

# **Copernicus Marine Service Training Workshop**

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**QGIS tutorial for #MarineData4Asia24**



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# 1. Introduction

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## 1.1. Scope of the document

The **MarineData4Asia** training event, promoted by Mercator Ocean International in the framework of the Copernicus Marine Service, aims at increasing user uptake and awareness in Asian countries: to achieve this target, the training event shows how to use technologies such as QGIS for manipulating the Copernicus Marine Product Catalogue, with the scope to provide examples on ecosystem monitoring studies and to focus on the main marine and coastal challenges impacting the continent.

In this tutorial, we will learn how to:

- Monitor the El Niño (and La Niña) event by computing SST anomalies to visualize the relevant pattern in the Pacific Ocean and for computing metrics in the Niño3.4 region.
- Visualize the Copernicus Marine products in the Indian Ocean, extracting EOVS values in some specific locations.
- Interpolate SST values in specific grid at given resolution to support additional data analysis (e.g., validation).

Technical material here described is complementary to the tutorial videos available on the Copernicus Marine Service [YouTube page](#).

## 1.2. Focusing on El Niño event in 2023 in the tropical Pacific Ocean region

The El Niño Southern Oscillation (ENSO) is an interannual climate pattern, that is characterized by changes in winds and sea surface temperatures in the tropical Pacific Ocean, with global impacts on weather, wildfire, ecosystems and economy [1]. El Niño and La Niña are 2 phases of ENSO [2]:

- El Niño is characterized by unusually warm ocean temperatures in the Equatorial Pacific;
- La Niña is, on the contrary, characterized by unusually cold ocean temperatures.

As described in [3], ENSO has a robust impact on East Asia climate, mainly by modifying the atmospheric circulation over the Western North Pacific and circulation in the Philippine Sea and Kuroshio. During El Niño winters, wind anomalies from the South embedded in the Western part of anticyclonic circulation insisting in the basin bring warm and moist air to East Asia, leading to abnormal wet and warm climate. Opposite changes are observed during La Niña.

Mercator Ocean International is operationally monitoring current El Niño event since its appearance in Spring 2023 through dedicated bulletins that show the evolution of sea surface temperature (SST) anomalies on monthly basis [4].

During this QGIS training session, we will focus on how to use the Copernicus Marine Service model data provided by the Global Monitoring and Forecasting Centre (GLO-MFC) to monitor El Niño evolution since June 2023 in the Pacific Ocean (**Figure 1**). Practical examples on how to visualize sea surface essential ocean variables (EOV) in some peculiar locations in the Indian Ocean will be also given, to conclude then on how to exploit geospatial analysis tools for interpolating on a given regular grid SST values from both model and satellite observations.

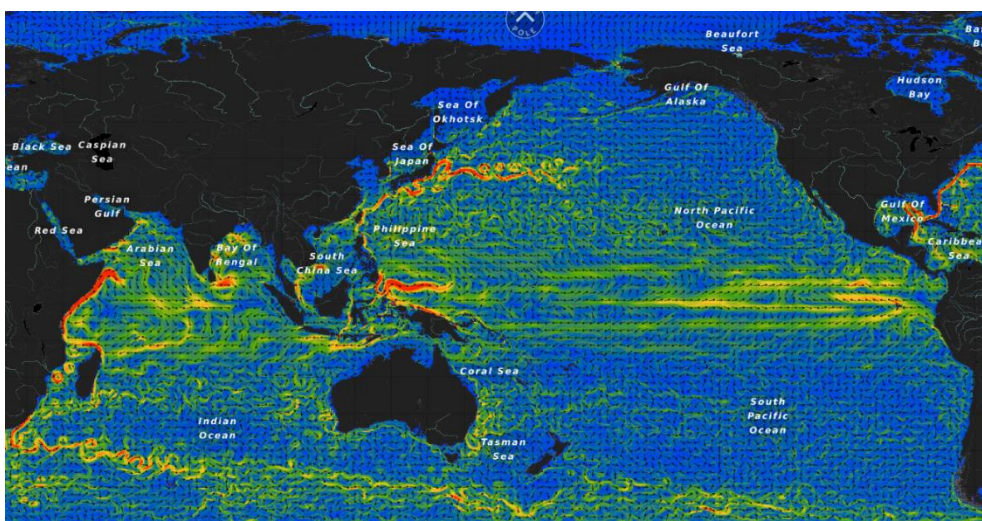


Figure 1: Application area considered during the MarineData4Asia Copernicus Marine Training Session.

## 2. Copernicus Marine Service Products, contextual information and GIS tool

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### 2.1. Copernicus Marine Service products

#### 2.1.1. List of used products, datasets and files

In this training on **MarineData4Asia**, we will focus on the **tropical Pacific Ocean region**, to understand how to evaluate the El Niño conditions during Jun-Nov 2023 and impacts in the Indian Ocean. In the following, we list the products and associated datasets and files as used during the training session.

In the following, the bounding boxes for the reference target regions used in this tutorial:

- Pacific Ocean: 180°W to 180°E; 60°S to 60°N.
- Indian Ocean: 30°E to 120°E; 30°S to 30°N.

Additionally, it is reported the full list of Copernicus Marine products downloaded and used from the Marine Data Store.

- [GLOBAL MULTIYEAR PHY 001\\_030](#), which is the Global Ocean Physics Reanalysis product (**GLO-PHY MY**). We will use the climatological (**climatology\_P1M-m**) dataset for temperature (**thetao**) related to the period from June to November 2023.
  - Dataset: **cmems\_mod\_glo\_phy\_my\_0.083-climatology\_P1M-m**
    - File: **CMEMS\_Pacific-Ocean\_thetao\_clim.nc**  
(downloaded through the **Copernicus Marine Toolbox**, whose link is reported in Appendix).
- [GLOBAL ANALYSISFORECAST PHY 001\\_024](#), which is the Global Ocean Physics Analysis and Forecast (**GLO-PHY NRT**). We will use the monthly means (**anfc\_0.083deg\_P1M-m**) dataset for temperature at 0.5 m depth (**thetao**), related to the period from June to November 2023. Additionally, we will use daily means (**anfc\_0.083deg\_P1D-m**) fields for temperature (**thetao**) and salinity (**so**) at 0.5 m depth, and mixed layer depth (**mlotst**) related to the period 01-07/11/2023.
  - Dataset: **cmems\_mod\_glo\_phy-thetao\_anfc\_0.083deg\_P1M-m**
    - File: **cmems\_mod\_glo\_phy-thetao\_anfc\_0.083deg\_P1M-m\_202306-202311.nc**
  - Dataset: **cmems\_mod\_glo\_phy-thetao\_anfc\_0.083deg\_P1D-m**
    - File: **cmems\_mod\_glo\_phy-thetao\_anfc\_0.083deg\_P1D-m\_SST-20231101-20221107.nc**
  - Dataset: **cmems\_mod\_glo\_phy-so\_anfc\_0.083deg\_P1D-m**
    - File: **cmems\_mod\_glo\_phy-so\_anfc\_0.083deg\_P1D-m\_SSS-20231101-20221107.nc**
  - Dataset: **cmems\_mod\_glo\_phy\_anfc\_0.083deg\_P1D-m**
    - File: **cmems\_mod\_glo\_phy-so\_anfc\_0.083deg\_P1D-m\_MLD-20231101-20221107.nc**  
(downloaded through the **Copernicus Marine Data Store**, using the subset function).
- [SST GLO PHY L4 NRT 010\\_043](#), which is the ODYSSEA Global Sea Surface Temperature Gridded Level 4 Daily Multi-Sensor Observations. We will use the daily fields for the period 01-07/11/2023.
  - Dataset: **cmems\_obs-sst\_glo\_phy\_nrt\_l4\_P1D-m**
    - File: **cmems\_obs-sst\_glo\_phy\_nrt\_l4\_P1D-m\_SST-20231101-20221107.nc**

#### 2.1.2. How to download data from the Copernicus Marine Service?

Here, we will shortly demonstrate the steps to download the **Global Model data** listed in Section 2.1.1 from the Copernicus Marine Service, using the new recent tools provided by the Service: the Copernicus Marine Toolbox and the function subset available directly in the Copernicus Marine Data Store.

##### 2.1.2.1. Example on how to use the Copernicus Marine Toolbox

The [Copernicus Marine Toolbox](#) is the new client that will be used to explore and download the Copernicus Marine data. In the reference link, **a detailed description of the steps to install and run it is given**; additional details are provided at the Jupyter Notebook video-tutorial given during this MarineData4Asia Training session. In this section, we only illustrate the basic commands run through a [Jupyter Notebook](#) for downloading GLO-PHY MY data as described in Section 2.1.1.

For running this example, you first need to install and configure the Copernicus Marine Toolbox in your local machine. Once done, you might simply follow these basic steps for getting the **"CMEMS\_Pacific-Ocean\_thetao\_clim.nc"** file from the Copernicus Marine Data Store.

**Step 1:** Importing the reference libraries. To run the Copernicus Marine Toolbox, you need to import the Copernicus Marine Client called `copernicus_marine_client` (as described in the [dedicated page](#) maintained by the Copernicus Marine Service Help Desk) and the `pprint` function, used to print/visualize the retrieved catalogue contents.

```
import copernicus_marine_client as copernicusmarine
from pprint import pprint
```

**Step 2:** Retrieve the whole Copernicus Marine Catalogue. This is done by using the function `“.describe”` given by the Copernicus Marine Toolbox. Then, using the function `“pprint”` you might visualize the metadata associated with products as available in the Copernicus Marine Service (this operation can require some time).

```
catalogue = copernicusmarine.describe(include_datasets=True)
pprint(catalogue)
```

**Step 3:** Select the desired dataset and print the content. We are interested to access data from the `cmems_mod_glo_phy_my_0.083-climatology_P1M-m` dataset. This can be easily done by using the following command:

```
catalogue_glo = copernicusmarine.describe(contains=["cmems_mod_glo_phy_my_0.083deg-
climatology_P1M-m"], include_datasets=True)
```

Again, the `“.describe”` function opens the Copernicus Marine product catalogue and by using the function `“contains”` it is possible to filter it by selecting only the dataset having keyword `“cmems_mod_glo_phy_my_0.083deg-climatology_P1M-m”`. This step can be skipped if you already have sufficient information on product/dataset, variable(s) you are interested in.

**Step 4:** Launching the subset of the selected dataset in the region of interest. This step is managed by the function `“.subset”` made available by the Copernicus Marine Toolbox. You need to include a list of information, like dataset name, variable(s) name(s), bounding box of the region of interest (min/max latitude, min/max longitude), start/end time of the period of interest, min/max depth, name of the output file and directory where to find it. In this case, we refer to the Pacific Ocean bounding box.

```
copernicusmarine.subset(
    dataset_id="cmems_mod_glo_phy_my_0.083deg-climatology_P1M-m",
    variables=["thetao"],
    minimum_longitude=-180,
    maximum_longitude=180,
    minimum_latitude=-60,
    maximum_latitude=60,
    start_datetime="1993-01-01T00:00:00",
    end_datetime="2016-12-31T23:59:59",
    minimum_depth=0,
    maximum_depth=0.5,
    output_filename = "CMEMS_Pacific-Ocean_thetao_clim.nc",
    output_directory = "copernicus-data"
)
```

By executing the cell, you will be asked to provide username and password of your Copernicus Marine account: after inserting, the download of the file containing the climatological monthly temperature fields given by the GLO-PHY MY system. After that, the download of the file will start as shown in **Figure 2**. Once completed, the output file `CMEMS_Pacific-Ocean_thetao_clim.nc` will be accessible through the local folder `copernicus-data` and ready to be used.

#### 2.1.2.1. Example on how to download the Copernicus Marine GLO-PHY product from the Copernicus Marine Data Store using the GUI

In this section, we illustrate how to download the monthly mean mixed layer depth field related 01-07/11/2023 directly from the Copernicus Marine Data Store by using the GUI, in the Indian Ocean bounding box.

**Step 1:** Access to the GLO-PHY NRT system main page from the Copernicus Marine Data Store (hyperlinked in Section 2.1.1). Visualization of the options for accessing relevant information about the selected product. As shown in **Figure 3**, the GLO-PHY NRT main page provides an overview of the most relevant information related to the Global Ocean Analysis and Forecasting System, including the options for accessing the data.

**Option 1:** by clicking on “Data Access” tab, you will be redirected to a second page that gives the list of available datasets with interfaces for downloading associated data (**Figure 4**):

- **Subset**, which is the new function for interactively select total or a portion of the interested region.
- **Files**, that returns the data archive structure of the selected dataset.
- **Maps**, that returns WMTS file that you might export to use in your dedicated webservice.

```

username:password:INFO - 2024-01-15T14:47:47Z - Selected dataset version is "202311"
INFO - 2024-01-15T14:47:47Z - Selected dataset part is "default"
C:\Users\sciliberti\anaconda3\lib\site-packages\scipy\_init_.py:146: UserWarning: A NumPy version >=1.16.5 and <1.23.0 is required for this version of
warnings.warn(f"A NumPy version >={np_minversion} and <{np_maxversion}")
INFO - 2024-01-15T14:47:54Z - Selected service is "CopernicusMarineDatasetServiceType.TIMESERIES"
WARNING - 2024-01-15T14:47:55Z - Some or all of your subset selection [1993-01-01 00:00:00, 2016-12-31 23:59:59] for the time dimension exceed the data:
INFO - 2024-01-15T14:47:55Z - Downloading using service arco-time-series...
INFO - 2024-01-15T14:47:55Z - <xarray.Dataset>
Dimensions: (depth: 1, latitude: 1441, longitude: 4320, time: 12)
Coordinates:
* depth (depth) float32 0.494
* latitude (latitude) float32 -60.0 -59.92 -59.83 ... 59.83 59.92 60.0
* longitude (longitude) float32 -180.0 -179.9 -179.8 ... 179.8 179.8 179.9
* time (time) datetime64[ns] 1993-01-01 1993-02-01 ... 1993-12-01
Data variables:
  thetao (time, depth, latitude, longitude) float32 dask.array<chunksiz=(12, 1, 128, 128), meta=np.ndarray>
Attributes: (12/17)
  CDI:          Climate Data Interface version 1.9.3 (...
  CDO:          Climate Data Operators version 1.9.3 (...
  Conventions: CF-1.6
  area:         GLOBAL
  contact:      servicedesk.cmems@mercator-ocean.eu
  credit:       E.U. Copernicus Marine Service Informa...
  ...
  product_user_manual: http://marine.copernicus.eu/documents/...
  quality_information_document: http://marine.copernicus.eu/documents/...
  references:     http://marine.copernicus.eu
  source:        MERCATOR GLORYS12V1
  title:         Monthly climatology fields for product...
  copernicus_marine_client_version: 0.10.3
INFO - 2024-01-15T14:47:55Z - Estimated size of the dataset file is 285.120 MB.
Do you want to proceed with download? [Y/n]:INFO - 2024-01-15T14:48:01Z - Writing to local storage. Please wait...

48% ██████████ 1373/2858 [00:26<00:16, 88.31it/s]

```

**Figure 2:** Log file and process related to download of climatological monthly temperature fields given by the GLO-PHY MY system as accessed through the Copernicus Marine Data Store.

Link to the GLO-PHY NRT system page after browsing through the Copernicus Marine Data Store.

**Option 1:** Tab for visualizing the available options for accessing data.

**Information about the selected product (e.g., documents, overview, etc.).**

**Option 2:** to explore the product through the MyOcean Viewer.

**Figure 3:** GLO-PHY NRT main page through the Copernicus Marine Service.

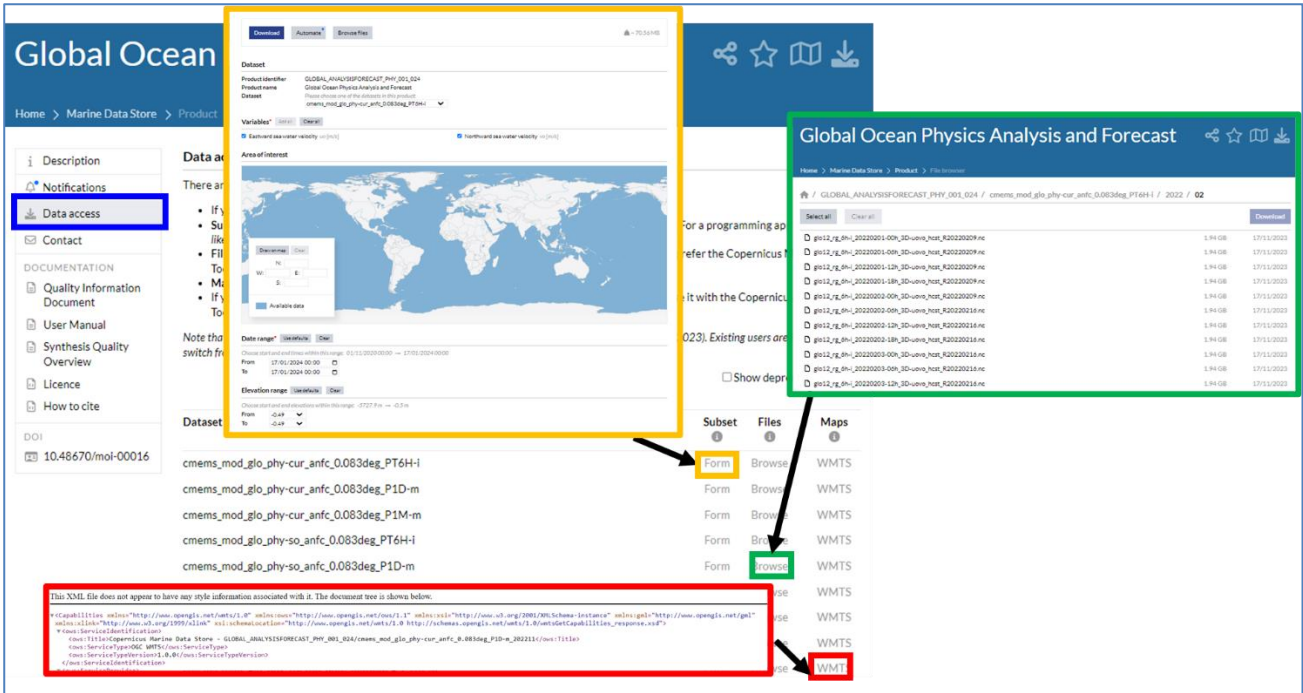


Figure 4: Option 1 for accessing Copernicus Marine data using a) subset (in orange), b) files (in green) or c) maps (in red).

**Option 2:** by clicking on “Explore in MyOcean Pro” tab, you will be redirected to the MyOcean Pro Viewer webpage that shows the 2D map of the selected field (Figure 5). The viewer gives the opportunity to:

- Add any new field as new layer.
- Download the file by selecting the bounding box and the range of dates.
- Access to information about the product/dataset, customize the map, save and export for next uses.

Once the spatio-temporal information for the selected variables is inserted into the GUI, you might launch the download of the file.

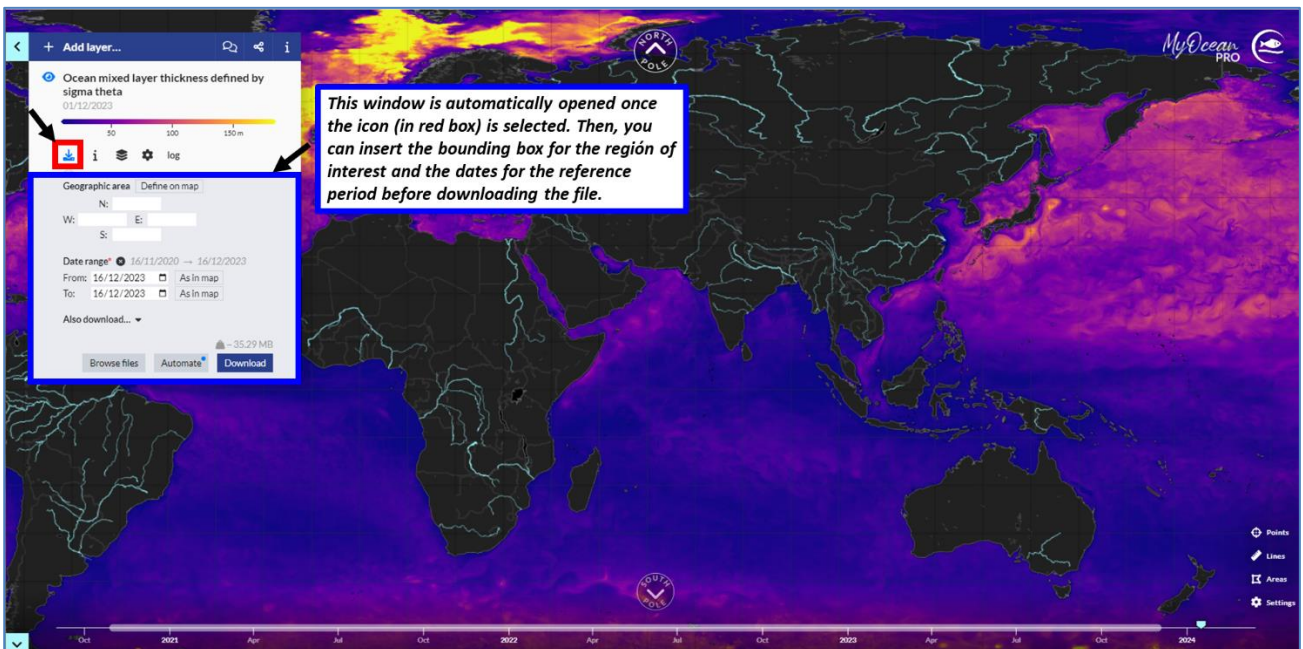


Figure 5: Option 2 for accessing Copernicus Marine data using the MyOcean Pro Viewer functionalities.

Additional information on how to access and download Copernicus Marine data are provided in the [Copernicus Marine E-Learning Material](#) and at the page dedicated to the [MarineData4Asia](#).

## 2.2. QGIS Software

### 2.2.1. Installation of QGIS

The GIS software used for this training is the **QGIS software in its version 3.28-Firenze Long Term Release** ([last available version as accessed on 15/01/2024](#)).

QGIS is the widely adopted open-source GIS software, supported by the Open Source Geospatial Foundation (OSGeo) and available on many Operating Systems like Windows, MacOS, Linux, IOS and Android.

To install QGIS, follow the instructions at [dedicated installation page](#) and download the [OSGeo4W Network Installer](#).

Then, choose the **Express Install** and **Check QGIS and GDAL** boxes before launching the Installation.

A video explaining the basic steps for downloading and installing QGIS is available at the page dedicated to Copernicus MarineData4Asia.

### 2.2.2. Installation of the CMEMS-NetCDF plugin and example on how to load a NetCDF file

The Copernicus Marine Service makes available the [CMEMS-NetCDF plugin](#), which enables the handling of data in NetCDF format. The user can follow the instructions on how to install it in QGIS by accessing the [dedicated webpage](#) prepared by the Copernicus Marine Team at the E-Learning section, which makes available:

- The link to download the plugin and
- The user manual,

together with some tutorial on how to use it.

To install the CMEMS-NetCDF plugin, from the top menu of QGIS select **Plugins > Manage and Install Plugins...**. Then, a window **Plugin | Install from ZIP** appears, and the user can browse through her/his personal folder to select the zip file containing the CMEMS-NetCDF plugin as downloaded from the Copernicus Marine E-Learning Section (link in Appendix). Finally, select **Install Plugin**. **Figure 6** visualizes the main steps performed through the GUI. The same steps can be performed in case an update of the plugin through a new zip file needs to be done. Once installed/updated, the CMEMS-NetCDF icon appears in the QGIS toolbar and it is ready to be used.

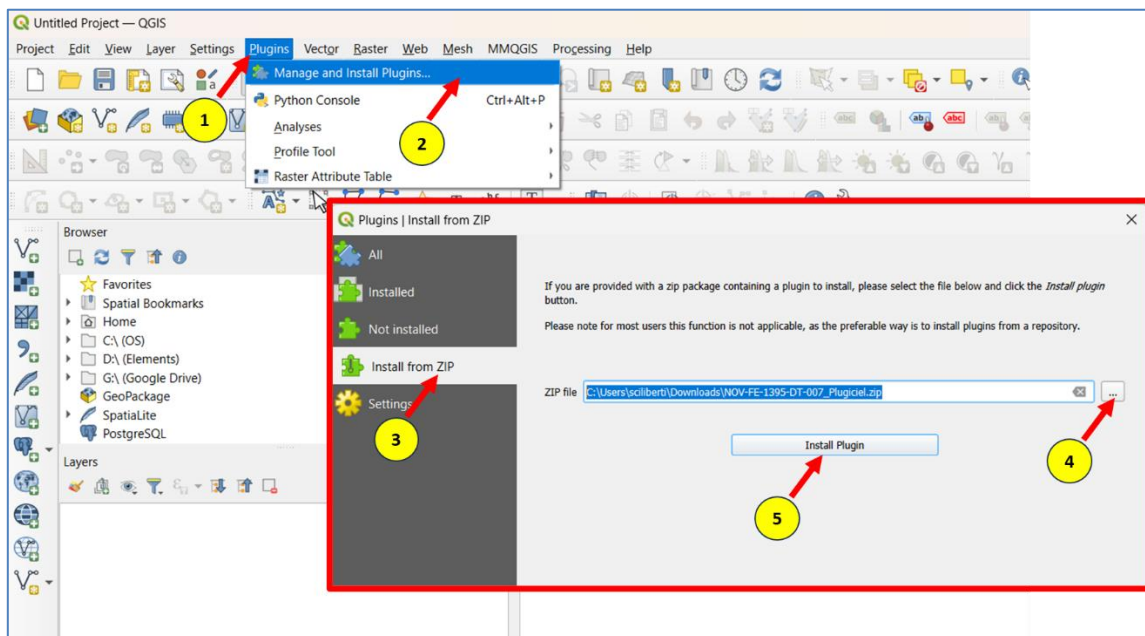


Figure 6: Steps for installing / updating the CMEMS-NetCDF plugin.

Once clicking on the CMEMS-NetCDF icon available in the toolbar or selecting **Plugins > NetCDF2GIS > Import NetCDF files** from the QGIS top menu, a GUI appears with functions to load and explore the NetCDF file structure and semantic, as schematized in [Figure 7](#).

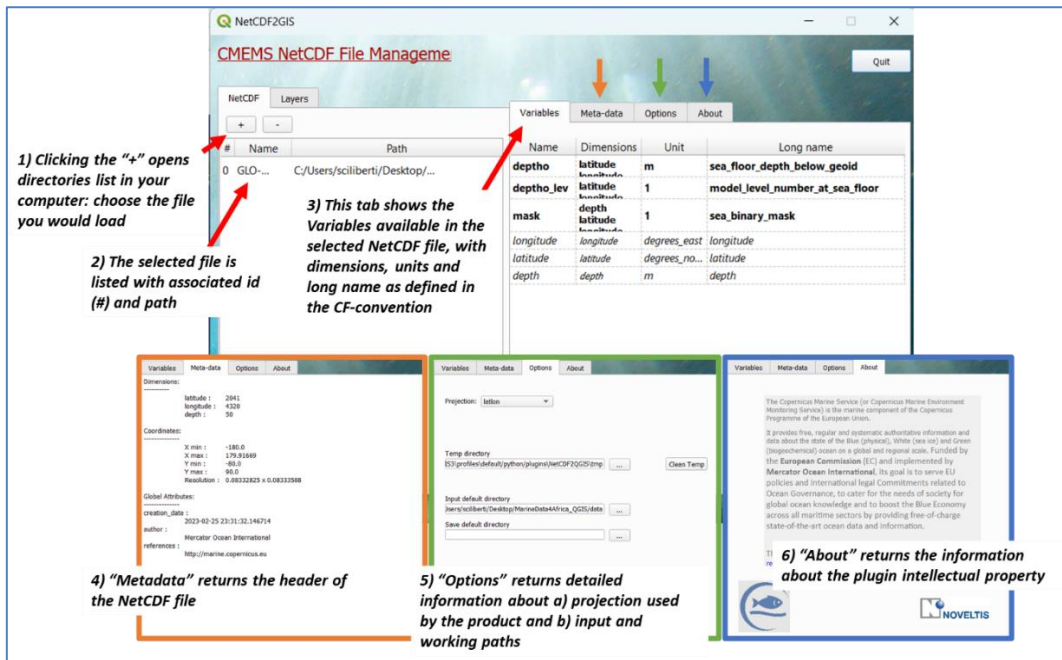


Figure 7: Overview of the CMEMS-NetCDF plugin GUI.

### 2.2.3. Installation of the QuickMapServices plugin

The QuickMapService is developed by NextGIS and allows to easily add basemaps and geoservices. Details are given in the [dedicated QGIS plugins page](#).

To install it, open the QGIS software and click on **Plugins > Manage and install Plugins** in the top menu. In the search bar, type "QuickMapService" and the window will be refreshed once the plugin is selected as in **Figure 8**. Click on "Install Plugin" (or "Reinstall Plugin" to refresh it).

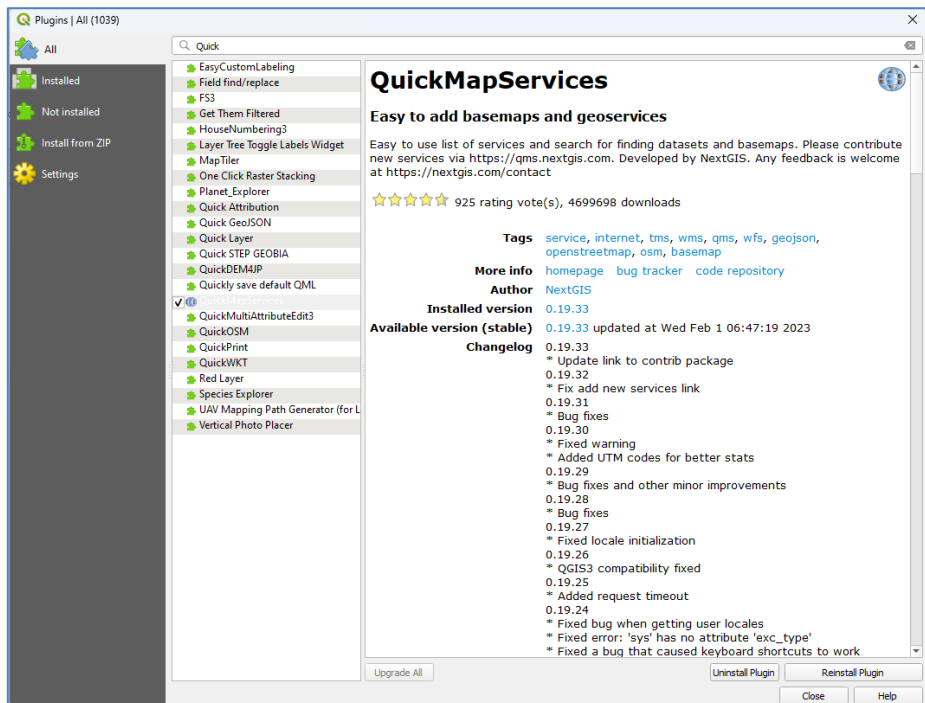


Figure 8: The QuickMapService plugin.

### 2.2.4. Installation of the DataPlotly plugin

DataPlotly is a Python-based plugin that allows the creation of D3 like plots thanks to the Plotly library and the Python API. It has been developed by [Faunalia](#). Details are given in the [dedicated QGIS plugins page](#).

To install it, open the QGIS software and click on **Plugins > Manage and install Plugins** in the top menu. In the search bar, type “DataPloty” and the window will be refreshed once the plugin is selected as in **Figure 9**. Click on “Install Plugin” (or “Reinstall Plugin” to refresh it).

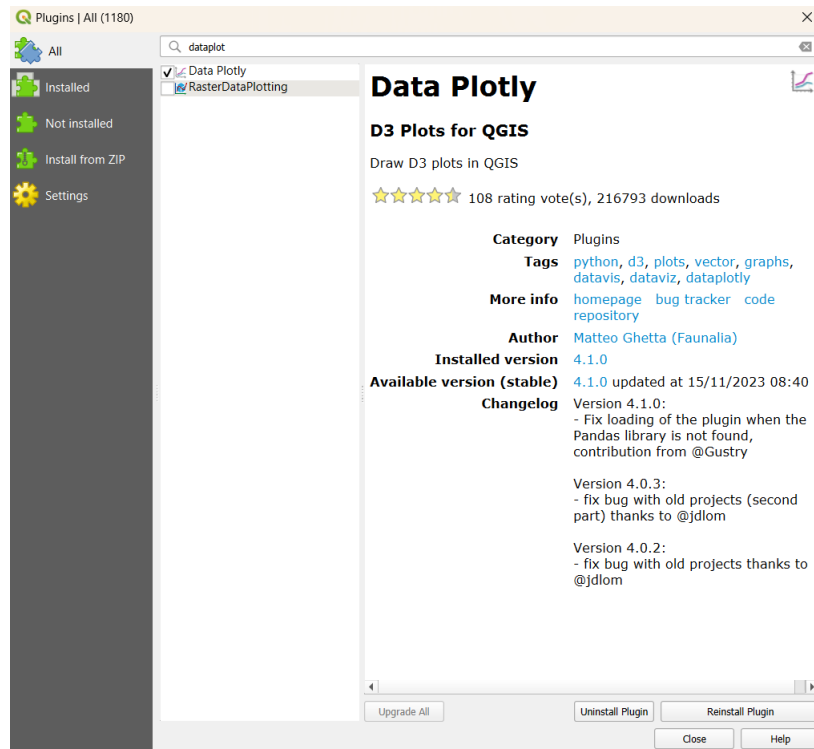


Figure 9: DataPloty plugin.

### 3. Launching a QGIS project and importing a basemap

This section opens with some basic instructions on how to create a new project – that will be used during the training session – and play with the available basemaps for supporting the visualization & analysis of the Copernicus Marine data.

#### 3.1. Open QGIS and create a new empty project

On the top menu, click on **Project > New** to create a new project (**Figure 10**).

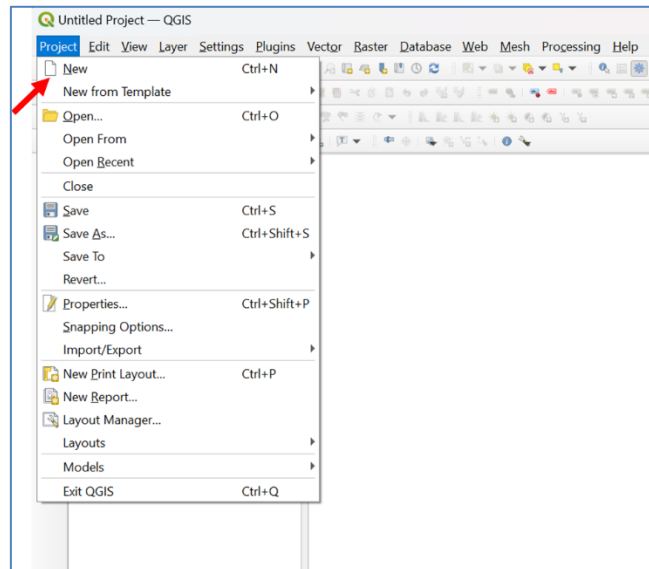


Figure 10: Launching a new project on QGIS.

Finally, save the project by selecting, in the top menu, **Project > Save as > <name>.prj** in a dedicated folder in your computer.

#### 3.2. Overview of installed plugins access and configuration of a basemap through QuickMapServices

Pre-installed plugins –**QuickMapServices**, **DataPloty**, **CMEMS-NetCDF** – can be invoked by clicking on **Plugins** in the top menu or directly clicking on the corresponding icons, as schematically shown in **Figure 11**.

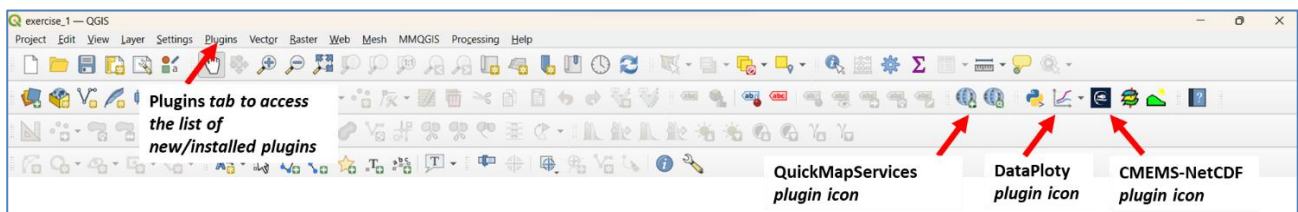


Figure 11: Options for invoking plugins: a) through top menu "Plugins" command or b) through specific icons.

The **QuickMapServices** is configured to help the user to easily geolocate any specific area. By clicking the corresponding icon in the toolbar, the user can select the preferred basemap on a pre-loaded list. In this training, we will use the **Google Hybrid map**. Once loaded, a map like the one in **Figure 12** is displayed on QGIS map canvas and ready to be used for next steps.

The **DataPloty** is here used to plot timeseries or scatter plots for given set of ocean variables, to support monitoring and validation activities.

The **CMEMS-NetCDF** plugin is, finally, used for opening and loading the NetCDF files related to Copernicus Marine products as described in Section 2.1.1.

Application of DataPloty and CMEMS-NetCDF plugins will be given in the next chapter.



Figure 12: Google basemap imported in QGIS.

## 4. Loading the Copernicus Marine Products

This section illustrates the steps for loading and visualizing one of the Copernicus Marine Products, whose detailed list is given in Section 2.1.1, using the **CMEMS-NetCDF** plugin. We will show how to open and visualize the mixed layer depth in the Indian Ocean:

- **cmems\_mod\_glo\_phy\_anfc\_0.083deg\_P1D-m\_MLD-20231101-20221107.nc**

This example is described with the purpose to give to the reader a general overview on how to deal with files characterized by 2D (and applicable to 3D data as well), with variables that depend on time (and that can be used for an animation).

It is important that at this step the reader has pre-installed the **CMEMS-NetCDF** plugin, as described in Section 2.2.2.

### 4.1. Steps for loading and display the mixed layer depth file

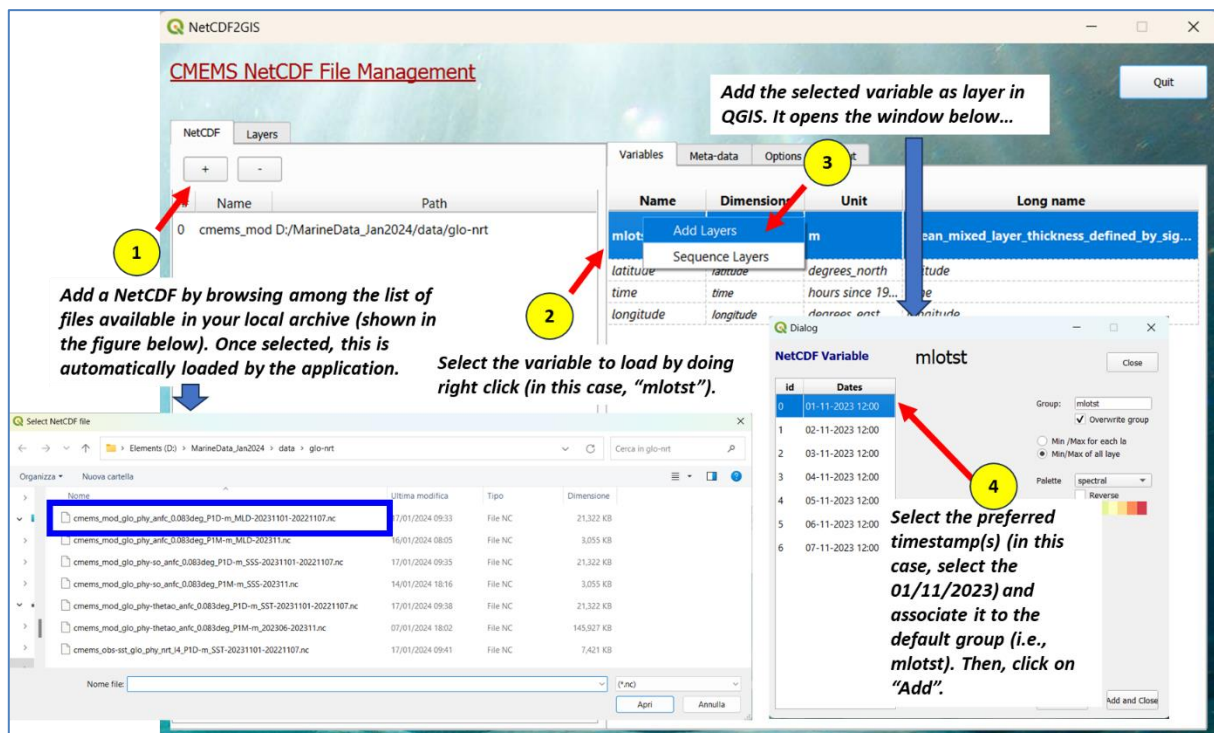
The objective of this section is to illustrate how to load and display the mixed layer depth file from GLO-PHY NRT **cmems\_mod\_glo\_phy\_anfc\_0.083deg\_P1D-m\_MLD-20231101-20221107.nc** using the CMEMS-NetCDF plugin.

A representation of the workflow is given in **Figure 13**.

**Step 1:** clicking on “+”, you may load the file you are interested in. Automatically, this function opens a window where you may browse in your local archive for selecting the NetCDF file.

**Step 2:** on the right side of the CMEMS-NetCDF application window, you will see the list of loaded metadata from the selected file. By doing a right click on the selected variable (in this case, the **mlofst** variable related to the mixed layer depth), a menu will appear with option to select “Add Layers” or “Sequence Layers”.

**Step 3:** by selecting “Add Layers”, the application opens a new window with details on the selected variable. Here, you may select the timestamp (and depth if available, but here not shown) and finally add to your QGIS project.



**Figure 13:** Steps to load the mixed layer depth file using CMEMS-NetCDF plugin.

Once the file has been loaded and the layer has been added, the mixed layer depth field will be displayed on QGIS map canvas. The workflow to customize the map is shown in **Figure 14**, while the final result is shown in **Figure 15**.

**Step 1:** the active layer “mlofst\_01112023\_0000” is displayed in QGIS after loading the NetCDF file through the CMEMS-NetCDF plugin. It is shown with default colormap.

**Step 2:** to customize it, do right click to visualize the right menu, with list of functions to modify the active layer.

**Step 3:** select “Properties”.

**Step 4:** after selecting, the menu as shown in the figure is displayed. You may modify the colormap, min/max values for the mixed layer depth and number of intervals for color distribution as you prefer.

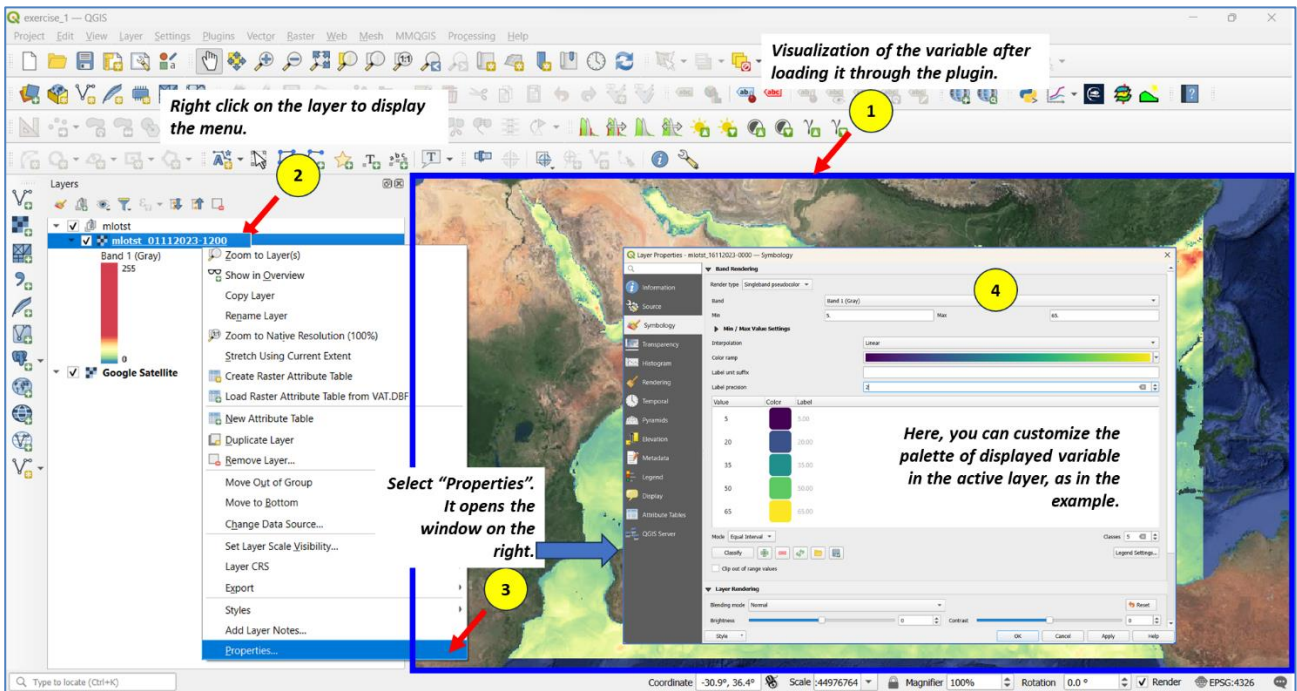


Figure 14: Overview of the loaded map and access to layer properties.

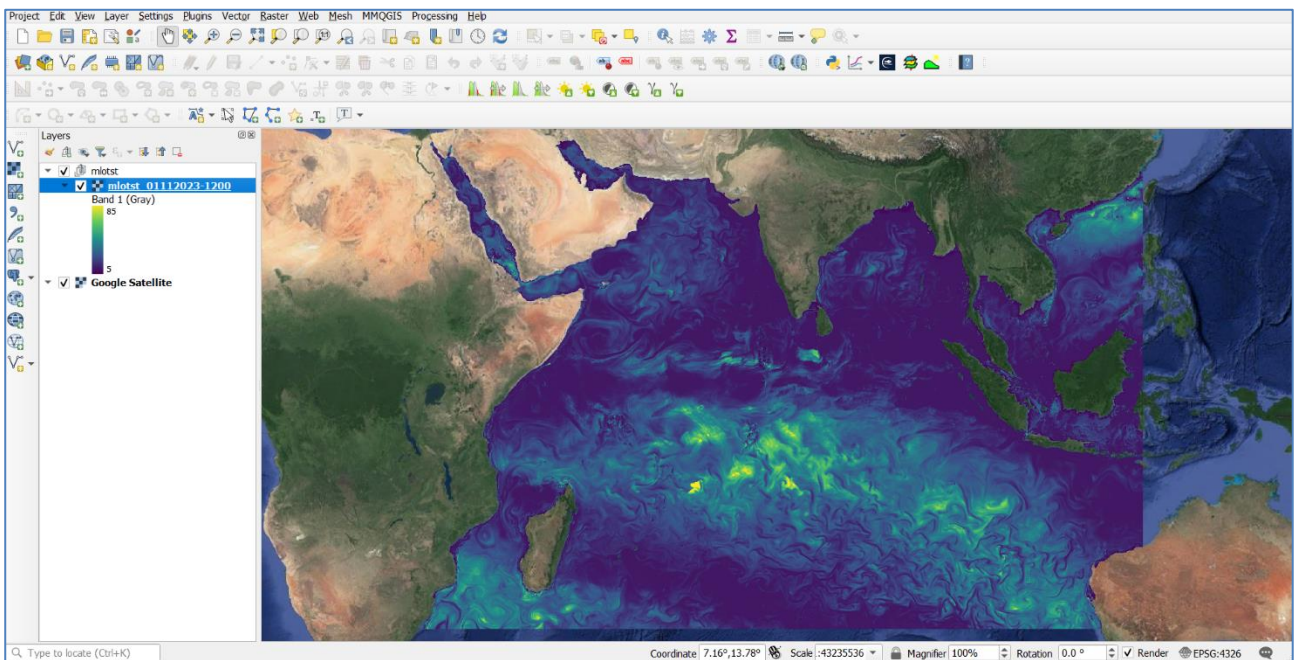


Figure 15: Final visualization of the map, after customizing layer properties.

## 5. Technical notes about specific QGIS functions used during the training session

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This section aims at providing some technical notes about used QGIS functions and plugins for performing the **MarineData4Asia** Training session. Demonstrative application is provided in the dedicated video.

### 5.1. Calculating SST anomalies to monitor El Niño event

In this exercise, we will illustrate how to use QGIS functionalities to easily monitor El Niño event evolution from Jun to Nov 2023 in the Pacific Ocean. The following steps will be described in detail in the next subsections:

- Loading upstream data in QGIS using CMEMS-NetCDF plugin.
- Calculating SST anomalies in the period Jun-Nov 2023 using Graphical Calculator.
- Characterization of the Niño3.4 region along the reference period by clipping the results at Niño3.4 bounding box.

#### 5.1.1. Loading input data

To load the input data, we use the CMEMS-NetCDF QGIS plugin. Once the plugin is launched, it is sufficient to perform sequentially the following commands:

- Load climatological “thetao” variable from GLO-PHY MY sytem:
  - **Step 1:** from the GUI, “Add a NetCDF file” and select the file related to GLOBAL\_MULTIYEAR\_PHY\_001\_030 climatological dataset from your local disk (see Section 2.1.1 for the file specifications).
  - **Step 2:** from the Variables menu, select “thetao” variable by doing right click on one of it and selecting “Add layer”. Then, a window pops-up.
  - **Step 3:** select the fields corresponding to the period from Jun to Nov at 0.49 m of depth. In “Group”, give the name of the new group, for instance “**thetao\_clim**”, and add the selected variable.
- Load monthly mean “theato” variable from GLO-PHY NRT system:
  - **Step 4:** from the GUI, “Add a NetCDF file” and select the file related to GLOBAL\_ANALYSISFORECAST\_PHY\_001\_024 monthly mean dataset from your local disk (see Section 2.1.1 for the file specifications).
  - **Step 5:** from the Variables menu, select “thetao” variable by doing right click on one of it and selecting “Add layer”. Then, a window pops-up.
  - **Step 6:** select the fields corresponding to the period Jun to Nov 2023 at 0.49 m of depth. In “Group”, give the name of the new group, for instance “**thetao\_nrt**”, and add the selected variable.

Steps are schematized in **Figure 16**. The results – how the maps are visualized in the QGIS map viewer – is shown in **Figure 17**.

#### 5.1.2. Calculating SST anomalies

The SST anomaly at month M is given as difference between the SST monthly mean and the corresponding SST monthly climatology at reference month M. To calculate SST anomaly, we use the Graphical Modeler. As reported in the QGIS documentation<sup>1</sup>, the Graphical Modeler allows you to create complex models using a simple and easy-to-use interface.

In the following, steps for configuring the Graphical Modeler are described:

**Step 1:** launch of the Graphical Modeler. The Graphical Modeler is accessed through **Processing > Graphical Modeler** (from the QGIS top menu).

**Step 2:** setup of the Graphical Modeler. Once launched, the Graphical Modeler window appears. We need to configure then the data model for performing the calculation, which consists on using 2 “Raster Layers” (accessible through “Input” tab), a “Raster Calculator” (accessible through “Algorithms” tab). The “Raster Calculator” requires and Expression to be set up:

**"sst\_nrt@1" - "sst\_clim@1"**

And the specification of the output raster – that we call “ssta”. An overview of the workflow is shown in **Figure 18**.

---

<sup>1</sup> [https://docs.qgis.org/3.28/en/docs/user\\_manual/processing/modeler.html](https://docs.qgis.org/3.28/en/docs/user_manual/processing/modeler.html)

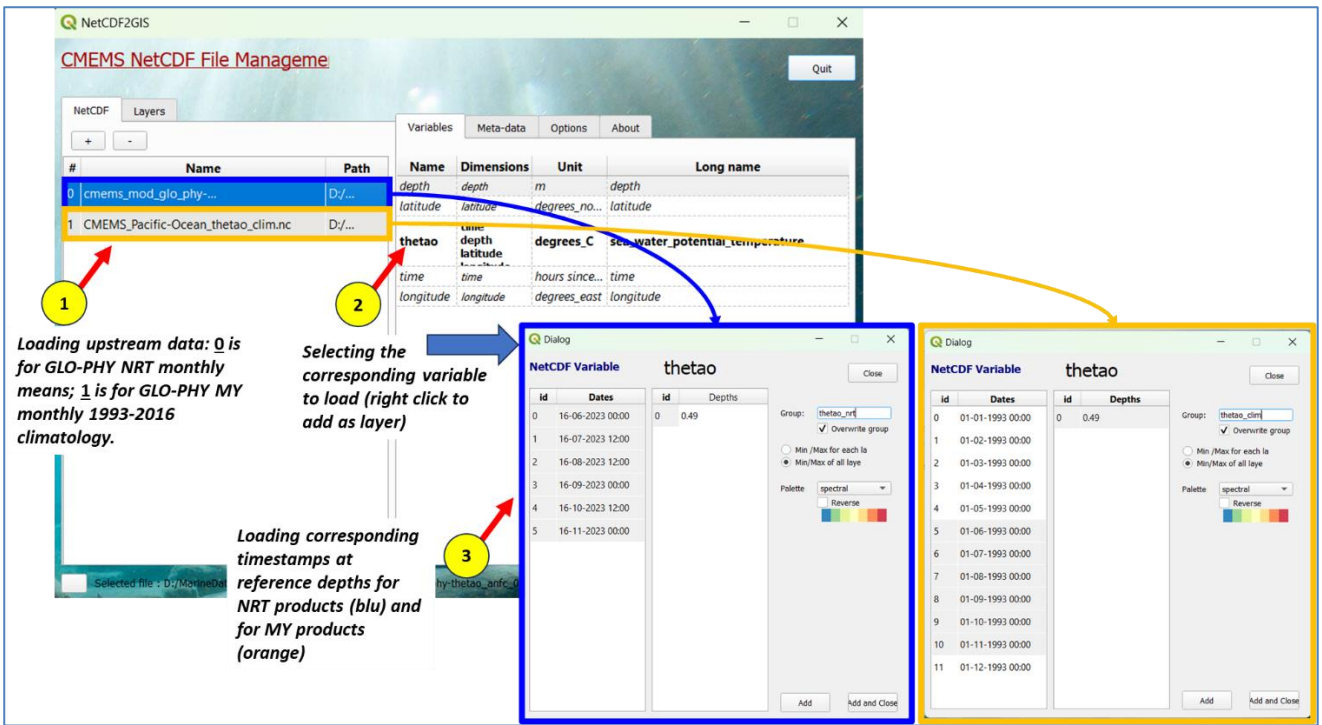


Figure 16: Loading input data.

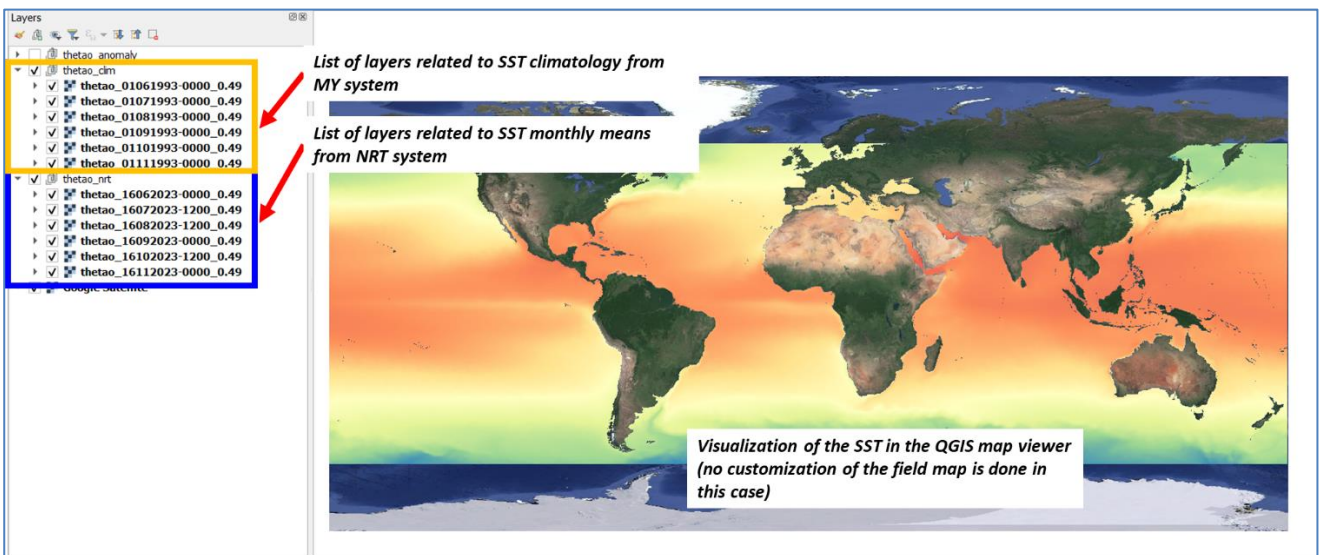


Figure 17: Visualization of loaded maps in QGIS.

**Step 3:** Graphical Modeler run. Once the Graphical Modeler is launched (Step 8 in **Figure 18**), a new window is opened, that links to the last phase of computation. By running in batch mode, you may load the input fields belonging to each group – monthly means from GLO-PHY NRT system “sst\_nrt”, monthly climatology from GLO-PHY MY system “sst\_clim”. An overview of the steps is given in **Figure 19**. After running the process, we can visualize the result as in **Figure 20**.

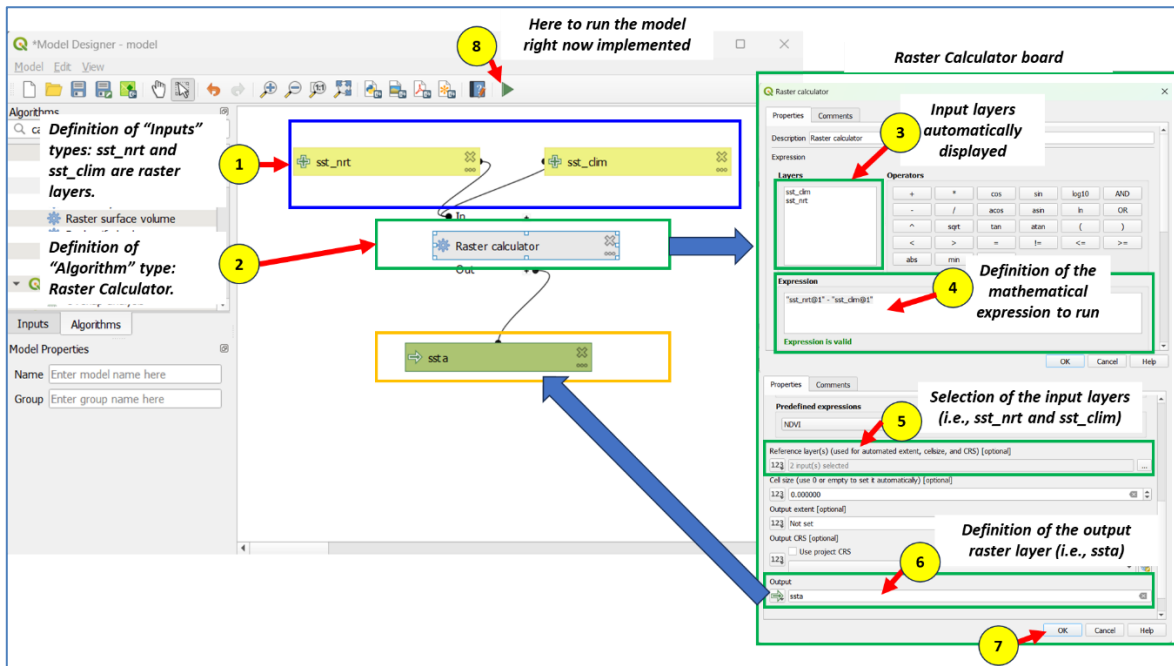


Figure 18: Steps for setting the Graphical Modeler for the calculation of SST anomalies.

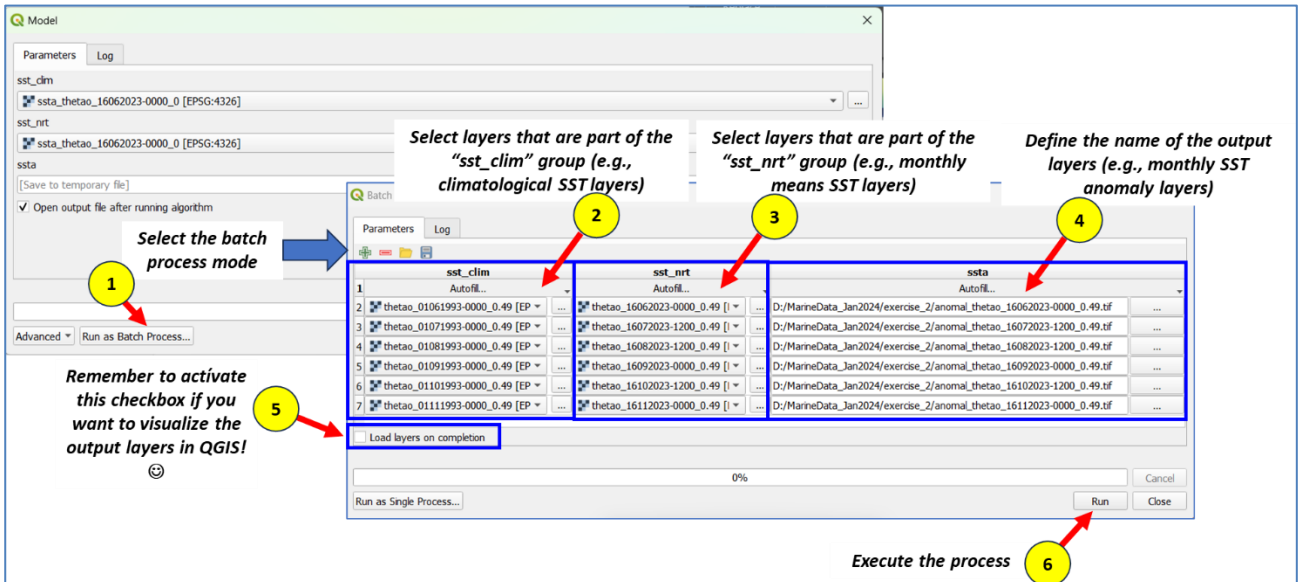


Figure 19: Steps for running the model implemented in the Graphical Modeler as batch process.

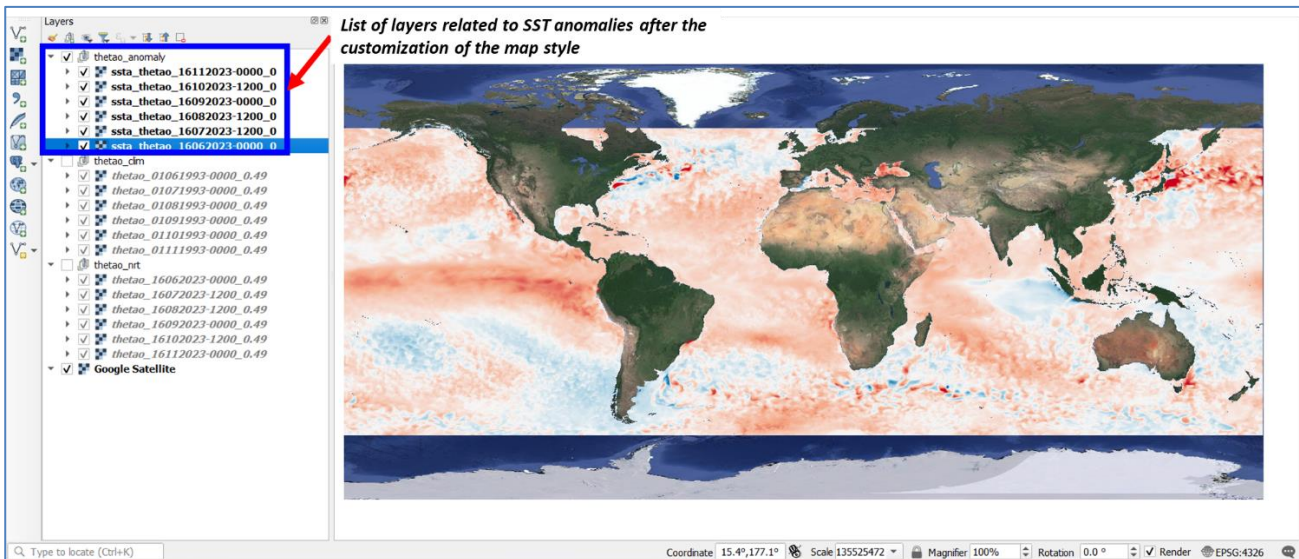


Figure 20: Visualization of SST anomalies maps, computed for the period Jun-Nov 2023 (here, the Nov 2023 is displayed).

### 5.1.3. Characterization of Niño3.4 region

Niño3.4 bounding box is defined as follows:  $170^{\circ}\text{W} \rightarrow 170^{\circ}\text{E}$ ;  $5^{\circ}\text{S} \rightarrow 5^{\circ}\text{N}$ : it is drawn in the map(s) by adding it a new layer. By following the next steps, you will be able to add a new layer in the main QGIS project.

**Step 1:** create a new shapefile. Select **Layer > Create Layer > New Shapefile Layer** from the QGIS menu. Then, a window for specifying which type of layer you want to create is opened.

**Step 2:** setup of the new layer.

- As “File name”, gives a name to the new shapefile, for example “nino3.4\_bb.shp” (browsing in your local computer).
- As “Geometry type”, select “Polygon”.
- Select “OK”.

**Step 3:** The new “nino34\_bb” is visualized as layer.

- Select “Toggle editing” icon.
- Select “Add polygon feature” icon.
- Draw the polygon related to the region of interest directly in the map.
- To improve the accuracy of the bounding box coordinates, select “Vertex tool”.
- Once activated, you can edit directly through the map the coordinates of the bounding box of the defined region, by giving the coordinates of the Niño3.4 bounding box.
- Once done, de-select the “Toggle Editing”. In this way, you save the shape of your polygon.
- The result of this list of commands is shown in **Figure 21**.

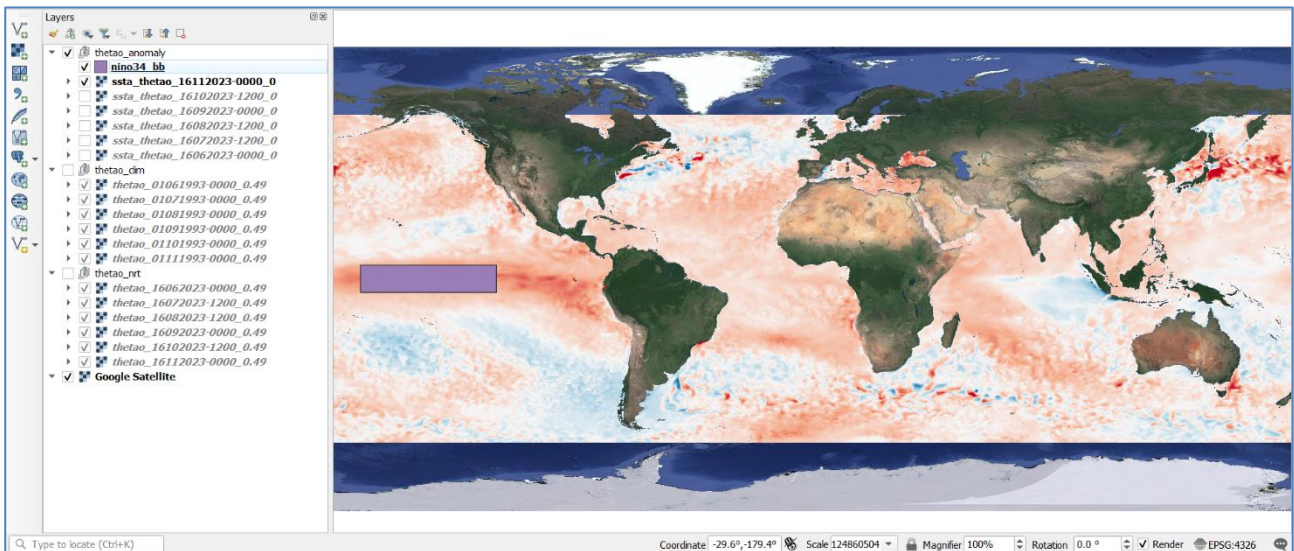


Figure 21: Specification of Niño3.4 region as polygon shapefile (purple box).

**Step 4:** clipping the SST anomaly layers into the Niño3.4 bounding box.

- Select **Raster > Extraction > Clip by mask layer** from the QGIS top menu.
- From the opened window, select **Run as batch process**.
- In the given window, specify:
  - As “Input layer”: the SST anomaly layers previously computed.
  - As “Mask layer”: the Niño3.4 region (nino34\_bb) previously defined.
  - As “Clipped (mask)”: after specifying the root “nino34\_” (as example), select the autofill function based on the input filename. In this way, QGIS will compose the final filename by adding to the input layer the prefix “nino34\_”.
  - Select “Load layers on completion” in order to visualize the output layers directly in the QGIS map viewer.
  - Run “OK”.
- The result is shown in .

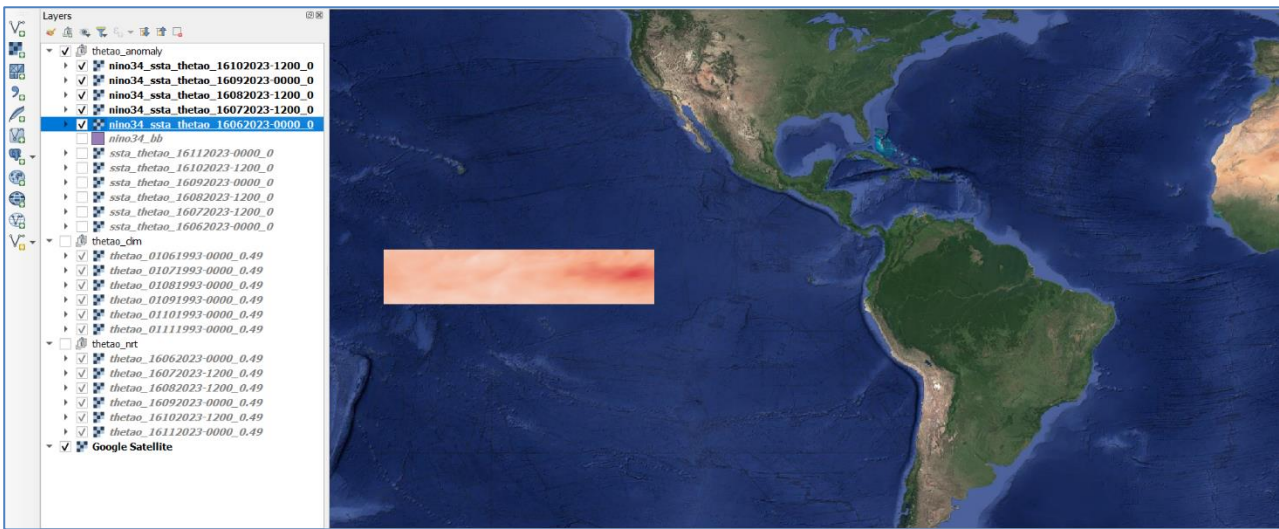


Figure 22: Extraction of SST anomaly values at Niño3.4 region using clipping function.

Step 5: calculation of basic metrics. In the Niño3.4 region, we can calculate the basic metrics – mean, maximum and minimum values, variance, for instance – by using the “Zonal Statistics” tool.

- Go to **Processing > Toolbox** from QGIS top menu. A box will be automatically opened, then type “Zonal Statistics” and select it by doing double click.
- Select the “Run as batch process”.
- Specify:
  - Input layer: the Niño3.4 bounding box layer.
  - Raster layer: the SST anomaly fields layers previously computed on Niño3.4 region.
  - Statistics to calculate: for example, mean, maximum, minimum and variance.
  - Zonal statistics: here you specify the name of the output layers. Select a keyword to be used as root of the filename – for example, “stats\_” – and then ask to QGIS to autofill the name of the layer by using the “Raster layer” filenames.
  - Run the process.

The workflow showing the steps are also reproduced in **Figure 23**.

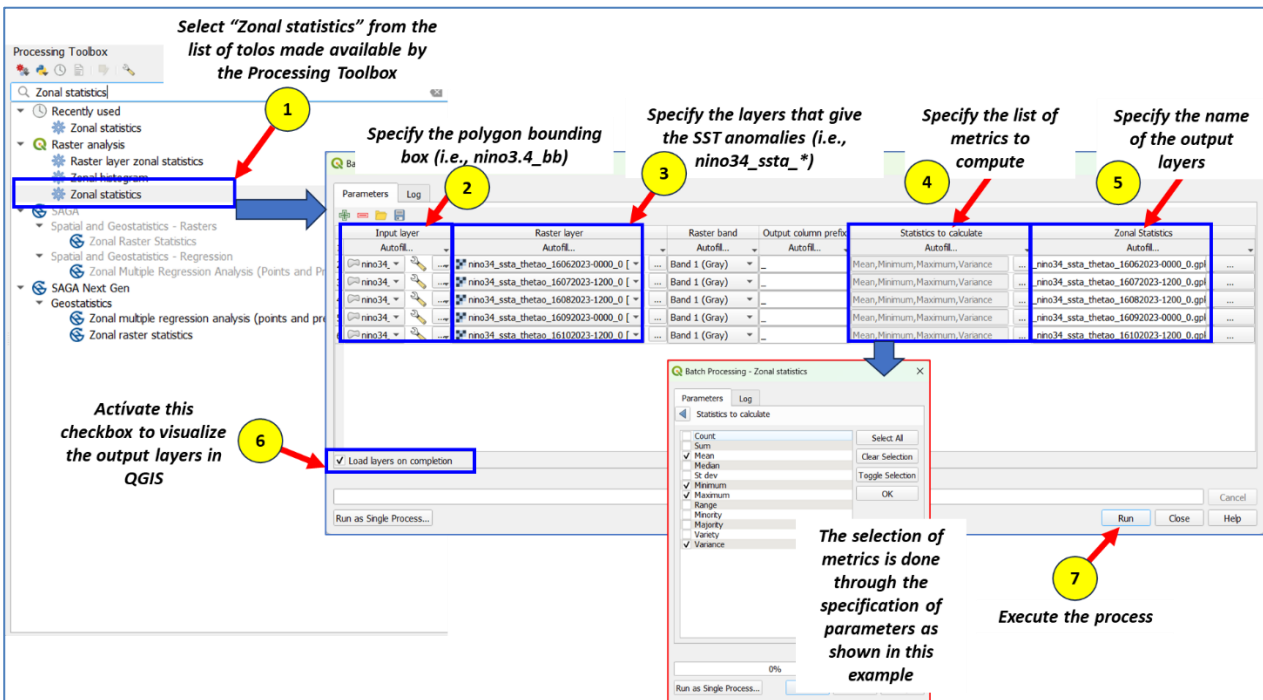


Figure 23: Steps for performing the calculation of metrics using Zonal Statistics tool.

After completing steps for performing the calculation of metrics using Zonal Statistics tool, QGIS returns new layers as highlighted with the blue box in **Figure 24**. To have a more comprehensive overview of metrics, we can operate a merging of the given statistical layers:

- Go to **Vector > Data Management Tools > Merge vector layers** from the QGIS top menu.
- Specify:
  - Input layers: the layers per months containing computed metrics.
  - Merged: the name of the final layer (i.e., nino34\_stats).
  - Press “Run”.

After this list of commands, you will visualize the merged layer “nino34\_stats” among the active layers. By opening the table of attributes, you will visualize the overall metrics, computed per each month for which we have the SST anomalies. A recap of the steps is displayed in

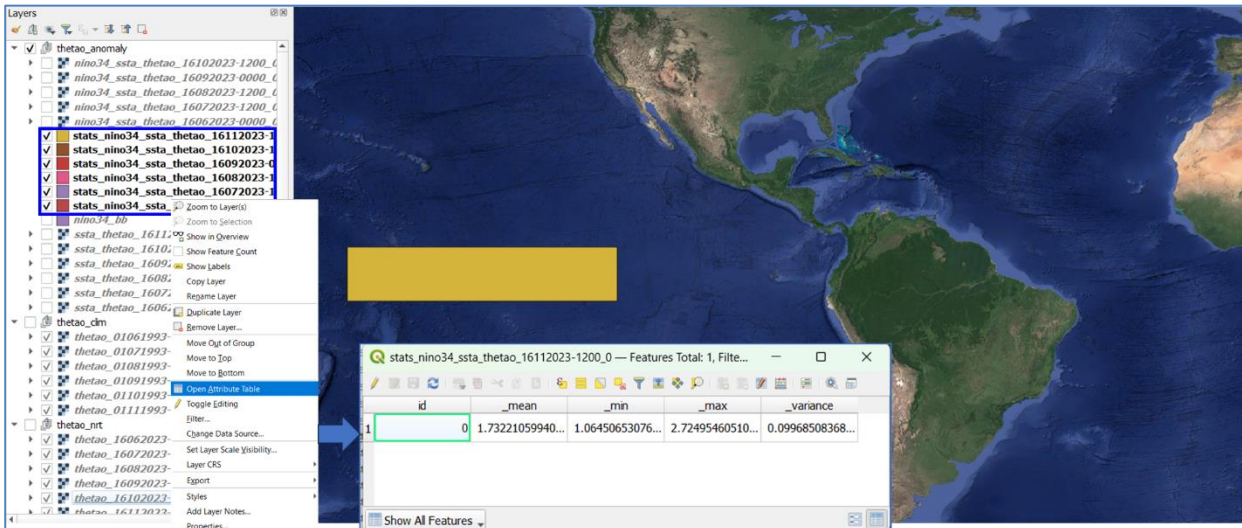


Figure 24: (in blue) List of layers referring to statistics. Inspection of one of the layers containing through its table of attributes.

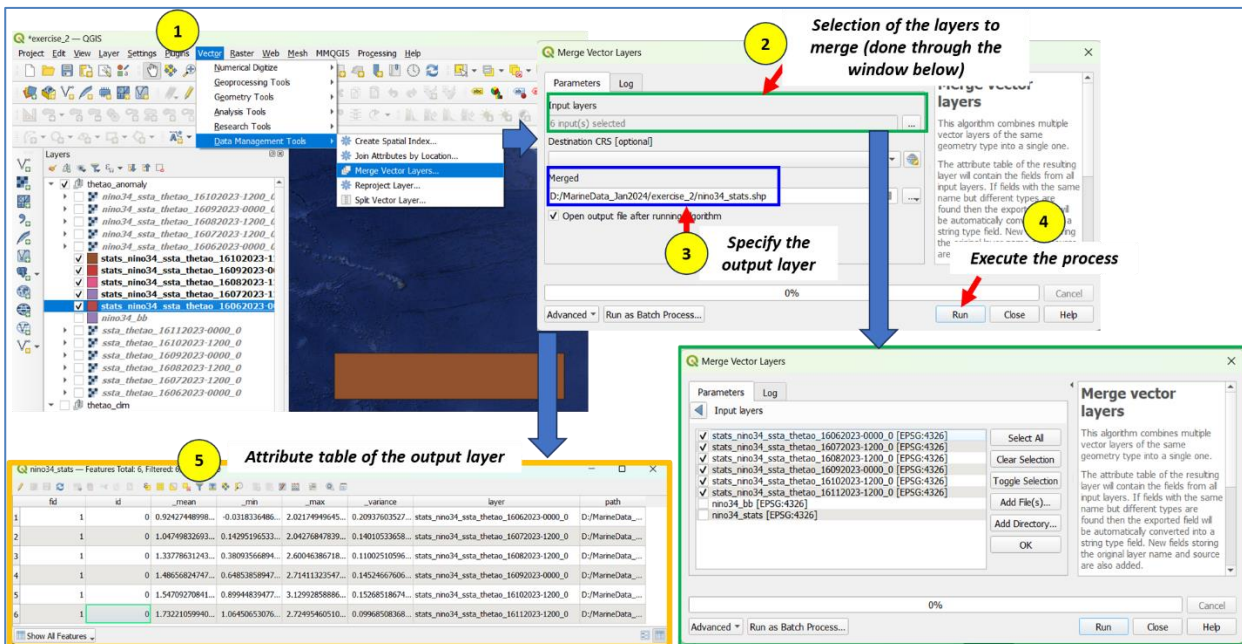


Figure 25: Steps for performing the merging of the layers containing statistics. The final result is available by inspecting the output layer's table of attributes (shown in step 5, with orange box).

To plot the timeseries of mean SST anomaly in the Niño3.4 region, we can use the DataPlotly plugin.

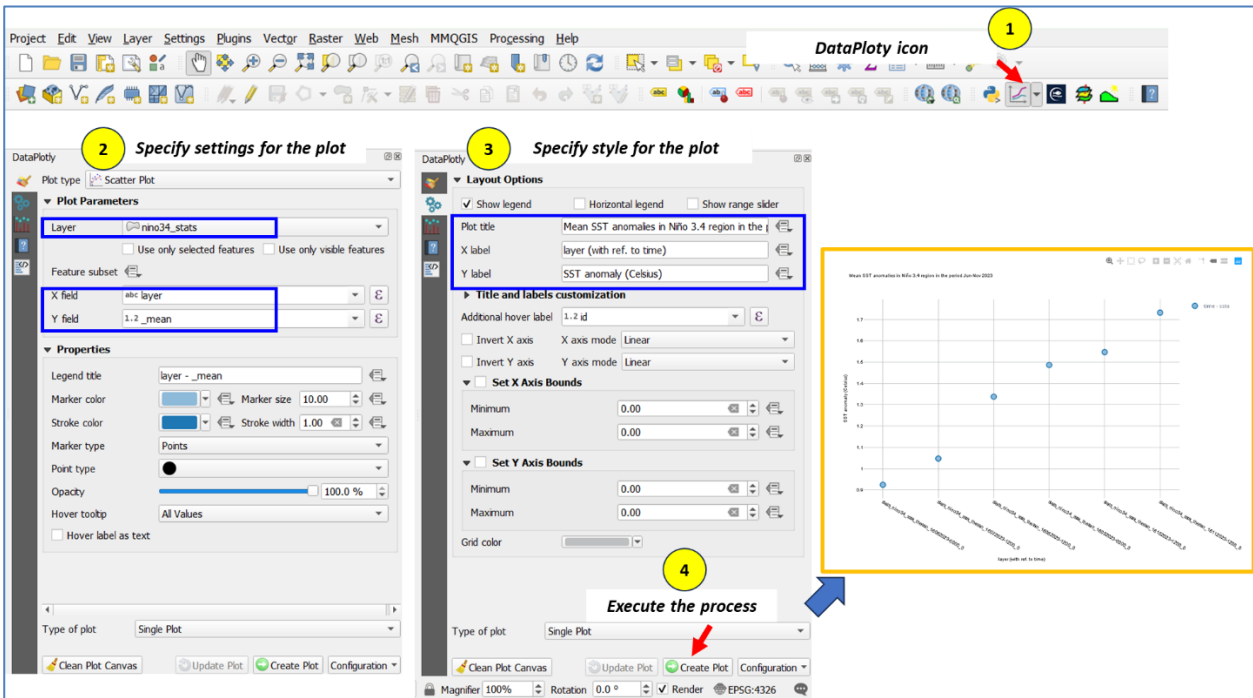
**Step 1:** select the DataPlotly tool from the list of available plugins, or by clicking at the corresponding icon (as shown in Section 3.2).

**Step 2:**

- In “Plot type”, select “Scatter plot”
  - Input layer: the layer containing statistics (i.e., “nino34\_stats”).
  - Field subset: as X field, specify “layer”; as Y field, specify for instance “\_mean”.
  - (customize colors as you prefer, here we keep the default settings).
- In “Layout Options”:

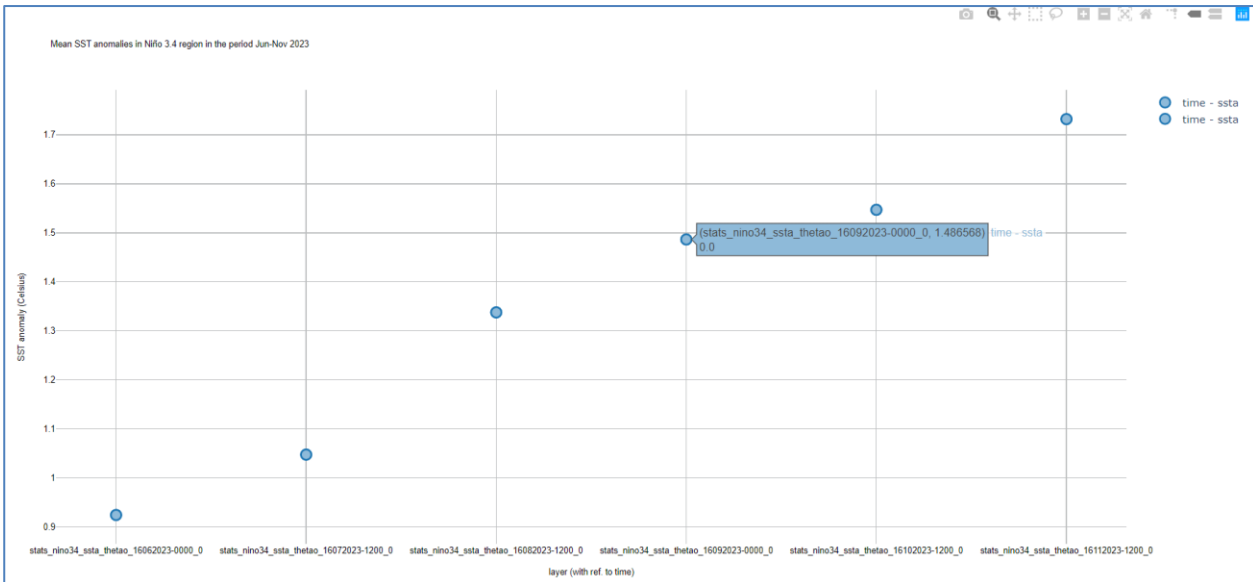
- Plot title: "Mean SST anomalies in Niño 3.4 region in the period Jun-Nov 2023".
- X label: "layer (with ref. to time)".
- Y label: "SST anomaly (Celsius)".
- Press "Create Plot".

A summary of the steps is shown in **Figure 26**.



**Figure 26:** Steps for creating plot of mean SST anomalies in Jun-Nov 2023 using DataPloty. The final graph (in orange box) can be exported as JPEG or HTML.

A zoom of the plot is shown in **Figure 27**: the graph (from QGIS or in HTML) is interactive, so you may visualize the value of the selected point from the tooltip (in the example, it is shown the value of the SST anomaly in Sep 2023).



**Figure 27:** Timeseries of SST anomalies in the Niño3.4 region in the period Jun-Nov 2023.

## 5.2. Extracting values of SST, SSS and MLD in the Gulf of Bengal

In this exercise, we will illustrate how to use QGIS functionalities to extract Essential Ocean Variables (EOV) values (i.e., SST, SSS and MLD) by:

- Loading upstream data in QGIS using CMEMS-NetCDF plugin.
- Defining the points where EOVS will be extracted.
- Extracting EOVS values from the Copernicus Marine products at selected locations.

- Evaluating SST in the Gulf of Bengal in the period 01-07/11/2023.

The target region is the Indian Ocean, with focus to the Gulf of Bengal.

### 5.2.1. Loading input data

In this exercise, we will use the daily means of SST, SSS and MLD as given by the GLO-PHY NRT system for the period 01-07/11/2023 (only one week, as example), and the SST daily satellite field as provided by the SST-TAC (details on products and datasets are given in Section 2.1.1). Steps for loading such files have been already introduced in the previous exercise (Section 5.1.1). Here, we show only some screenshot of the fields as displayed in QGIS, after customization of the palette:

- SST field from GLO-PHY NRT system on 01/11/2023 expressed in Celsius in **Figure 28**.
- SSS field from GLO-PHY NRT system on 01/11/2023 expressed in PSU in **Figure 29**.
- MLD field from GLO-PHY NRT system on 01/11/2023 expressed in m in **Figure 30**.
- SST satellite field from SST-TAC on 01/11/2023 expressed in Kelvin in **Figure 31**.

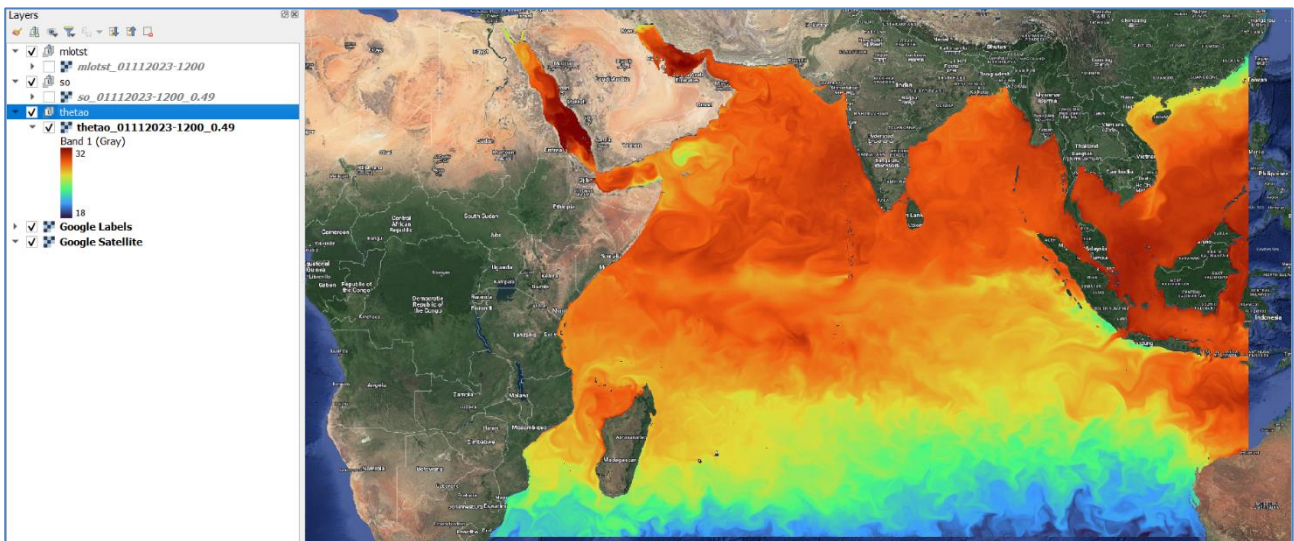


Figure 28: SST from GLO-PHY NRT system (01/11/2023).



Figure 29: SSS from GLO-PHY NRT system (01/11/2023).

### 5.2.2. Definition of the locations for the extraction of the EOv values

To specify which are the locations of interest to be monitored and for which we would like to retrieve the Copernicus Marine data, we need first to create a layer containing the coordinates of such points.

**Step 1:** creation of layer of points.

- Go to **Layer > Create Layer > New Shapefile Layer** from QGIS top menu.
- At the opening of the dedicated window, specify:

- File name: “points.shp” (to be saved in your local computer, so select the full path).
- Geometry type: in this case it is “Points”.
- Press “OK”.

**Step 2:** definition of points to monitor in the Indian Ocean region.

- Select the layer named “points”.
- Select “Toggle Editing” icon to activate “points” layer modification.
- Select “Add Point Features” icon to activate the possibility to set points in the map.
- Draw points in location you prefer (in this example, we select 4 points close to Maldives, Port of Colombo in Sri Lanka, area of influence of Gange River in the Gulf of Bengal, Singapore, respectively).
- Once digitized, you can customize the “points” layer, including modification of the attributes table for including an extra field, called “location” (as text) where you may include the name of the location to easily identify it.

The view of selected points is given in **Figure 32**. At this step, there is no geolocalization of the selected points (that will be then completed in the next phase).

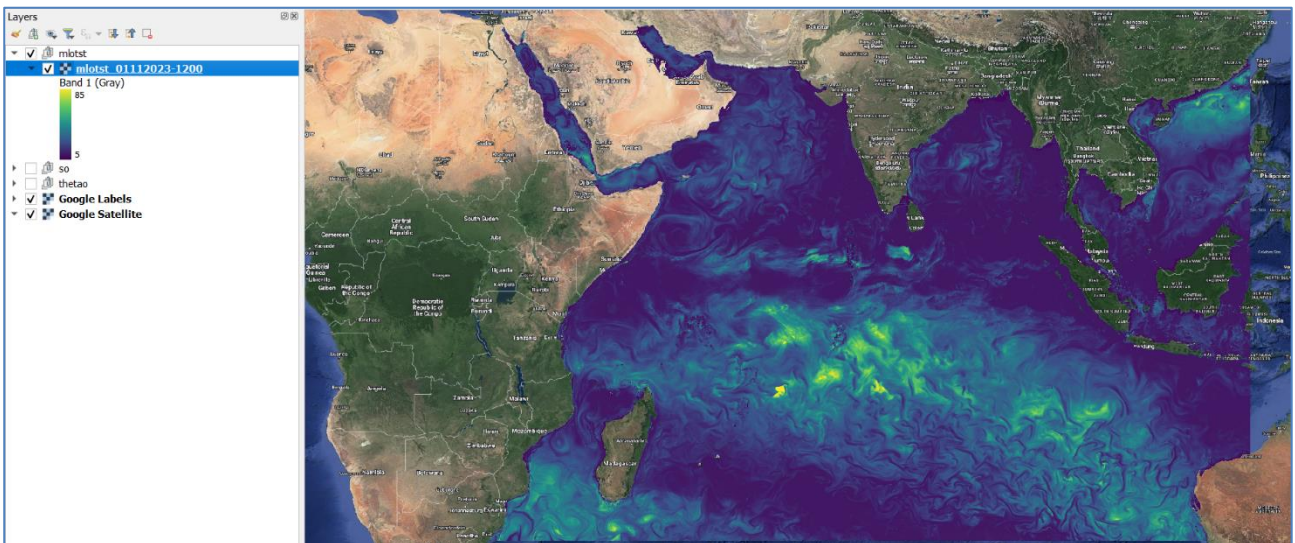


Figure 30: MLD from GLO-PHY NRT system (01/11/2023).

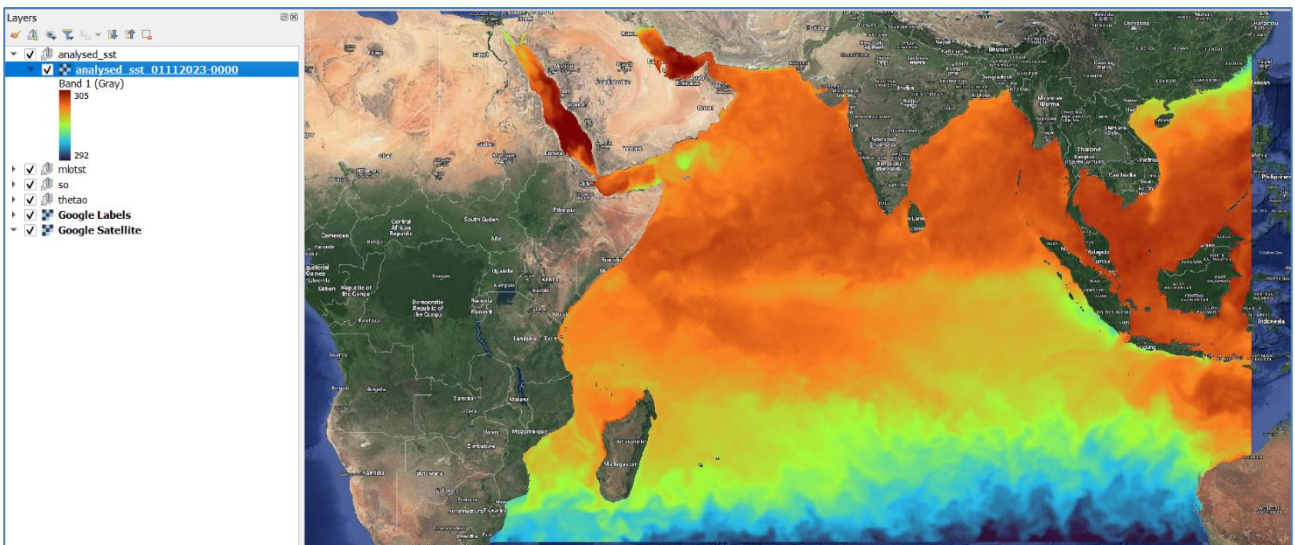


Figure 31: SST satellite observation (01/11/2023).

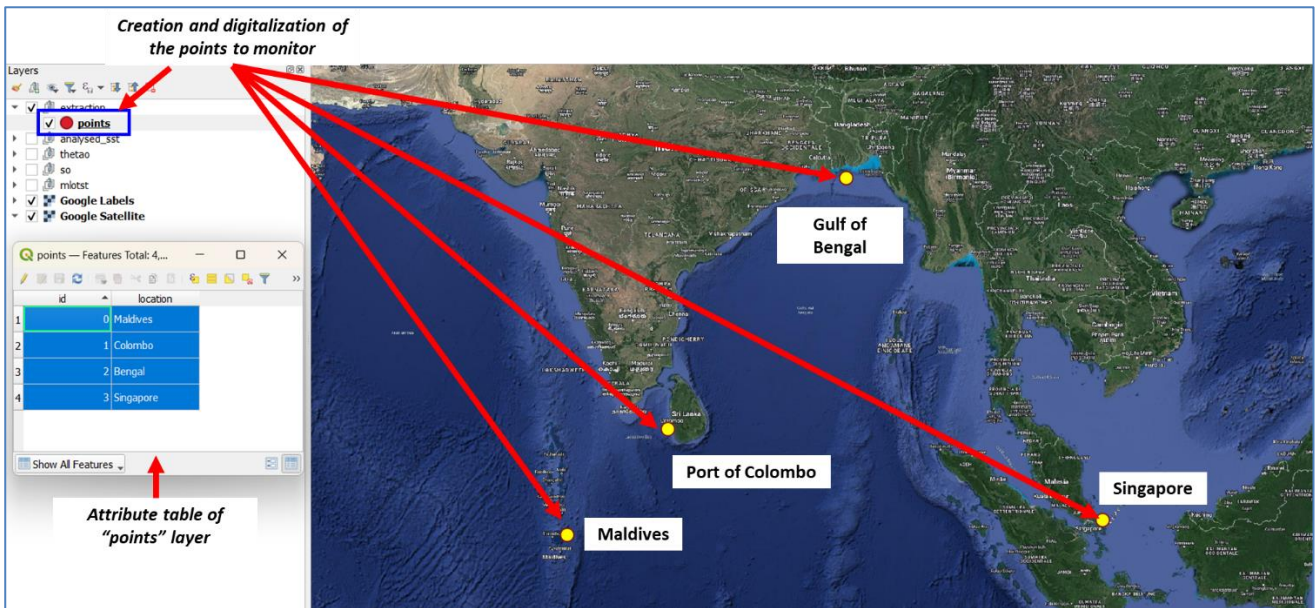


Figure 32: Visualization of points in the Indian Ocean where to extract EOV values from the Copernicus Marine products.

### 5.2.3. Extraction of EOV at selected points

To perform the extraction of the scalar values provided by the Copernicus Marine products in the points of interest, we use the tool called “Sample raster values”, accessible through the **Processing Toolbox**. Once launched, the “Sample raster values” can be run in standalone or as batch process. Here, we propose to use as batch process in order to make a more comprehensive extraction of the values.

Once the “Run as Batch Process” is selected, a new window will open and it requires:

- Input layer: the layer “points” that specifies the location of interest.
- Raster layer: the list of active layers containing the Copernicus Marine information for SST, SSS and MLD as given by the GLO-PHY NRT system.
- Sampled: here is where we specify the name of the layers containing the sampled information. We specify a tag (i.e., “sample\_”) and the function autocompletes the layer name by adding an extra fieldname from the Raster layer.
- Be sure to have “Load layer on completion” active before running.
- Press “OK”.

After running the process, expected layers will appear in the QGIS Layers board as shown in **Figure 33** (in this example, we have 3 main samples related to SST, SSS, MLD on 01/11/2023). Selecting one of these layers and opening the “Attribute Table”, you will be able to see the corresponding EOV values at each location (in **Figure 33** we are displaying the SST values, but similarly can be done for SSS and MLD).

Regarding SST observations from satellite, it is needed to convert original values, expressed in Kelvin, to new ones, expressed in Celsius. To do this, it is sufficient to implement a Graphical Modeler that will be in charge of units conversion:

- Go to **Processing > Graphical Modeler** from the QGIS top menu.
- Once the Model Designer window is open, you may consider:
  - Inputs: a “Raster layer”, that will represent the SST expressed in Kelvin. It is called generically “sst”.
  - Algorithm: you may select the “Raster Calculator”, that needs to be instructed to implement the formula for the conversion Kelvin to Celsius, by doing the following:
    - Expression: “sst@1” - 273.15
    - Using model input: sst
    - Output: sst\_celsius
  - At this point, you will display the workflow.
  - Run the “Run model” icon.
- Once this is run, a new window “Model” is displayed.
- Go to “Run as Batch Process”.
- Once this is run, a new window “Batch Processing – model” is displayed. Give the following specification:
  - sst field: it needs to be instructed to open the layers that need to be converted from Kelvin to Celsius.

- sst\_celsius field: it will contain the name of the output layer (for example, using the tag "celsius\_" and letting the modeler to autofill the name with the name of the SST layer).
- Check "Load layers on completion".
- Launch "Run".

At the end of this step, you will see the new layers containing SST satellite observations expressed in Celsius that can be used in the next steps.

#### 5.2.4. Evaluation of SST in the Bay of Bengal

QGIS can be extremely powerful for analysing correlations between model and observational values. In this example, we will see how to extract SST values from GLO-PHY NRT system and from satellite in the Gulf of Bengal by using a grid of 0.5° resolution.

**Step 1:** creation of a grid in the region of interest.

- Go to **Processing > Toolbox** from the QGIS top menu and search for "Create grid".
- Once selected, a window will appear where you need to specify the following information:
  - Grid type: Rectangle (Polygon).
  - Grid extent: here we give the bounding box of the Bay of Bengal that is 79°E → 96°E; 7°N → 20°N.
  - Horizontal spacing: 0.5 (given in degrees).
  - Vertical spacing: 0.5 (given in degrees).
  - Grid: indicate where the new layer will be saved and how it is called (in this example, it will be saved locally as "grid.shp").
  - Run "OK". Then, at this point the grid is created.
- Go to **Vector > Geometry Tools > Centroids** from the QGIS top menu.
- Once selected, a window will appear where you need to specify the following information:
  - Input layer: the "grid" shapefile as previously computed.
  - Centroids: indicate where the new layer will be saved and how it is called (in this example, it will be saved locally as "grid\_centroids.shp").
  - Run "OK". Then, the distribution of centroids will be displayed in the map.
- Go to **Layer > Create Layer > New Shapefile Layer** from the QGIS top menu. The scope here is to define in which region we would like to extract SST information.
- Once selected, a window will appear where you need to specify the following information:
  - File name: indicate where the new layer will be saved and how it is called (in this example, it will be saved locally as "region.shp").
  - Geometry type: Polygon.
  - Run "OK".
- In the map, you may now activate the new layer "region" in "Toggle Editing" mode and start digitizing the region of interest.

At the end of this sequence of commands, you will display on QGIS map viewer something like what shown in **Figure 35**.

**Step 2:** processing the grid to work on the region of interest.

- Go to **Processing > Toolbars > Clip by mask layer** from the QGIS top menu.
- Once selected, a window will appear, where you need to specify the following information:
  - Input layer: here you give the shapefile containing the grid centroids ("grid\_centroids").
  - Mask layer: here you give the shapefile containing the region of interest ("region").
  - Clipped (mask): indicate here where the new layer will be saved and how it is called (in this example, it will be saved locally as "grid\_centroids\_clip.shp").
  - Run "OK".

At the end of this sequence of commands, displayed in **Figure 34**, you will display on QGIS map viewer the centroids clipped into the region of interest. In such points, we are going to extract SST from model and observations. The final shape of the points where we are going to extract the information is shown in **Figure 35**.

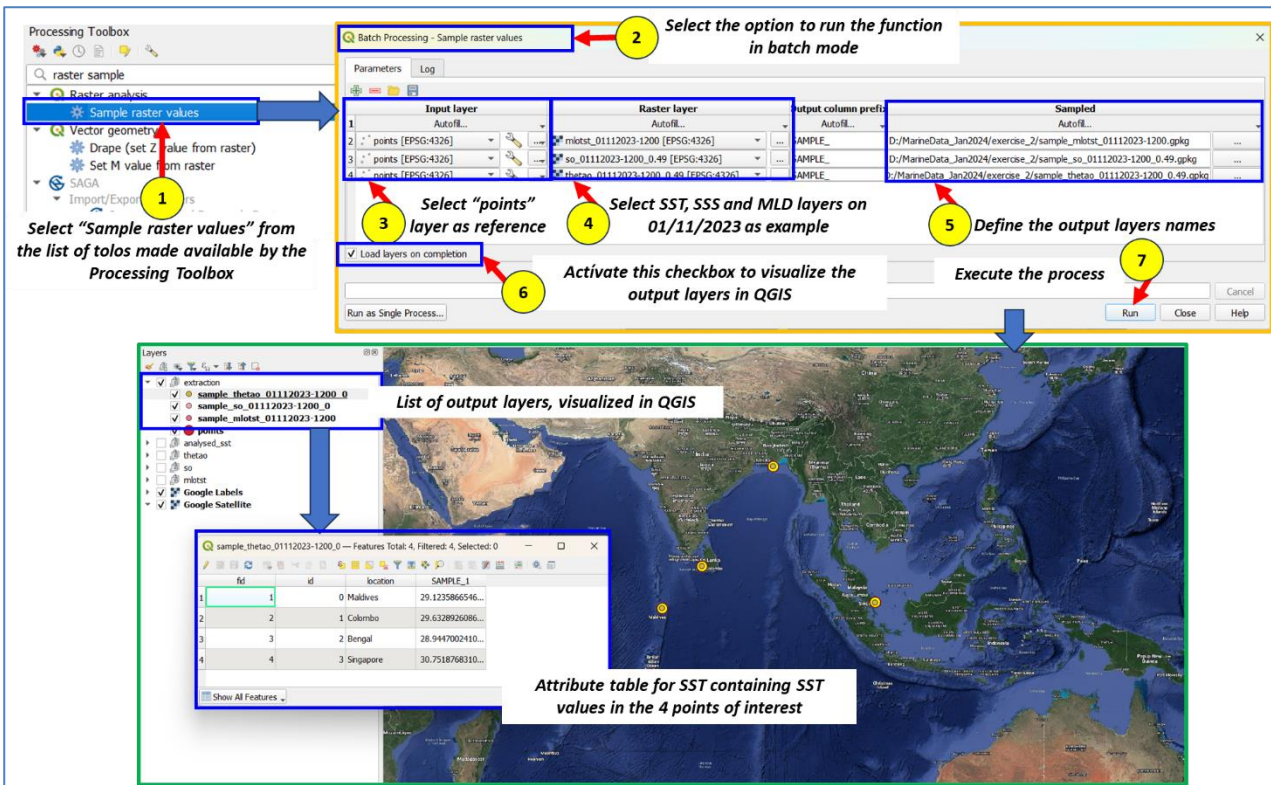


Figure 33: Steps for extracting SST, SSS and MLD values on 01/11/2023 for the 4 selected locations from the GLO-PHY NRT product.

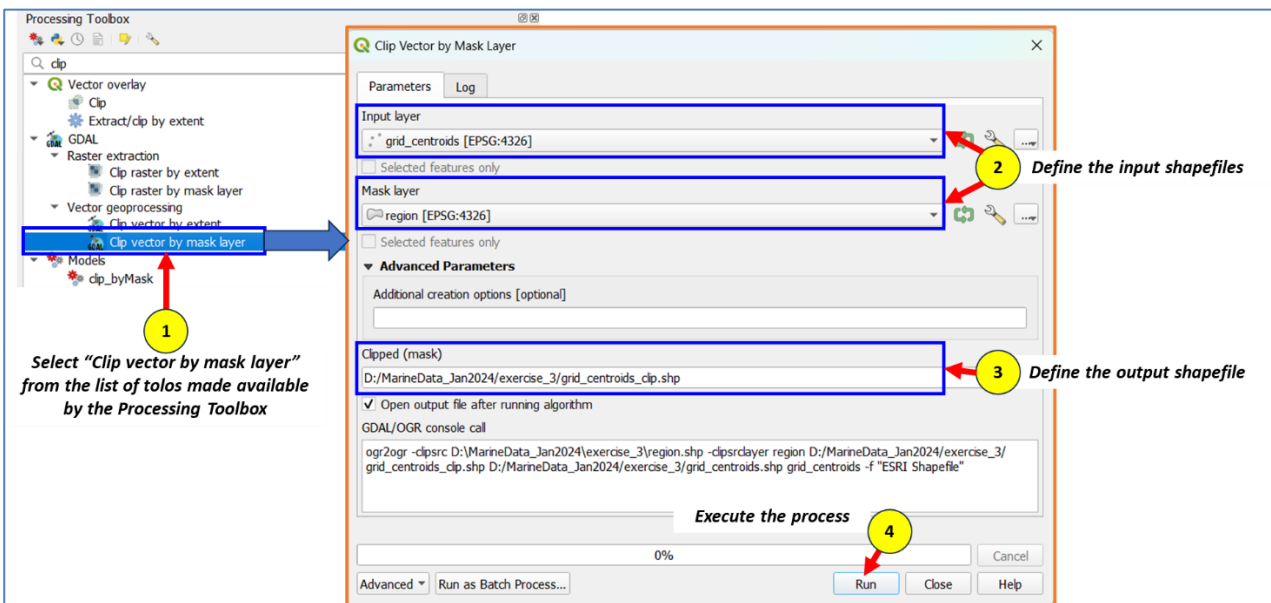


Figure 34: Steps for clipping grid centroids in the region of interest.

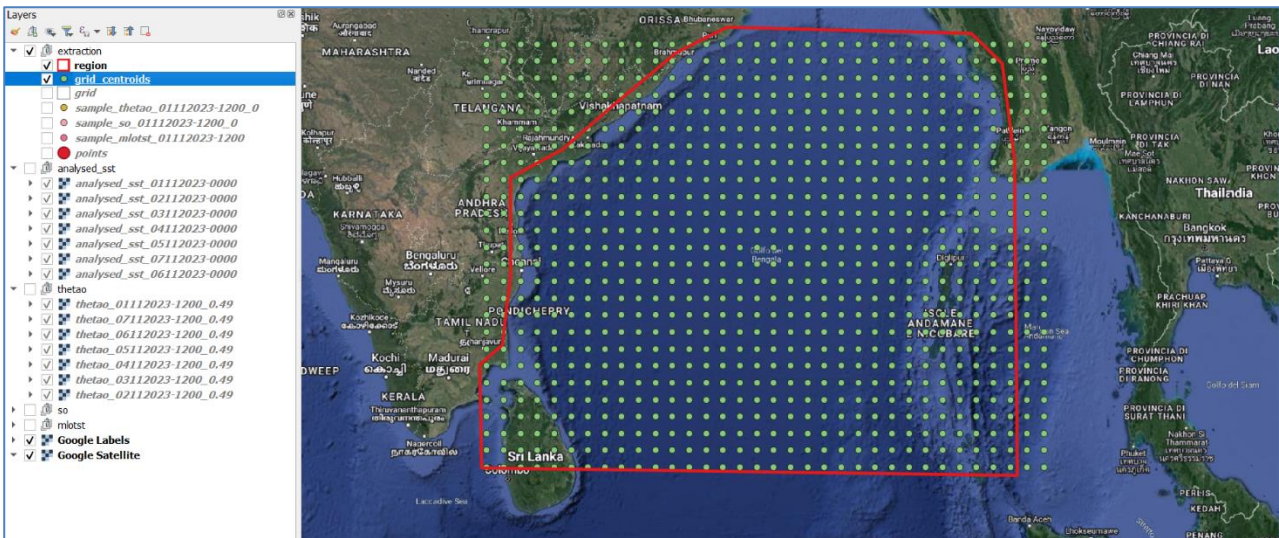


Figure 35: Generation of grid centroids (green dots) and region of interest (red polygon) in the Bay of Bengal.

**Step 3:** extract Copernicus data in the Bay of Bengal using the selected grid.

- Go to **Processing > Toolbars > Add raster values to points** from the QGIS top menu.
- Once selected, a window will appear. Select the batch mode processing and specify the following information:
  - Points: here you give the shapefile containing centroids in the region of interest (“grid\_centroids\_clip”).
  - Grids: from the open layers, here you select the layers related to SST from GLO-PHY NRT and from satellite observations.
  - Result: indicate here where the new layer will be saved and how it is called (in this example, it will be saved locally as “points\_SST.shp”).

At the end of this sequence of commands, summarized also in **Figure 36**, you will display a new layer that contains numerical results from the extraction of SST values from GLO-PHY NRT and from satellite observations after converting from Kelvin to Celsius (Section 5.2.3). By accessing the “Attribute Table”, you will display the daily SST values given by the 2 source of products over the week 01-07/11. A screenshot of the table containing the extracted data is shown in **Figure 37**.

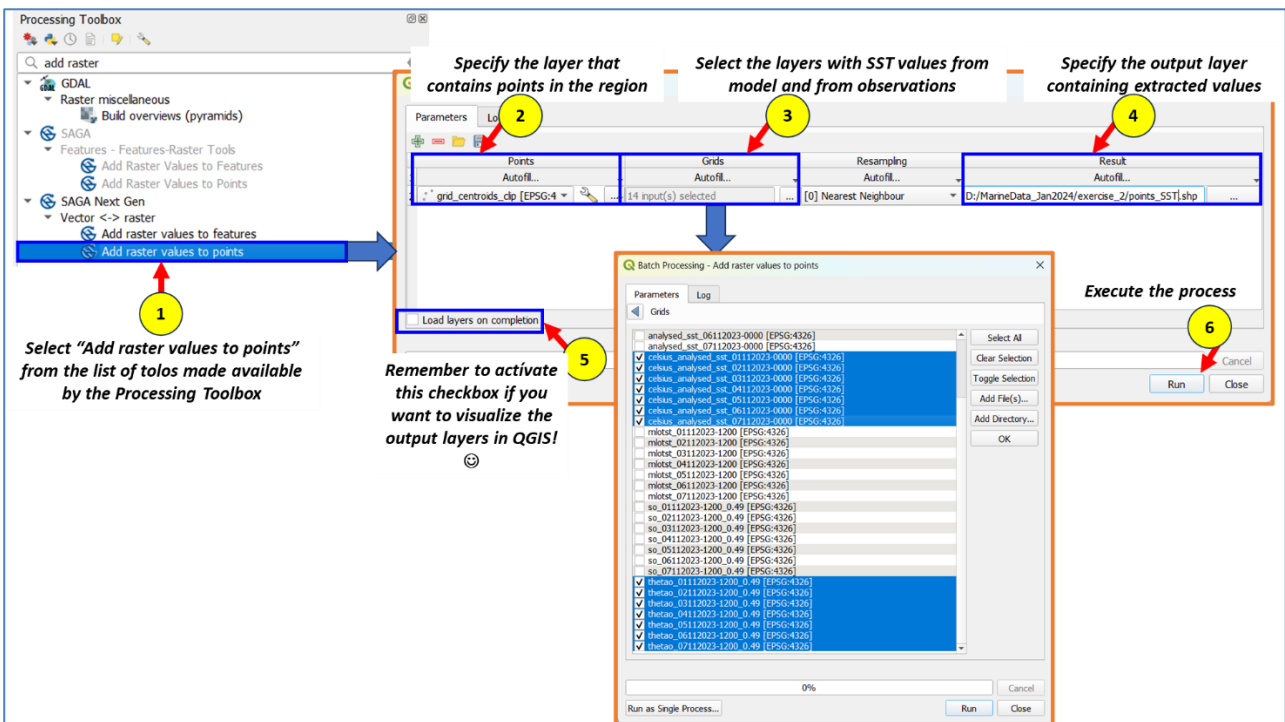


Figure 36: Steps for extracting SST data at given grid points.

id	left	top	right	bottom	celsiusanal	celsiusanal_1	celsiusanal_2	celsiusanal_3	celsiusanal_4	celsiusanal_5	celsiusanal_6	theta01112	theta0211	
22	67	80.0000000000	13.0000000000	80.5000000000	12.5000000000	29.6453351050	29.6946638910	29.7087436070	29.6800731860	29.6645651470	29.7937873190	29.4786251370	29.7927942230	29.7183521
23	68	80.0000000000	12.5000000000	80.5000000000	12.0000000000	29.7080205190	29.7083604200	29.6920676860	29.6831829450	29.6715028610	29.7381472000	29.7078828810	29.6047475320	29.5916150
24	69	80.0000000000	12.0000000000	80.5000000000	11.5000000000	29.6655166580	29.6558909150	29.7162263810	29.7055056400	29.6949045270	29.7432861570	29.7955389070	29.4395015930	29.4562080
25	70	80.0000000000	11.5000000000	80.5000000000	11.0000000000	29.6228706290	29.6105779650	29.6254211490	29.6103370000	29.5908937120	29.6944133280	29.7652334290	29.3830249120	29.4165820
26	71	80.0000000000	11.0000000000	80.5000000000	10.5000000000	29.6016264160	29.5942073750	29.5543557980	29.5508871300	29.5449625520	29.6769762270	29.8569293130	29.4869627960	29.4721850
27	72	80.0000000000	10.5000000000	80.5000000000	10.0000000000	29.5844511200	29.6034220290	29.5616530940	29.5594290660	29.6281905790	29.6769810860	29.8134386490	29.5731913430	29.5838620
28	73	80.0000000000	10.0000000000	80.5000000000	9.5000000000	29.4415062770	29.5296430650	29.4423226010	29.4478342460	29.5518526230	29.6643629710	29.7787053890	30.1197657550	30.0676230
29	74	80.0000000000	9.5000000000	80.5000000000	9.0000000000	29.5406007210	29.6136842410	29.1816842860	29.1960271650	29.2517568180	29.2544343800	29.4715977100	30.2826029040	30.1873080
30	75	80.0000000000	9.0000000000	80.5000000000	8.5000000000	29.5294562880	29.5535506960	29.0844678230	29.0750851210	29.0765869710	28.6986085030	29.2925470500	NULL	NULL
31	76	80.0000000000	8.5000000000	80.5000000000	8.0000000000	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
32	77	80.0000000000	8.0000000000	80.5000000000	7.5000000000	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
33	78	80.0000000000	7.5000000000	80.5000000000	7.0000000000	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
34	87	80.5000000000	16.0000000000	81.0000000000	15.5000000000	29.5629779790	29.7006263890	29.4873065650	29.5361161270	29.5160770180	29.4749583930	29.2396513110	29.7242876570	29.5794240
35	88	80.5000000000	15.5000000000	81.0000000000	15.0000000000	29.3620470820	29.6189136600	29.4694237840	29.5235516360	29.4438754610	29.4377800820	29.2005085450	29.5070460100	29.4748290
36	89	80.5000000000	15.0000000000	81.0000000000	14.5000000000	29.0722836570	29.5419097800	29.4631921350	29.5648889930	29.4091134220	29.4737418390	29.2497753810	29.4592603780	29.2641250
37	90	80.5000000000	14.5000000000	81.0000000000	14.0000000000	29.2485449740	29.5634007820	29.5455377930	29.5988212200	29.4585088680	29.5038364550	29.3804042660	29.3559928330	29.1908400
38	91	80.5000000000	14.0000000000	81.0000000000	13.5000000000	29.3270393850	29.5486726210	29.6134423990	29.5570442240	29.5081858040	29.5780620000	29.4616435960	29.3812562810	29.2701470
39	92	80.5000000000	13.5000000000	81.0000000000	13.0000000000	29.5611406920	29.6935111280	29.6782190270	29.5868954740	29.5595340300	29.6781553400	29.3071771300	29.5597613130	29.4460970
40	93	80.5000000000	13.0000000000	81.0000000000	12.5000000000	29.6351719620	29.7057370330	29.7380020900	29.6408846550	29.6056186850	29.8147144170	29.6863434830	29.4763952960	29.4880720
41	94	80.5000000000	12.5000000000	81.0000000000	12.0000000000	29.6678532210	29.6928266570	29.6954095400	29.6454032230	29.6101416020	29.8222540840	29.8198977560	29.3840215930	29.2708600
42	95	80.5000000000	12.0000000000	81.0000000000	11.5000000000	29.6920313910	29.7002603080	29.6887983560	29.6565350880	29.6489210450	29.6937350290	29.7901590410	29.2761884460	29.2979980

Figure 37: SST values from GLO-PHY NRT system and from satellite observations interpolated at the same grid for the Bay of Bengal.

From the shapefile containing the SST values in the period of interest and represented in Figure 37, it is then possible to perform any additional manipulation. As example, we can create a scatter plot for day 01/11/2023 of SST values using DataPloty, as shown in Figure 38.

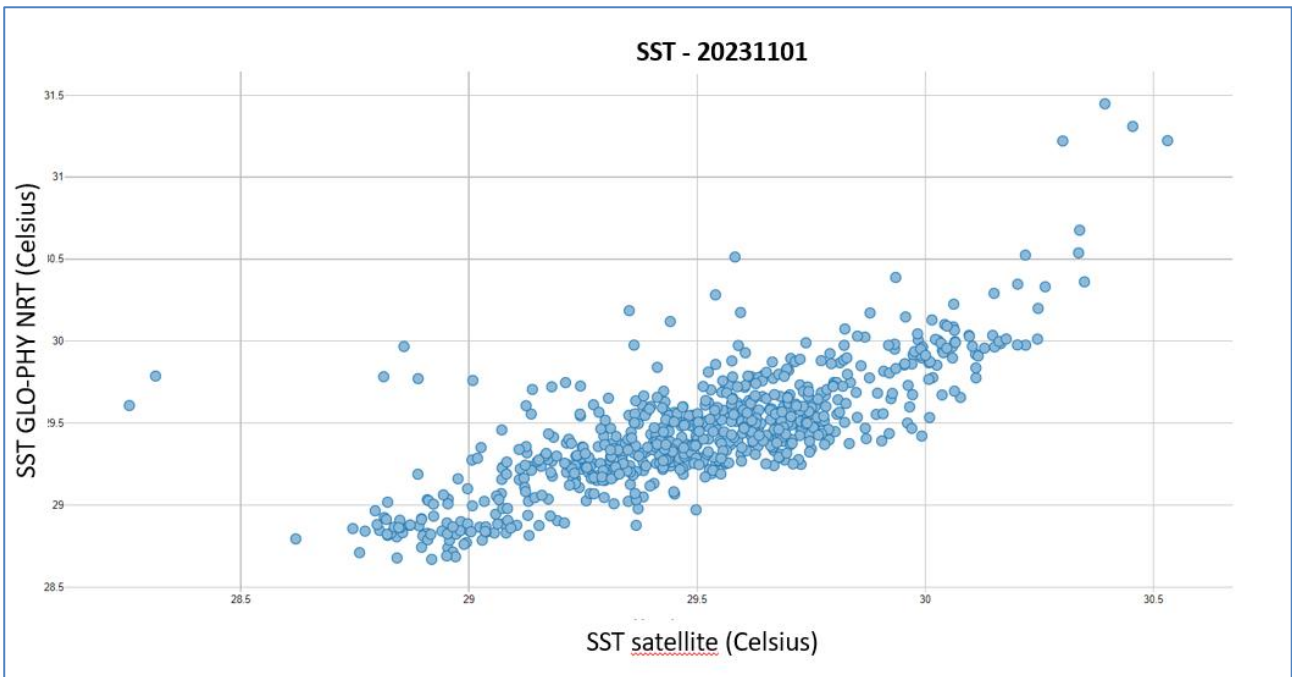


Figure 38: Scatter plot for SST values on 20231101.

## Conclusions

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This report focused on presenting the way we can use the Blue Ocean products provided by the Copernicus Marine Service in QGIS for monitoring El Niño events in the tropical Pacific Ocean and key areas in the Indian Ocean and Bay of Bengal.

The document is divided in 3 main parts:

- The first part gave an overview of the study area and the description of the Copernicus Marine products specifically used in the demonstrative phase: the Global Ocean Physics Reanalysis system, Global Ocean Physics Analysis and Forecasting system, the Global SST L4 satellite observations.
- The second part described the QGIS software, focusing particularly on the used plugins: the CMEMS-NetCDF plugin for loading, reading and processing the NetCDF files provided by the Copernicus Marine Service; the QuickMapServices for loading basemap used as background of the ocean fields, to improve readability of geographical information. Examples on how to use them are provided; DataPloty, for plotting charts and timeseries of EOVI in specific points/regions..
- The third part showed the main technical implementations discussed also during the training session, providing to users an overview of the main functions and tools used for tracking the Jun-Nov 2023 El Niño event occurring in the tropical Pacific Ocean. It is presented how to run a batch process for computing SST anomalies data, how specify points where to visualize timeseries of EOVI in the Indian Ocean and, finally, how to automatically interpolate Global Ocean data (both from forecasting system and from satellite observations) in the Bay of Bengal for supporting validation of model results.

These technical notes complemented the training session given during the **MarineData4Asia** Event, organized by Mercator Ocean International for the Copernicus Marine Service on 25-26/11/2023.

**Please, visit the dedicated User Learning Service promoted by the Copernicus Marine Service to access the e-learning material and discover other interesting exercises.**

# Appendix

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## Cited in the report:

[1] NOAA (online). What are El Niño and La Niña? <https://oceanservice.noaa.gov/facts/ninonina.html> (last access: 17/01/2024).

[2] National Weather Service – NOAA (online). What is ENSO? <https://www.weather.gov/mhx/ensowhat> (last access: 17/01/2024).

[3] Geng, X., Noh, K.-M., Kim, K., and Kug, J.-S. (2023). Midwinter breakdown of ENSO climate impacts in East Asia. *npj Clim. Atmos. Sci.*, 6, 155. <https://doi.org/10.1038/s41612-023-00474-4>

[4] de Carvalho, A. F. and the Mercator Ocean International team (online). El Niño update 2023. <https://www.mercator-ocean.eu/actualites/el-nino-update-november-2023/> (last access: 17/01/2024).

## **Useful links:**

QGIS: <https://docs.qgis.org/3.28/en/docs/index.html>

Copernicus Marine Service: <https://marine.copernicus.eu/>

Copernicus Marine E-Learning Material: <https://marine.copernicus.eu/services/user-learning-services/tutorials>

Copernicus Marine QGIS plugin installation: <https://marine.copernicus.eu/services/user-learning-services/qgis-plugin-cmems-netcdf>

Copernicus Marine Toolbox: <https://help.marine.copernicus.eu/en/articles/7970514-copernicus-marine-toolbox-installation>

Copernicus Marine YouTube Channel: <https://www.youtube.com/@copernicusmarineservice1453>

Copernicus Webinar - MarineData4Asia:

- <https://events.marine.copernicus.eu/marinedata4asia-2024#bl-7d0b3f5b-c3a6-4b40-8749-390d707a7040>
- <https://marine.copernicus.eu/events/webinar-marine-data-4-asia>

CF Conventions: <https://cfconventions.org/>

NetCDF: <https://www.unidata.ucar.edu/software/netcdf/>