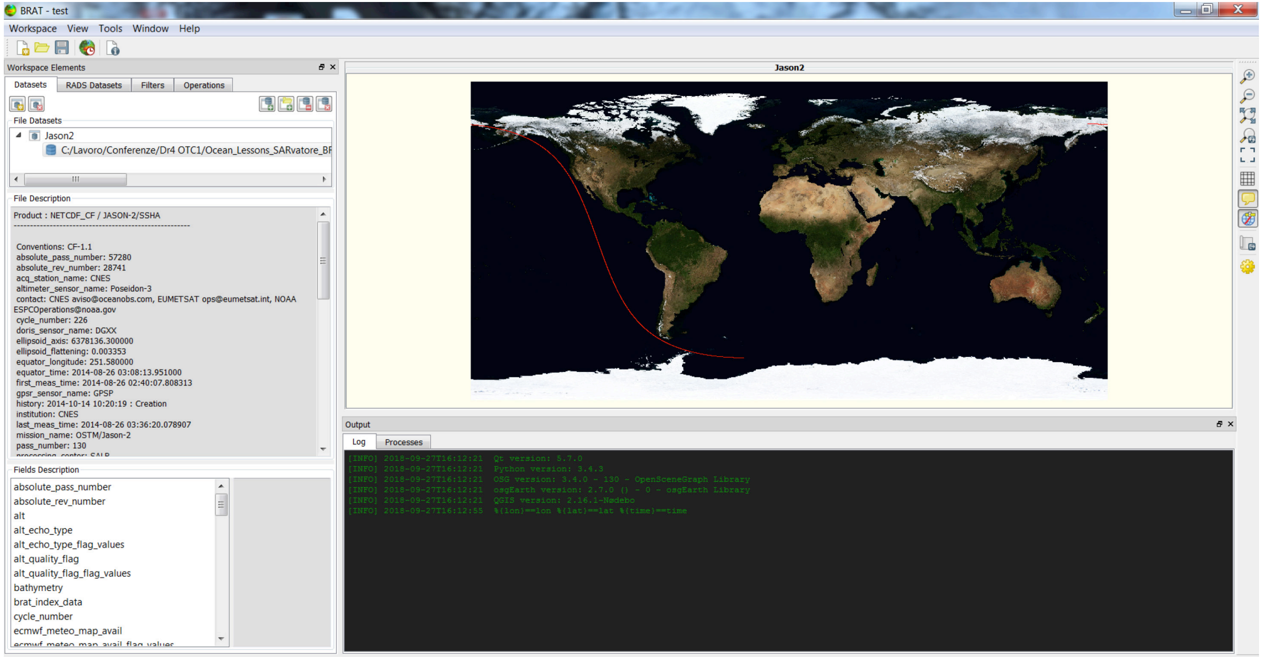

```
[WARN] 2018-10-10T10:02:12  Stats_Operations_2 :
         ==========================
         Result for 'ssha'
         ==========================

[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) & Σ icon produce netCDF and txt files as output products.

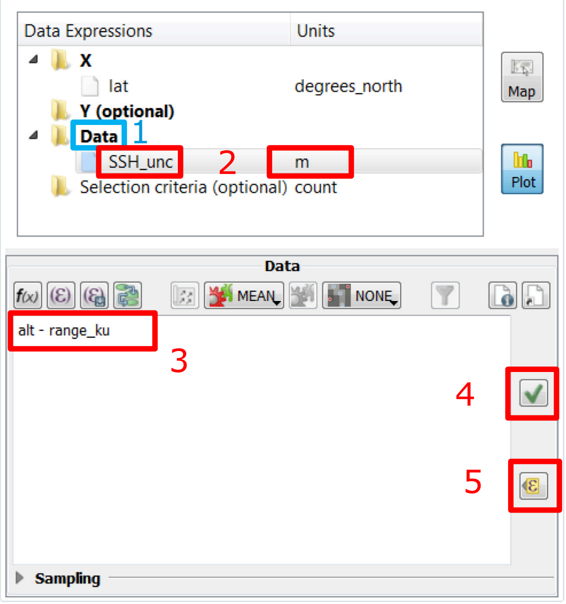
Practical n.3: The Uncorrected Sea Surface Height (SSH)

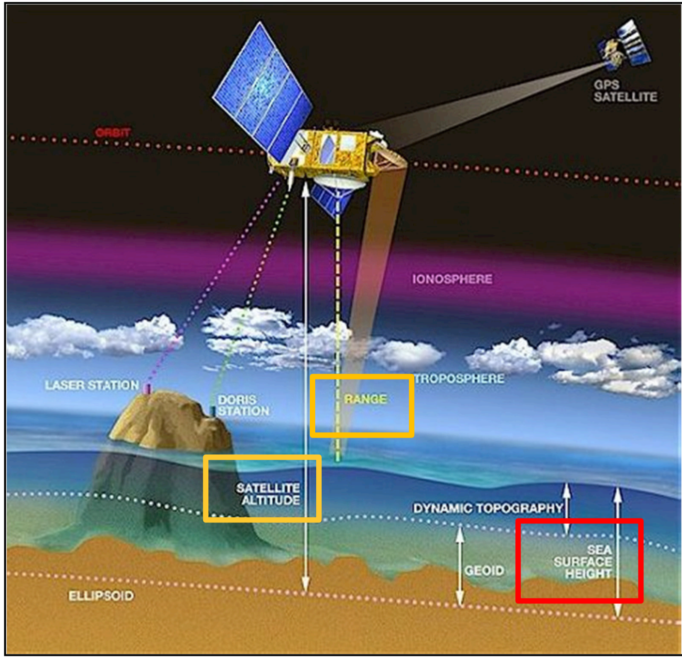
Folder: J2 (also in the BRAT DEMO Folder)

Track used: JA2_GPR_2PdP226_130_20140826_024007_20140826_033620.nc

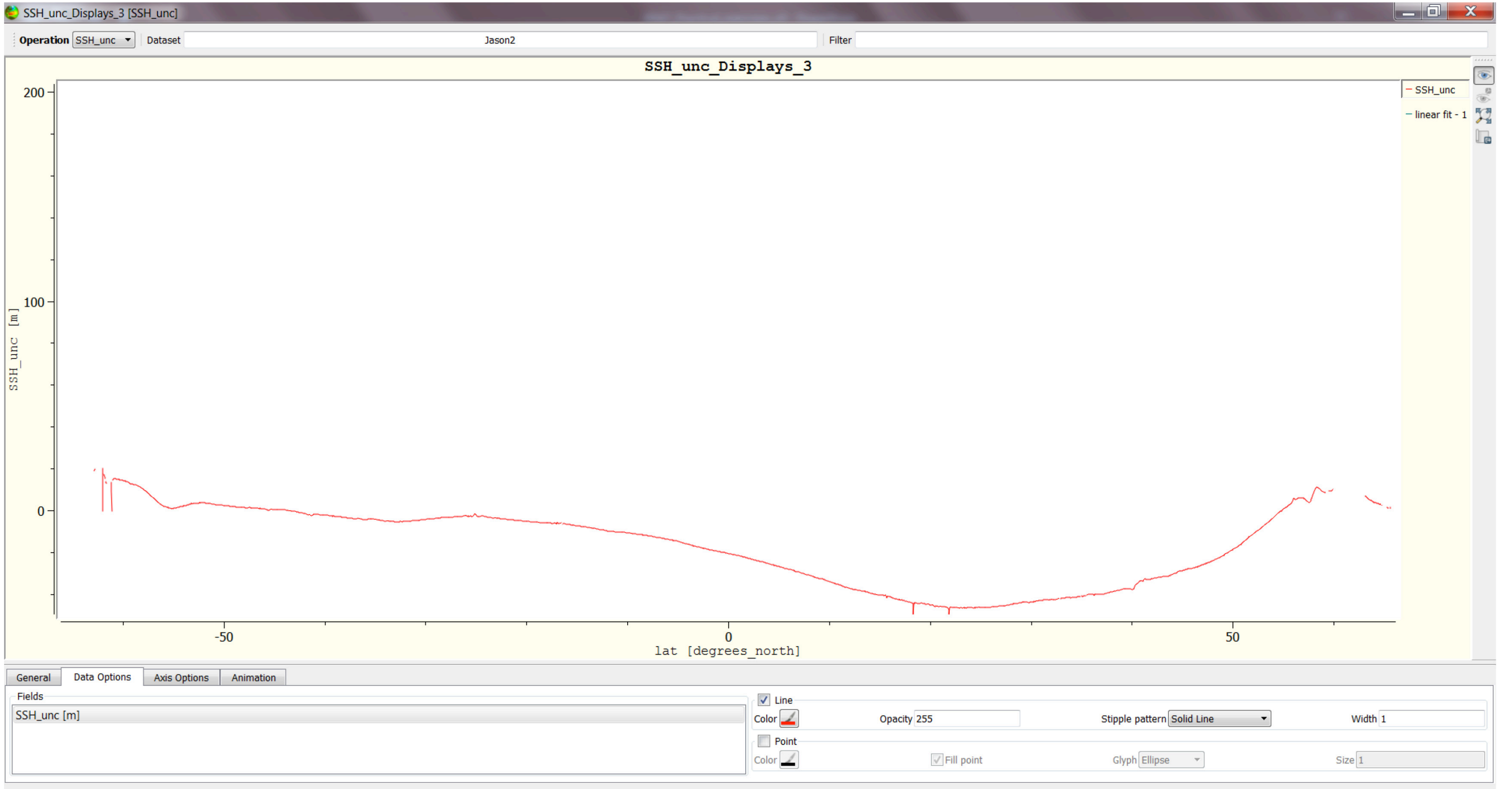


- Quantity derived from the altitude and the range not including the geophysical corrections.
- Create an "**Empty expression**" (right click on 'Data'). We name it '**SSH_unc**' and put 'm' as Units.
- The **formula** to be inserted is '**alt –range_ku**' [m].
- Check the correctness of the formula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



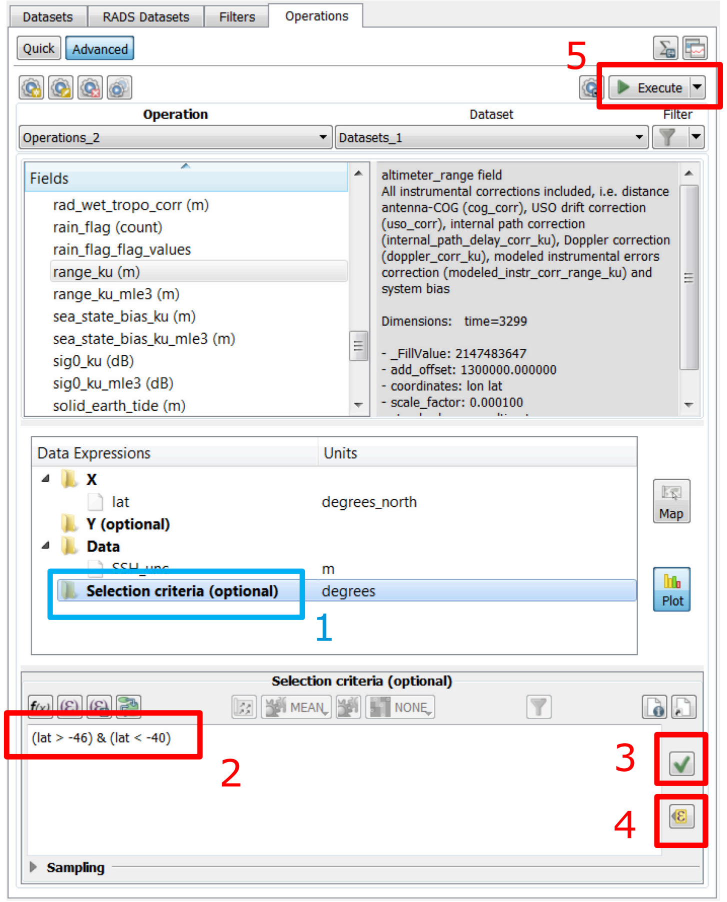


The Uncorrected Sea Surface Height (SSH) (2)

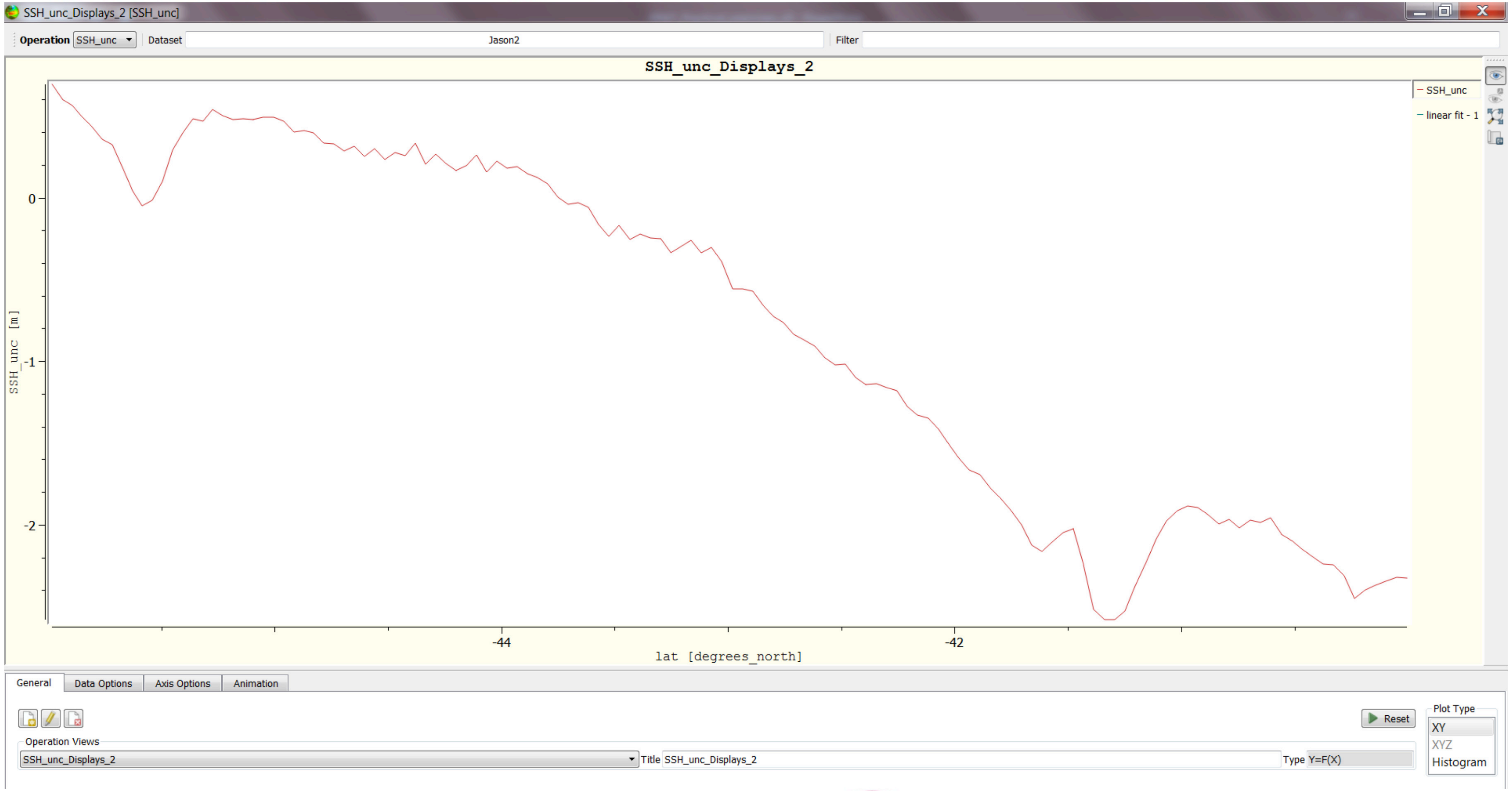


Filtering in Latitude (using Selection Criteria)

- 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 ◁ε.
- Click on "**Execute**" to plot the filtered trend.

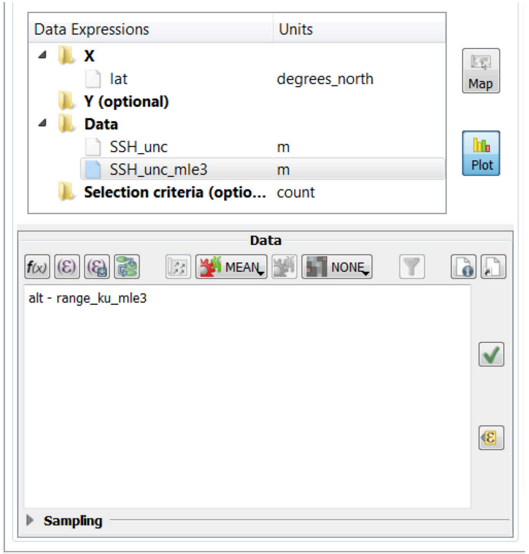


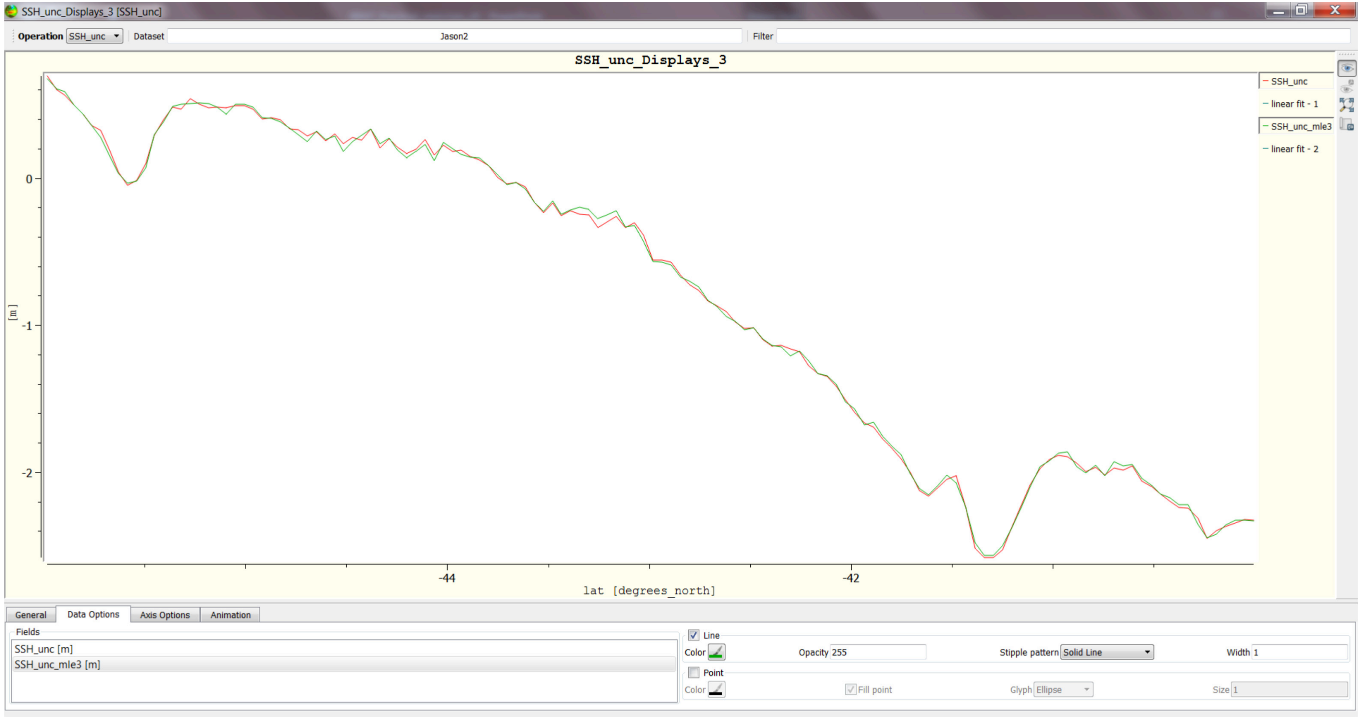
Filtering in Latitude (using Selection Criteria)



Comparing outputs from 2 Retrackers

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





Impact of Geophysical Corrections on SLA

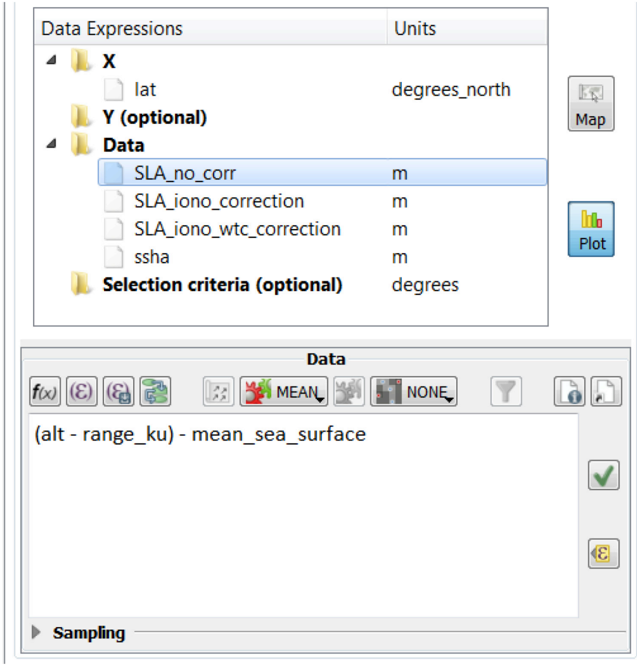
- Using the same input file, we evaluate the impact of geophysical corrections on SLA (= SSH-MSS).

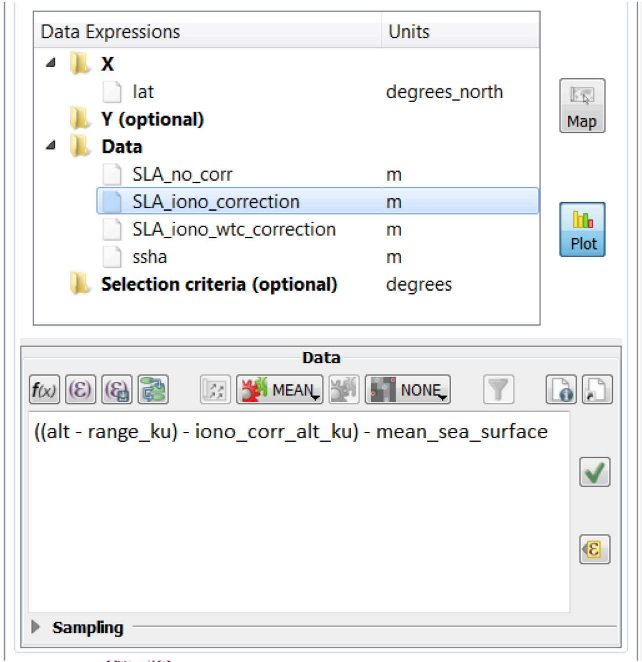
- We compare the SLA obtained with the uncorrected SSH (no geo corrections applied) to the SLA obtained with: 1) a few corrections (ionosphere and WTC) and 2) all corrections applied.

- 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.

Impact of Geophysical Corrections on SLA (1)

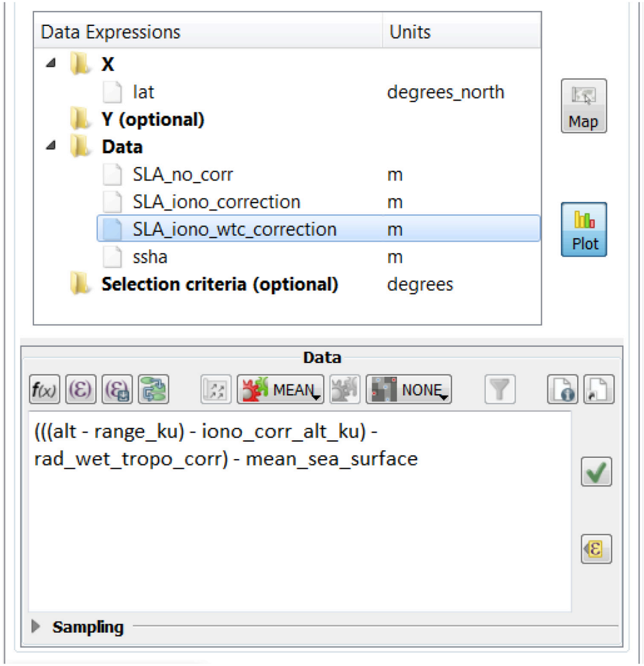
- By using the same product, we create the following plot composed of 4 expressions named and formulated as follows:

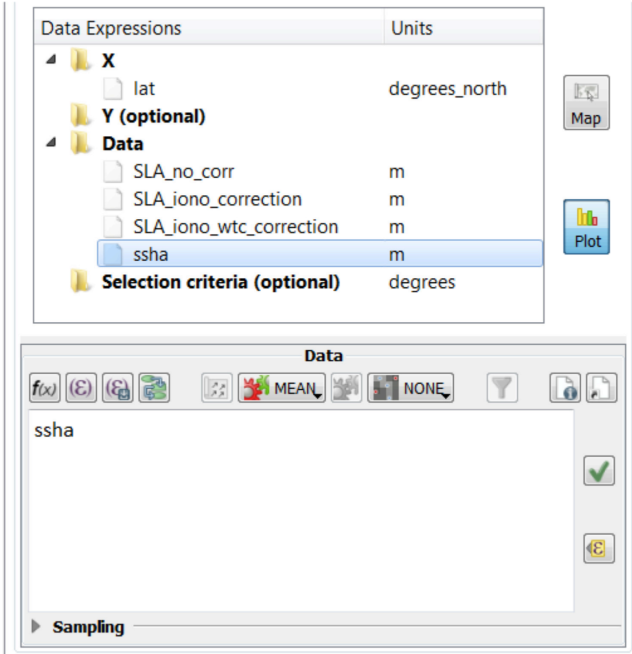




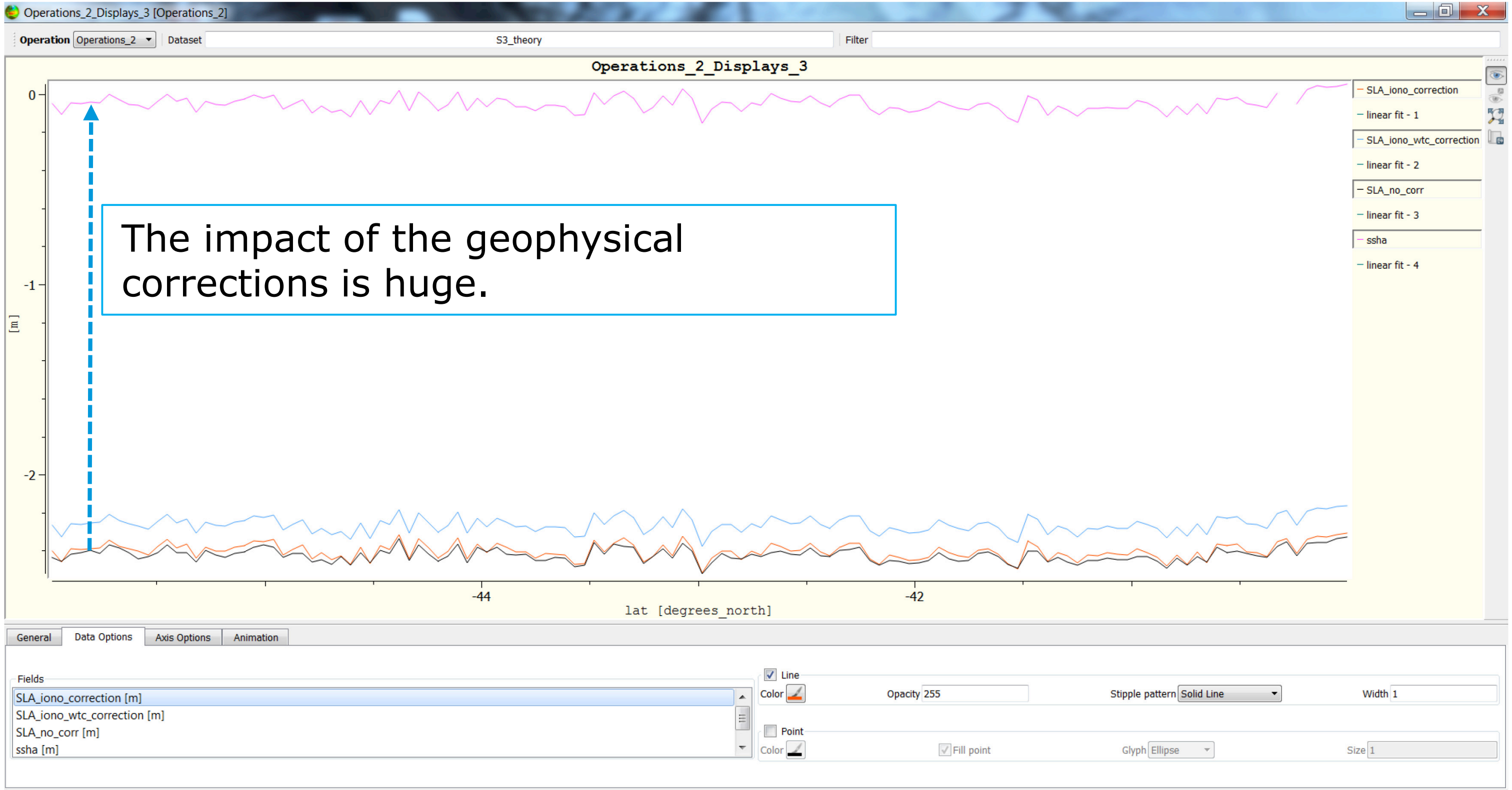
Impact of Geophysical Corrections on SLA (2)

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





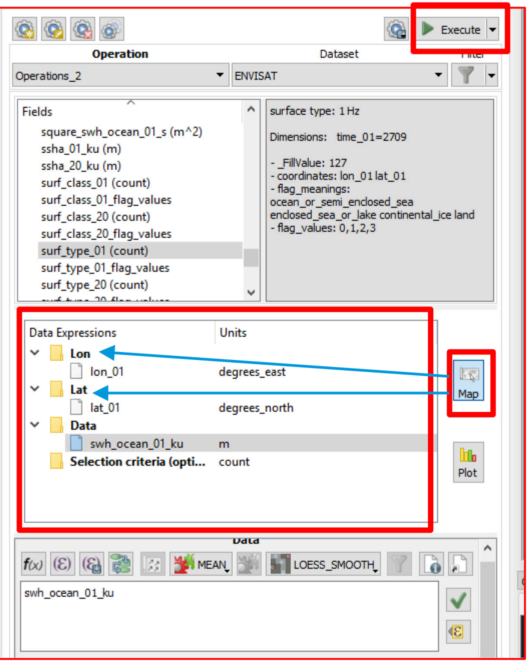
Impact of Geophysical Corrections on SLA (3)

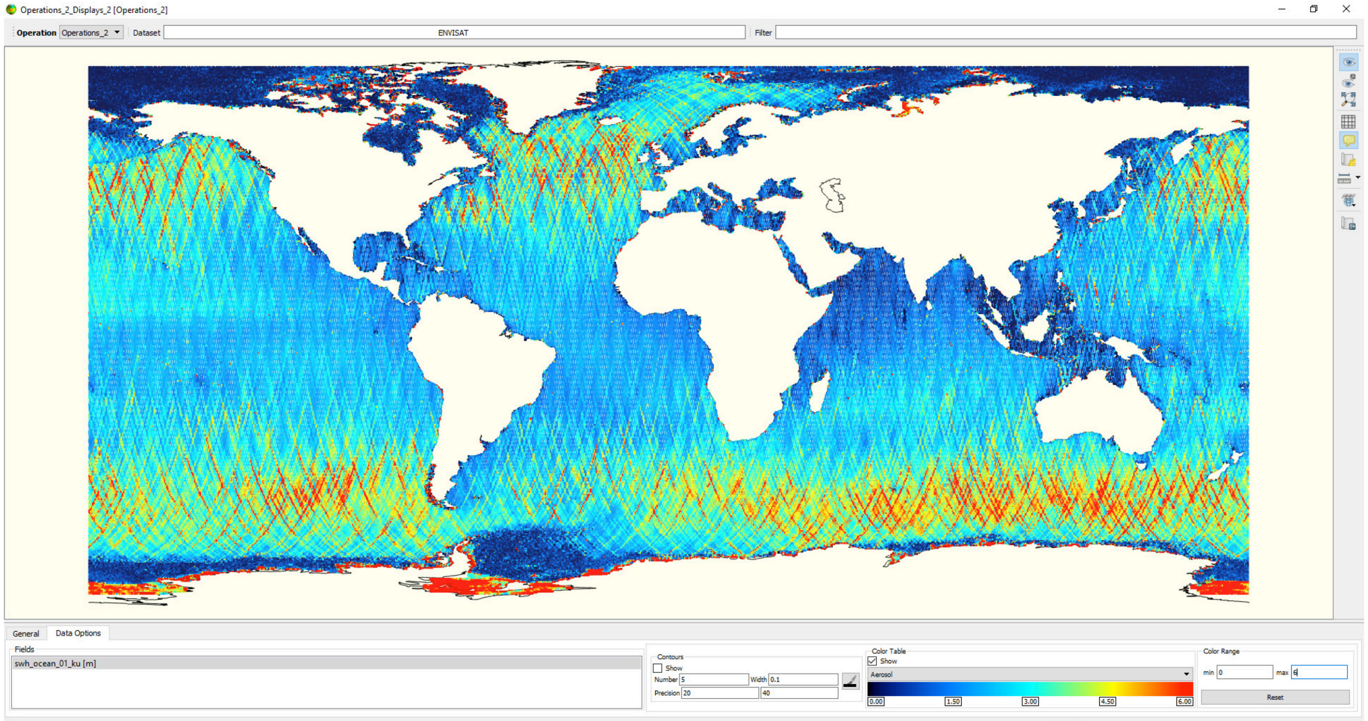


Impact of Geophysical Corrections on SLA (4)

Global SWH (no filtering)

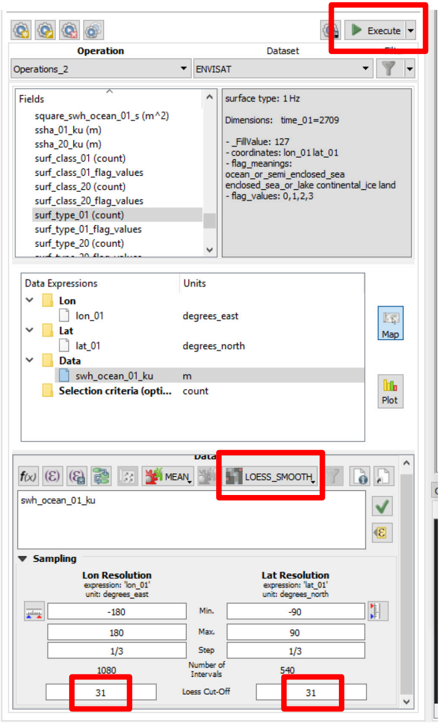
- Input data: ENVISAT (Cycle 25). Plot data using the MAP (lat, lon) option.
- All fields are at 1 Hz (lon_01, lat_01 & swh_ocean_01_ku)

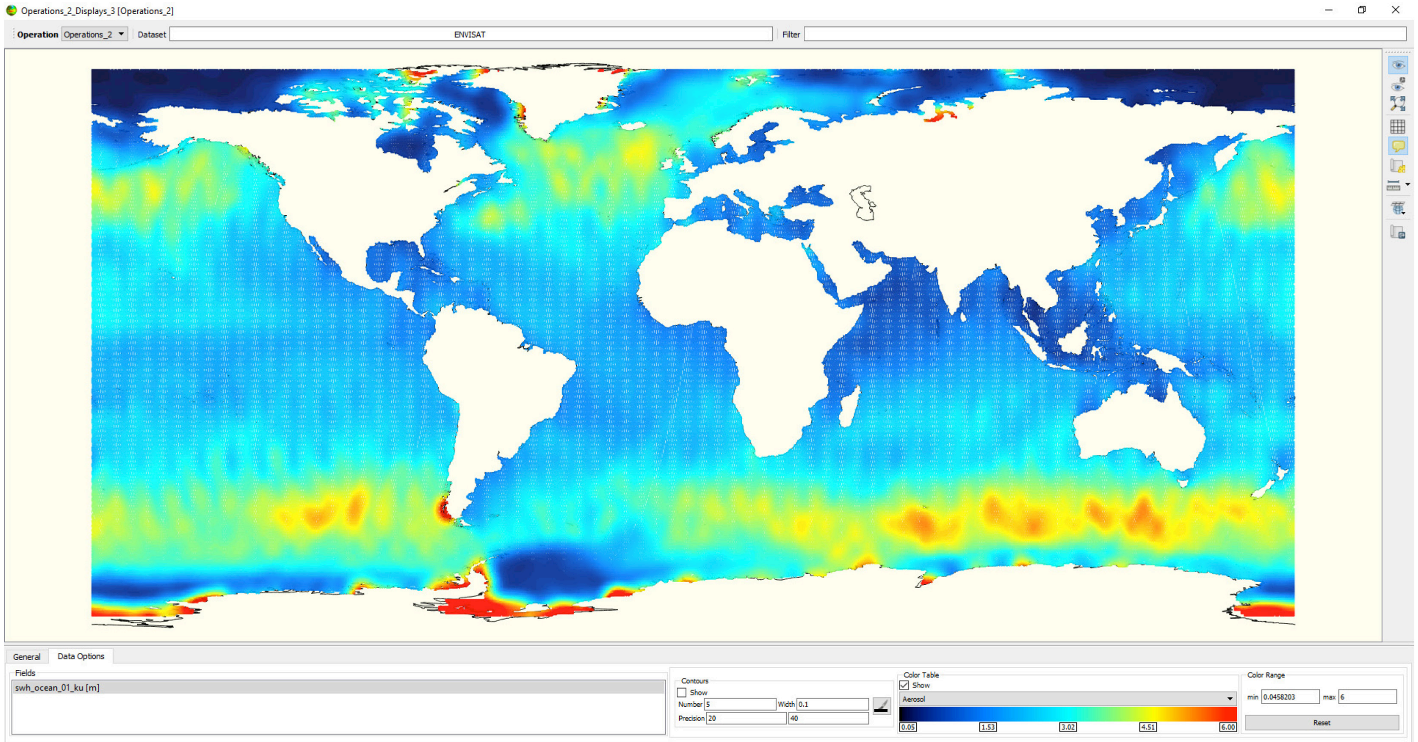




Global SWH (Loess Smooth Filtering)

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:





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

- **Typhoon Maria** was a powerful tropical cyclone that affected Taiwan & China.

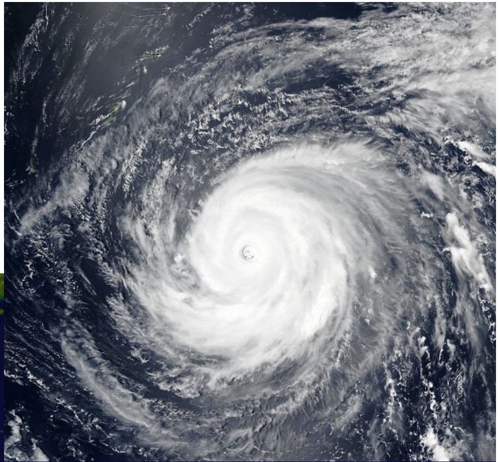
- The typhoon reached its first peak intensity on July 6; subsequently, Maria weakened due to an eyewall replacement cycle, but it re-intensified and reached its second peak intensity on July 8.

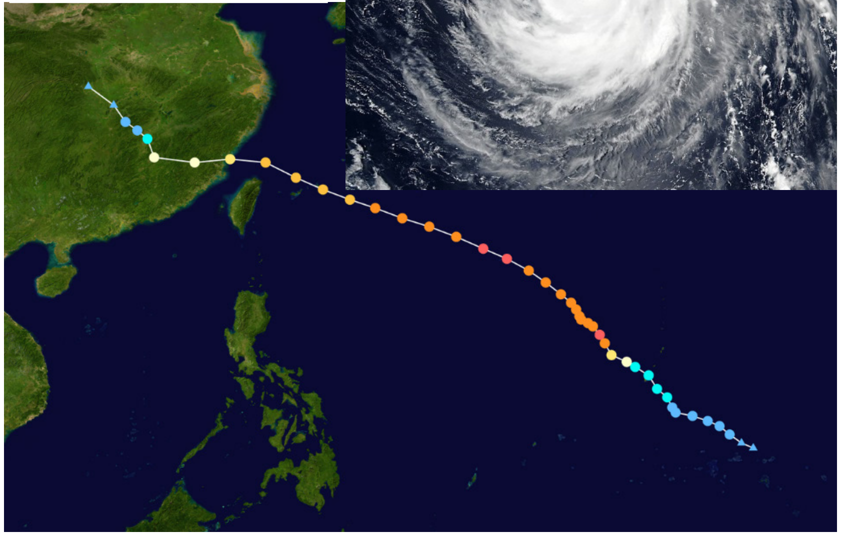
- Later, it started to gradually weaken due to colder sea surface temperatures.

- 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)

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

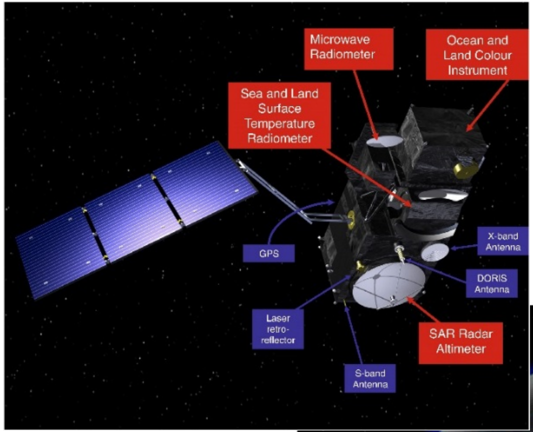
- S3A_SR_2_WAT____20180710T013336_20180710T021747_20180804T173801_2651_033_174______MAR_O_NT_003.SEN3 (also available in SARvatore with a useful .kml track file).

- 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.



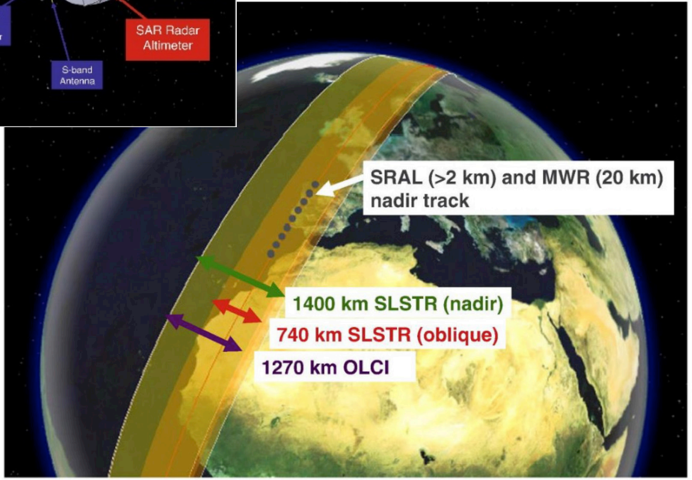
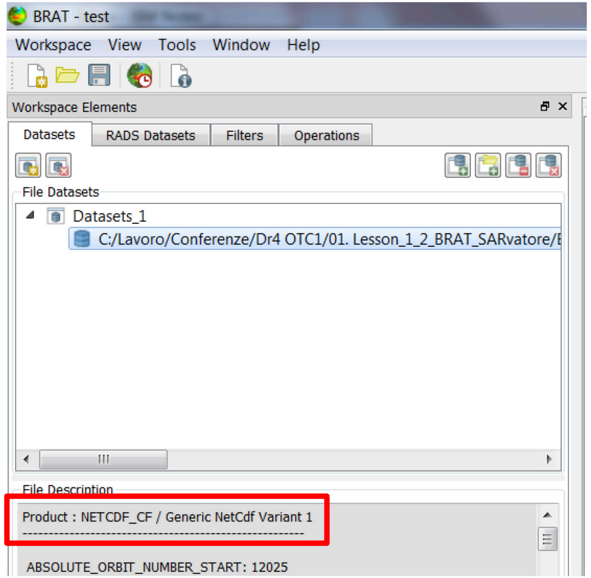


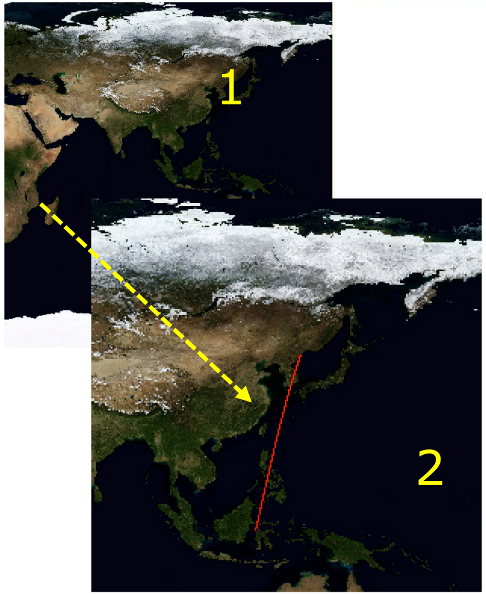
Figure 1-3: SENTINEL-3 Ground Track Resolution (Credit: ESA)

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:

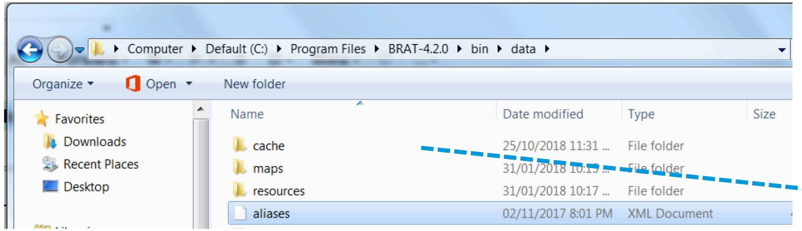
- In opening the product in BRAT, the netCDF file is associated with the **NETCDF_CF / Generic NetCdf Variant 1_** format.





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.

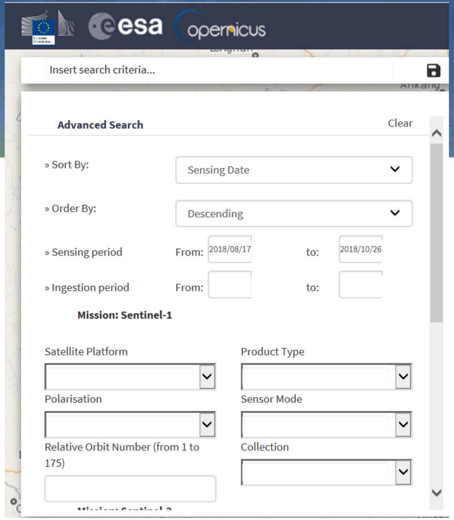
Sentinel-3 Data Access

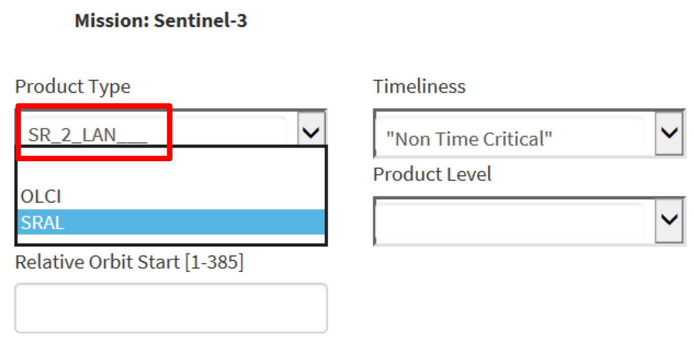
- **L2 Sentinel-3 altimetry data** from SRAL are available in two flavors:

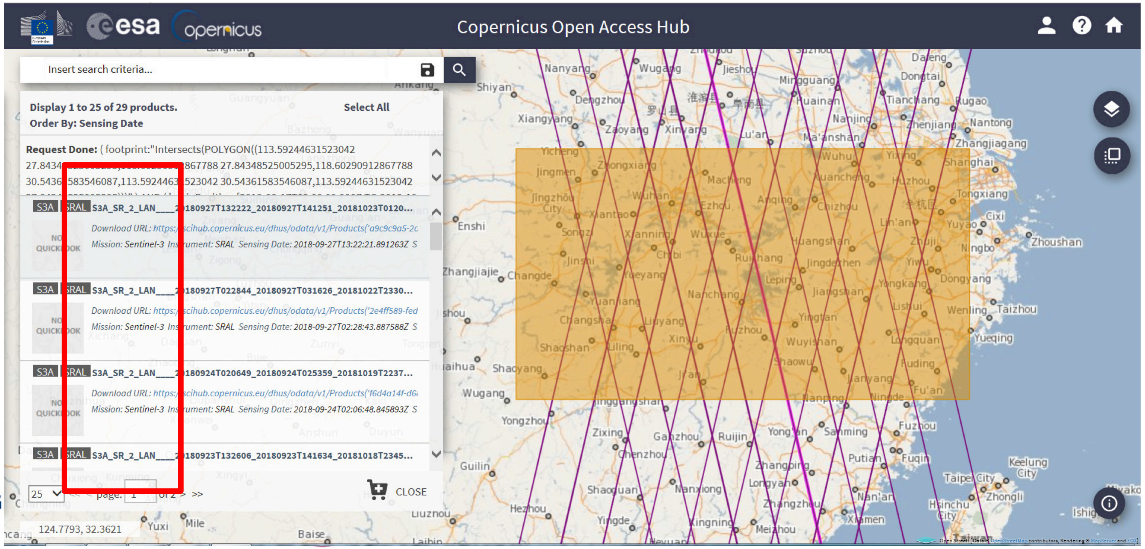
- Land Products “**S3A_SR_2_LAN_XXX**” (distributed by ESA at **https://scihub.copernicus.eu/dhus/#/home)** including inland water areas & coastal zone.

- Water Products “**S3A_SR_2_WAT_XXX**”(distributed by EUMETSAT at **https://coda.eumetsat.int/#/home**) including coastal zone & open ocean.

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

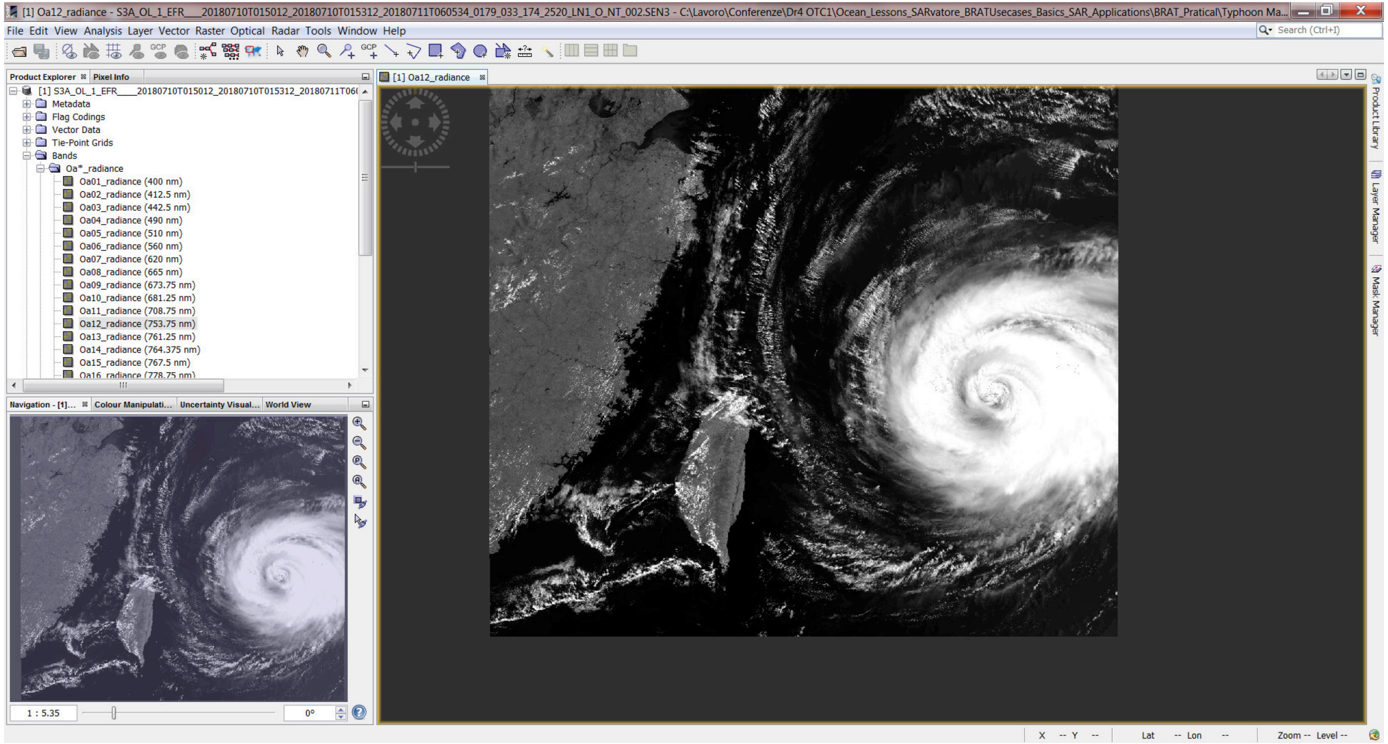






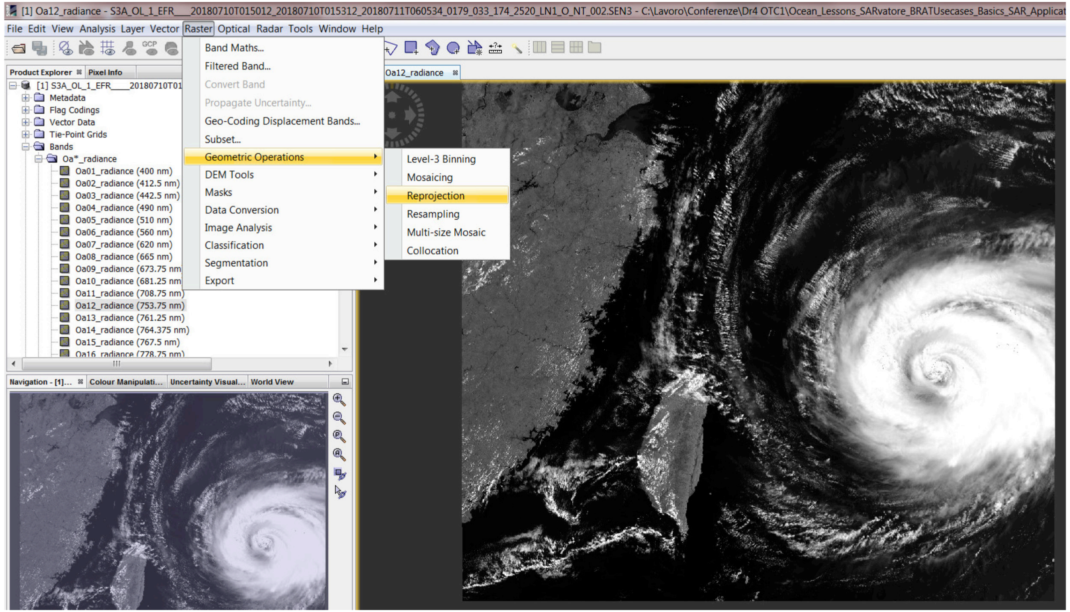
Practical n.4: Typhoon Maria (OLCI & S3-A) (3)

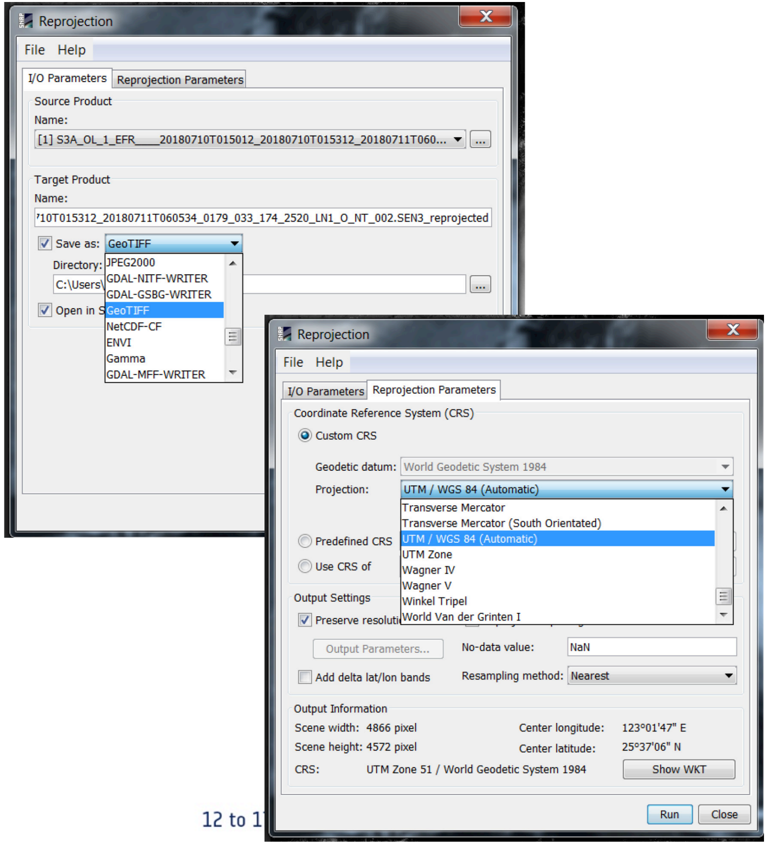
- The OLCI product can be opened in SNAP (open the xfdumanifest.xml file).



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

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





Practical n.4: Typhoon Maria (OLCI & S3-A) (5)

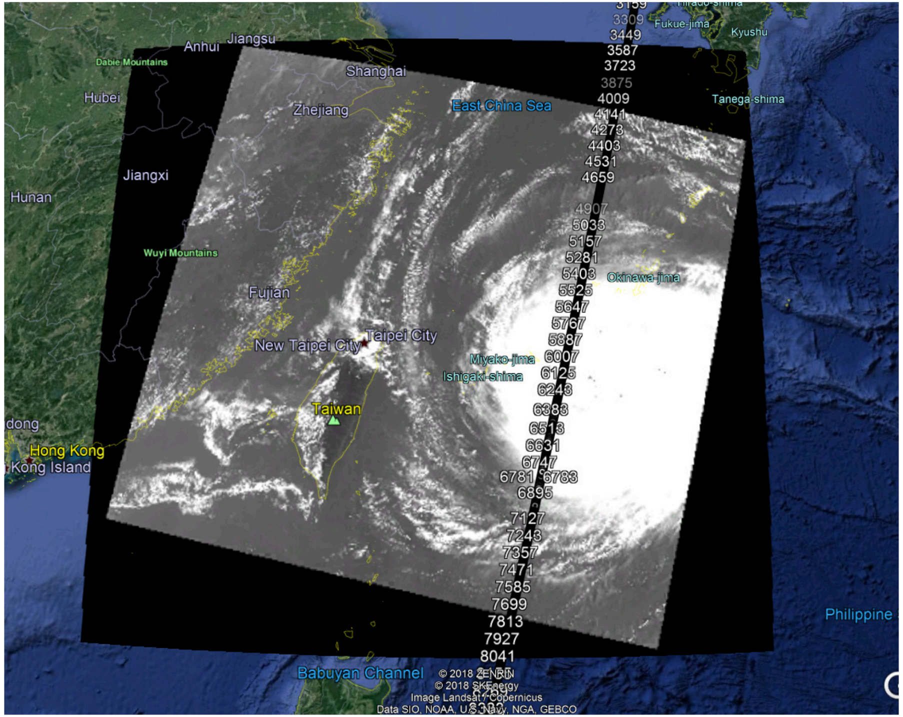
- Once the GeoTiff is created, it can be opened in Google Earth along with the **.kml of the S3A track available in SARvatore (folder: Typhoon_Maria\GPOD\Typhoon_detected)**.

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

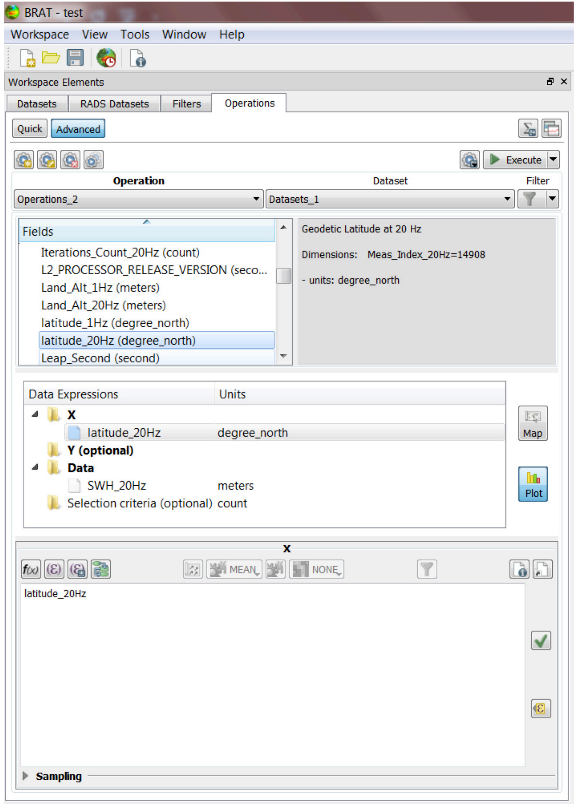
- Variation in SWH, SLA, wind speed and Sigma0 are expected in comparison to the typical case (no typhoon).

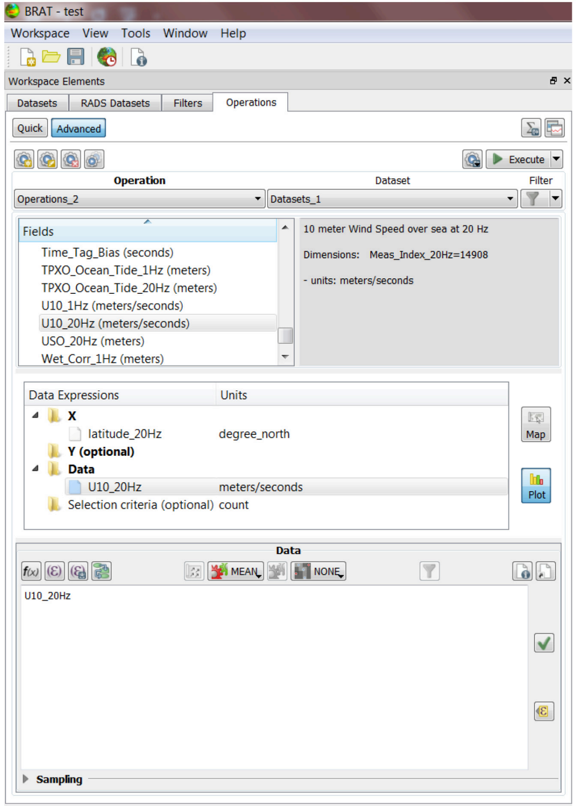
- We compare with a track acquired one month before the event:

- RES_S3A_SR_1_SRA_A__**20180609**T013721_20180609T022751_20180704T225338_3029_032_117_GPOD_SAR_O_NT_003

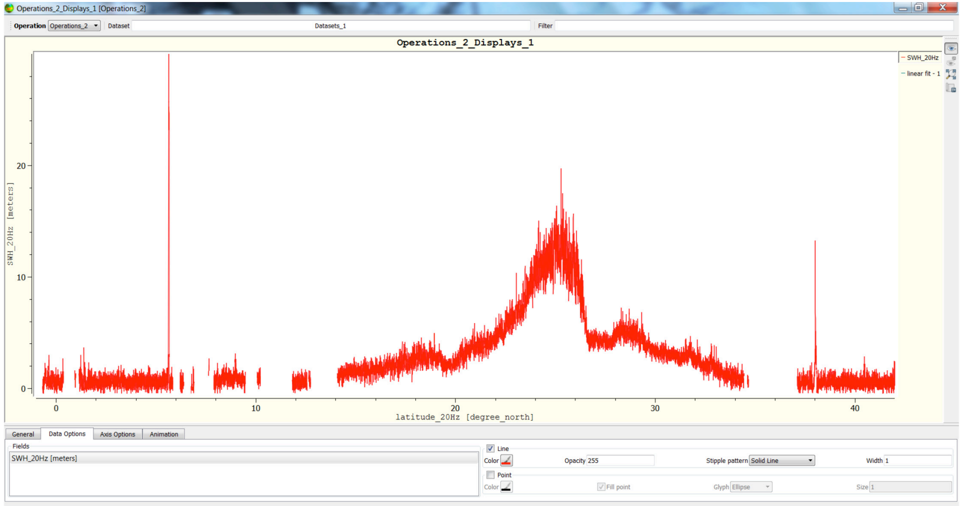


Plotting on BRAT

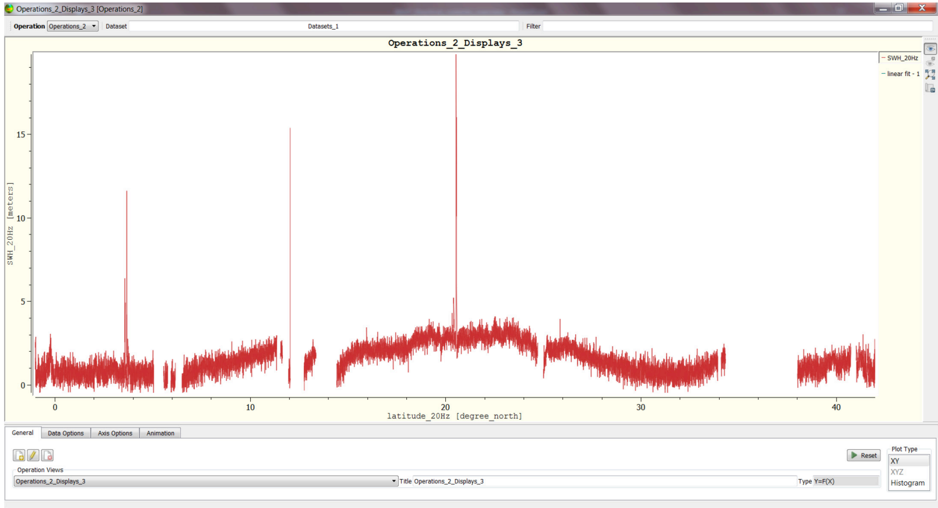




Impact of Typhoon Maria on SWH_20Hz estimates

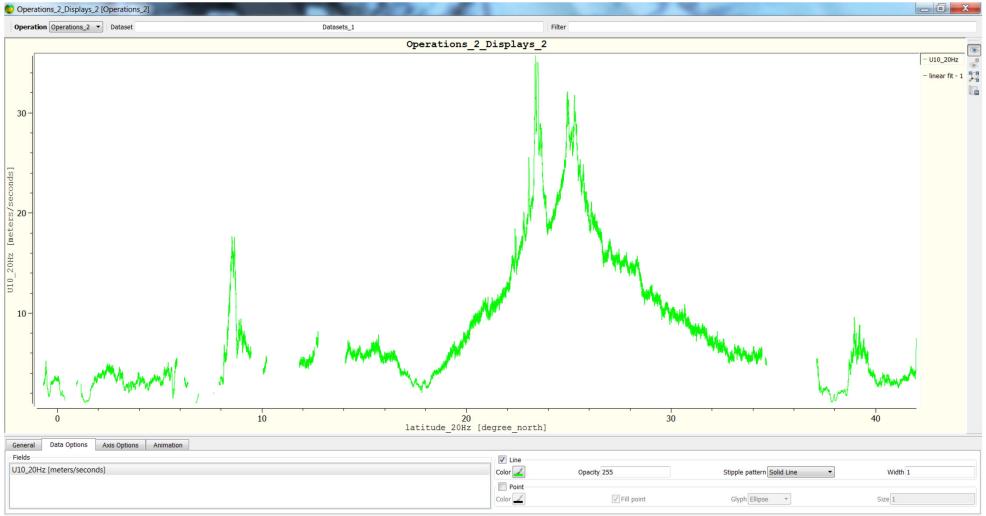


TYPHOON

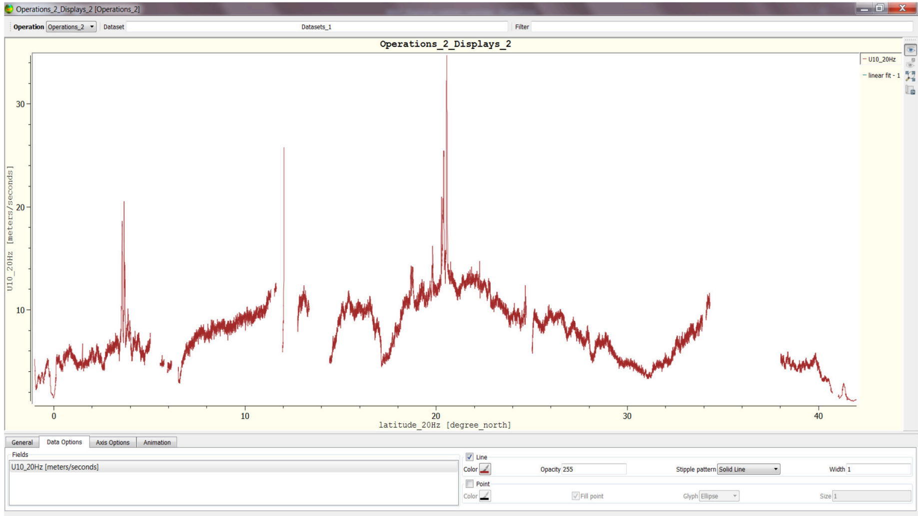


NO TYPHOON

Impact of Typhoon Maria on Wind-speed (U10_20Hz) estimates

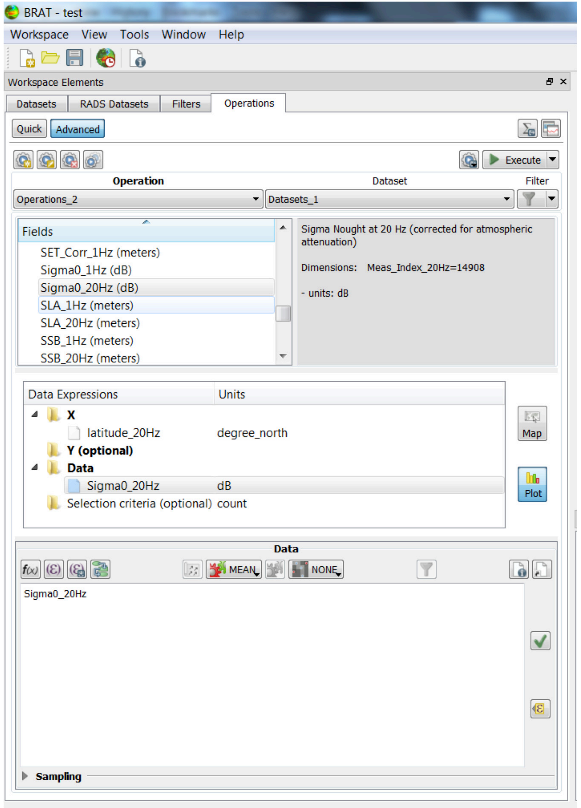


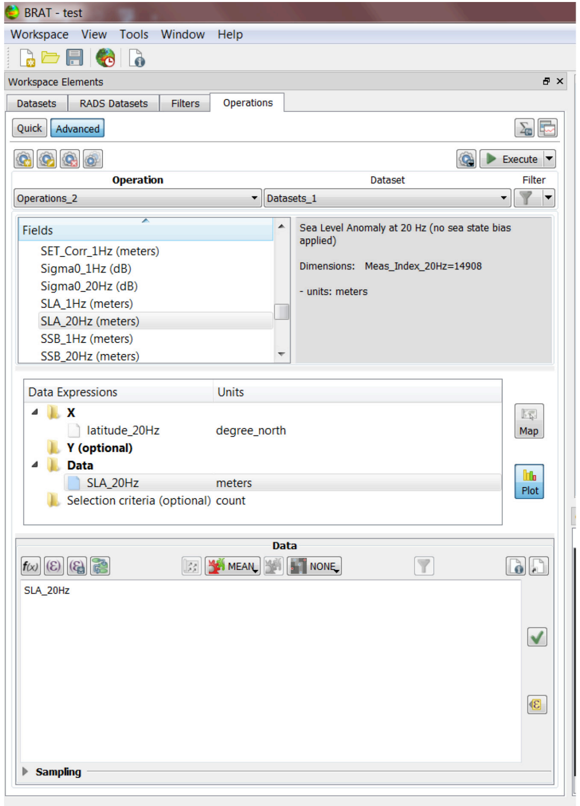
TYPHOON



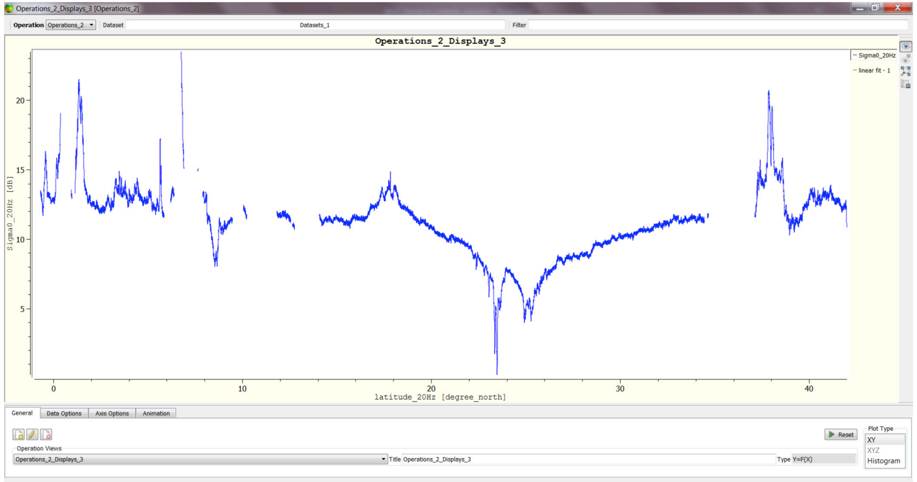
NO TYPHOON

Plotting on BRAT

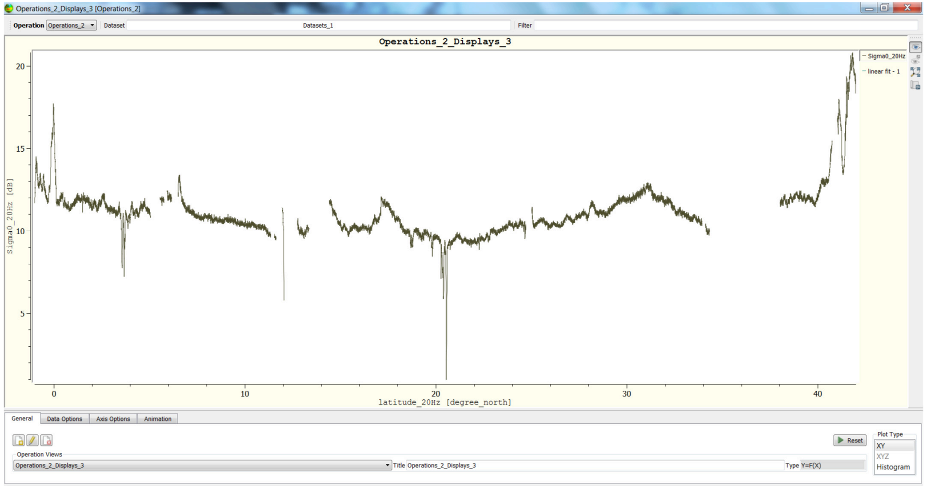




Impact of Typhoon Maria on Sigma0 (Sigma0_20Hz) estimates

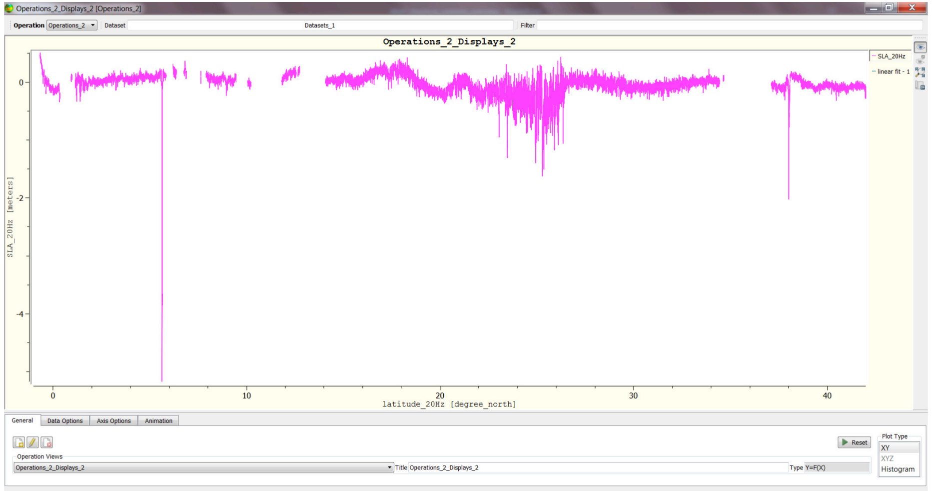


TYPHOON

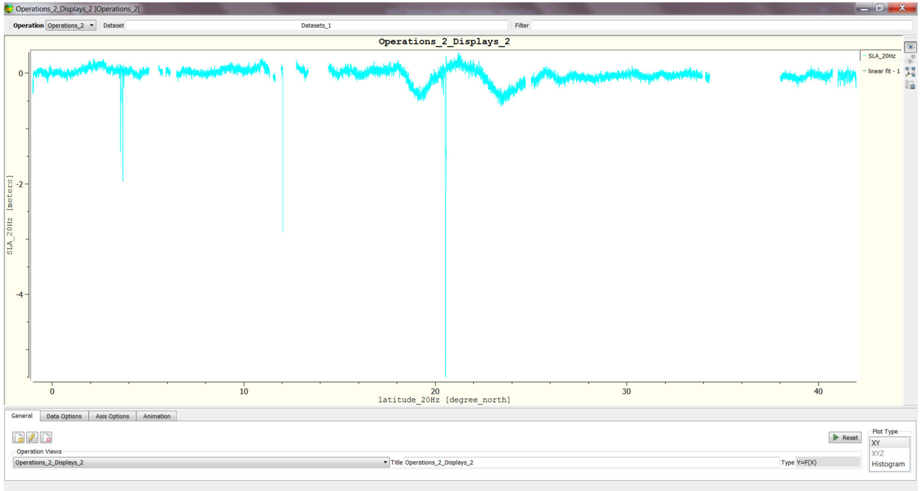


NO TYPHOON

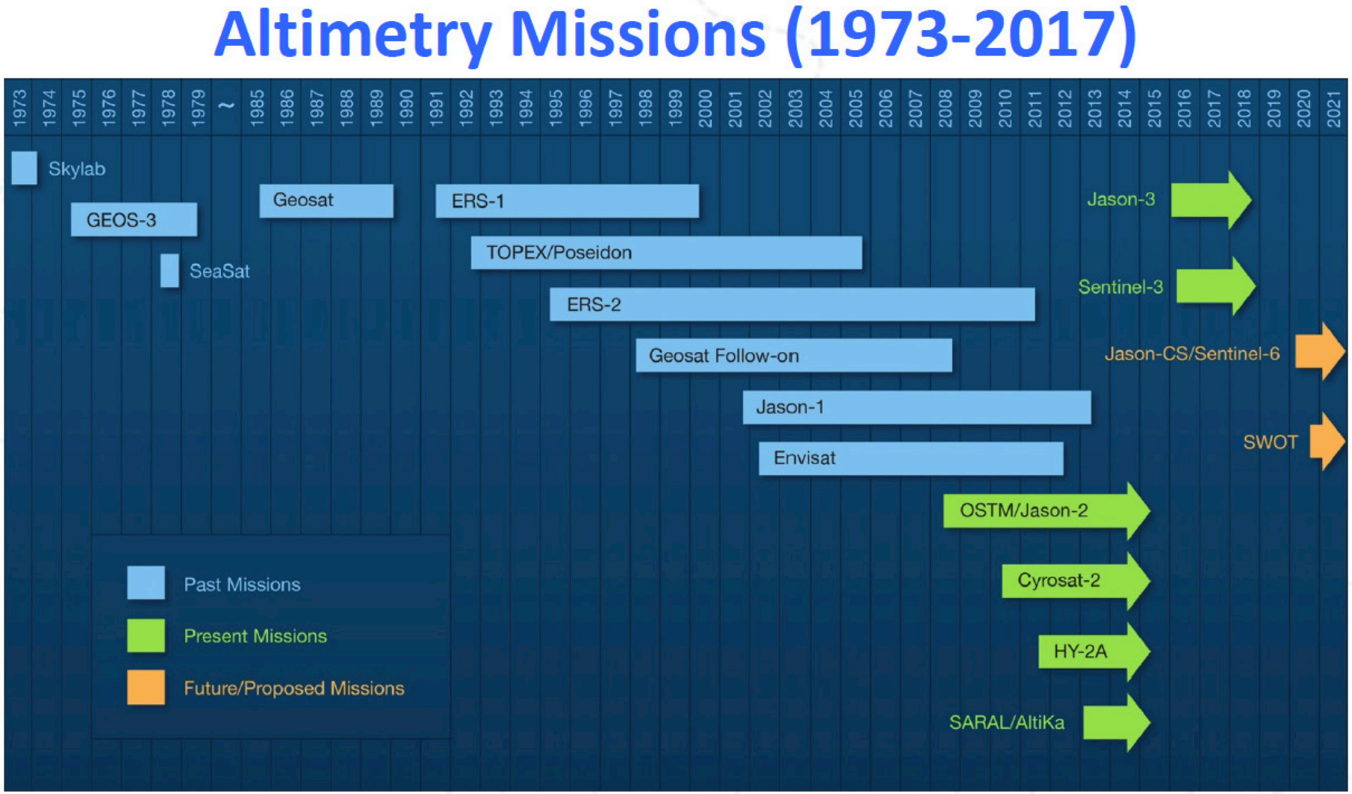
Impact of Typhoon Maria on SLA (SLA_20Hz) estimates



TYPHOON



NO TYPHOON

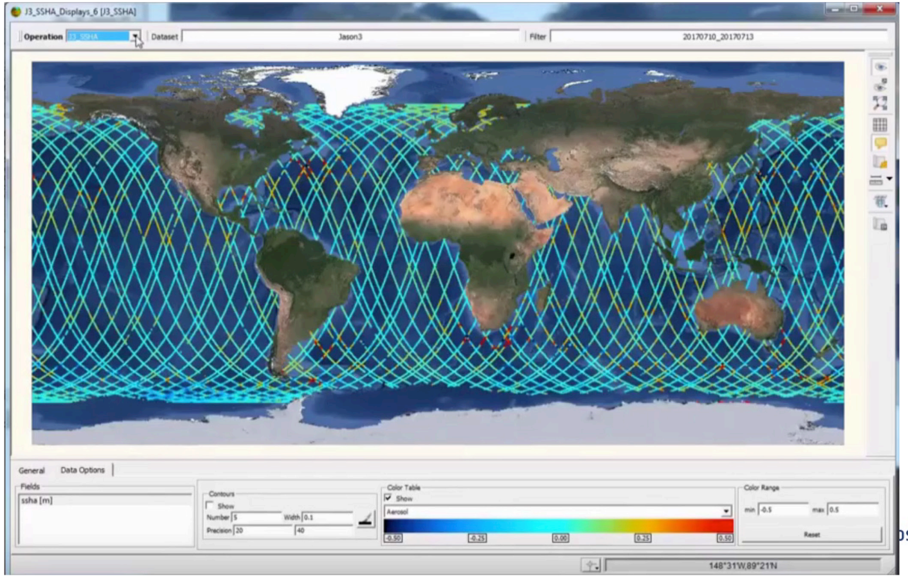


- The Sentinel-3 constellation includes 4 satellites.
- Sentinel-3 A & B have been successfully launched.
- Sentinel-3 C & D will be launched in 2021.

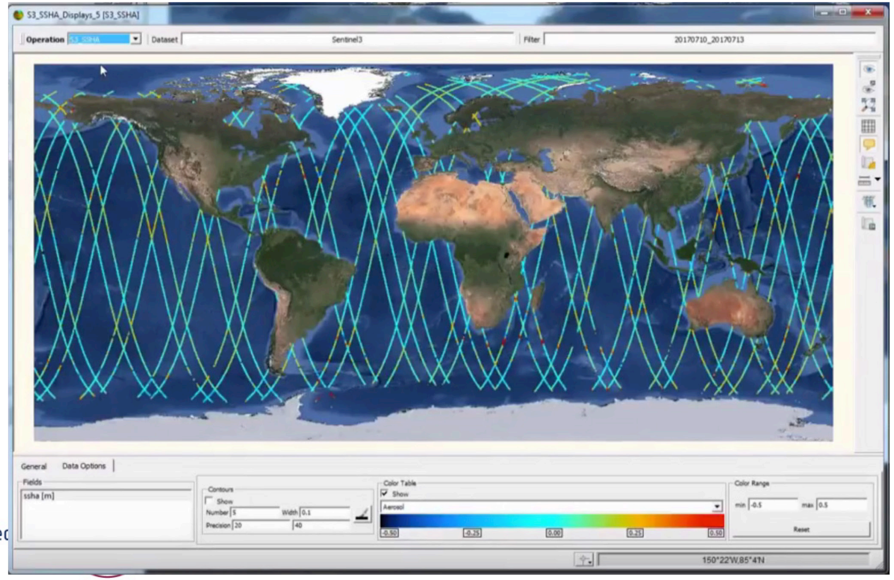
Multi_Mission Products (1)

- BRAT offers the possibility to combine data form 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

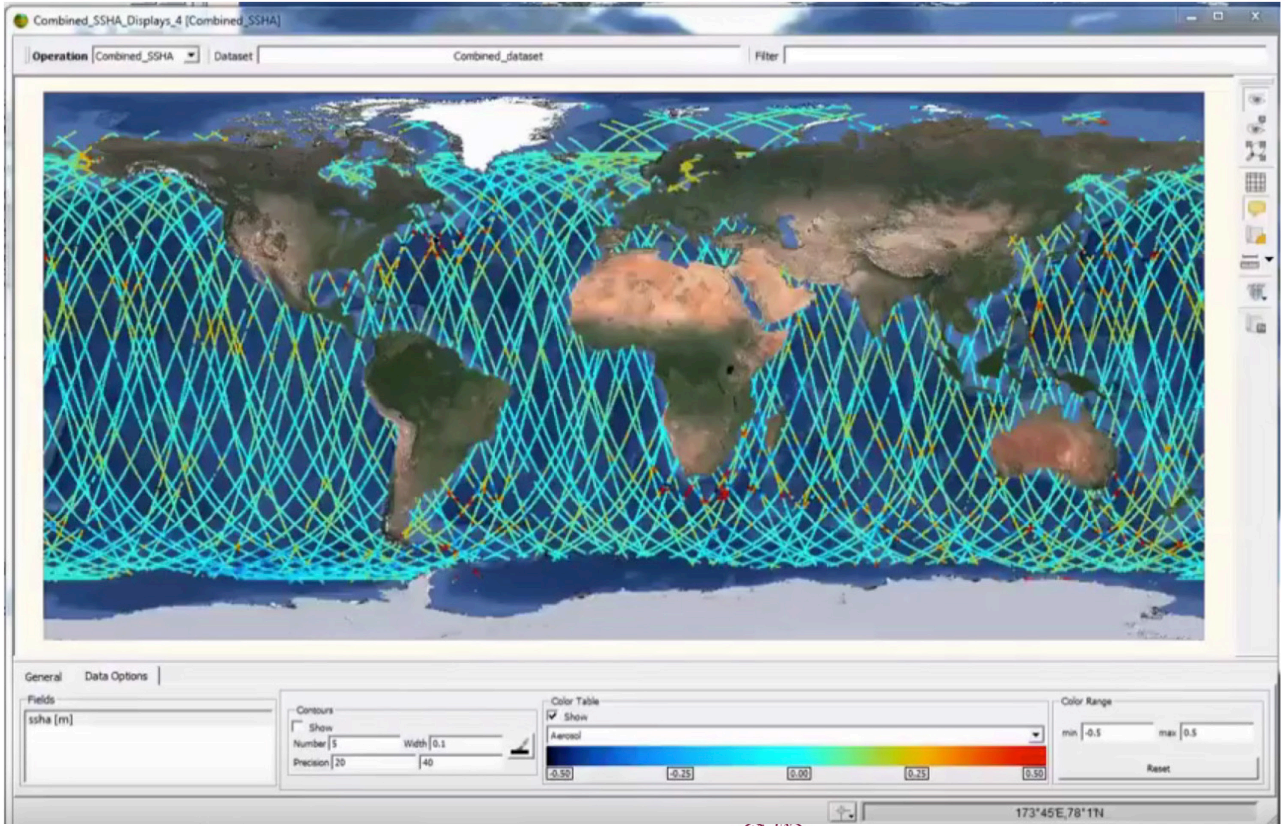
Jason-3 (LRM mission)



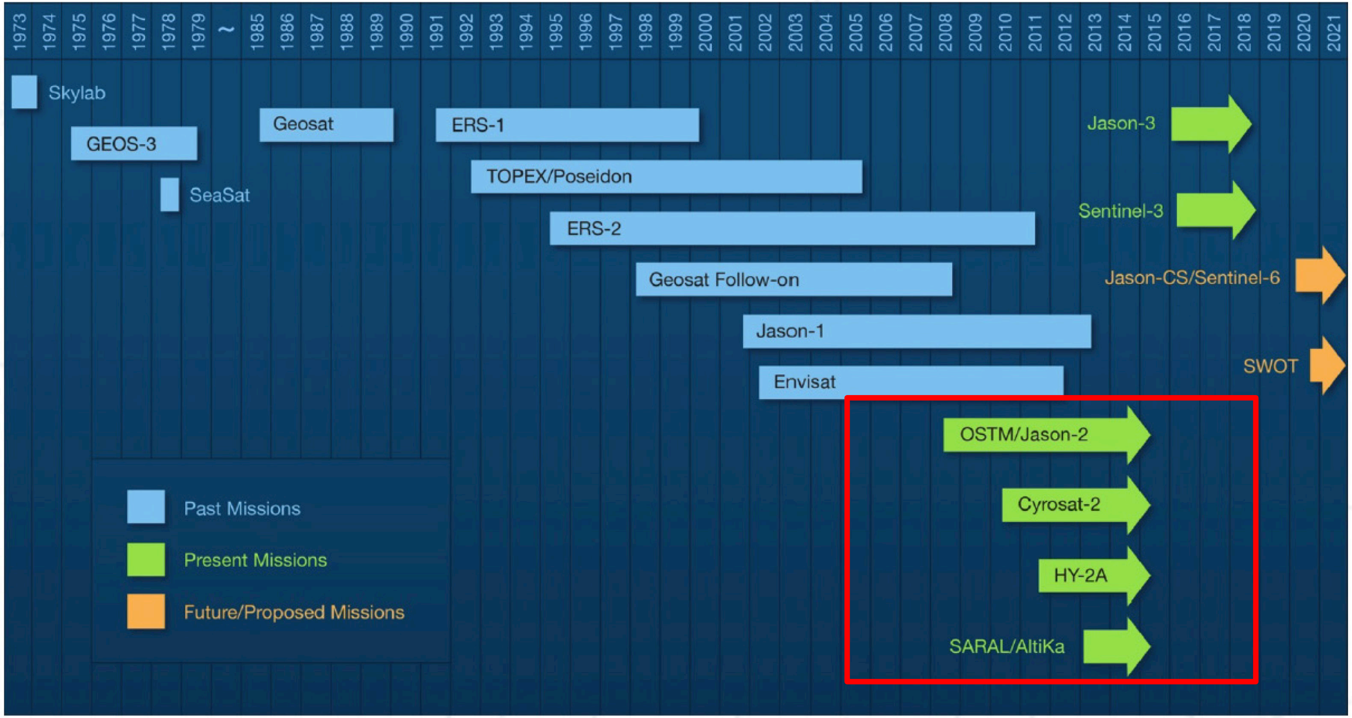
Sentinel-3 (SAR mission)



Multi_Mission Products (2) – Combined SSHA Map



Altimetry Missions (1973-2017)



Multi_Mission Product from CMEMS L3 data

- 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)

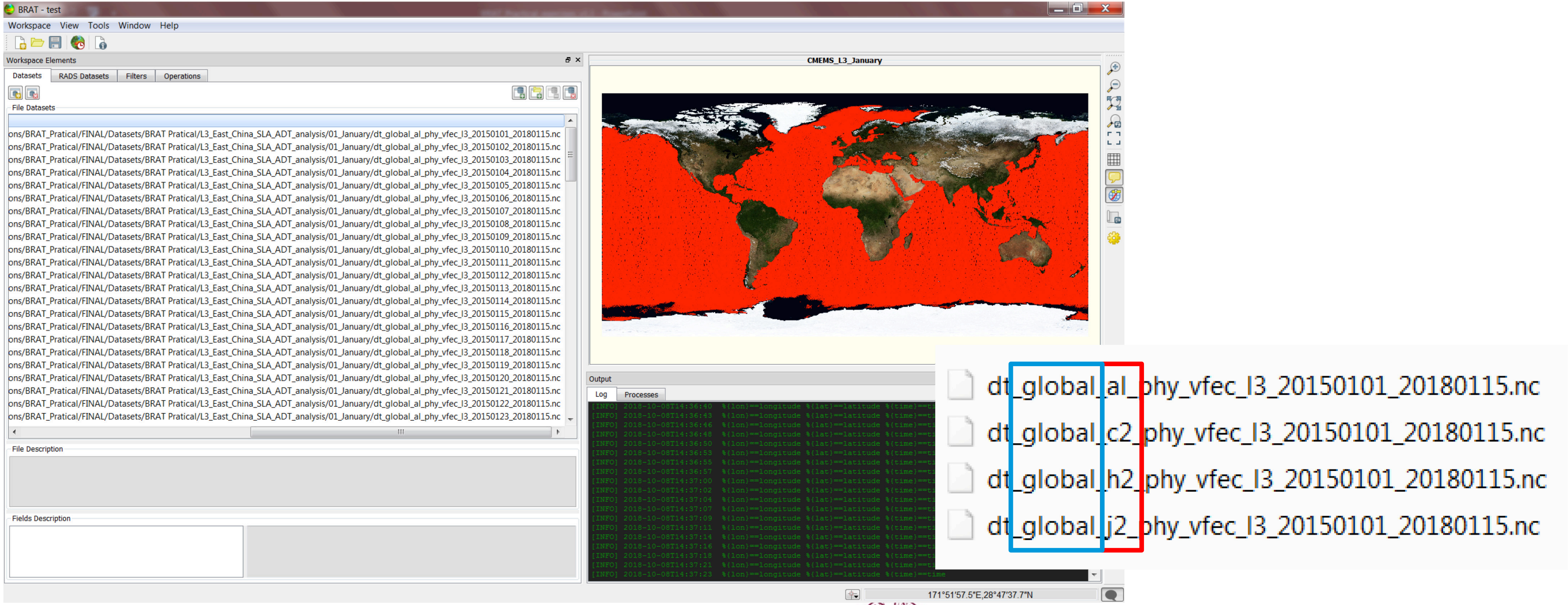
- Products can be downloaded from the website (1 month of data is available in the Dataset provided along with figures & stats): http://marine.copernicus.eu/

- Here we show how to combine 2015 L3 data from 4 satellites (HY-2A, CryoSat-2 Jason-2 & AltiKa)

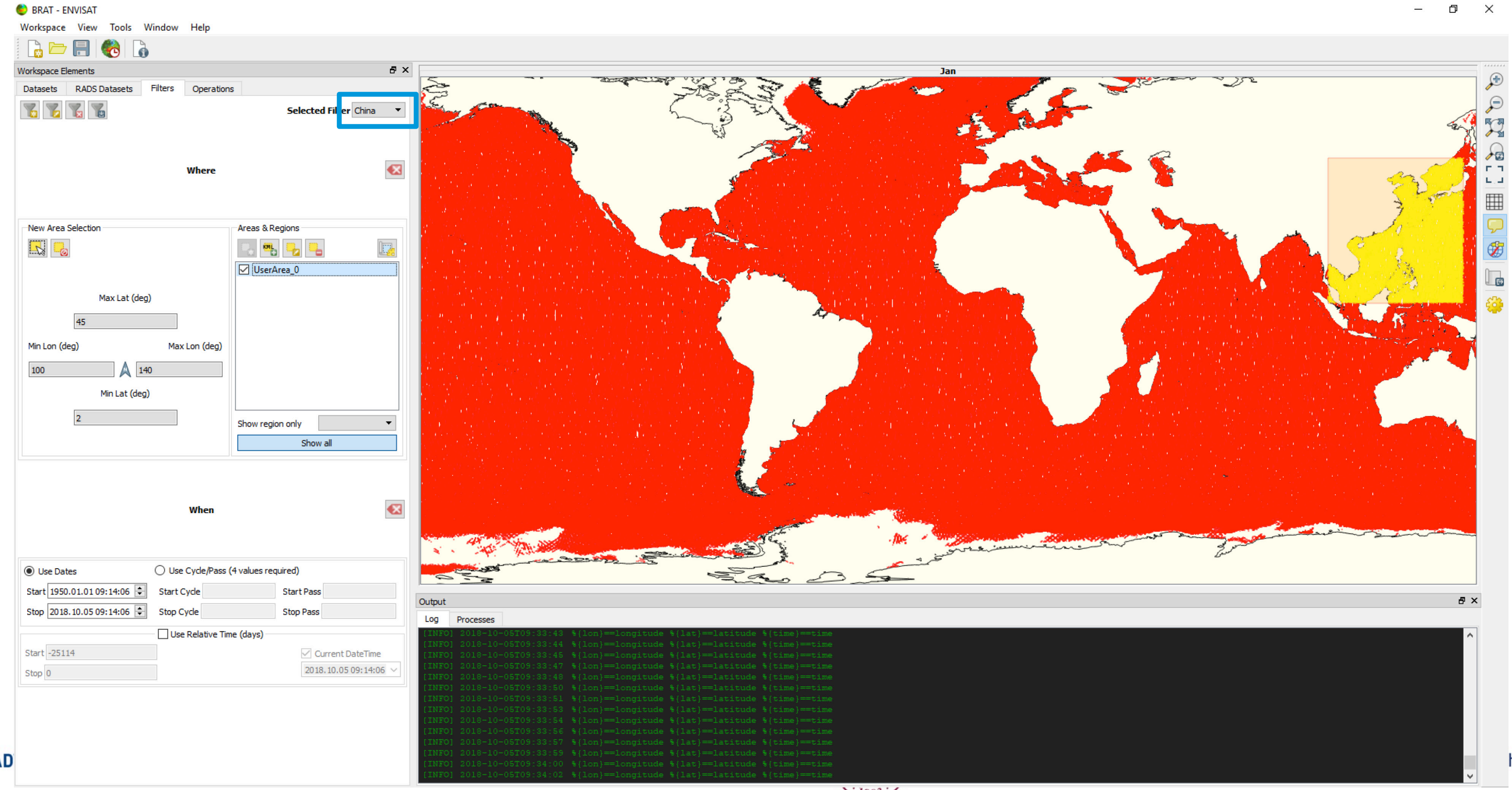
- We derive monthly maps (SLA & ADT) and monthly time series.

Multi_Mission Product from CMEMS L3 data

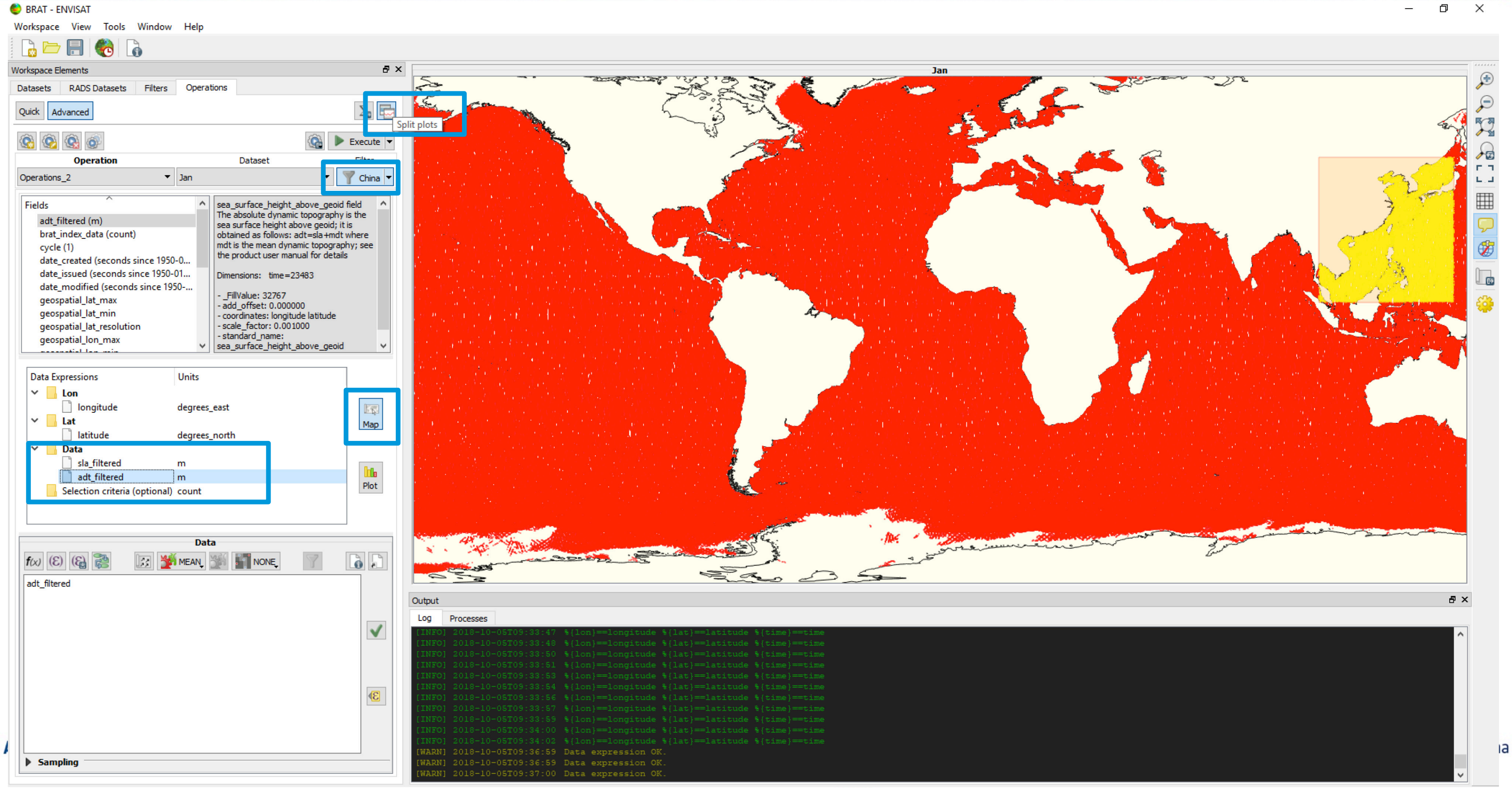
- Each monthly dataset is composed of monthly data from the 4 satellites (indicated in file naming as: al,c2,h2, j2) offering global coverage. Data from the month of January are available in the folder **L3_SLA_ADT**.



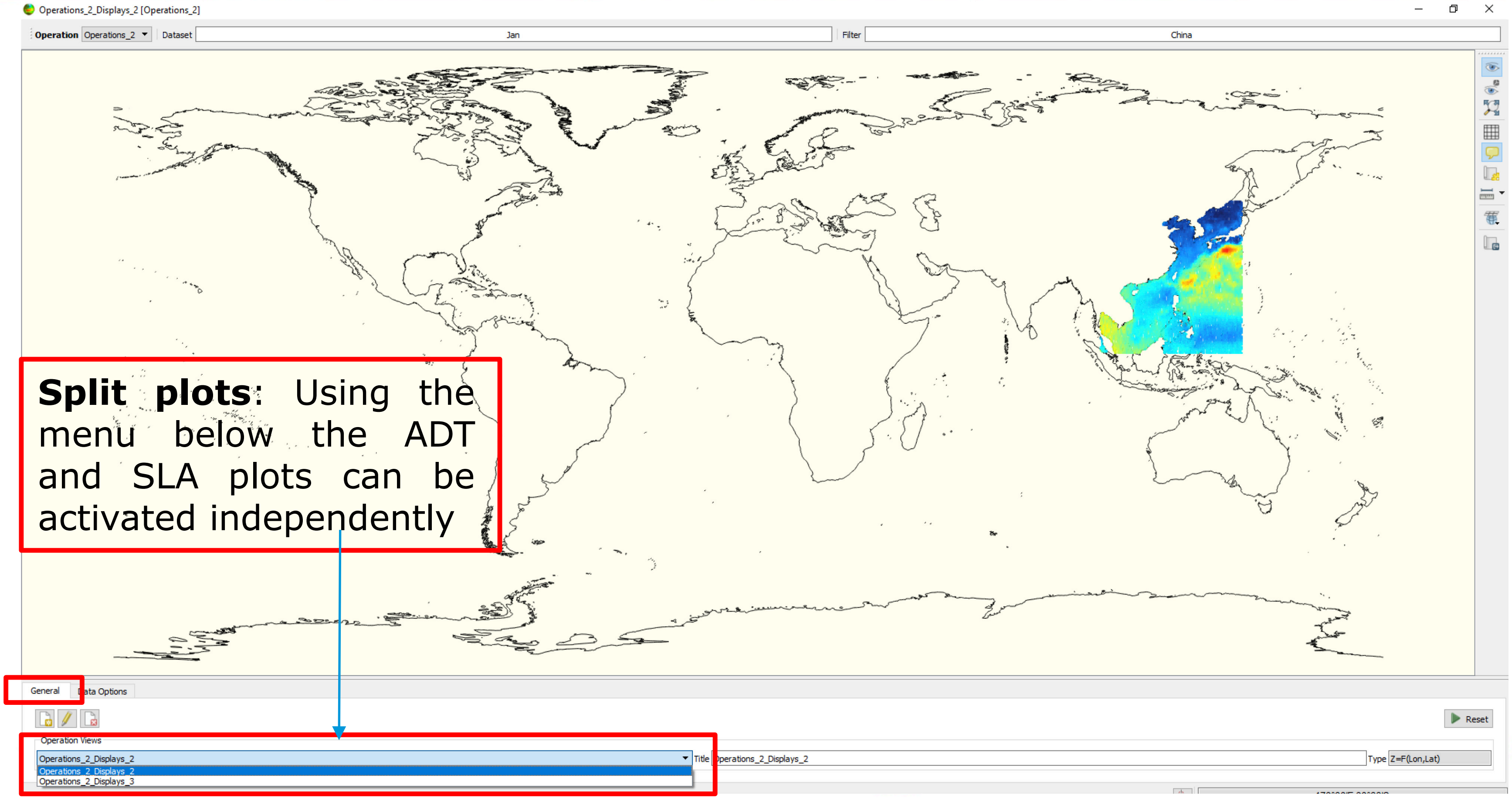
Geographical Data Selection



Split plots function for SLA and ADT



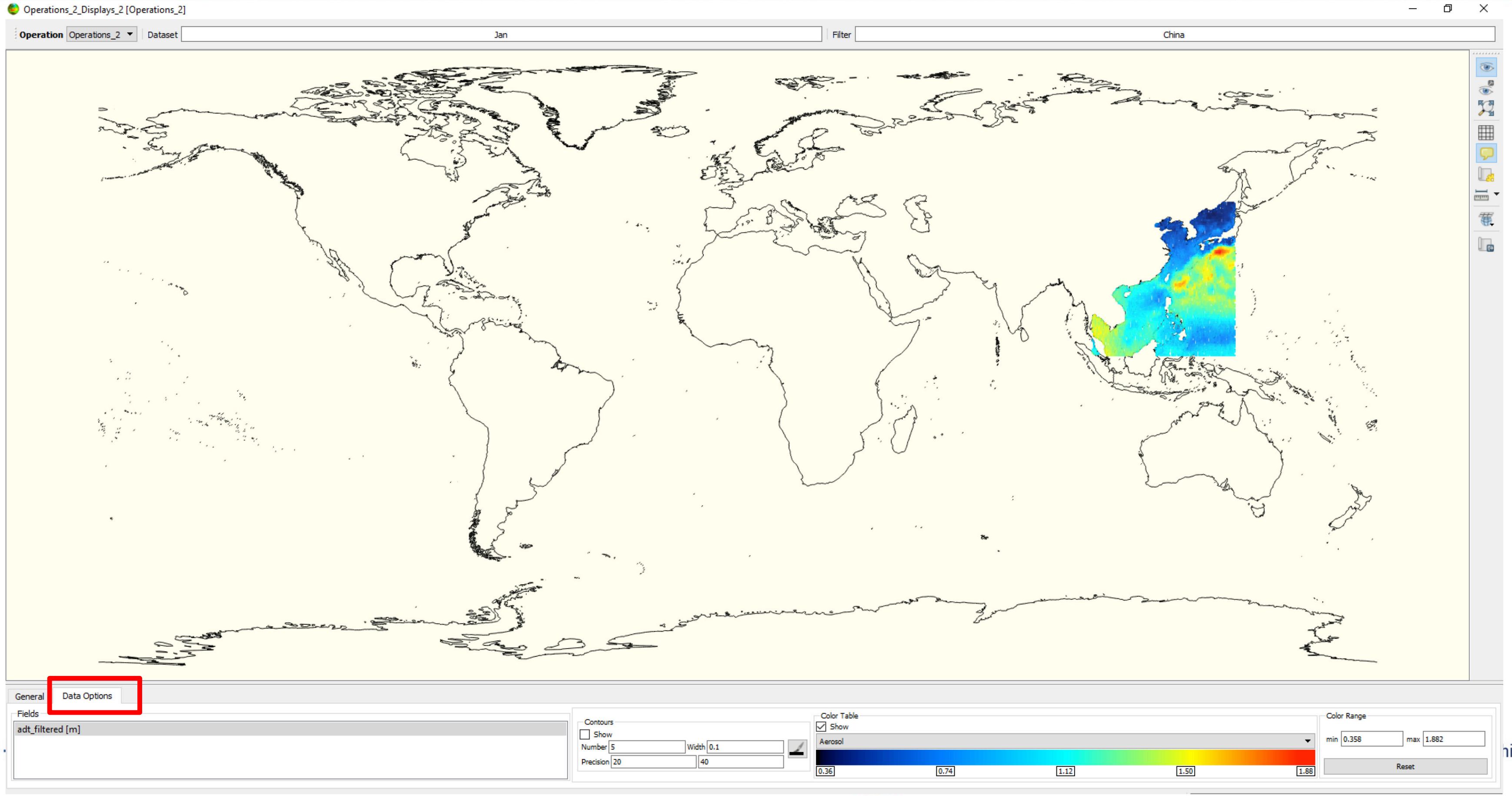
Map Selection



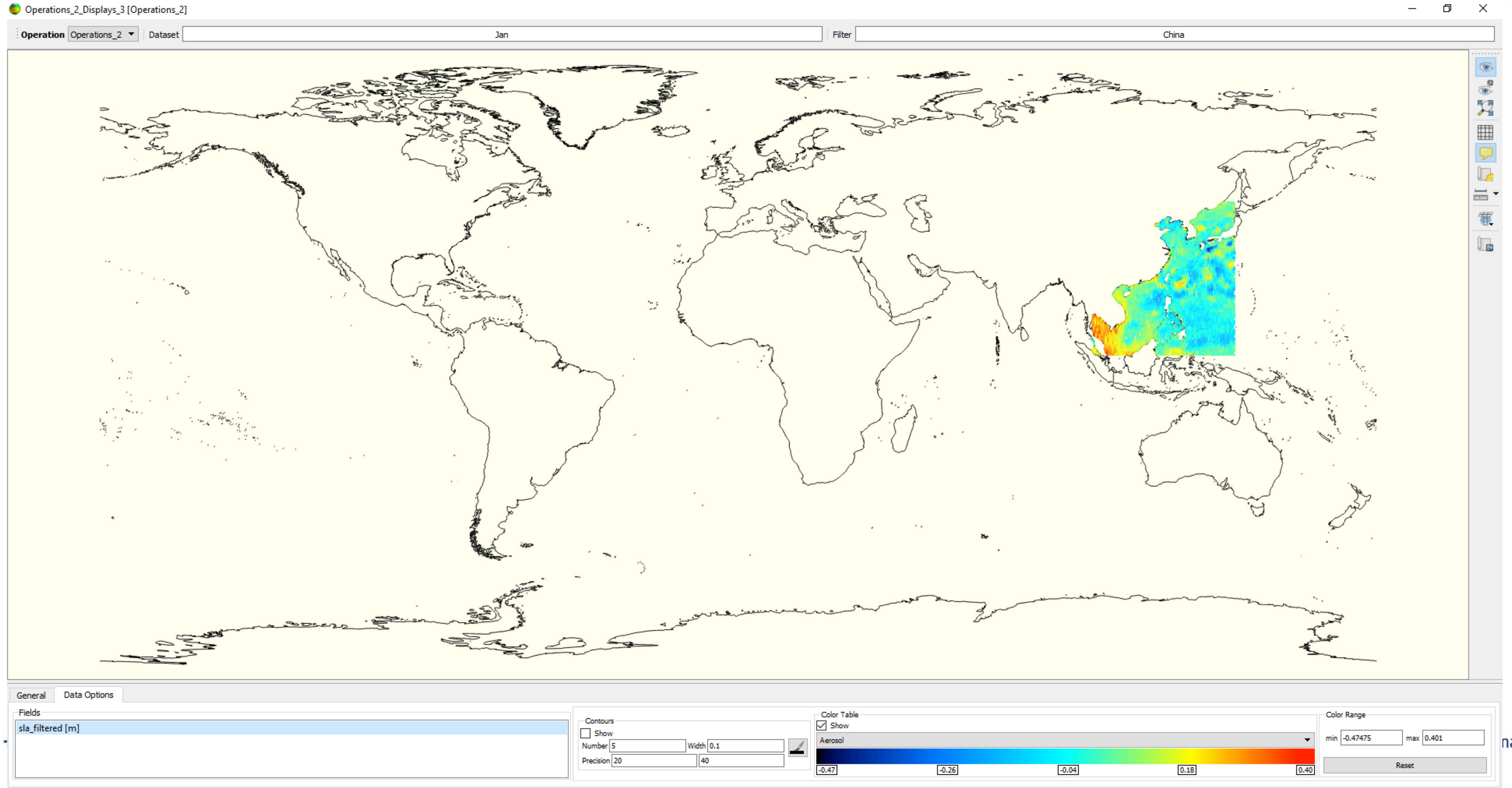
Split plots: Using the menu below the ADT and SLA plots can be activated independently

China

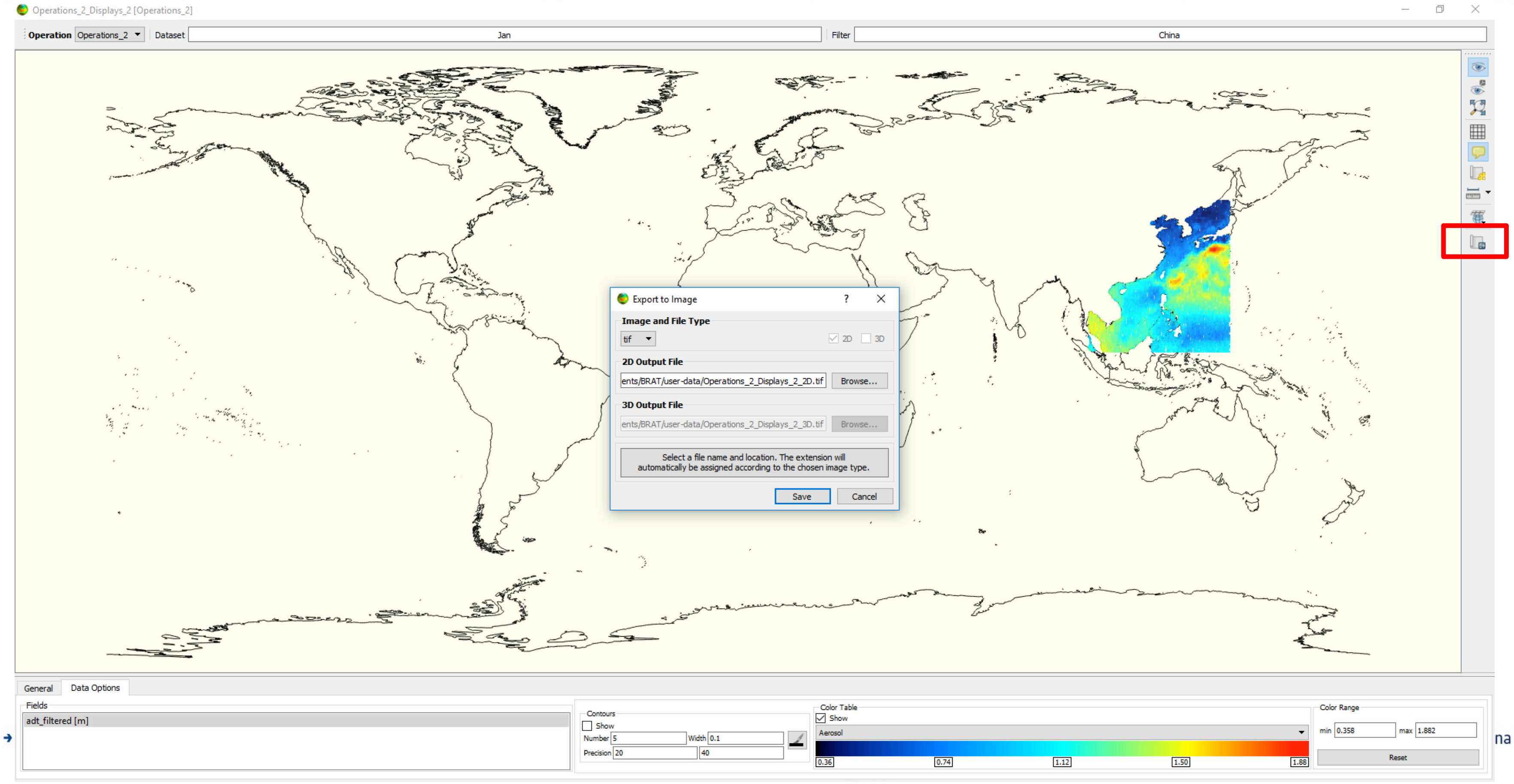
Filtered ADT Map



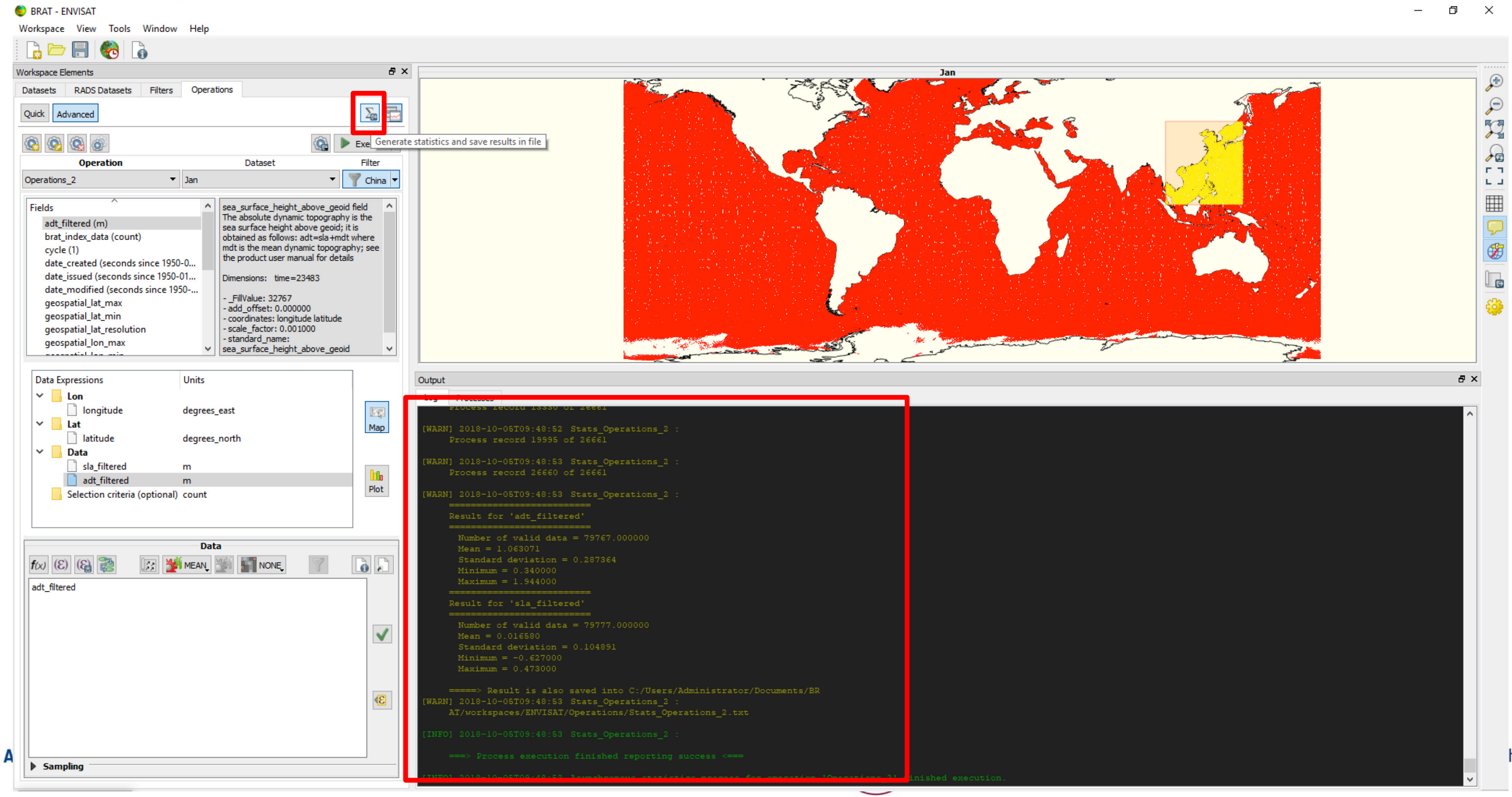
Filtered SLA Map



Exporting the images



Calculating Monthly Statistics

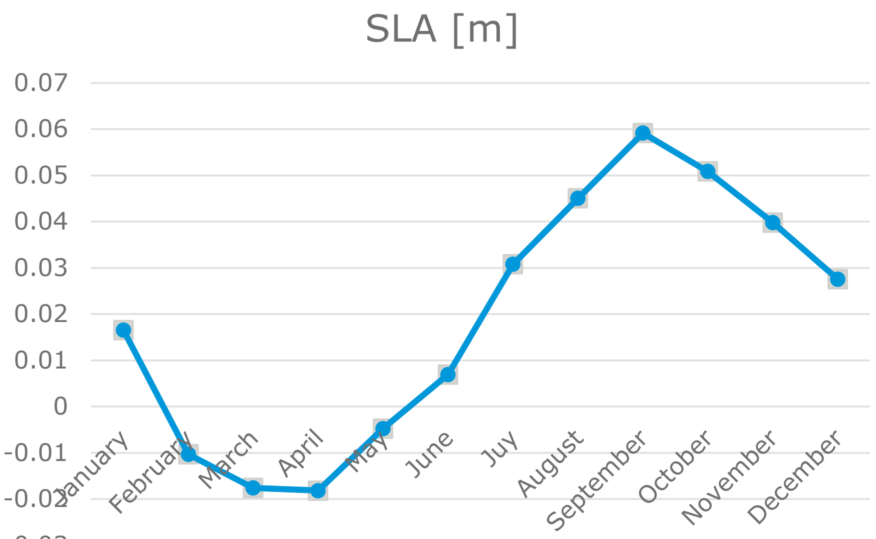


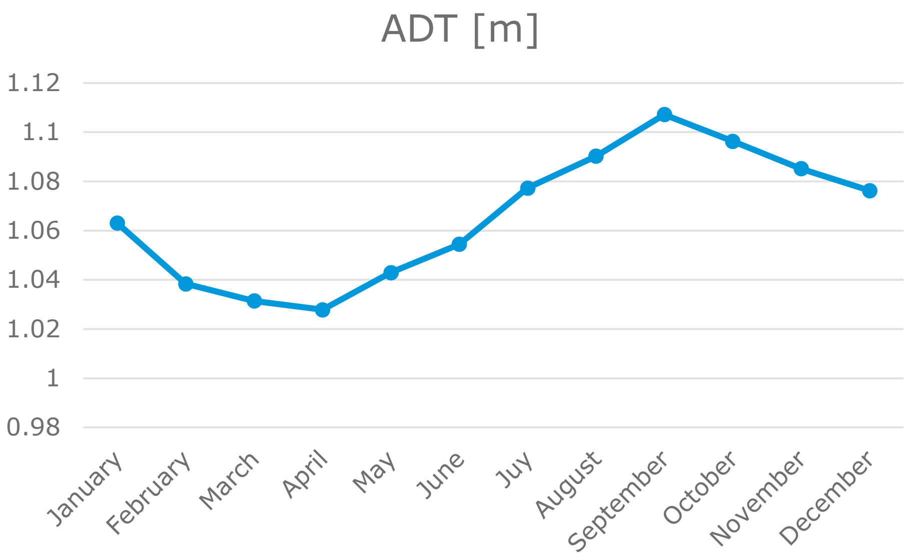
Calculating Monthly Statistics (2)

SLA [m]		January	February	March	April	May	June	Juy	August	September	October	November	December
	valid data points	79777	73242	81313	76344	75378	74243	76700	73737	76384	77741	77737	79808
	mean	0.01658	-0.01031	-0.01758	-0.01816	-0.00475	0.00696	0.0308	0.04503	0.059176	0.05086	0.039829	0.02756
	std	0.10489	0.09468	0.09052	0.0956	0.10338	0.11441	0.12632	0.14008	0.144755	0.14975	0.154872	0.154263
	min	-0.627	-0.679	-0.851	-0.886	-0.681	-0.724	-0.646	-0.801	-0.739	-0.611	-0.532	-0.634
	max	0.473	0.466	0.428	0.359	0.429	0.512	0.63	0.606	0.627	0.614	0.546	0.523

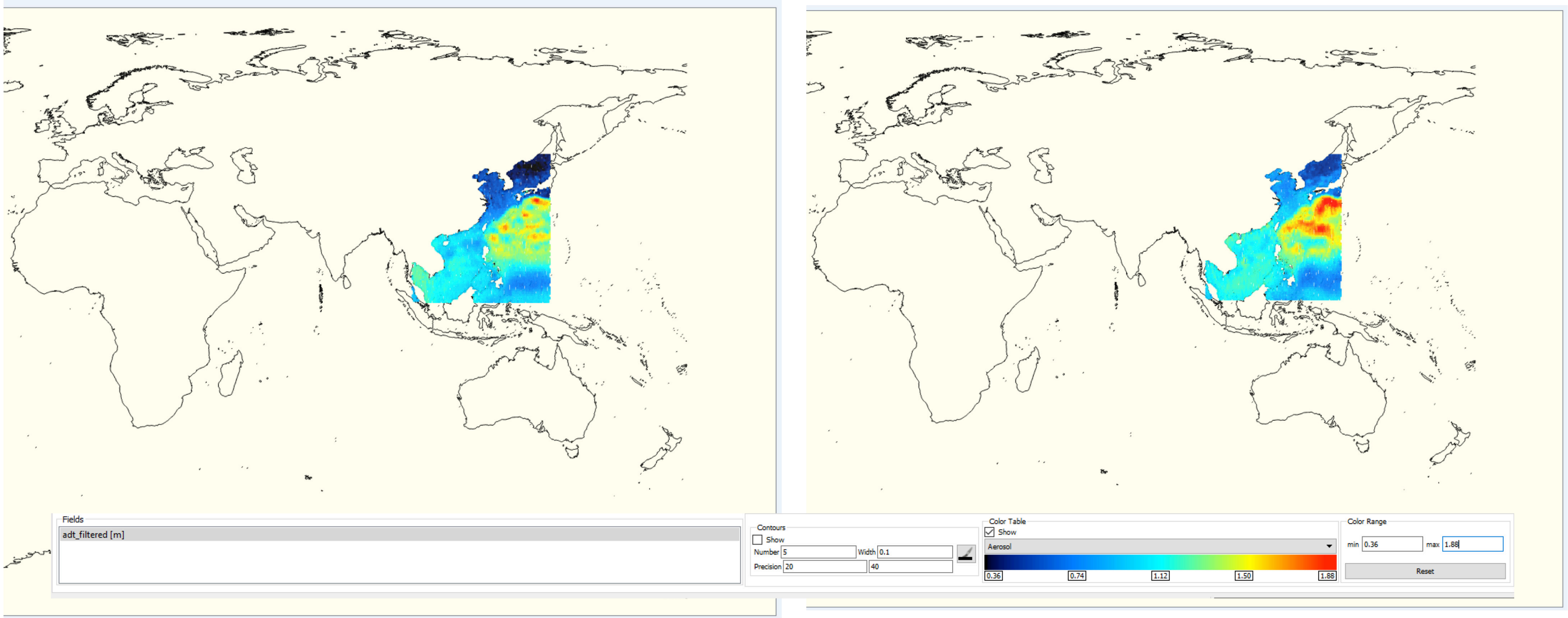
ADT [m]		January	February	March	April	May	June	Juy	August	September	October	November	December
	valid data points	79767	73230	81303	76332	75367	74226	76689	73723	76371	77721	77725	79793
	mean	1.06307	1.03841	1.03145	1.02784	1.04295	1.05447	1.07731	1.09023	1.107174	1.09632	1.08516	1.076235
	std	0.28736	0.28232	0.29692	0.307	0.30555	0.31318	0.31018	0.29877	0.30596	0.303	0.295889	0.305641
	min	0.34	0.18	0.232	0.206	0.248	-0.029	0.204	0.237	0.352	0.274	0.339	0.2
	man	1.944	1.989	1.98	1.949	1.948	1.917	2.039	2.194	2.127	2.117	2.109	2.096

Plotting Results

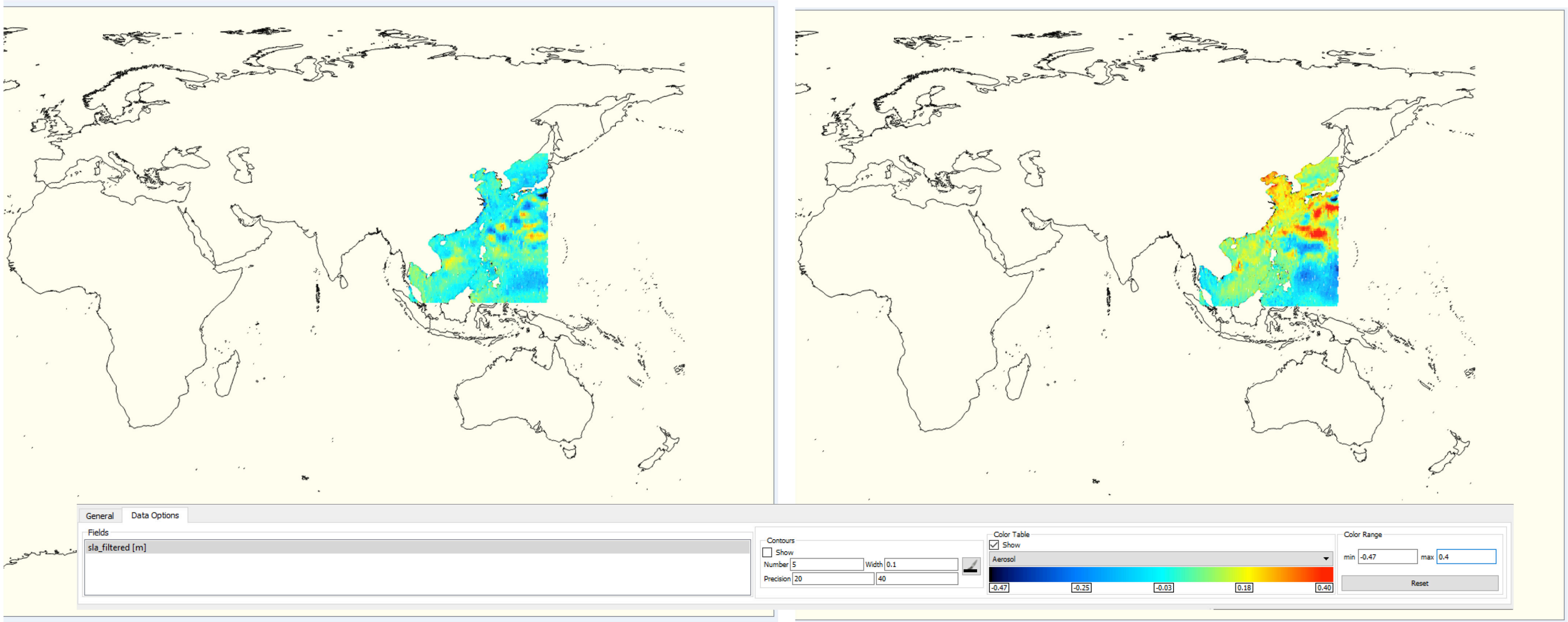




ADT (April vs September) ->

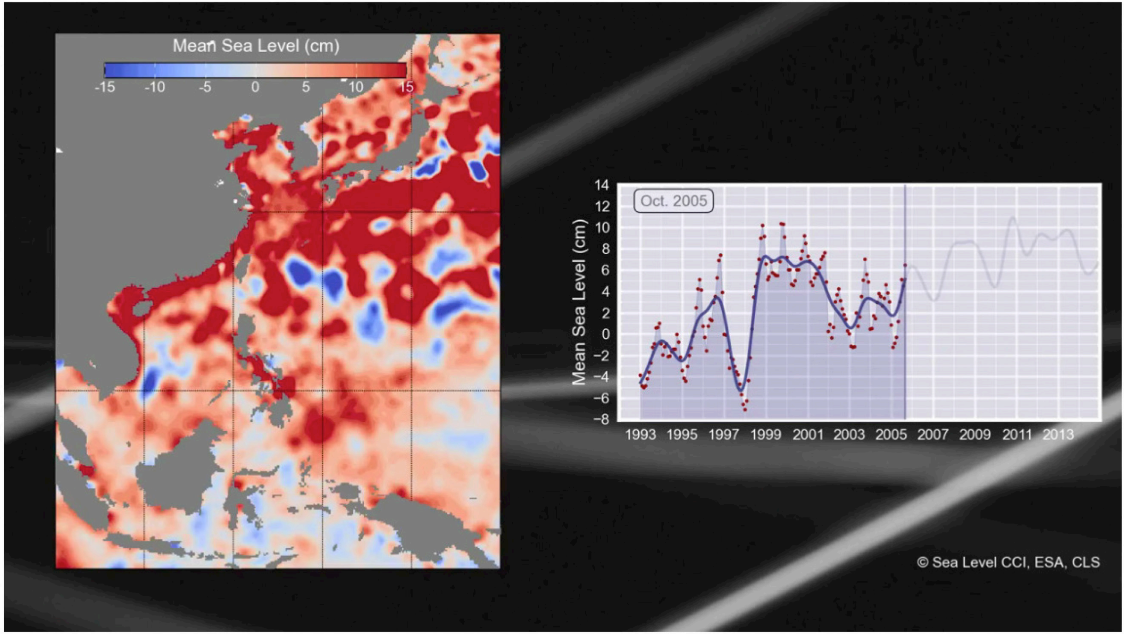


SLA (April vs September)



SLA Evolution – SLCCI Dataset

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)

The Scenario

• 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.).

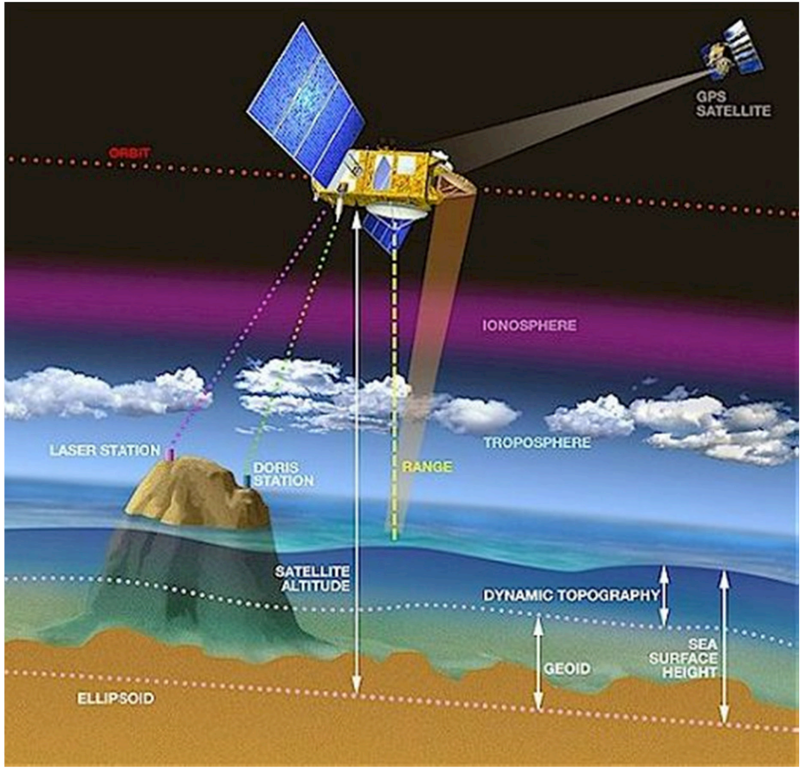
• Geoids (i.e. the ocean surface excluding the influence of wind and tides) are obtained from other missions (e.g. GRACE, GOCE).

• 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): Satellite_Altitude - Corrected_Range.

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



Datasets used in this Practical

- 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

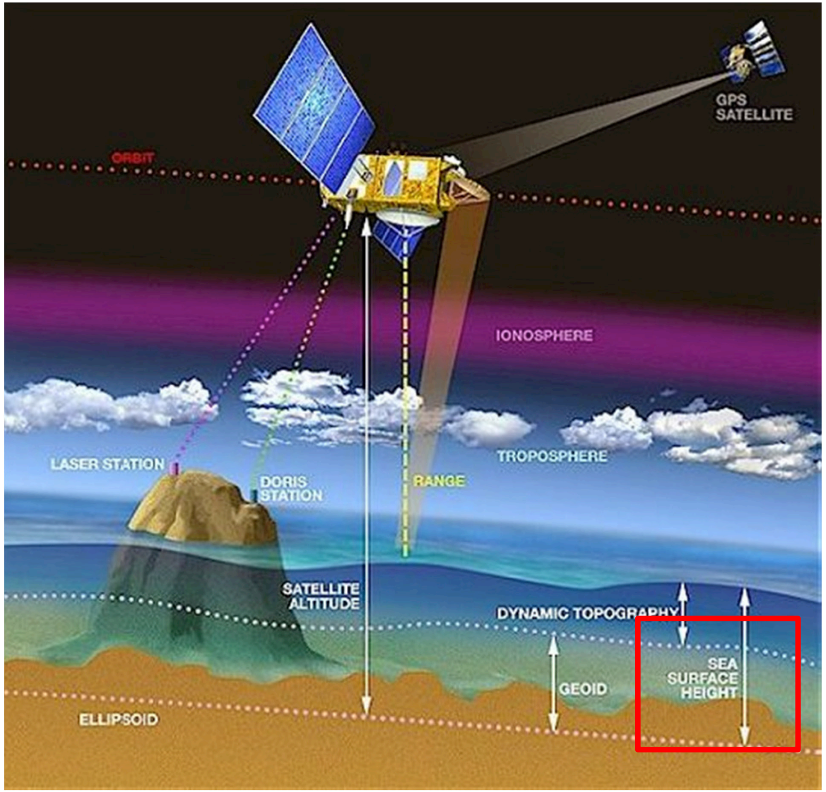
  The SLA grids are calculated after merging data from altimetry missions (TOPEX/Poseidon, Jason-1/2, GFO, ERS-1/2, Envisat, CryoSat-2 and SARAL/Altika) into monthly grids with a spatial resolution of 1/4 of degree.

  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

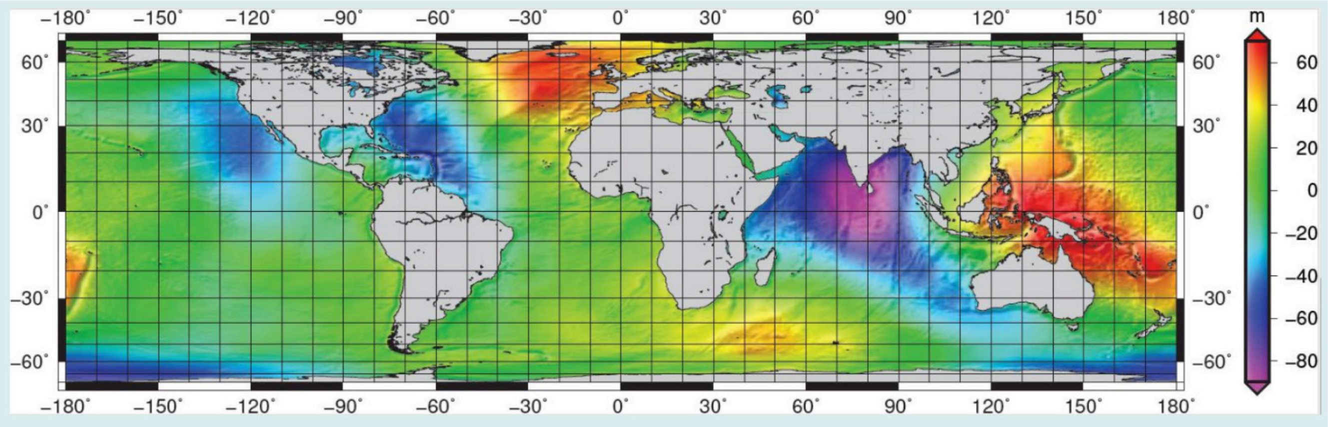
- Mean Sea Surfaces (MSS) are essentially satellite altimetry by-products.
- MSS are used to obtain the sea level anomalies by subtracting SSH-MSS.
- The mean sea surface is the displacement of the sea surface relative to a mathematical model of the earth and it closely follows the geoid. **Amplitudes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



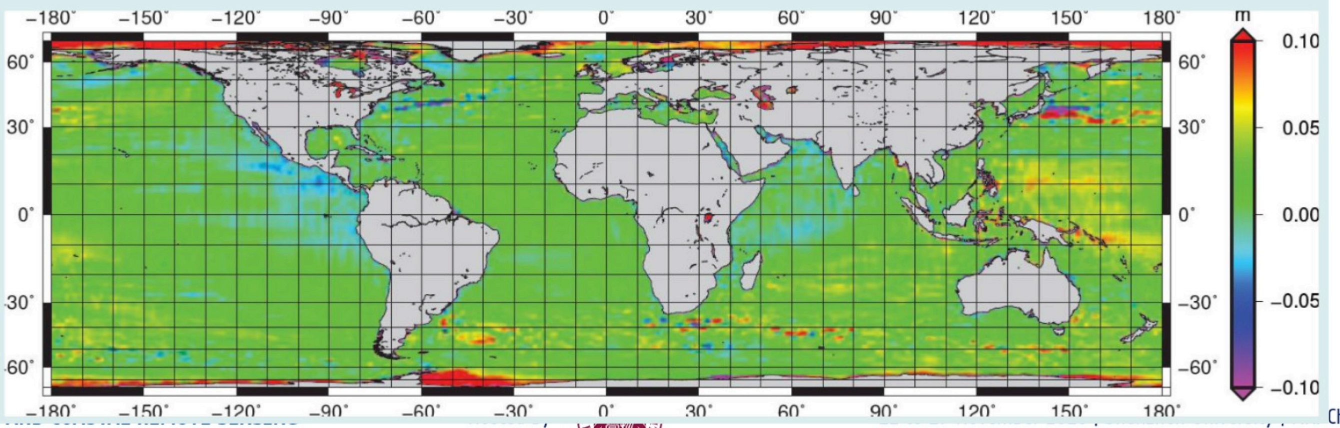
Mean Sea Surface – Comparison

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

- DTU15MSS



- DTU15-DTU13



Practical n.1: Sea Level Anomaly & Eddies

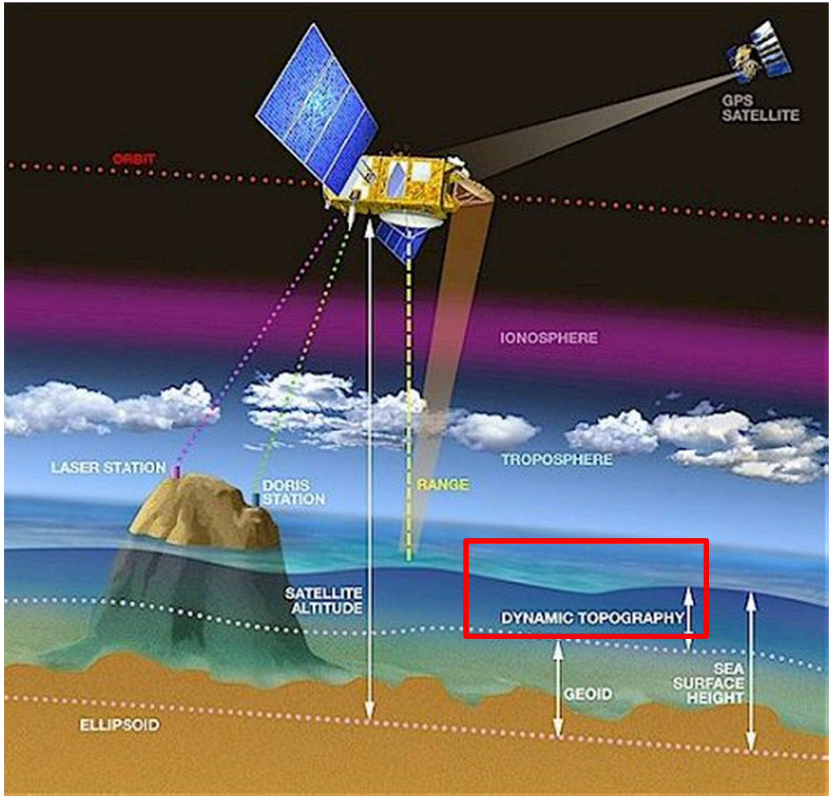
- **Sea level anomalies** are **sea surface heights** (SSH) with respect to the **mean sea surface** (MSS). It is not to be confused with what is usually called '**Mean Sea Level**' (MSL), which is a measure of the **sea level** variations over time.

- 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.

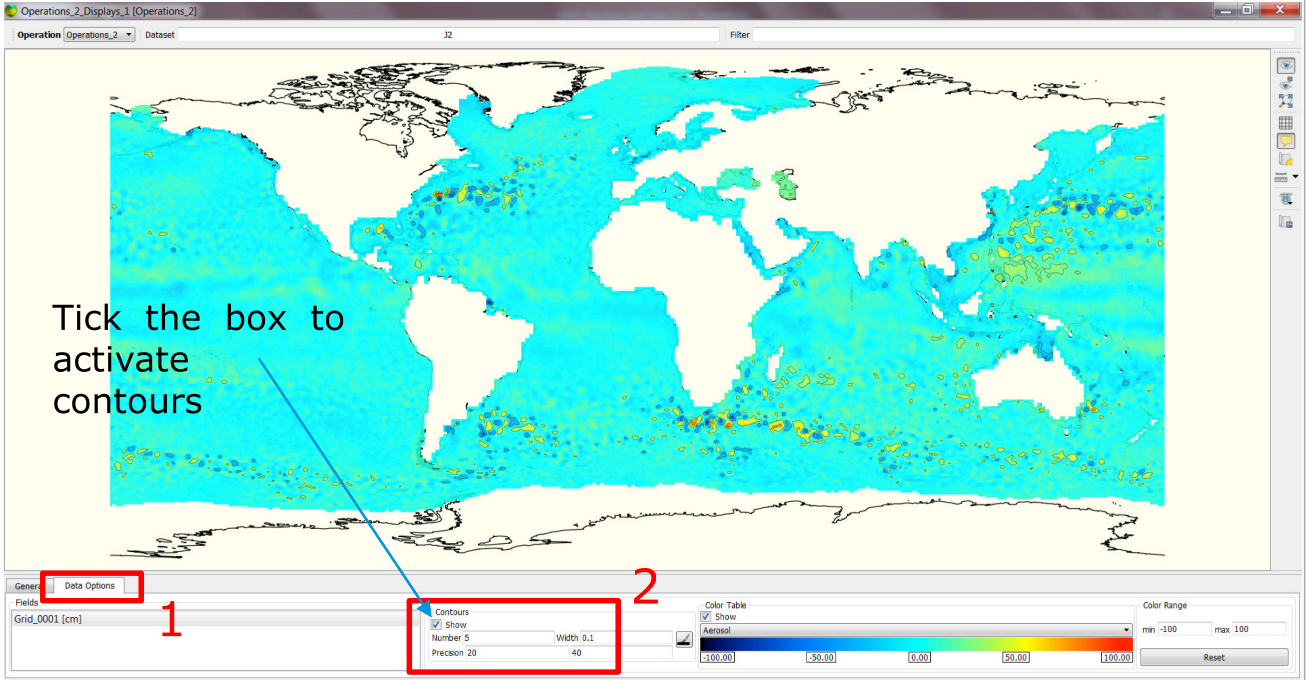


Eddies detection with SLA data

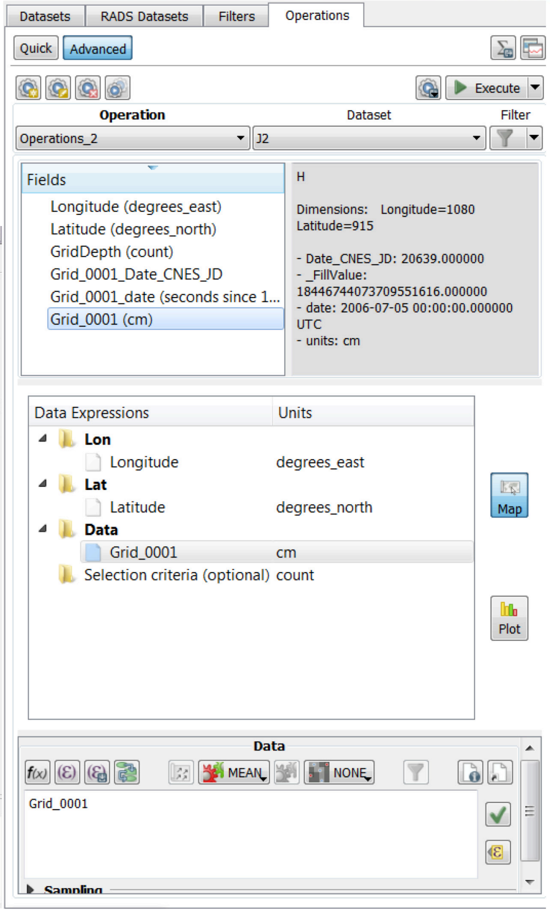
- SSALTO/DUACS - DT MSLA - Merged Product

Folder: SLA (also in the BRAT DEMO folder)

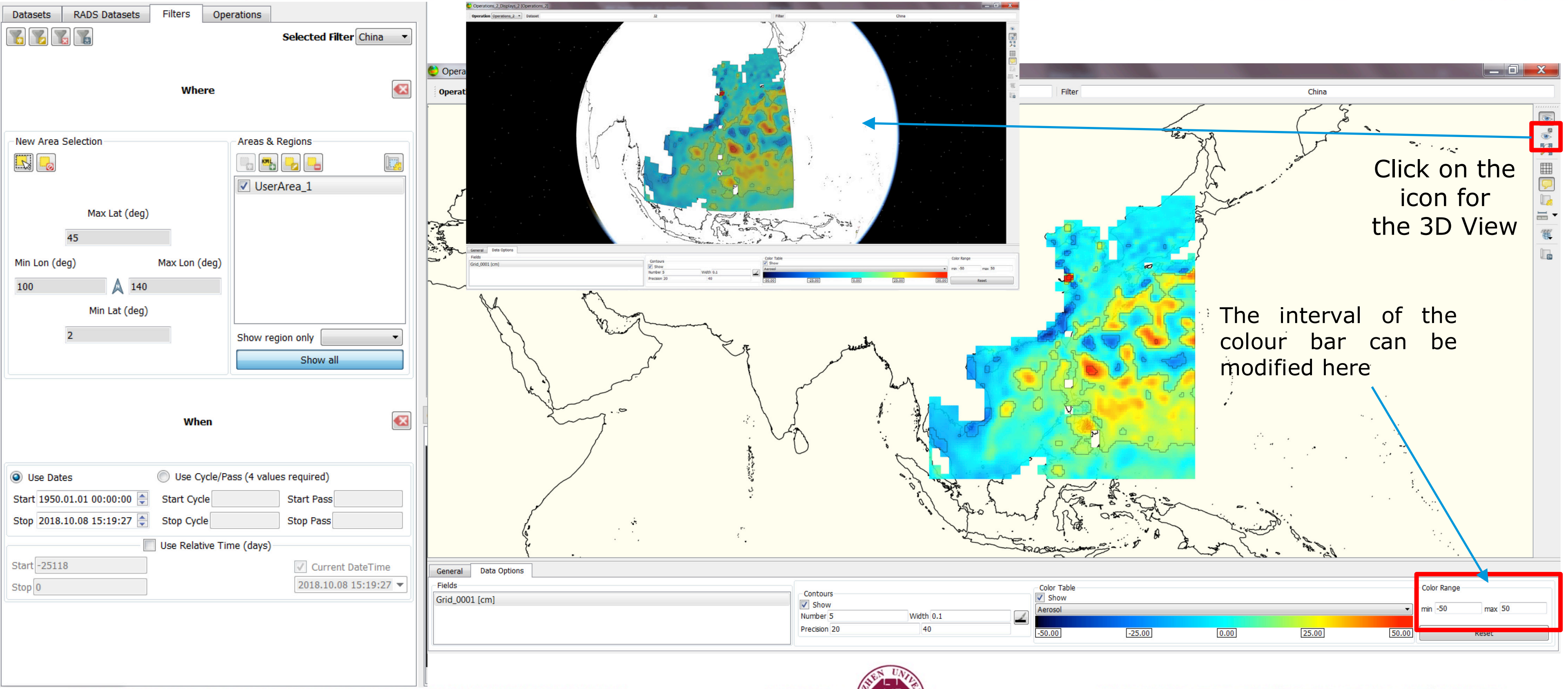
File:dt_upd_global_merged_msla_h_20060705_20060705_20070110.nc



Tick the box to activate contours



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



Click on the icon for the 3D View

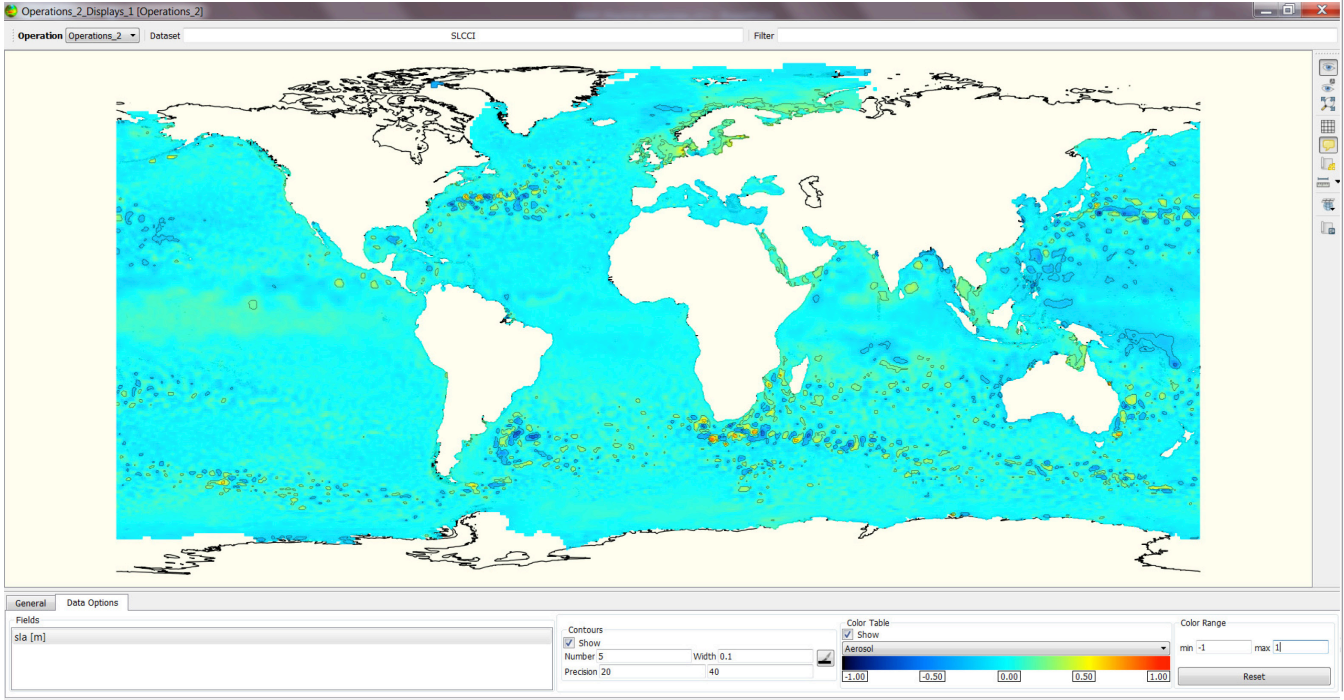
The interval of the colour bar can be modified here

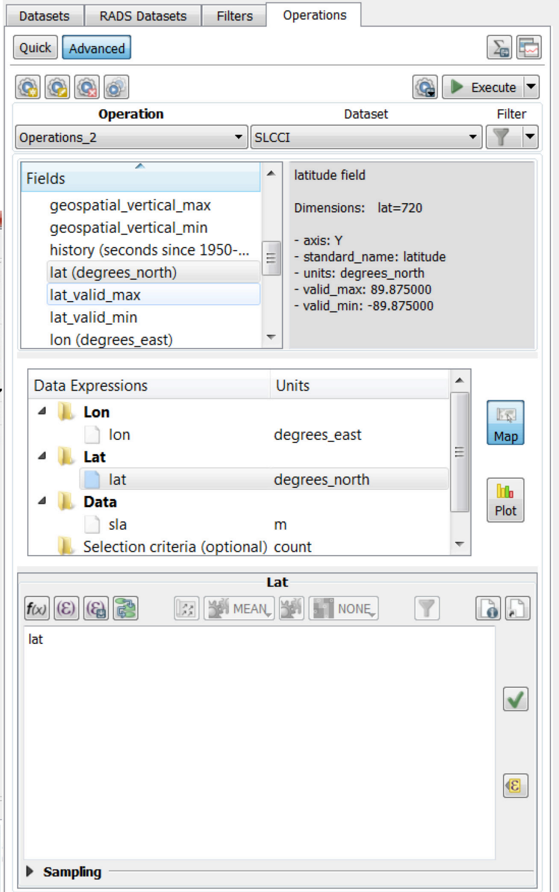
Eddies detection with SLA data

- SLCCI Product for comparison

Folder: SLA

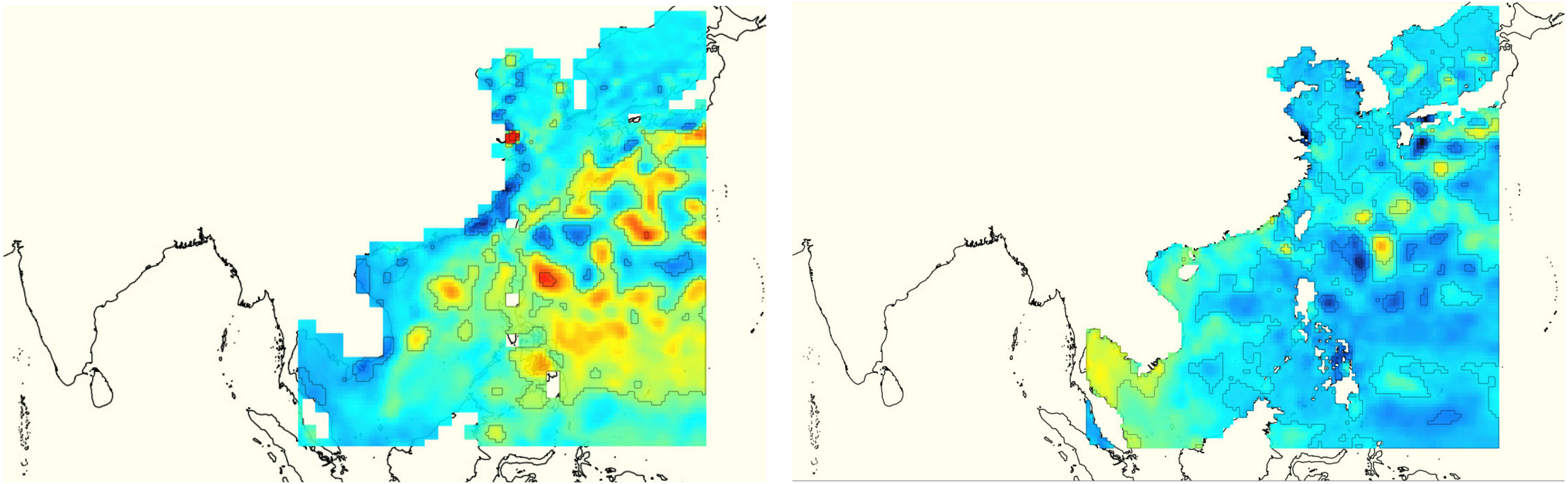
File: ESACCI-SEALEVEL-L4-MSLA-MERGED-19930115000000-fv02.nc

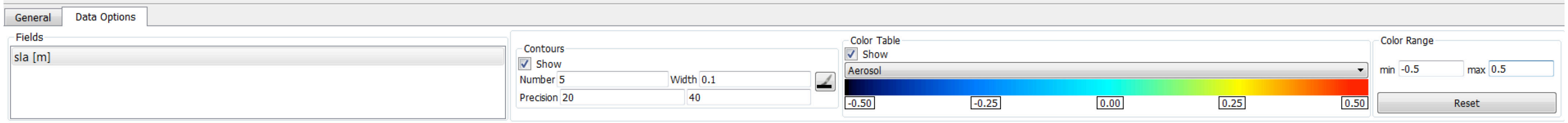




SLA data (SSALTO/DUACS vs. SLCCI)

- **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.



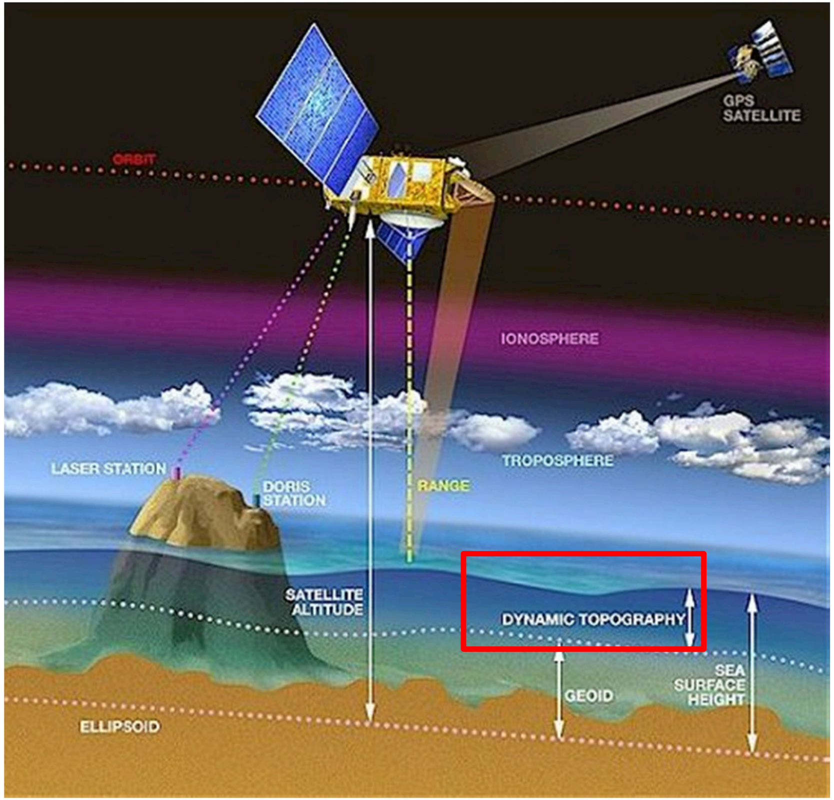


Mean Dynamic Topography

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

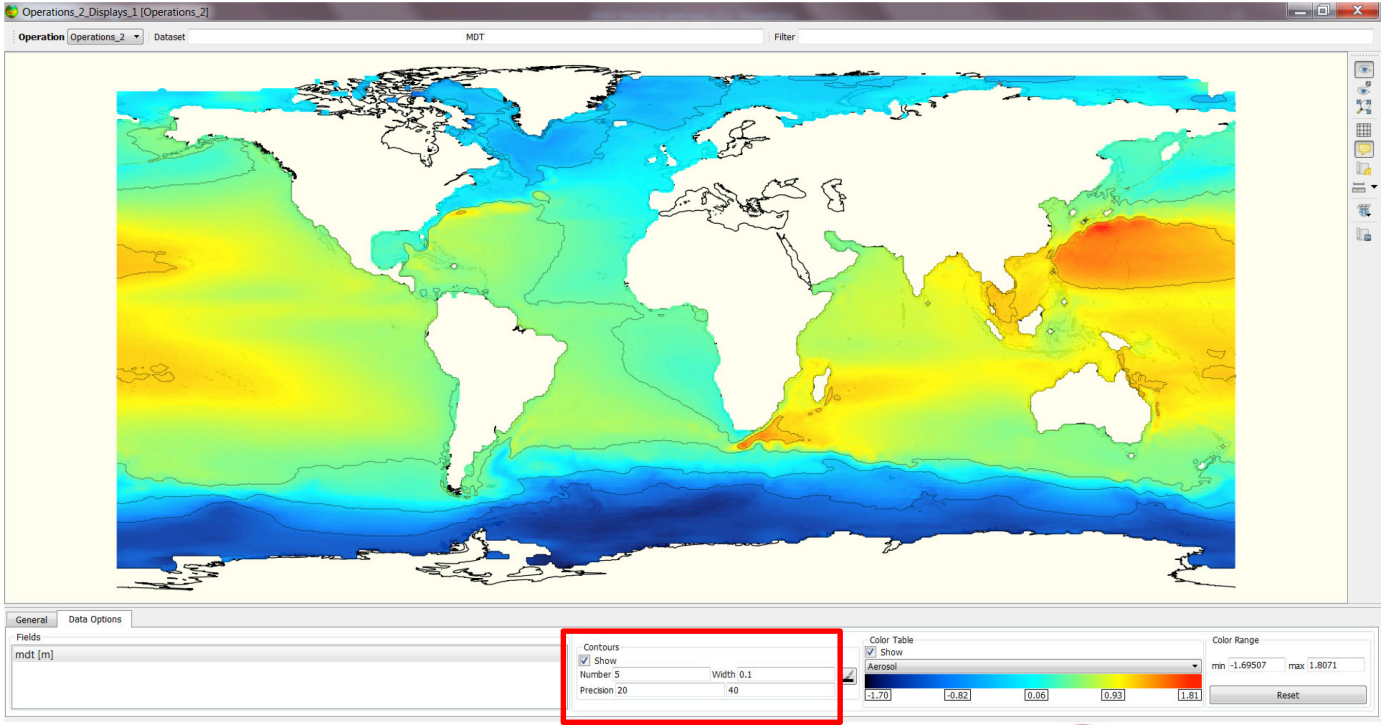
- It contributes to the calculation of the **absolute dynamic topography (ADT),** which is given by the sum of **sea level anomaly (SLA)** and **mean dynamic topography (MDT).**

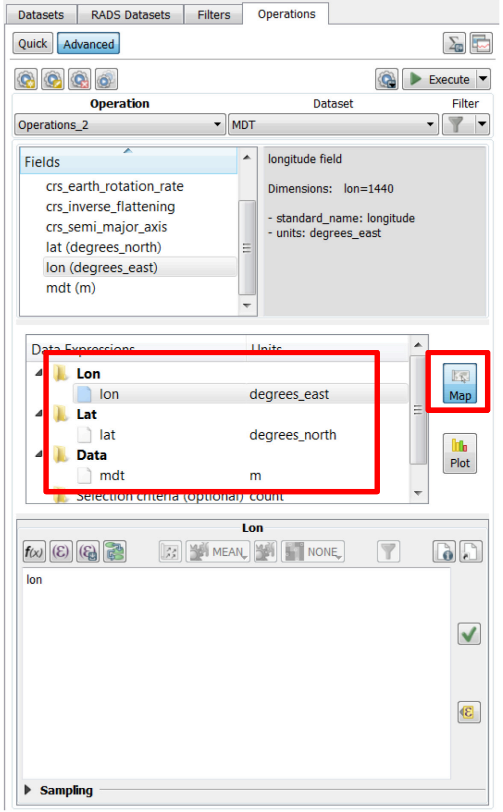
- The MSS and the geoid shall be referenced to the same ellipsoid.



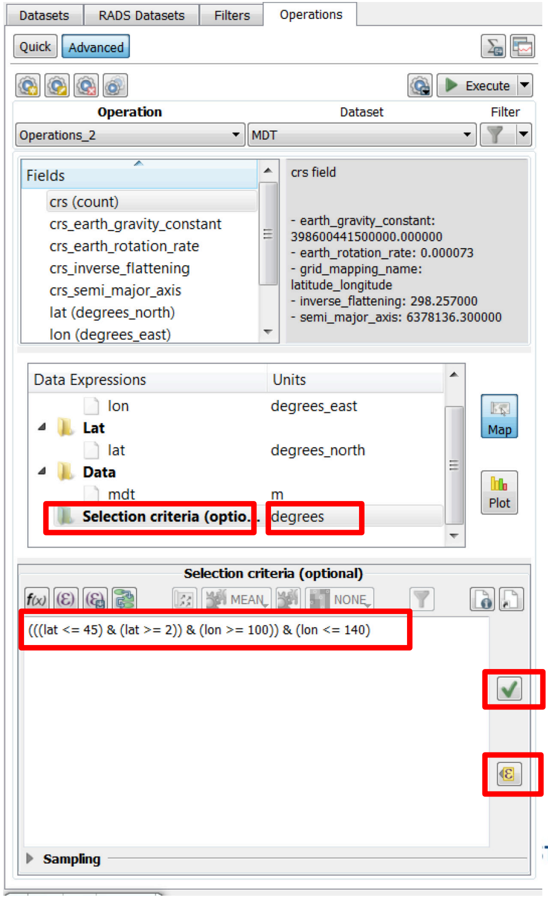
Mean Dynamic Topography (2)

- Input File: MDT_CNES_CLS_09_15M

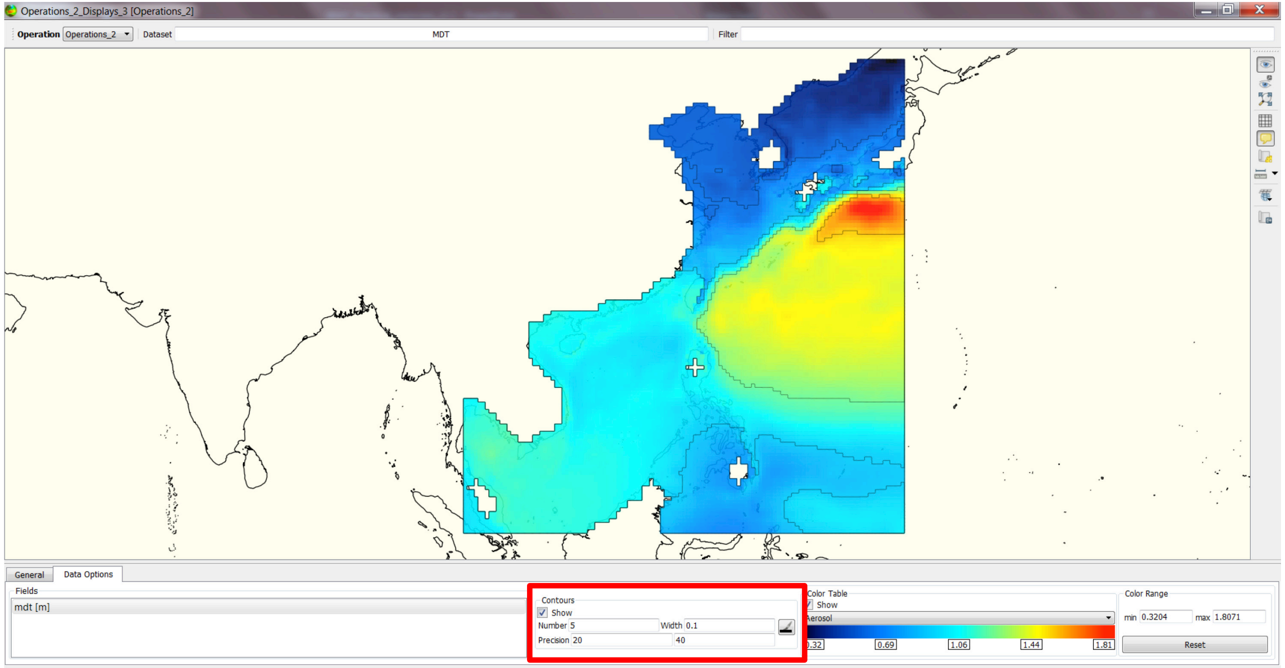




Mean Dynamic Topography (3)

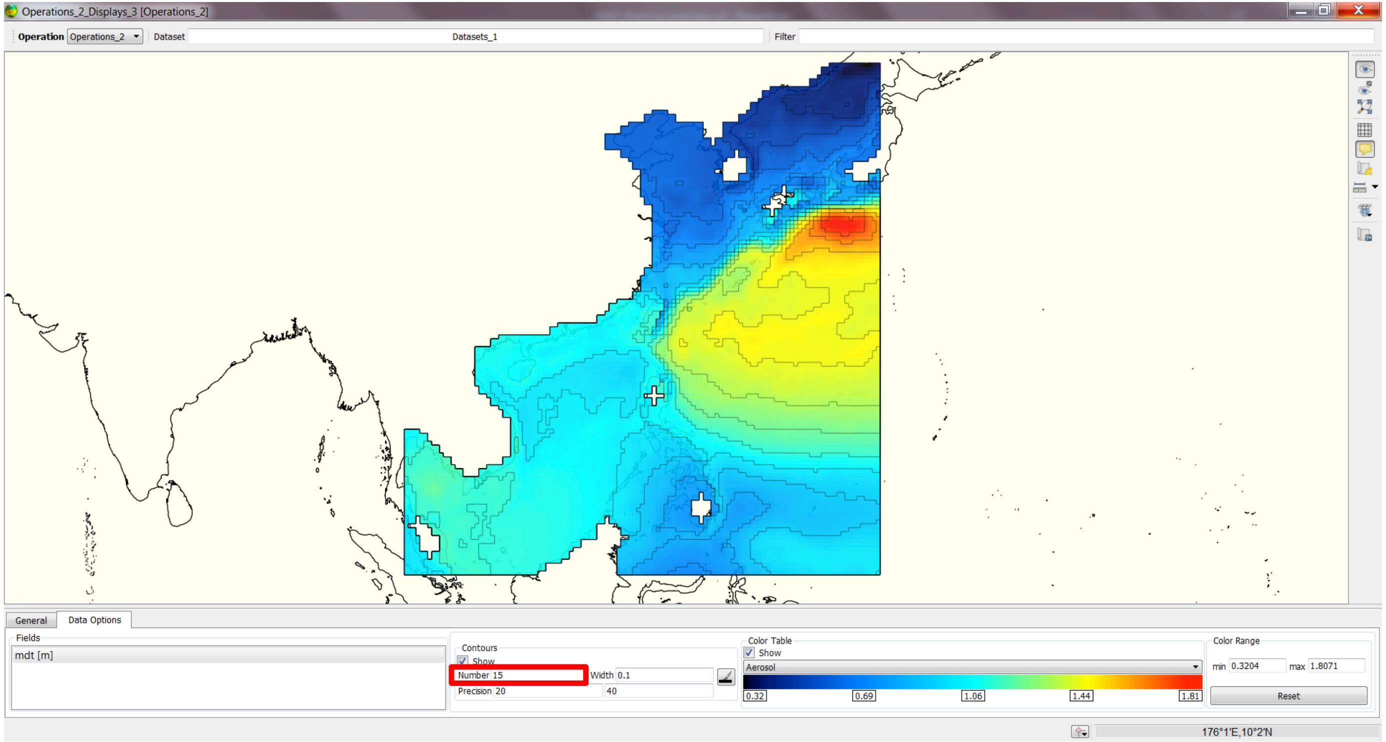


- In this case the geographical filtering shall be made using the selection criteria box (the 'Filters' tab requires the presence of a time vector, which is absent in the adopted MDT product).



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):

$$ADT = MDT + SLA$$

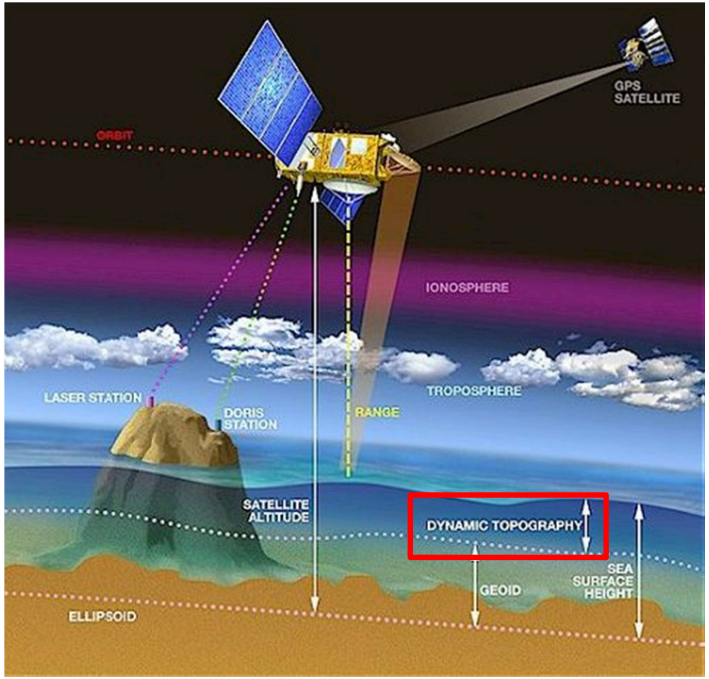
(MSS used to generate the SLAs must be defined over the same averaging period as the MDT!)

It is used to evaluate the **instantaneous total surface geostrophic currents** using the typical geostrophic equations (*) :

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

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]

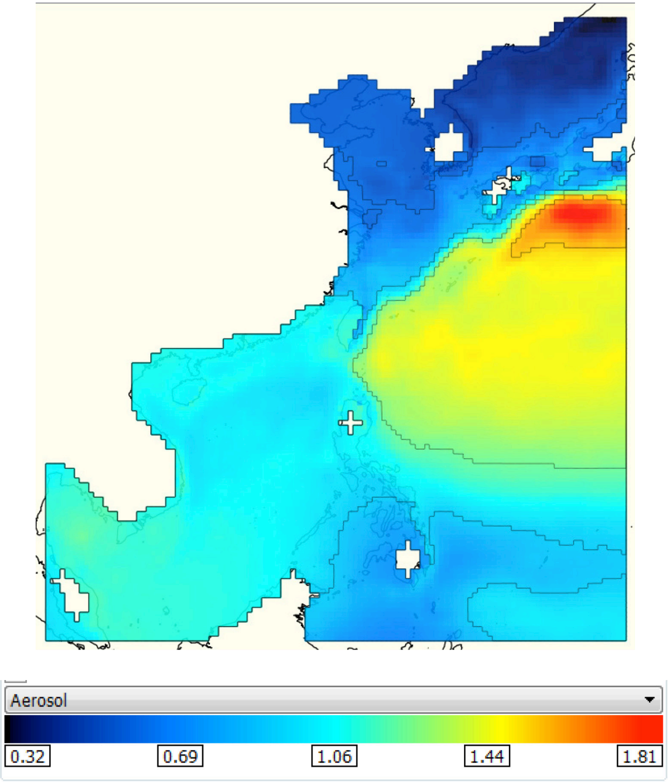
+

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

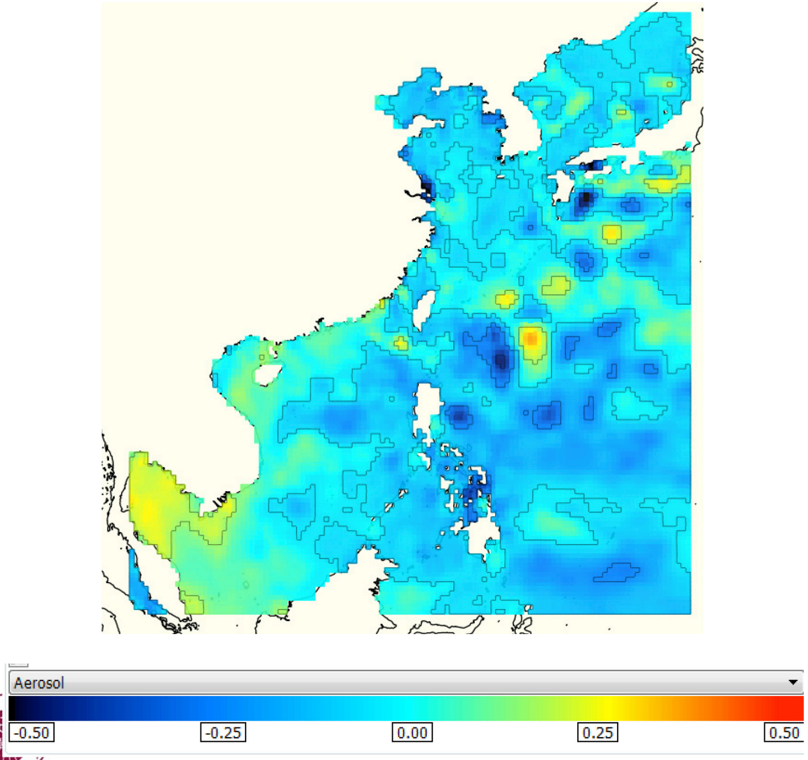
The MSS used to generate the SLAs must be defined over the same averaging period as the MDT.

Comparing MDT_CNES_CLS_09_15M & SLA (SLCCI v2.0 data)

MDT_CNES_CLS_09_15M [m]



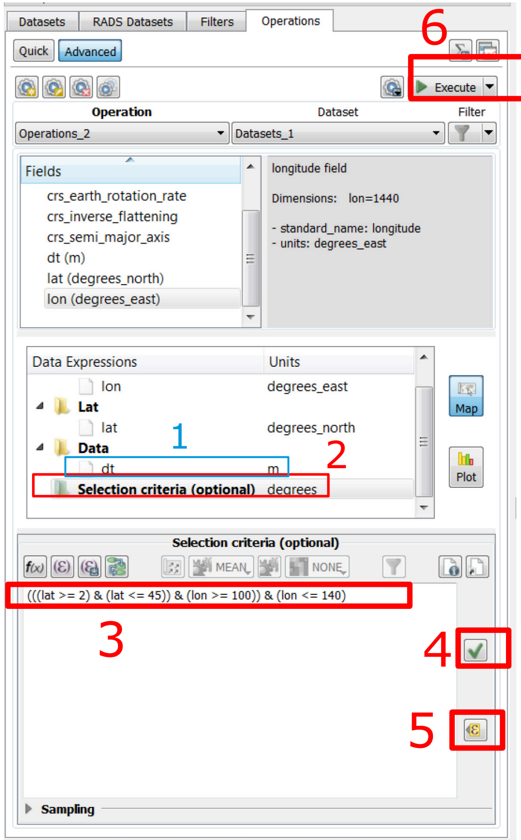
SLA (SLCCI v2.0 data) [m]



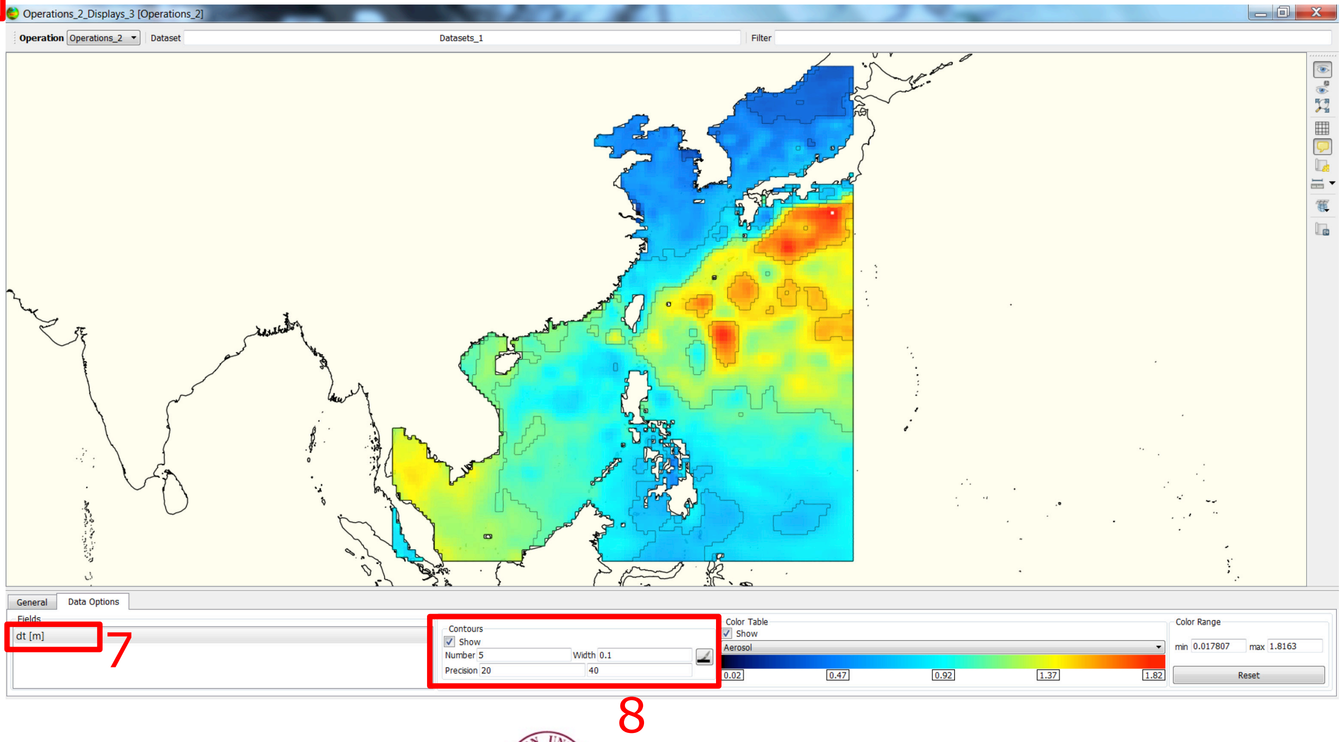
Hosted by

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).



Absolute Geostrophic Velocity (1)

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

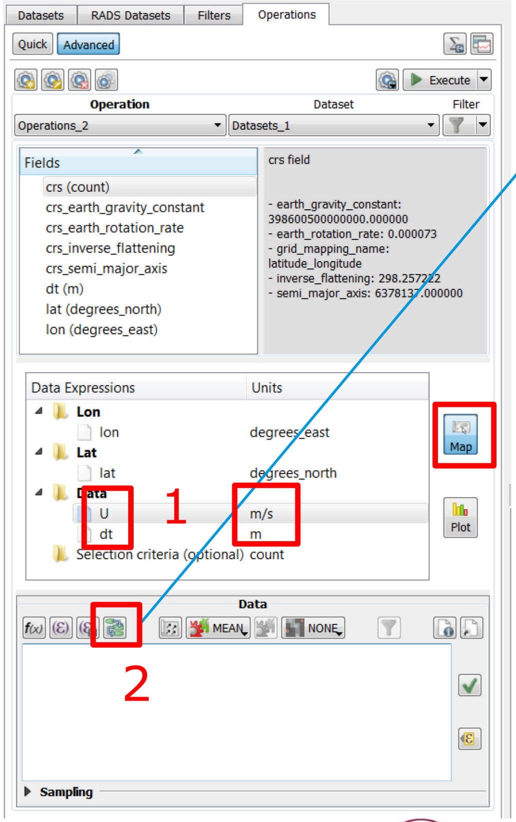
- 2-5: Highlight **U** and select the algorithms icon (2) to insert the BRAT algorithm **BratAlgoGeosVelGridU.**

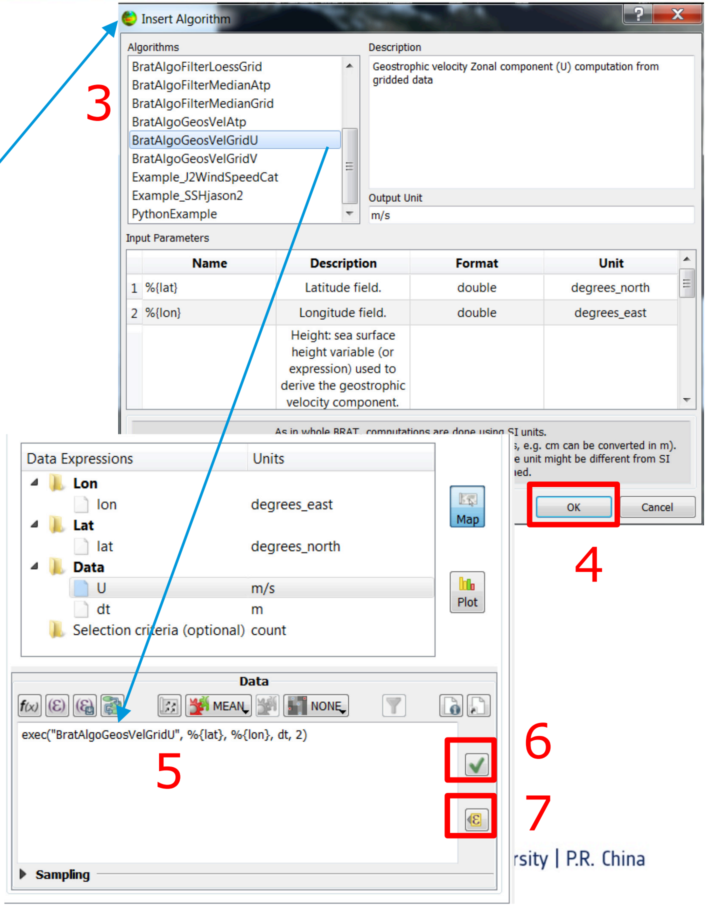
- Modify the default expression to

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 ◁ε.





Absolute Geostrophic Velocity (2)

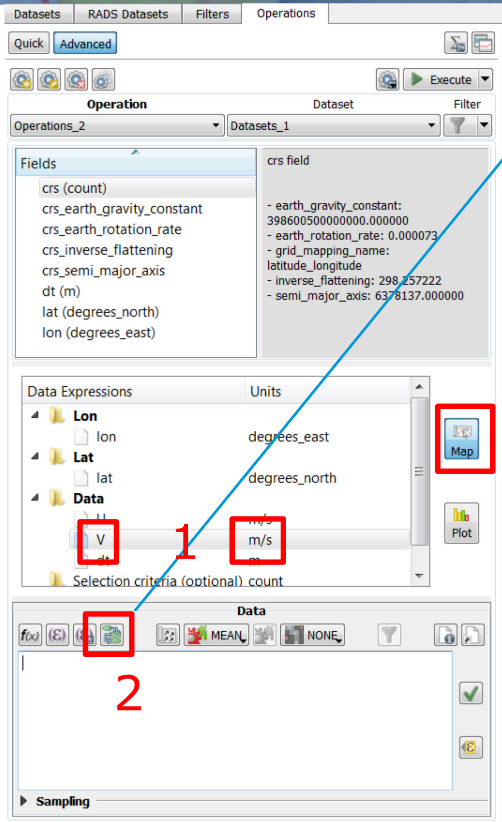
- 1: Create another expression named **V [m/s]**

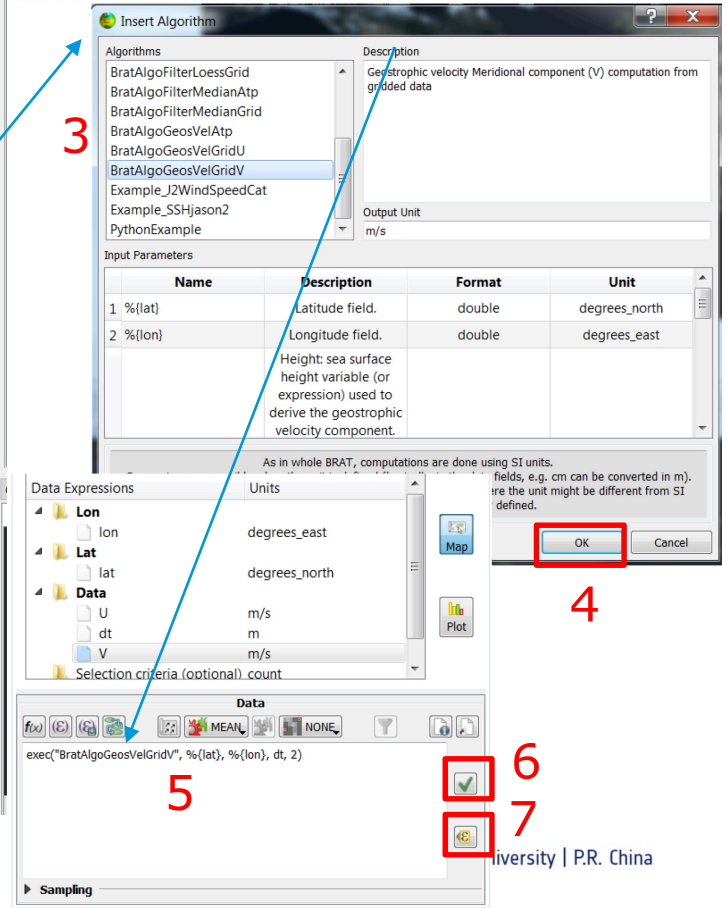
- 2-5: Highlight **V** and select the algorithms icon (2) to insert the BRAT algorithm **BratAlgoGeosVelGridV**.

- Modify the default expression to

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

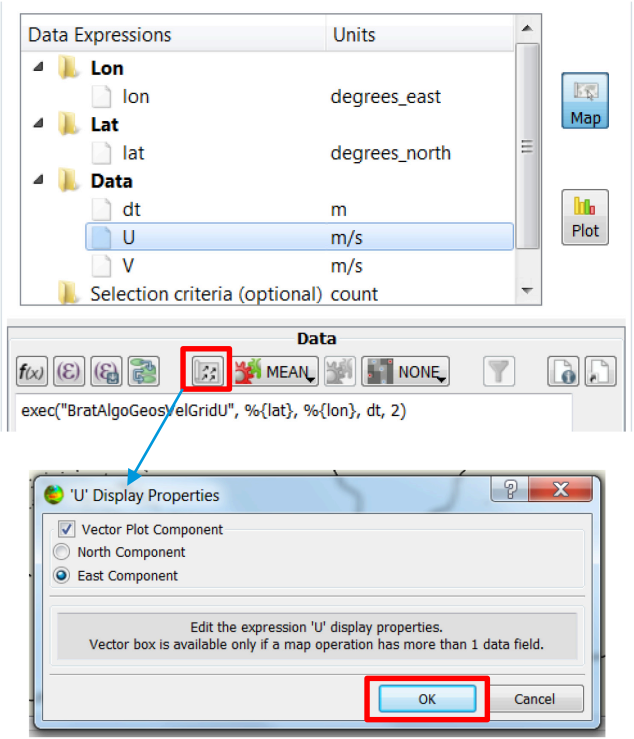
- 6-7:Check the correctness of the formula with ✓ and save it with ⧏ε.

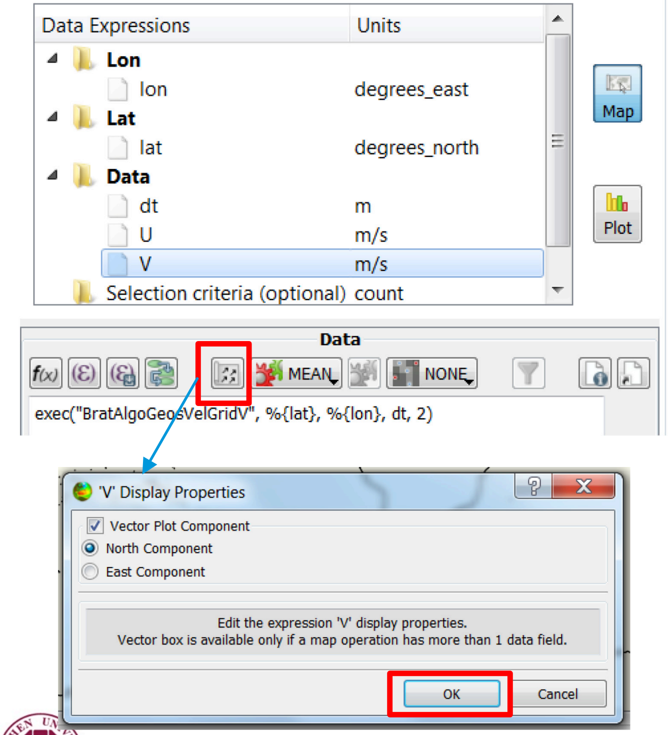




Absolute Geostrophic Velocity (3)

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

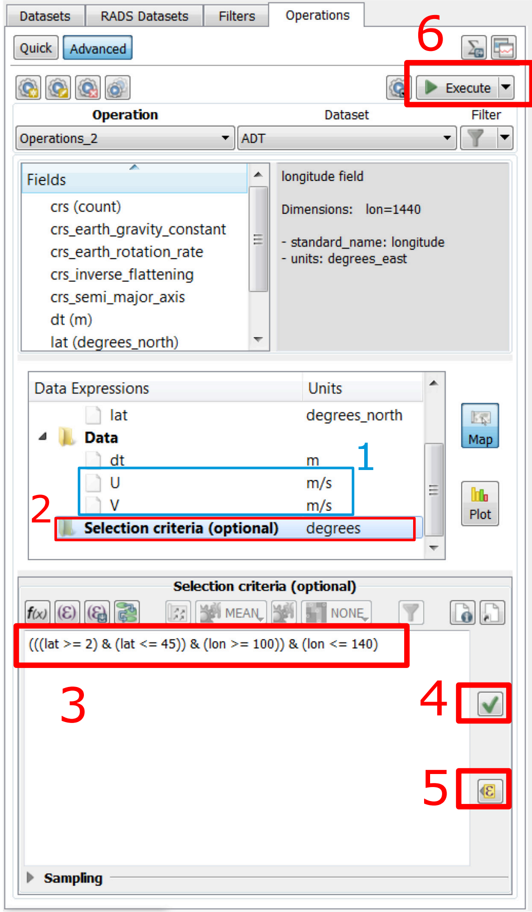


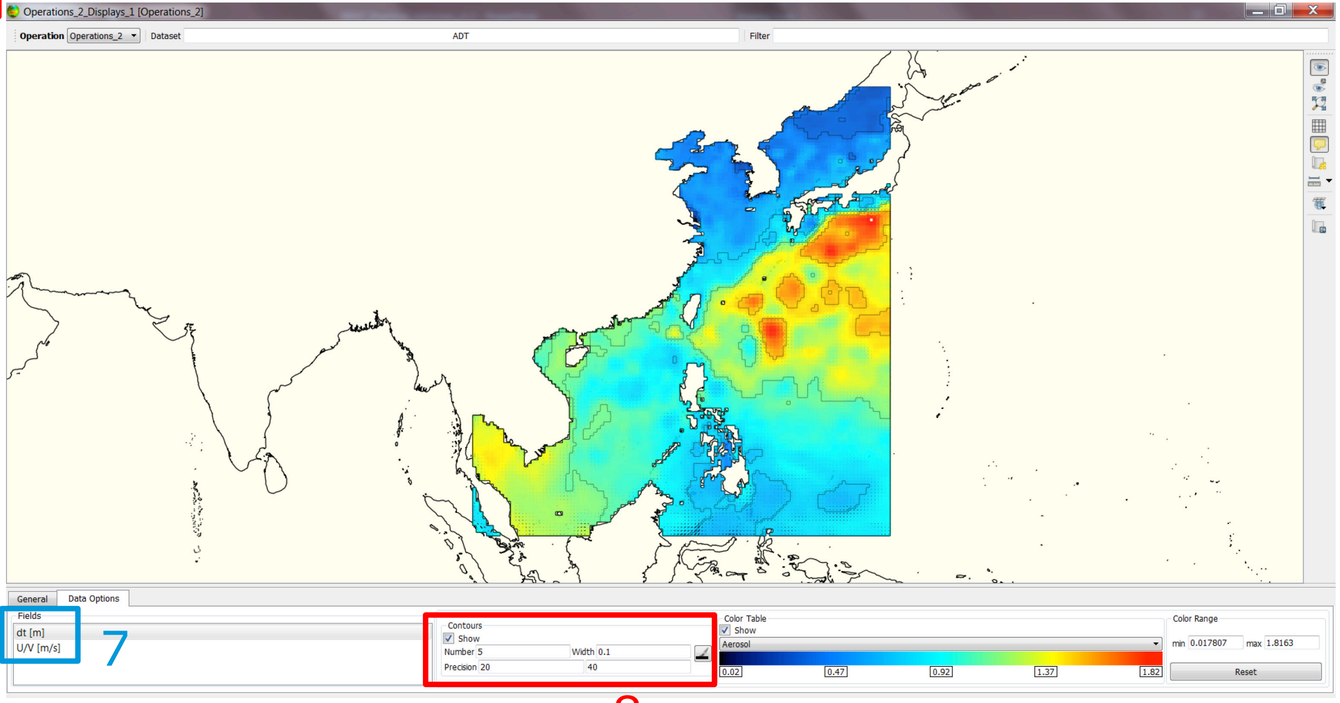


Absolute Geostrophic Topography and Velocities

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

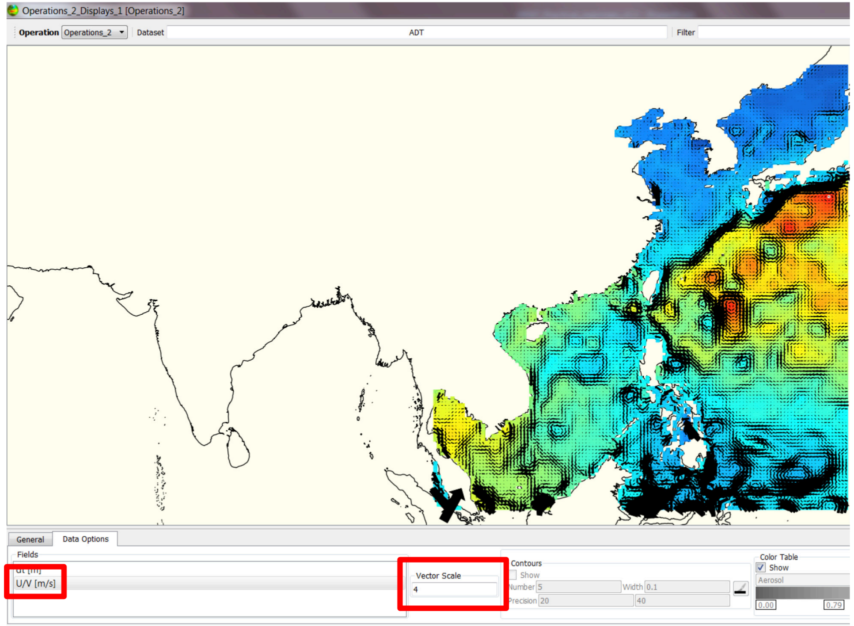
7-8: Two maps are selectable now: **dt [m]**, as before, and **U/V [m/s]**.

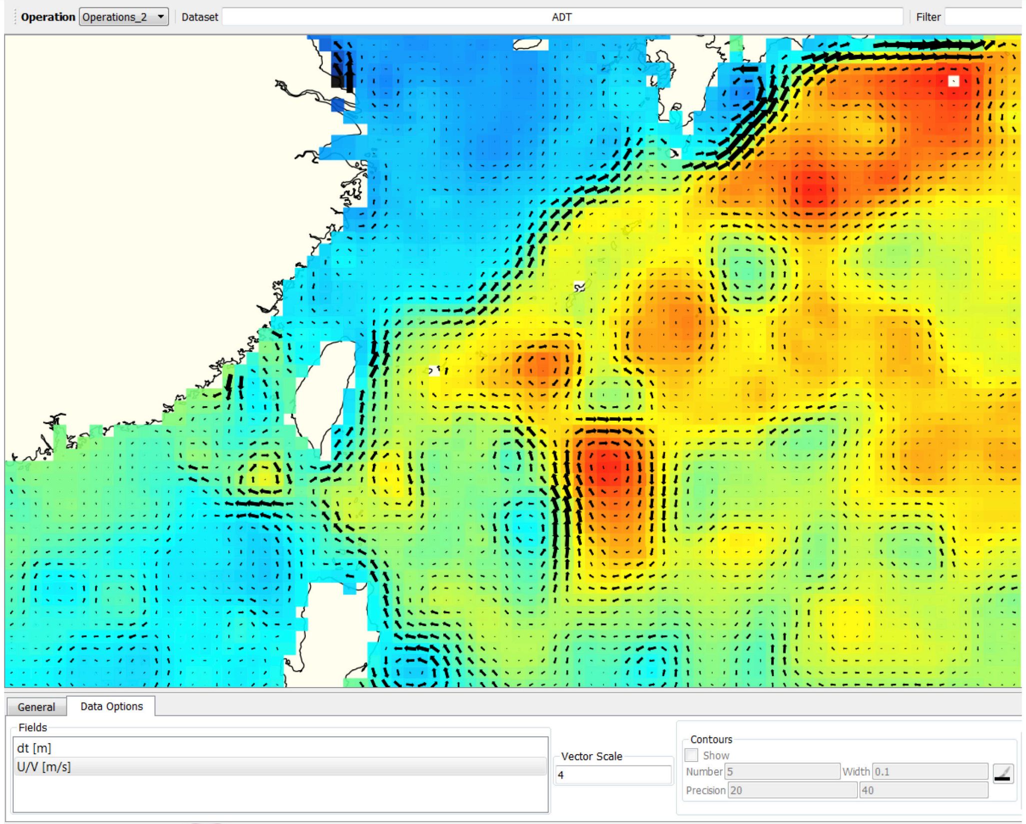




Absolute Geostrophic Velocities

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')