Copernicus Marine Data 4 Africa Workshop

User Manual - QGIS scenario

For the attention of: Gaëlle HENAFF-STERBIK
Marine DELORME

	Function	Name	Signature	Date
Prepared by	Project manager/ Project Team	Alexandre HOMERIN Daria ANDRIEVSKAIA		26/02/2025
Approved by	Deputy CEO	Mahmoud EL HAJJ		26/02/2025

NOVELTIS
153 rue du Lac – 31670 Labège – France
Tél. : +33 (0)562 88 11 11 – Fax : +33 (0)562 88 11 12 – E-mail : noveltis@noveltis.fr

Distribution list

INTERNAL	EXTERNAL	
Name	**Name**	**Company / Organisation**
Documentation NOVELTIS	Gaëlle HENAFF-STERBIK	Mercator Ocean
Richard BRU	Marine DELORME	Mercator Ocean
Project Team		

Document status

Copernicus Marine Data 4 Africa Workshop User Manual - QGIS scenario			
Issue	**Revision**	**Date**	**Reason for the revision**
1	0	26/02/2025	Initial version

Modification status				
Issue	Rev	Status *	Modified pages	Reason for the modification

** I = Inserted D = Deleted M = Modified*

Acronyms

CRS	Coordinate Reference System
GIS	Geographic Information System
MHW	Marine Heat Wave

Table of contents

1. Introduction

1.1. Scope of the document

This document describes the different steps of the Copernicus Marine Service GIS training for Africa. It is complementary to the tutorial videos available on the atlas Mercator platform here.

1.2. Context

The Agulhas Current is one of the strongest western boundary currents in the world, flowing southward along the east coast of Africa. Originating from the warm tropical waters of the Indian Ocean, it transports vast amounts of heat and energy toward the Southern Ocean. This current plays a crucial role in global ocean circulation, particularly through the Agulhas Leakage, where warm water from the Indian Ocean enters the Atlantic, influencing climate and weather patterns. The interaction between the Agulhas Current and surrounding waters affects regional ecosystems, fisheries, and even coastal weather events.

One significant phenomenon impacting the Agulhas Current is the occurrence of marine heatwaves (MHWs)—periods of prolonged and extreme ocean warming. These heatwaves have been increasing in frequency and intensity due to climate change, with major events recorded in the Agulhas region, including during 2019–2020. Such temperature anomalies can disrupt marine ecosystems, leading to coral bleaching, reductions in phytoplankton (primary production), fish migration shifts, and potential impacts on fisheries. Additionally, MHWs may alter ocean circulation patterns, intensify coastal storms, and contribute to temporary sea level rise due to thermal expansion. Studying marine heatwaves in the Agulhas Current region is crucial for understanding the broader implications of ocean warming.

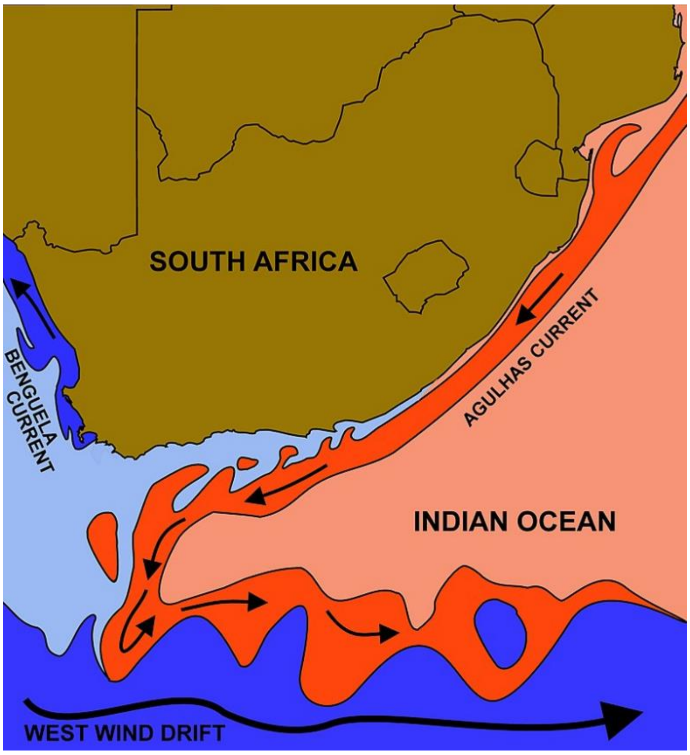


Figure 1: The courses of the warm Agulhas current (red) along the east coast of South Africa, and the cold Benguela current (blue) along the west coast. Credit: wikipedia.org.

In this context, the operational, precise and reliable Copernicus Marine Service products for Africa are a great asset to analyse and forecast the aforementioned phenomena in this area. One way to carry out analysis and get the maximum out of these products is to exploit them in a GIS software. This tutorial aims at demonstrating the processing of Copernicus Marine products for Africa in the QGIS software with the NETCDF2GIS plugin. It is directed towards an audience who wishes to learn how to display and process Copernicus Marine products in the QGIS software. After presenting the products, we will explain the basics of QGIS and the use of the NETCDF2GIS plugin to conveniently import such products.

1.3. Objectives of the Copernicus Marine Data 4 Africa Workshop

A Geographic Information System (GIS) is a software application that provides the ability to present and analyse spatial and geographic data such as digital maps or geo-localized data. The data provided by the Copernicus Marine Service portal can be extracted as a NetCDF format, which is a common data format that can handle several complex variables (longitude, latitude, time, etc.). In order to use such products, NOVELTIS has developed a QGIS plugin: **NETCDF2GIS** which enables to deal easily with NetCDF timeframes and depth levels, and to operate some advanced functions on NetCDF files. Section 2.2.3 describes the plugin installation. The objective of this training is to use a ***geographic information system*** to visualize and analyse Copernicus Marine data with the NETCDF2GIS plugin. In this way, we will be able to:

- Conveniently ingest in QGIS various types of Copernicus Marine Service products for Africa;
- Create maps out of these products' variables;
- Convert a raster picture into a contour vector layer;
- Filter data by condition;
- Work with raster layer calculator;
- Compute vector fields from directional components.

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

2.1. Copernicus Marine Service products used in this training

2.1.1. General information

In this Copernicus Marine Service GIS workshop for Africa, we will focus on marine heatwaves along the Agulhas Current using the following products:

- **GLOBAL_MULTIYEAR_PHY_001_030:** Global Ocean Physics Reanalysis is the CMEMS global ocean eddy-resolving (1/12° horizontal resolution, 50 vertical levels) reanalysis covering the altimetry (1993 onward). It is largely based on the current real-time global forecasting CMEMS system. This product includes daily and monthly mean files for temperature, salinity, currents, sea level, mixed layer depth and ice parameters from the top to the bottom. The global ocean output files are displayed on a standard regular grid at 1/12° (approximatively 8 km) and on 50 standard levels. The product is available here.
  The characteristics of this product are the following:
  - Spatial resolution: 0.083° × 0.083°
  - Temporal resolution: daily mean, monthly mean
  - Download monthly mean for the period of January, 2000 – July, 2020.
- **GLOBAL_MULTIYEAR_BGC_001_029:** Global Ocean Biogeochemistry Hindcast is the biogeochemical hindcast for global ocean, which is produced at Mercator-Ocean (Toulouse, France). It provides 3D biogeochemical fields since year 1993 at 1/4 degree and on 75 vertical levels. It uses PISCES biogeochemical model (available on the NEMO modelling platform). No data assimilation in this product. The product is available here.
  The characteristics of this product are the following:
  - Spatial resolution: 0.25° × 0.25
  - Temporal resolution: daily mean, monthly mean
  - Download monthly mean for the period of July, 2019 – July, 2020.

The Copernicus Marine Service products can be downloaded through the Copernicus Marine Data Store web portal, after registration (following the steps described in §2.1.2 below).

As previously mentioned, some Copernicus Marine products are provided in NetCDF format. This format is especially designed to handle multi-dimensional scientific datasets, depending on coordinates such as latitude, longitude, time and depth. The NetCDF files can contain several variables such as temperature, salinity or current velocities and directions depending on one of these coordinates or more. Finally, the NetCDF files contain metadata (or attributes) that describe the variables content (variable attribute such as name, unit, scale factor, etc.) and provide general information on the product (global attributes).

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

The download data procedure is exhaustively described on the Copernicus Marine Service website. There are three options on how to acquire products: downloading original files as originally produced in NetCDF format; downloading a subset of data for specific variables, geographical area, time range and depth range; or accessing and visualizing data from an URL. You are free to choose the option that suits you best. Please, open the link and follow the instructions.

As an example, we will shortly demonstrate the download process of the Global Ocean Biogeochemistry Hindcast (**GLOBAL_MULTIYEAR_BGC_001_029**) monthly mean chlorophyll concentration variable for the period of July, 2019 – July, 2020:

- First, go to the Copernicus Marine Data Store and register or log in to your existing account.
- Then, in *Filters* tab choose **Green Ocean** among other universes, click on the corresponding product (Figure 2) and choose *Data access* tab in the menu on the left.

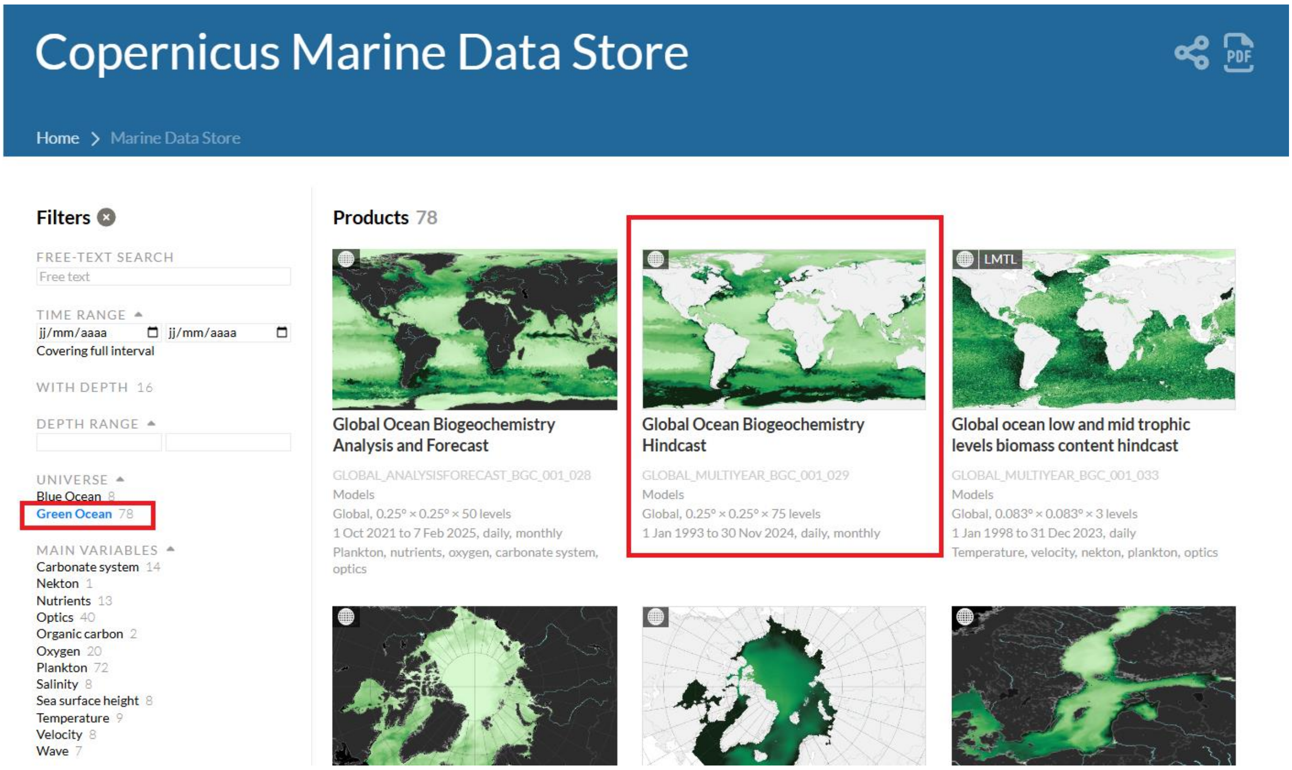


Figure 2: Filter products by universe and select Global Ocean Biogeochemistry Hindcast product.

- In *Data Access* tab, select the monthly product and click on *Subset – Form* (Figure 3).

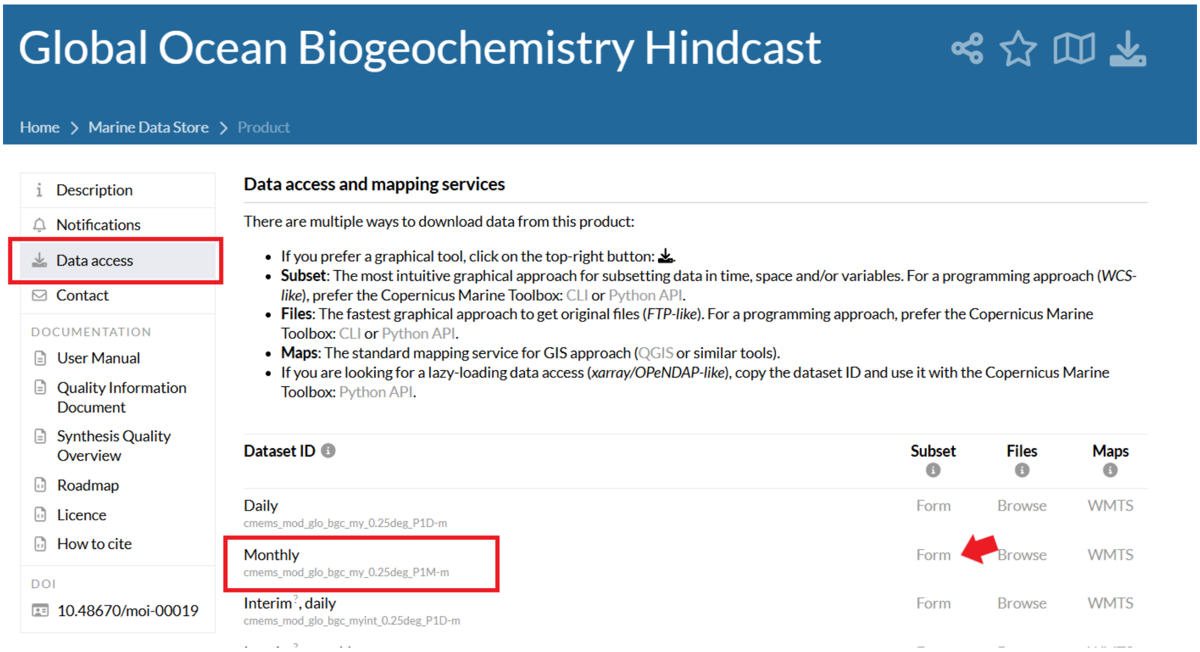


Figure 3: Select the product.

- You have now access to the subset parameters selection (Figure 4), where you can choose variables, period and extents of the region.

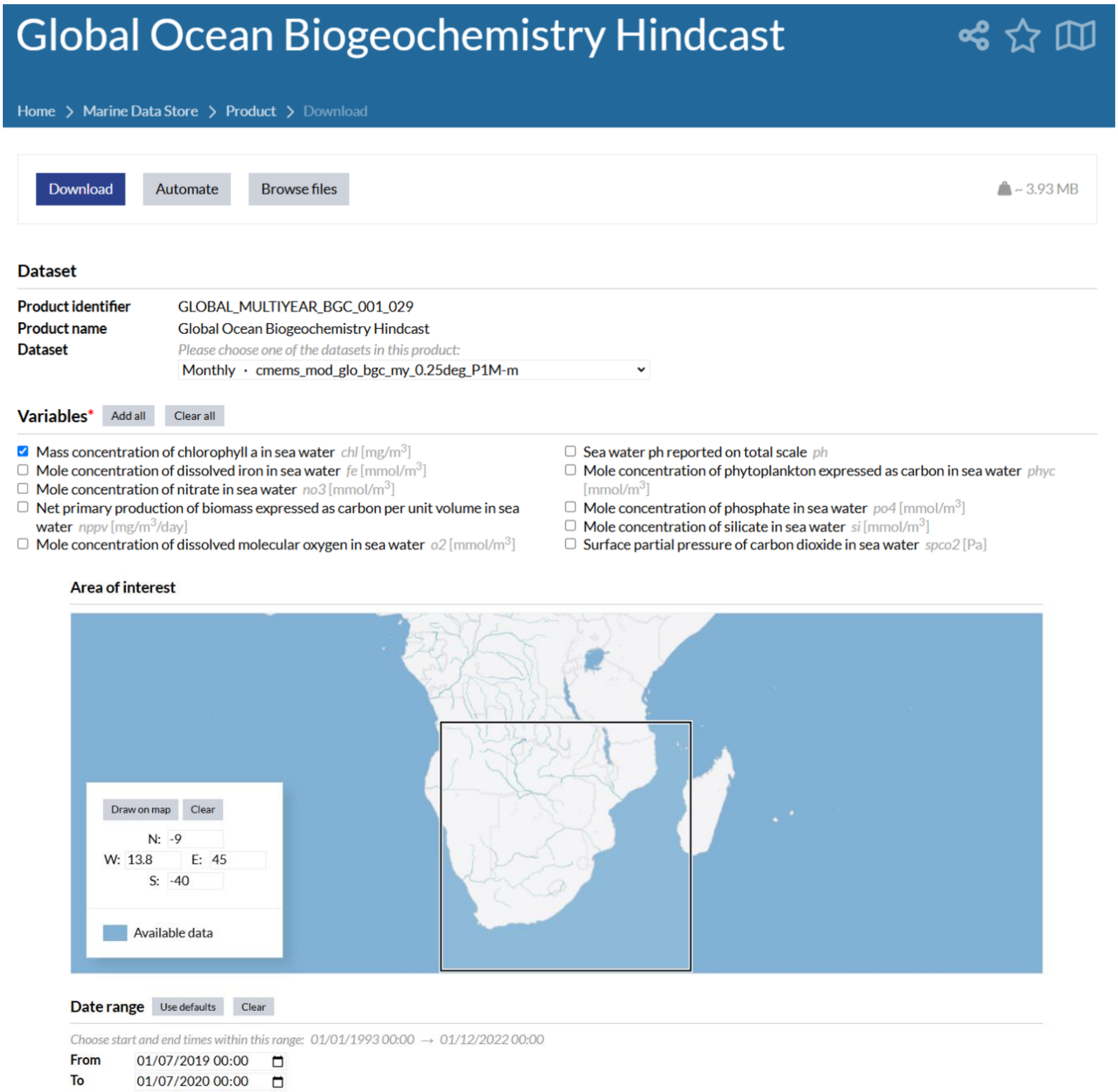


Figure 4: Product spatial and temporal extent to download.

- Once this selection is made, you can launch the download of your file (Figure 5).

Figure 5: Launch product download.

We thus applied this procedure to download monthly mean chlorophyll concentration variable for the period of July, 2019 – July, 2020.

<u>HINT:</u> *For greater convenience, each NetCDF file downloaded from the Copernicus Marine Service has been renamed with the dates to which it corresponds. For example, this Global Ocean Biogeochemistry Hindcast product containing monthly mean chlorophyll concentration variable has been renamed as follows:* **cmems_mod_glo_bgc_mm_07-2019_07-2020.nc**. *We will refer to these files as such in the rest of the document.*

2.2. QGIS Software

2.2.1. Installation of QGIS

The GIS tool used for this training is the **QGIS software in its version 3.20.3**.

QGIS is a free open-source widely used system, which is part of the OSGeo program.

To install QGIS, see: https://www.qgis.org/fr/site/forusers/download.html and download the OSGeo4W Network Installer.

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

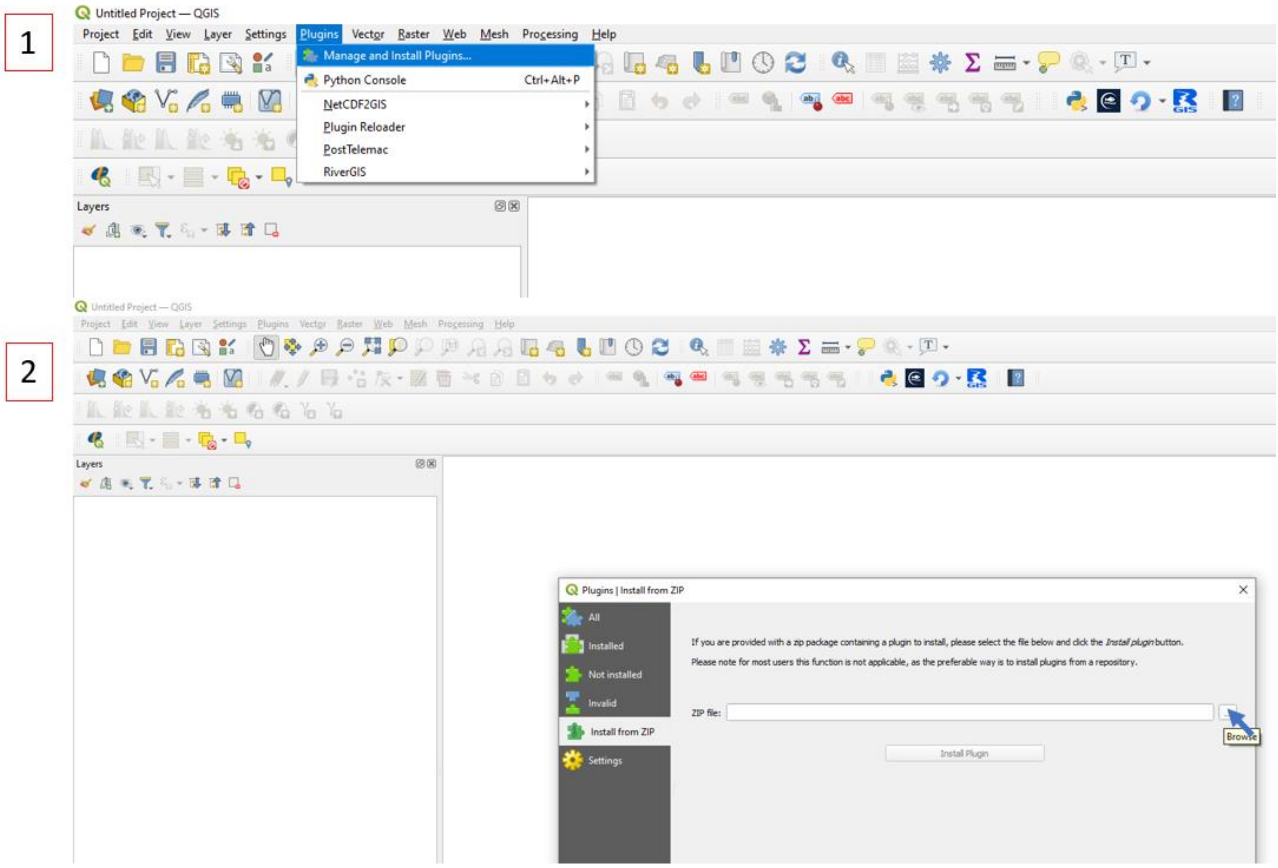
2.2.2. Presentation of the NETCDF2GIS plugin in QGIS

As previously mentioned, the WEkEO products are provided in NetCDF format, which can be directly ingested by QGIS using the **OsGeo gdal** library. However, the automatic ingestion available by default on QGIS is not always ideal to handle multidimensional products. Therefore, in order to facilitate the manipulation of these data, NOVELTIS has developed a NETCDF2GIS plugin. This plugin lets the user easily display variable fields with the possibility to select specific timeframes or depths from the NetCDF files or to apply advanced operations on these data.

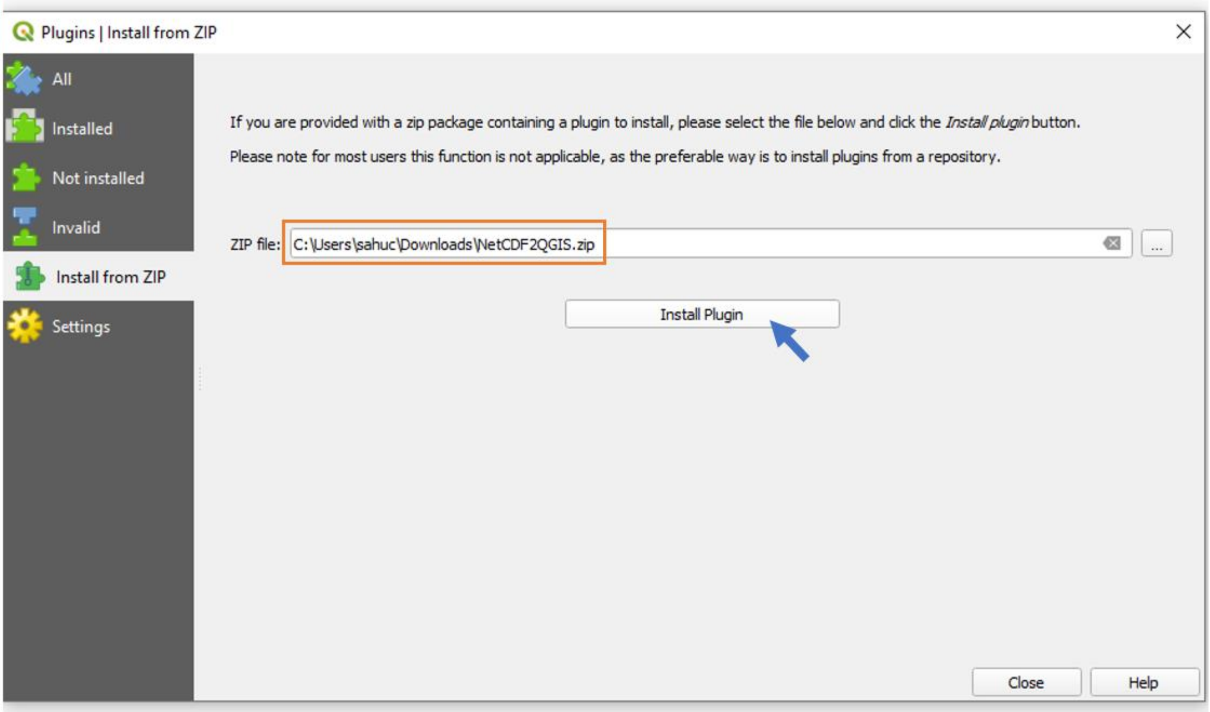
2.2.3. Installation of the NETCDF2GIS plugin

Download the NETCDF2GIS.zip from the Mercator Ocean user platform (here).

Open the QGIS software and click on **Plugins > Manage and install Plugins** (Figure 6: **step 1**). Click on the **Install from ZIP** tab and browse to the NETCDF2GIS.zip location (Figure 6: **step 2**). Once selected, click on **Install Plugin** (Figure 6: **step 3**) and the NETCDF2GIS icon will appear on the plugin bar in your QGIS window (Figure 6: **step 4**).



3



4

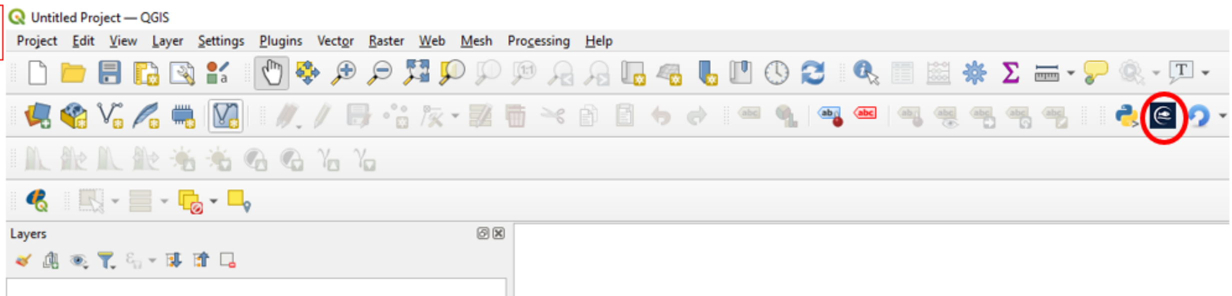


Figure 6: NETCDF2GIS plugin installation steps.

You can now use NETCDF2GIS and launch it by clicking on the plugin's icon (Figure 6: **step 4**). We will use the plugin in the following section of this tutorial.

3. Prepare the QGIS Project and load the data

In this section of the training, we prepare the QGIS project by defining the background maps and information, and by setting the longitude/latitude default projection: the classical EPSG 4326.

3.1. Open QGIS and create a new empty project

Click on **"Project" > "New"** to create a new project (Figure 7).

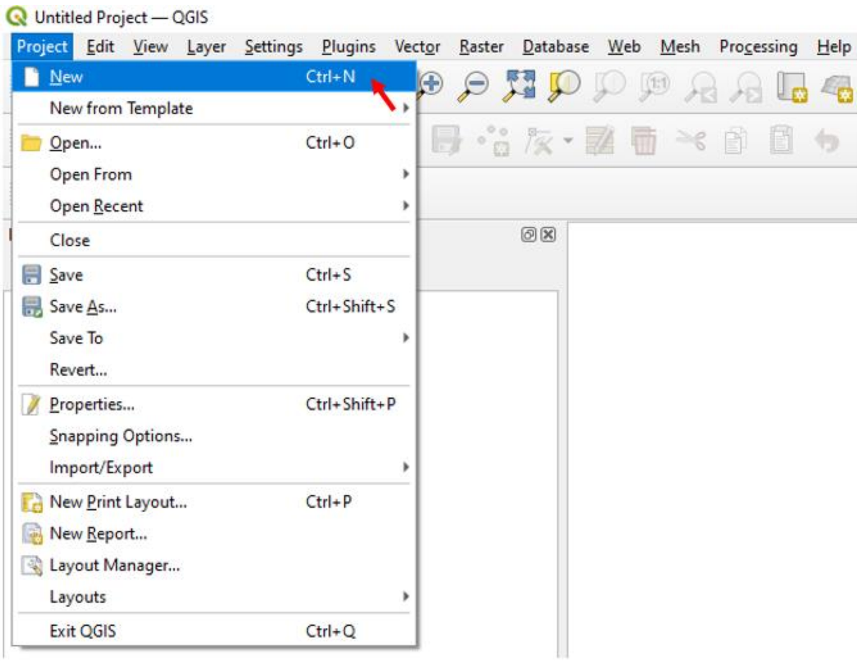


Figure 7: Create a new project on QGIS.

3.2. Add background layers

For the background layers there are plenty of options available. We will choose one of the layers based on Google maps since they have good resolution and topographic names that can be of help. Here, you have some of them, feel free to choose the one that suits your needs best:

Google Maps: https://mt1.google.com/vt/lyrs=r&x={x}&y={y}&z={z}

Google Satellite: http://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Google Satellite Hybrid: https://mt1.google.com/vt/lyrs=y&x={x}&y={y}&z={z}

Google Terrain: https://mt1.google.com/vt/lyrs=p&x={x}&y={y}&z={z}

Google Roads: https://mt1.google.com/vt/lyrs=h&x={x}&y={y}&z={z}

As an example, we use Google Satellite Hybrid:

- **Layer > Add layer > Add XYZ layer (Figure 8)**
- **Click on New**
    - **Set the name: Google Satellite Hybrid**
    - **Set the URL: https://mt1.google.com/vt/lyrs=y&x={x}&y={y}&z={z}**
    - **Click Ok**
- **Choose the newly added layer from the list**
- **Click Add and Close**

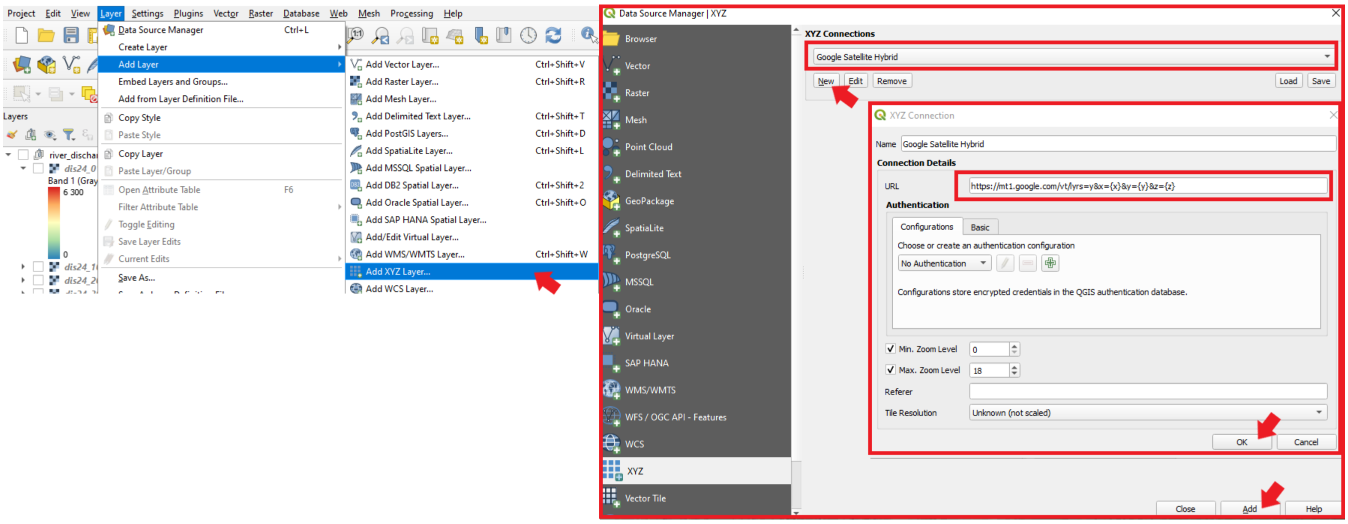


Figure 8: Add Google satellite view as background.

We will now have a background like the following:

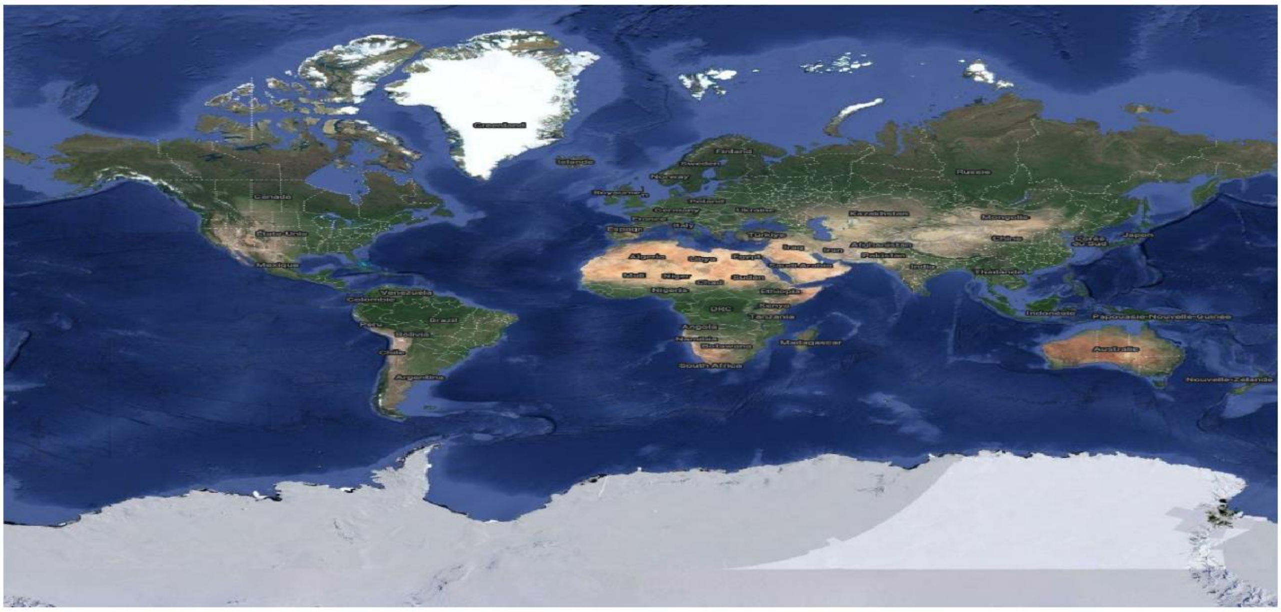


Figure 9: Background Layer.

4. Mapping of the Copernicus Marine Service Products

In this workshop, we will deal with NetCDF files products from the Copernicus Marine Service platform. For such product type, we will use NETCDF2GIS plugin described in section 2.2. After opening the plugin, click on the NetCDF tab and click on the “+” icon to import a file (Figure 10). If you want to import several NetCDF files simultaneously, you can drag and drop them from your directory directly to the NetCDF tab.

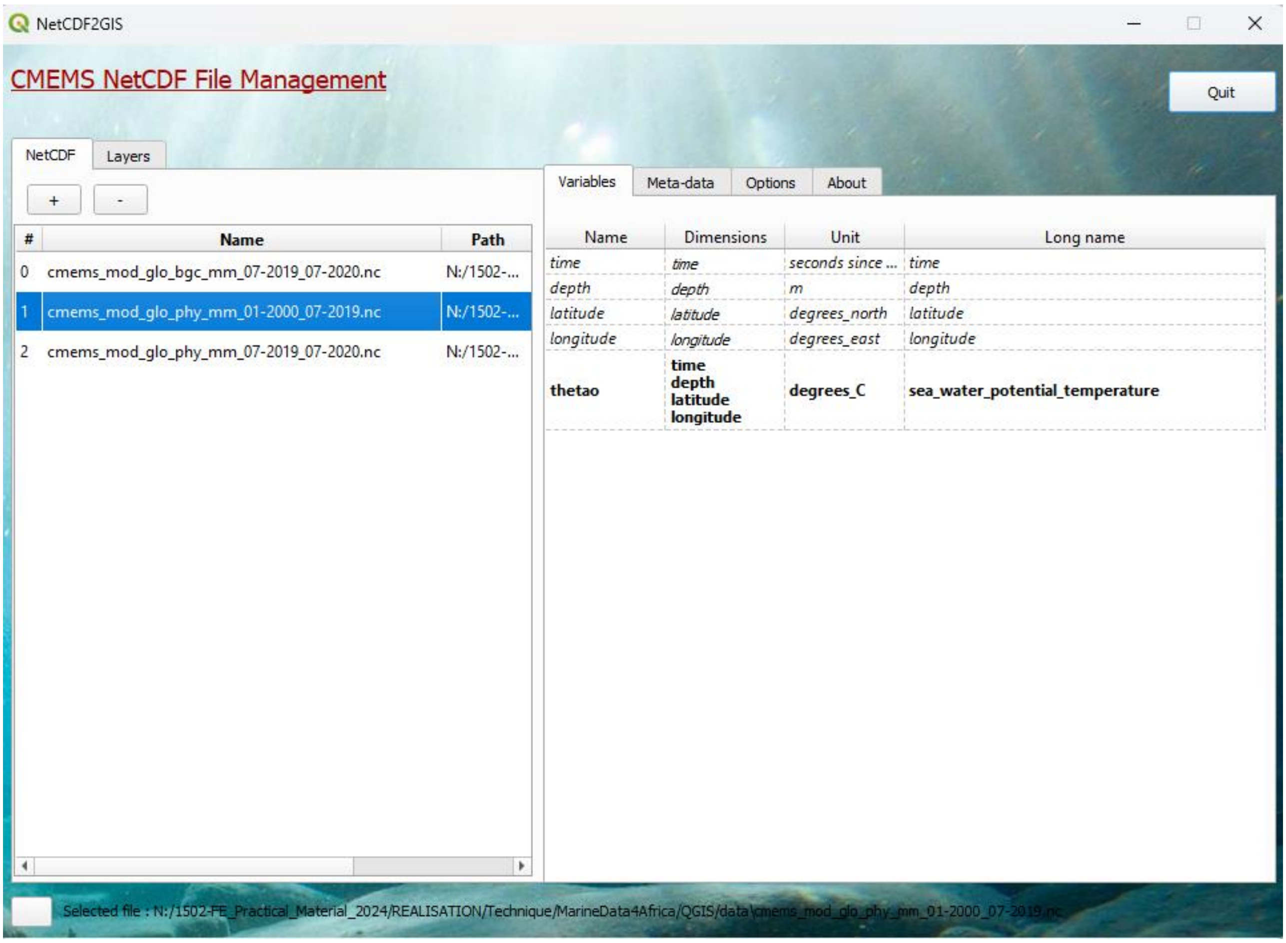


Figure 10: NETCDF2GIS plugin – loading NetCDF data.

Once a product is imported, you will have access, on the right panel, to several pieces of information on your data:

- In the **Variables tab**, you will find information on the Name/Dimensions/Unit/Long name of each variable of the NetCDF data
- In the **Meta-data tab**, you will find elements on the dimensions of the file, and some global attributes as well as **the projection of the model**
- In the **Options tab**, you can choose and set the display projection of the selected variable, and your working directories
- In the **About tab**, you will find general information about the plugin itself.

We will import the following NetCDF files into the NETCDF2GIS plugin:

- **cmems_mod_glo_phy_mm_07-2019_07-2020.nc**;
- **cmems_mod_glo_phy_mm_01-2000_07-2019.nc**;
- **cmems_mod_glo_bgc_mm_07-2019_07-2020.nc**.

The NetCDF files have been conveniently renamed after their download from the Copernicus Marine Service platform (see details in § 2.1.2).

During the training, we will display the following variables from the aforementioned NetCDF files:

- eastward/northward sea water velocity (Global Ocean Physics Reanalysis monthly mean product): **uo/vo** (m/s);
- sea water temperature (Global Ocean Physics Reanalysis monthly mean product): **thetao** (C°);
- mole concentration of dissolved oxygen (Global Ocean Biogeochemistry Hindcast monthly mean product): **o2** (mmol/m3).

4.1. Sea water temperature

4.1.1. Map the variables

For our first product exploration, we will display monthly mean sea water temperature throughout the period of interest – from July, 2019 to July, 2020.

First, add the NetCDF file cmems_mod_glo_phy_mm_07-2019_07-2020.nc to the NETCDF2GIS plugin:

- **First check the metadata of the product to find additional information**
- **On the variable panel, select the thetao (sea water temperature) variable**
- **Right click on it and select the Add Layers (Figure 11)**
- **In the pop-up window select all the timeframes by clicking on the first timeframe and, holding down Shift until the last timeframe is reached**
- **Click on Add and Close**
- **Now, sea water temperature variable is displayed in your QGIS project.**

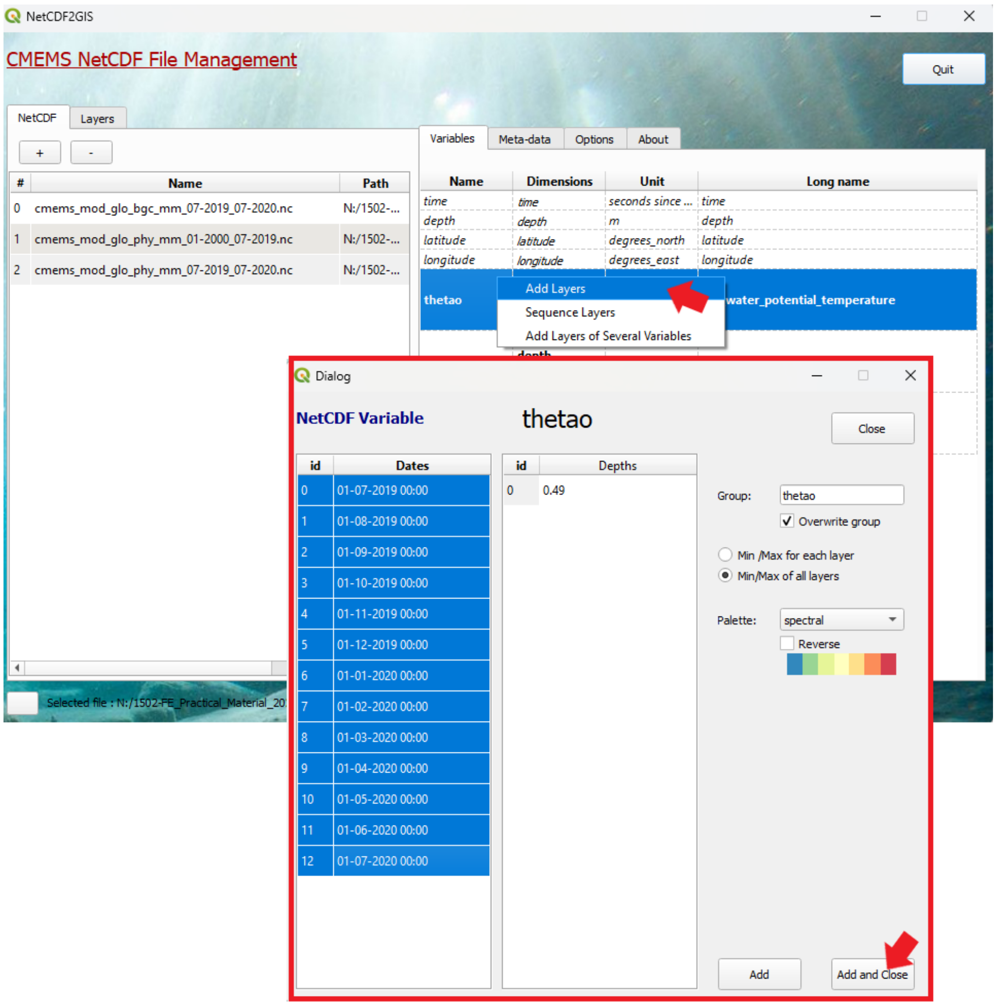


Figure 11: Map the variables.

4.1.2. Change the style of layers

We are now going to tune the value range and colour palette of the variable to have a better visualisation, and then, we will apply this style to every timeframe we have loaded in the project.

- **Double click on thetao_01072019-0000_0.49 layer to open Properties**
- **In Symbology, choose Render type: Singleband pseudocolor**
- **Set the minimum/maximum value for sea water temperature: [10 to 32]**
- **Set the palette as Spectral**
- **By right clicking on the colour ramp, invert the colour bar from blue to red**
- **Set the label precision to 1**
- **Set the Mode to Equal interval and define the number of classes to 5**
- **Click on Apply and OK (Figure 12)**

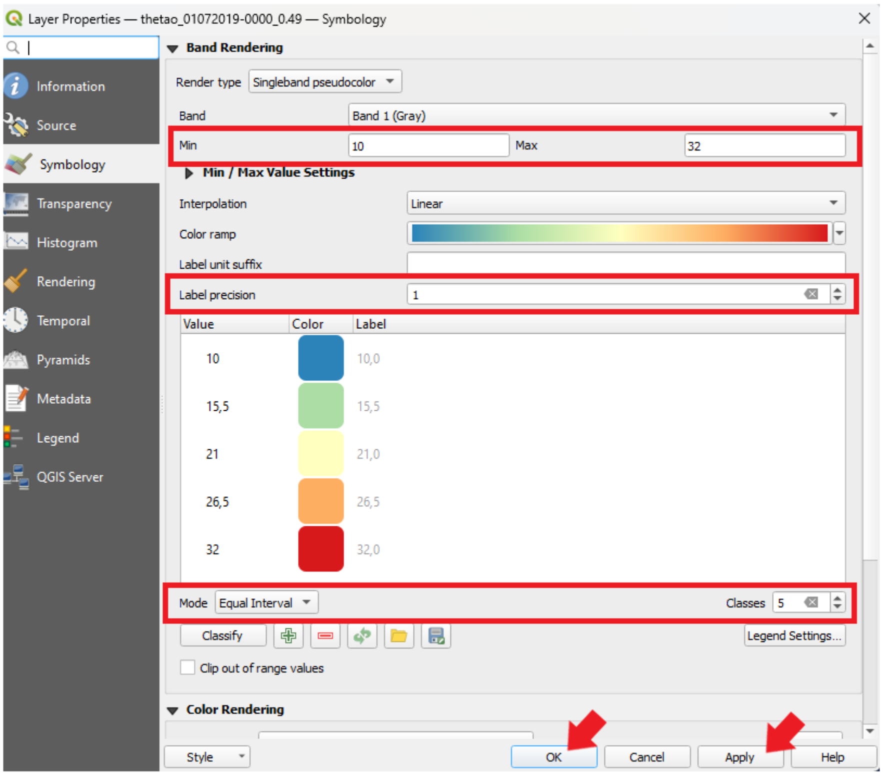


Figure 12: Change layer properties.

Then copy the style of this layer to all the other layers:

- **Right click on the thetao_01072019-0000_0.49 layer > Style > Copy style**
- **Select other layers of sea water temperature by clicking on the first and last timeframes and holding Shift**
- **Right click on any selected layer and Paste style (Figure 13).**

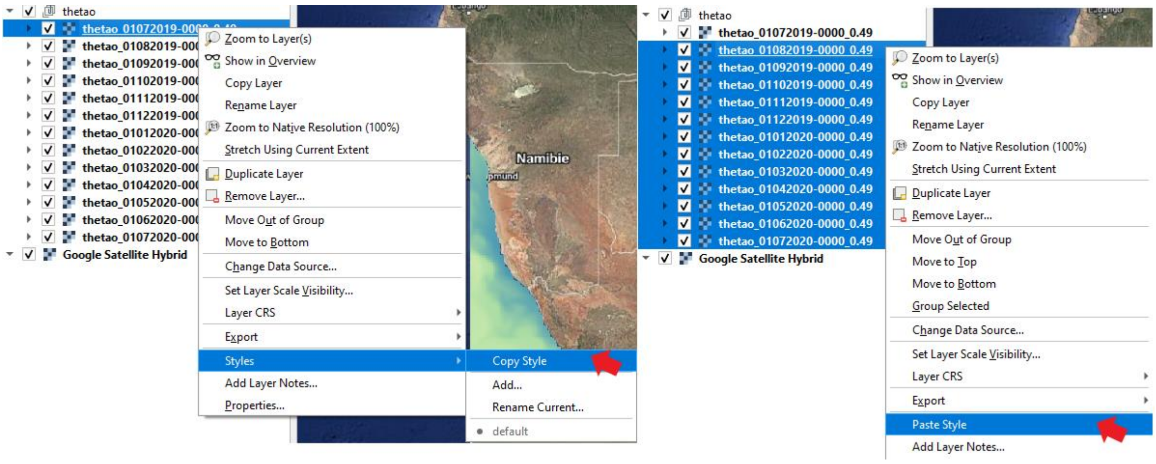
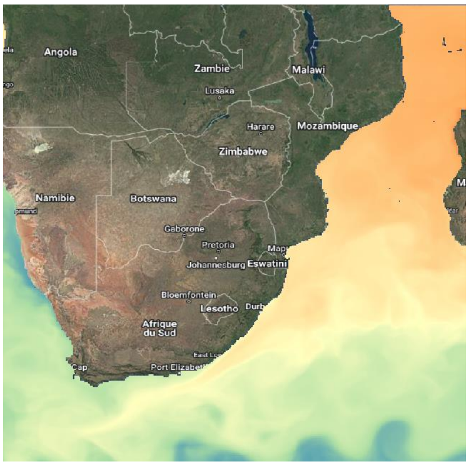
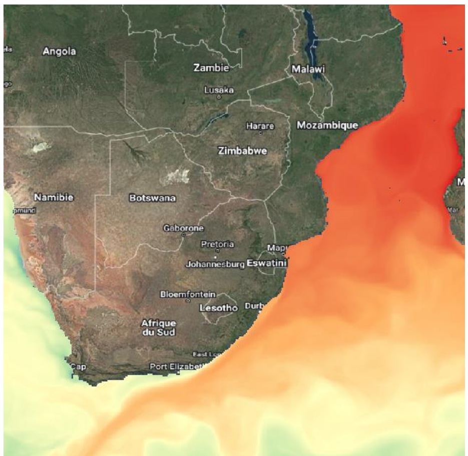


Figure 13: Copy Style from a layer and paste it onto other layers.

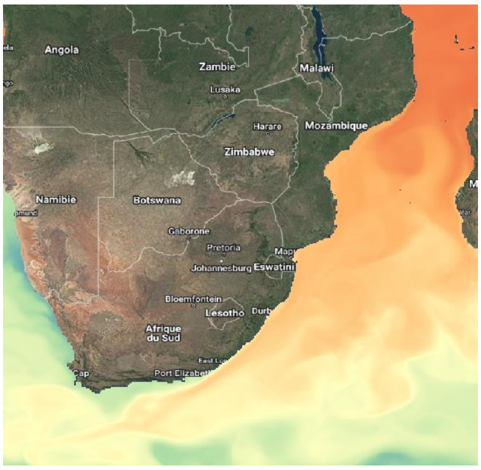
Now, you can activate and deactivate each layer, and see the evolution of sea water temperature during the year. We can clearly see how the water temperature started to increase in October 2019, peaking in February 2020 and decreasing from March 2020 onwards. Additionally, we can spot how this warm water is spreading along the south-east coast of Africa towards its southern tip. Below we include the images of sea water temperature before, during and after the marine heatwave.



a) Sea water temperature in September 2019, before the MHW.



b) Sea water temperature in February 2020, during the MHW.



c) Sea water temperature in May 2020, after the MHW.

Figure 14: Comparison of sea water temperature before, during, and after the MHW of the case study.

4.1.3. Compute contours

Let’s see how we can use this information about sea water temperature during the peak of MHW in order to estimate the potential impact of marine heatwaves on the ocean. For this, we would need to look at the combination of sea water temperature and the biogeochemical product variables, which we will study in the next exercise. For now, we will prepare another layer based on sea water temperature layers that will serve the further analysis.

4.1.3.1. Compute contour lines

Here, we want to obtain contour lines delimiting the zones of the same water temperature. We will focus only on February 2020 in this exercise, but you can perform the same procedure for other months too!

- **Open the Processing Toolbox > search for Contour (Figure 15)**
- **In dialog window:**
  - **Input layer: thetao_01022020-0000_0.49**
  - **Interval between contour lines: 2**
  - **Attribute name: temp**
  - **Save to file: contour_feb_2020.shp**
- **Click on Run and Close**

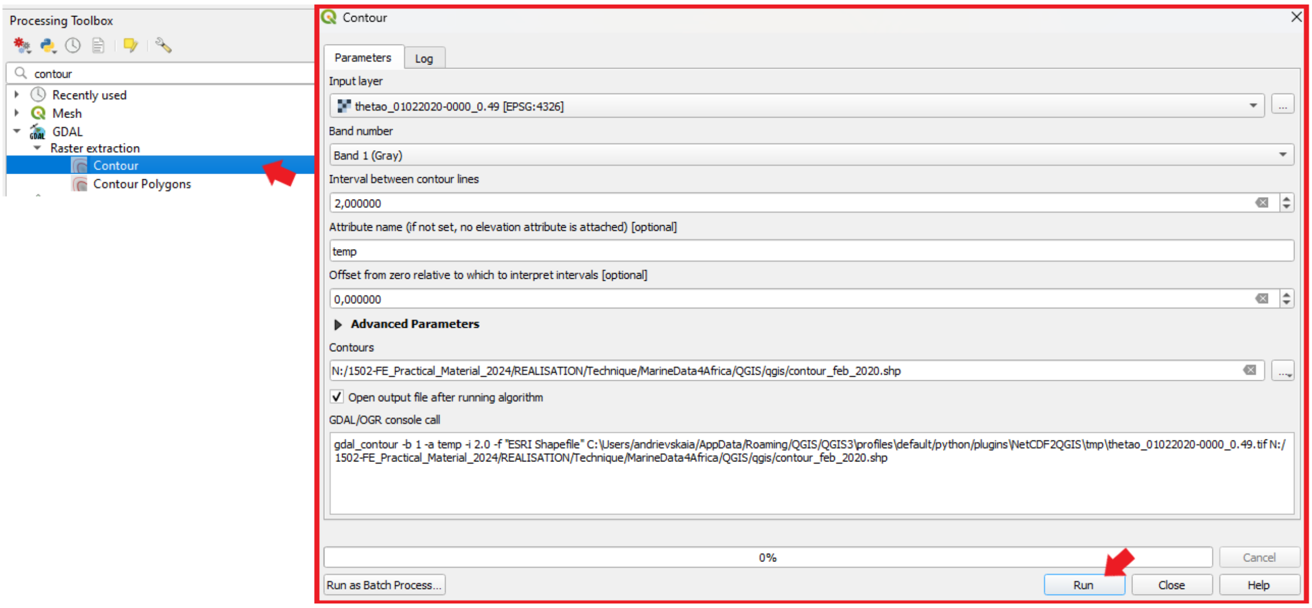


Figure 15: Contour lines tool.

Before looking at the result, we will adjust our new layer for better visualisation:

- **Double click on contour_feb_2020 layer to open Properties**
- **In Labels, choose Render type: Single Labels**
- **Value: temp**
- **Click on Apply and OK (Figure 16)**

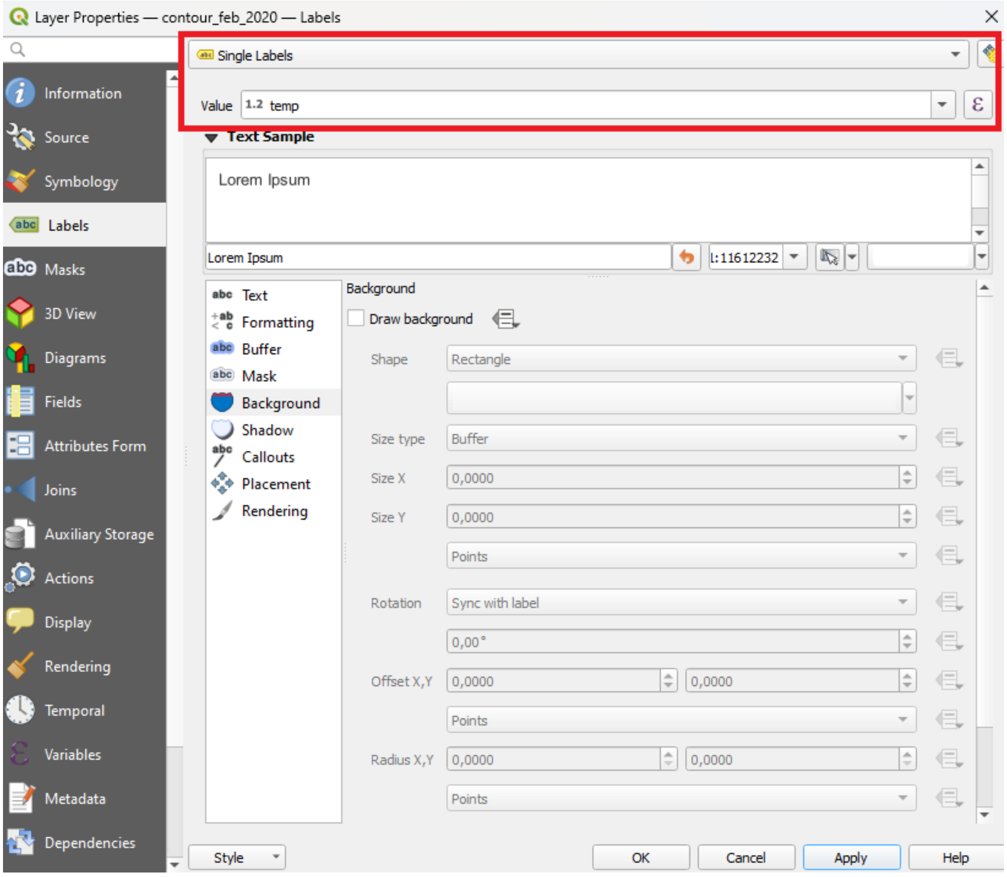


Figure 16: Adjusting labels of the layer.

As a result, a new shapefile layer of contour lines with the sea water temperature values will be produced and it should look like as follows:

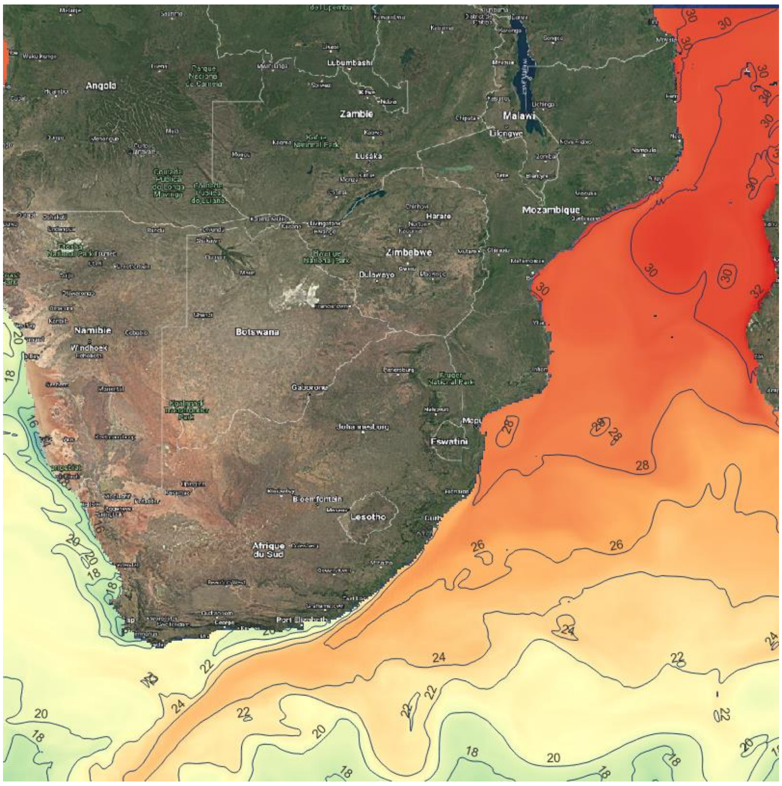


Figure 17: Superposition of sea water temperature in February 2020 and its contour lines.

From the superposition of both sea water temperature and contour line layers, we have a clear picture of how warm water spreads in the region.

4.1.3.2. Compute contour polygons

Next step is to perform the same procedure but this time to obtain polygon vector as an output, in order to use it in the next exercise:

- **Open the Processing Toolbox > search for Contour Polygons (Figure 18)**
- **In dialog window:**
  - **Input layer: thetao_01022020-0000_0.49**
  - **Interval between contour lines: 2**
  - **Attribute name for minimum elevation of contour polygon: temp_MIN**
  - **Attribute name for maximum elevation of contour polygon: temp_MAX**
  - **Save to file: contour_feb_2020_polygon.shp**
- **Click on Run and Close**
- **Adjust the style of the resulted layer by adding labels as described in section 4.1.3.1: choose temp_MAX as label value**

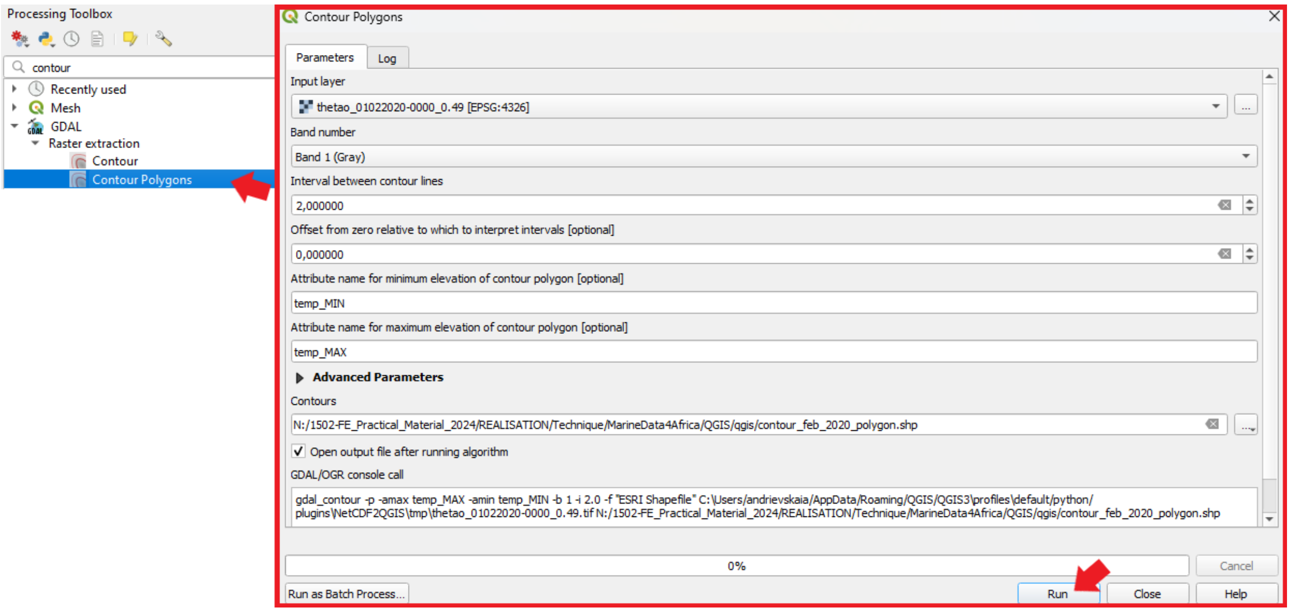


Figure 18: Contour polygons tool.

The result should look like:

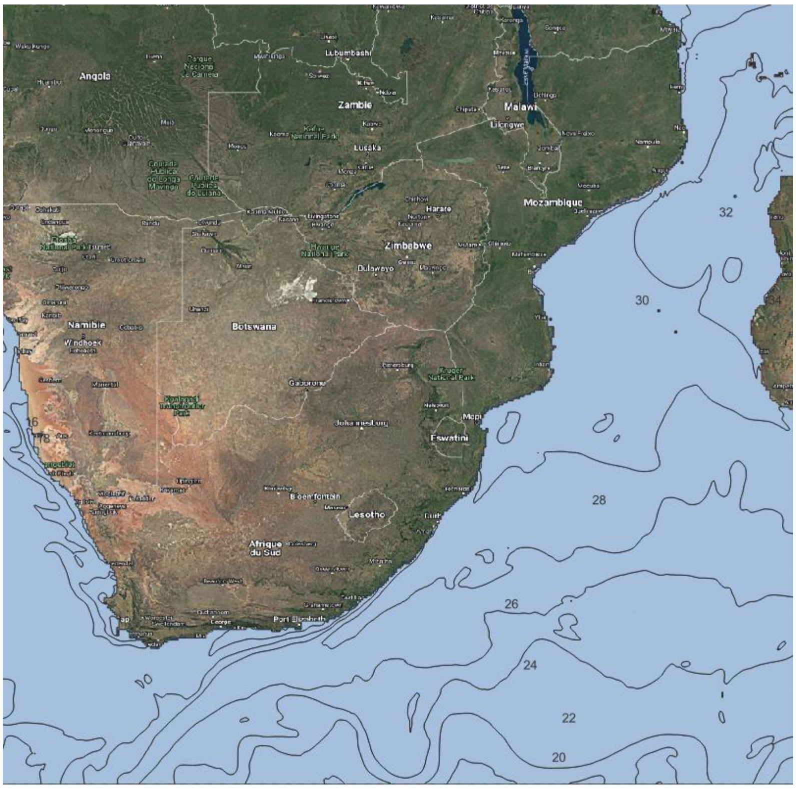
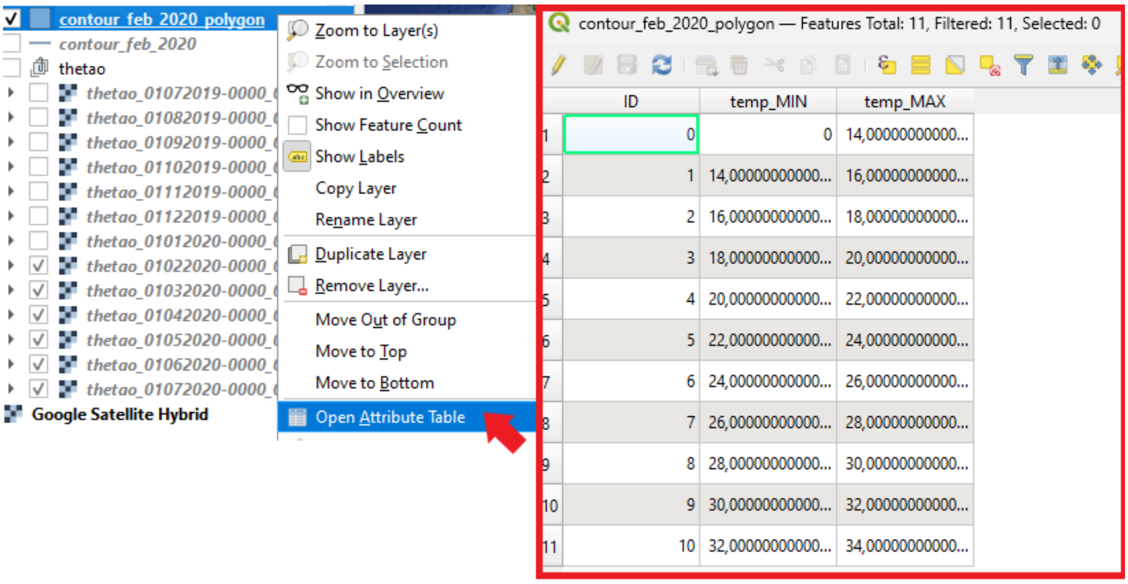


Figure 19: Sea water temperature contour polygons.

As such, we now have a vector layer of polygons containing minimum and maximum sea water temperature values under those polygons. We will use this layer later but now you can right click on it and open its Attribute Table to see what is in it:



	ID	temp_MIN	temp_MAX
1	0	0	14,00000000000...
2	1	14,00000000000...	16,00000000000...
3	2	16,00000000000...	18,00000000000...
4	3	18,00000000000...	20,00000000000...
5	4	20,00000000000...	22,00000000000...
6	5	22,00000000000...	24,00000000000...
7	6	24,00000000000...	26,00000000000...
8	7	26,00000000000...	28,00000000000...
9	8	28,00000000000...	30,00000000000...
10	9	30,00000000000...	32,00000000000...
11	10	32,00000000000...	34,00000000000...

Figure 20: Open vector layer's attribute table.

4.2. Dissolved oxygen concentration

For the next exercise, we will study dissolved oxygen concentration to assess the potential impact of the marine heatwave in the Agulhas Current region on ocean oxygen levels. Warmer water holds less oxygen, and prolonged heating can slow down the mixing of oxygen between surface and deeper layers. This can lead to oxygen depletion (hypoxia), which negatively affects marine life, particularly fish and other organisms that rely on well-oxygenated waters. By analysing dissolved oxygen alongside sea water temperature, we can determine whether the heatwave contributed to deoxygenation, providing insights into broader climate and ecosystem impacts.

4.2.1. Map the variables

First, add the NetCDF file containing the Global Ocean Biogeochemistry Hindcast product to the NETCDF2GIS plugin:

- **First check the metadata of the product to find additional information**
- **On the variable panel, select the o2 (mole concentration of dissolved oxygen in mmol/m^3) variable**
- **Right click on it and select the Add Layers (Figure 21**Erreur ! Source du renvoi introuvable.**)**
- **In the pop-up window select all the timeframes by clicking on the first timeframe and holding Shift until the last timeframe is reached**
- **Click on Add and Close**
- **Now, dissolved oxygen concentration is displayed in your QGIS project**

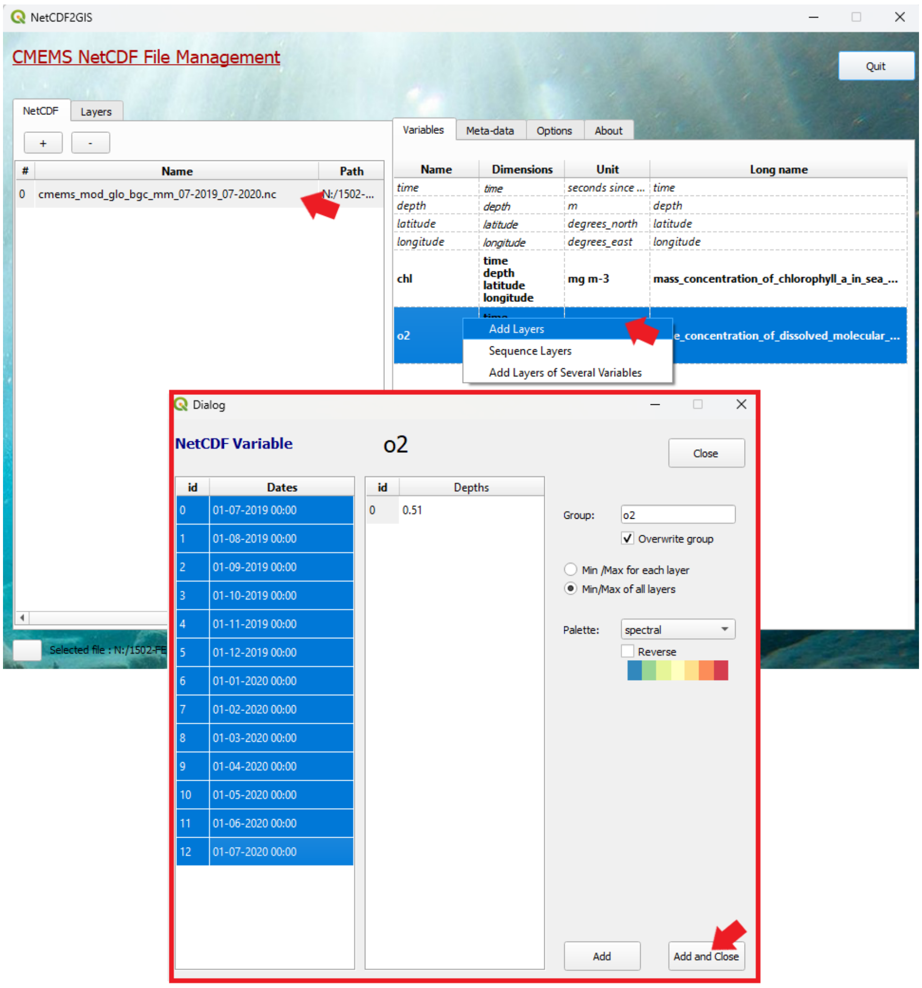


Figure 21: Map the variable.

4.2.2. Change the style of layers

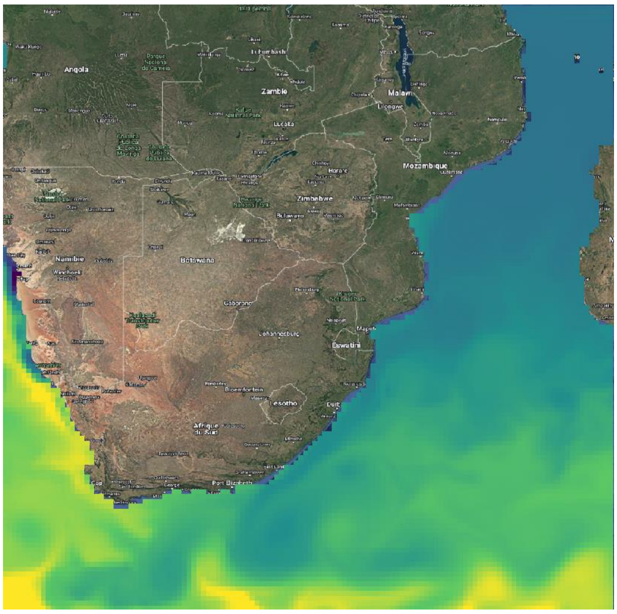
We are now going to tune the style of the new layers as we did before in the § 4.1.2:

- **Right click on the first timeframe layer and open Properties**
- **In Symbology, choose Render type: Singleband pseudocolor**
- **Set the minimum/maximum value for the temperature: [170 to 270]**
- **Set the palette as Viridis**
- **By right clicking on the colour ramp, invert the colour bar from dark to light**
- **Set the label precision to 1**
- **Set the Mode to Equal interval and define the number of classes to 5**
- **Click on Apply and OK**

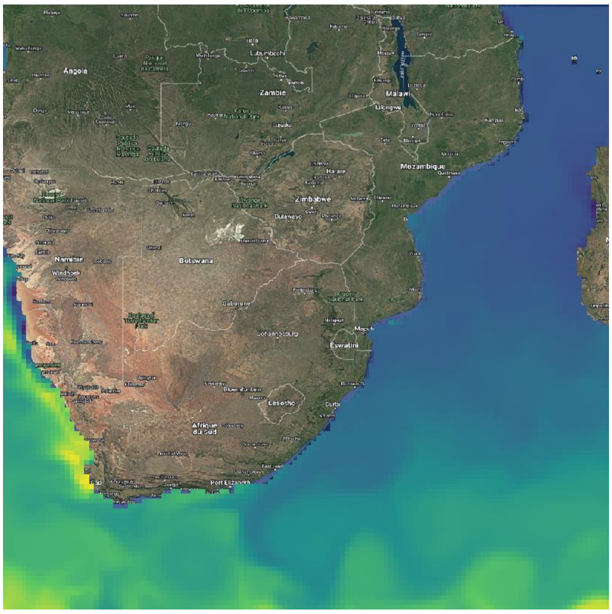
Then copy the style of this layer to all the other layers:

- **Right click on the first timeframe layer > Style > Copy style**
- **Right click on other timeframe layers and Paste style**

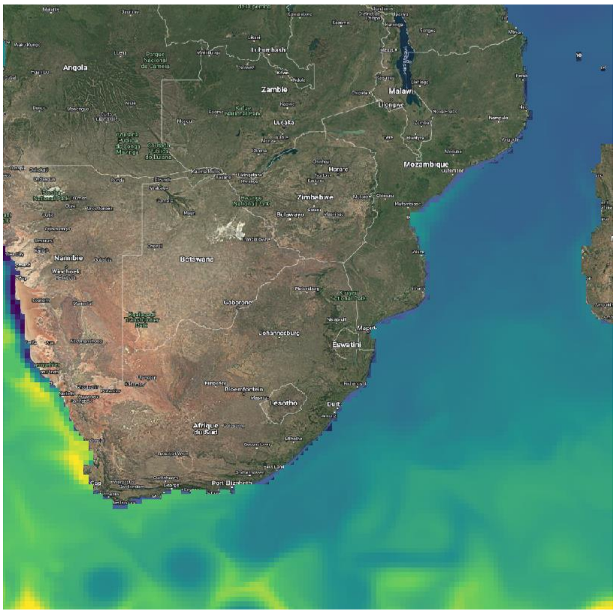
Then, you can activate and deactivate each layer, and see how mean dissolved oxygen concentration changed throughout the studied period.



a) September 2019, before the MHW.



b) February 2020, during the MHW.



c) May 2020, after the MHW.

Figure 22: Comparison of dissolved oxygen concentration before, during, and after the MHW of the case study.

Above, we included only the three timeframes to save space: before, during, and after the MHW. From the figures above and the layers you have loaded in the QGIS, we observe a gradual decrease in dissolved oxygen concentration from September 2019 to February 2020, followed by an increase from March to July 2020. This pattern aligns with the changes in sea water temperature —as the temperature peaked, oxygen levels dropped, and when temperatures began to cool, oxygen levels started to recover. This relationship highlights the impact of the marine heatwave in the Agulhas Current region, where warmer water holds less oxygen, potentially affecting marine life and ocean health. Let's try to assess this impact!

4.2.3. Correlation between the two variables

Now, let's have a look on how sea water temperature correlates with dissolved oxygen concentration. We will use the prepared polygon layer in section 4.1.3.2:

- **First drag and drop the contour_feb_2020_polygon above dissolved oxygen layers in the Layers tab**
- **Right click on it and open Properties**
- **In Symbology, set opacity at 50%**
- **Right click and choose Filter (Figure 23)**
- **In the dialog window:**
    - **Set expression as "temp_MAX" >= 27**
- **Click on OK**

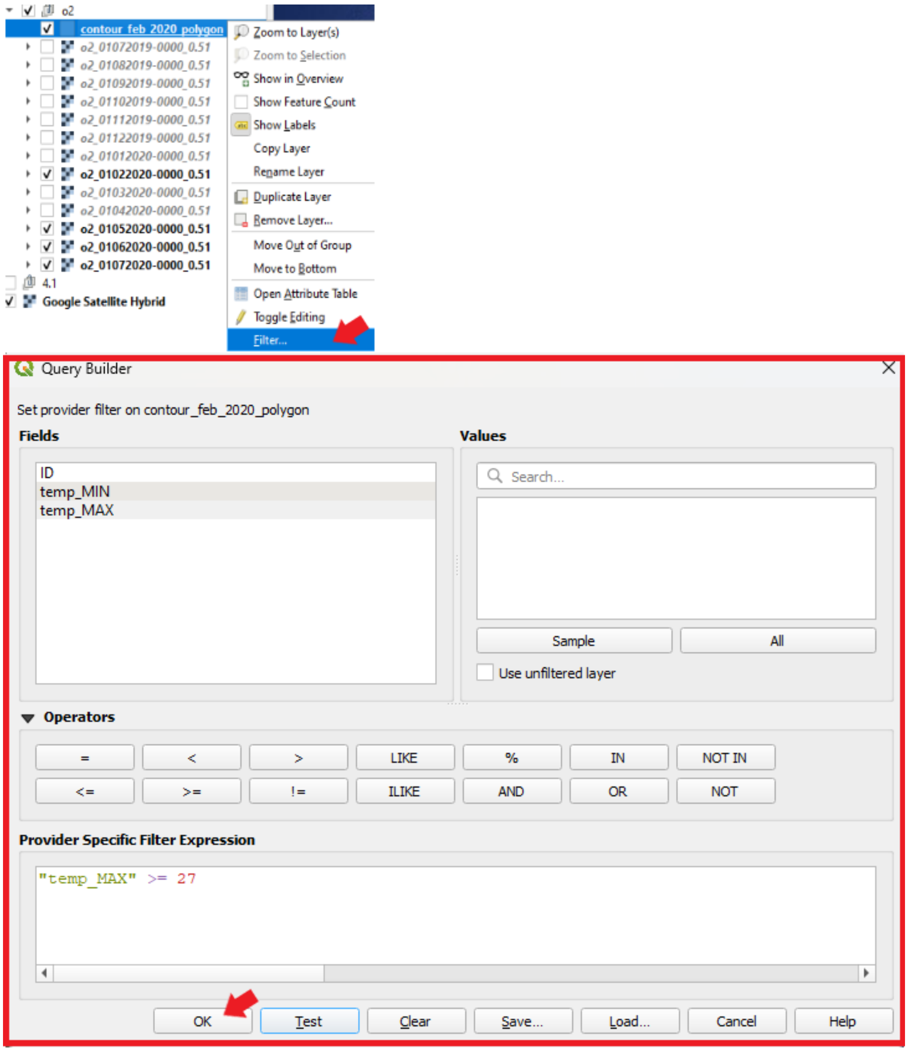


Figure 23: Filter function.

Superposed over the activated February 2020 timeframe of dissolved oxygen concentration, the resulted layer should look like this:

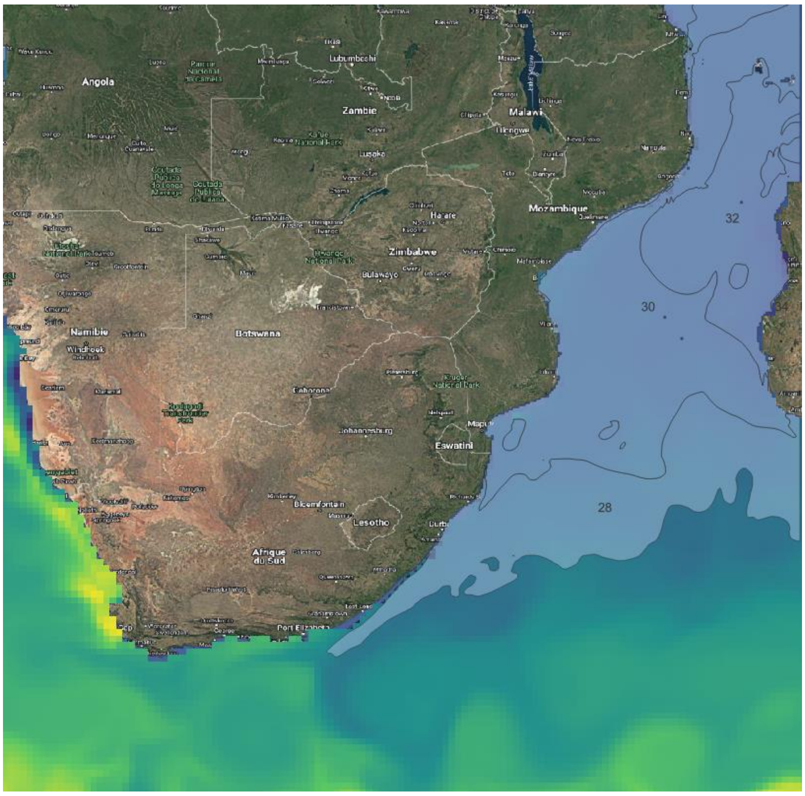


Figure 24: Superposition of dissolved oxygen concentration and sea water temperature vector polygons filtered above 27 degrees, February 2020.

We see that, indeed, the zones with high sea water temperatures are overlapping with an area where dissolved oxygen concentration is at its lowest.

Now, we will estimate numerically dissolved oxygen concentration on the zones covered by these polygons:

- **Open the Processing Toolbox > search for Zonal Statistics (Figure 25)**
- **In dialog window:**
  - **Input layer: contour_feb_2020_polygon**
  - **Raster layer: o2_01022020-0000_0.51**
  - **Output column prefix: o2_**
  - **Statistics to calculate: mean, min, max**
  - **Save to file: o2_stats.shp**
- **Click Run and Close**

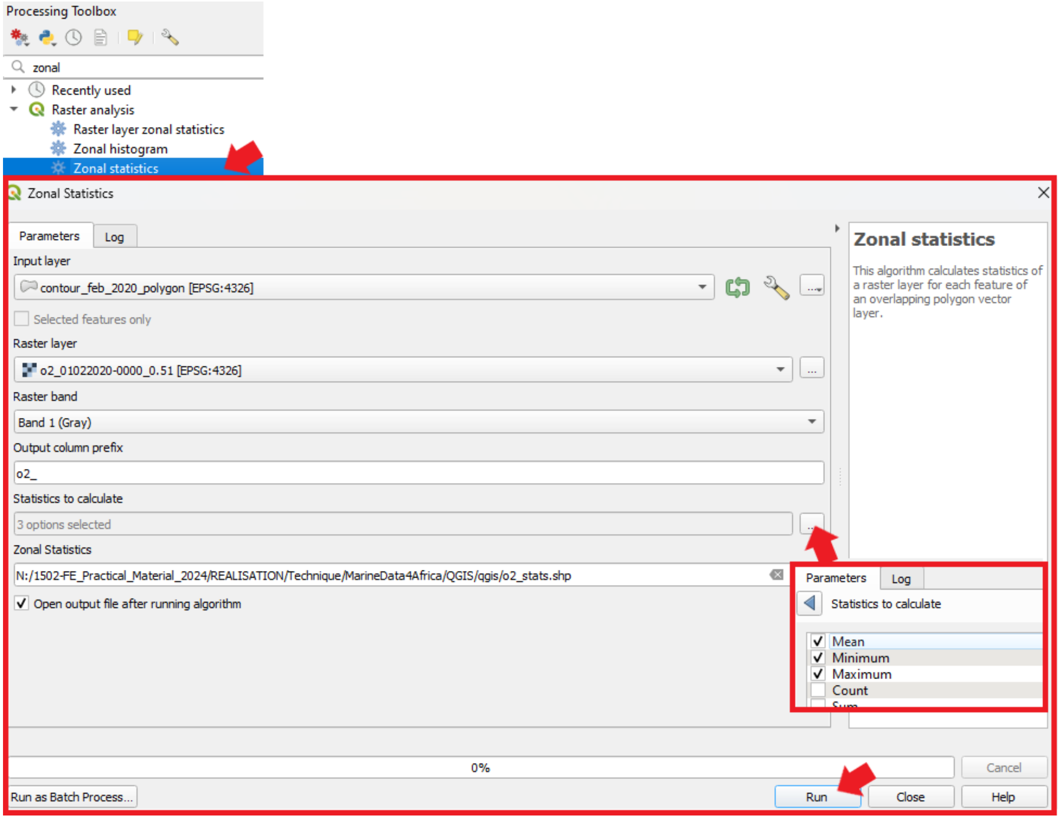


Figure 25: Zonal statistics tool.

As a result, the new polygon layer looking exactly the same as the previous one will be produced. The difference is in its attribute table. If you open its attribute table by right clicking on the new layer and choosing Open Attribute Table, you will see the following table:

o2_stats — Features Total: 4, Filtered: 4, Selected: 0

	ID	temp_MIN	temp_MAX	o2_mean	o2_min	o2_max
1	7	26,00000000000...	28,00000000000...	206,3266360186...	200,7306823730...	215,2906494140...
2	8	28,00000000000...	30,00000000000...	199,8259601729...	188,7325286865...	216,8235168457...
3	9	30,00000000000...	32,00000000000...	196,8614035866...	180,5985260009...	201,9230346679...
4	10	32,00000000000...	34,00000000000...	191,1173852576...	180,5985260009...	193,8362884521...

Figure 26: Statistics for dissolved oxygen.

From this table, we can clearly see a negative correlation between sea water temperature and dissolved oxygen - as water temperature increases, dissolved oxygen decreases. This pattern is expected and now we performed a short numerical analysis to prove it.

4.3. Sea water temperature anomaly

Now, as we know that the peak of the studied MHW fell on February 2020, we would like to see the sea water temperature anomaly for this event. The term “temperature anomaly” means a departure from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value. In order to get the temperature anomaly, we need to compare our February 2020 data with historical data for the same region and timeframe. In this exercise, we will operate with the data from 2000-2019.

4.3.1. Load historical data

First, we need to load the historical data in our project. It is stored in **cmems_mod_glo_phy_mm_01-2000_07-2019.nc** file. Since it spans over 20 years, to save time, we will focus only on the month of February, as we recognised the peak conditions during this month in 2020. You can additionally look at other months during the MHW period or even out of this period. To add the historical data, you can repeat the procedure described in §4.1.1, with small adjustments:

- **In the dialog window of the thetao variable, choose only the timeframes corresponding to the month of February each year: 01-02-200, 01-02-2001, 01-02-2002, etc.**
- **Set the group name *thetao_his***
- **Click on Add and Close**

You can also repeat the procedure of copy-pasting the style of the layers from the section 4.1.2, to have matching settings between the historical data and the data for the study case.

4.3.2. Calculate climatology

Next step is to calculate a so-called climatology for the period of 2000-2019, or, simply saying, the mean for the month of February for these 20 years. For that:

- **Open the Processing Toolbox > search for Raster Calculator**
- **In the function window:**
  - **Set the expression as follows:**

    ("thetao_01022000-0000_0.49@1" + "thetao_01022001-0000_0.49@1" + "thetao_01022002-0000_0.49@1" + "thetao_01022003-0000_0.49@1" + "thetao_01022004-0000_0.49@1" + "thetao_01022005-0000_0.49@1" + "thetao_01022006-0000_0.49@1" + "thetao_01022007-0000_0.49@1" + "thetao_01022008-0000_0.49@1" + "thetao_01022009-0000_0.49@1" + "thetao_01022010-0000_0.49@1" + "thetao_01022011-0000_0.49@1" + "thetao_01022012-0000_0.49@1" + "thetao_01022013-0000_0.49@1" + "thetao_01022014-0000_0.49@1" + "thetao_01022015-0000_0.49@1" + "thetao_01022016-0000_0.49@1" + "thetao_01022017-0000_0.49@1" + "thetao_01022018-0000_0.49@1" + "thetao_01022019-0000_0.49@1") / 20

    (or set it manually by choosing the layers in the Layers window on the left)
  - **Reference layer: any used layer, for example, *thetao_01022000-0000_0.49***
  - **Output CRS: EPSG:4326**
  - **Save to file *climatology_feb.tif***
- **Click on Run and Close (Figure 27)**
- **Copy-paste the style from other sea water temperature layers to the produced climatology layer**

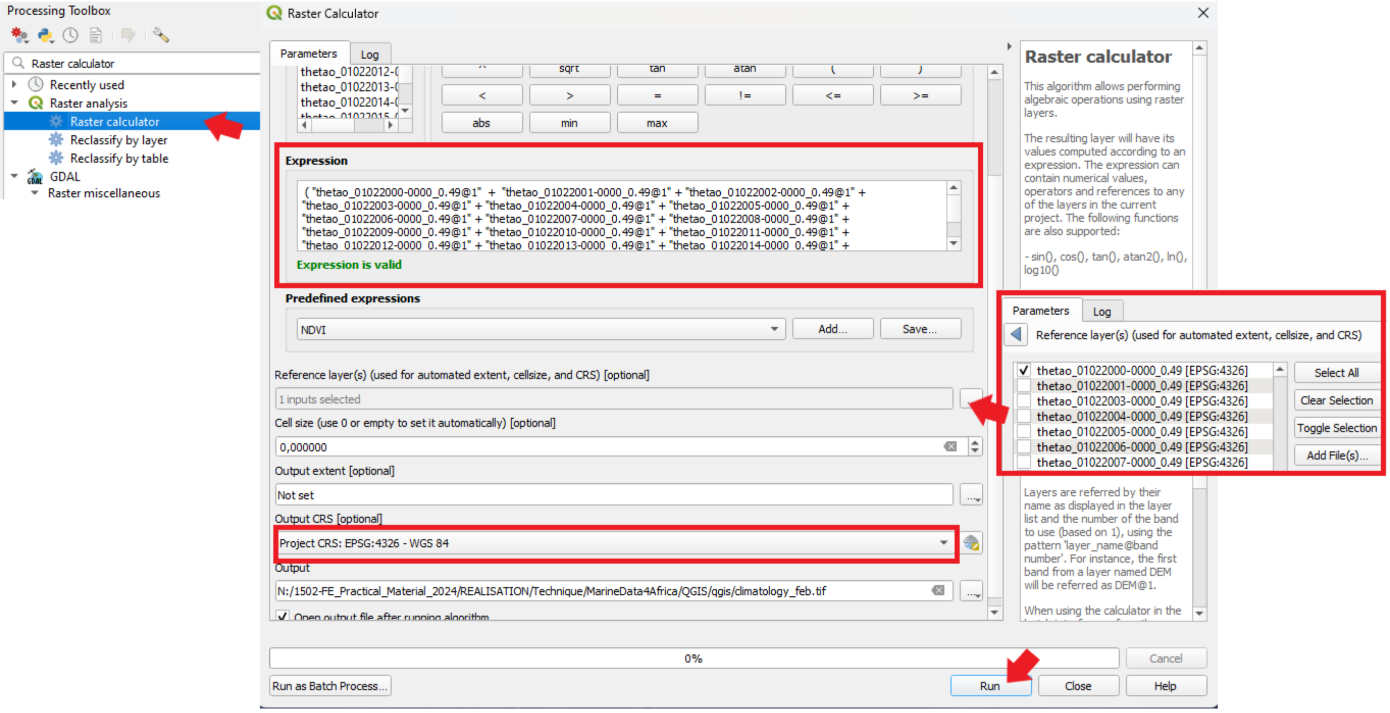


Figure 27: Raster calculator tool.

As a result, we should obtain the following:

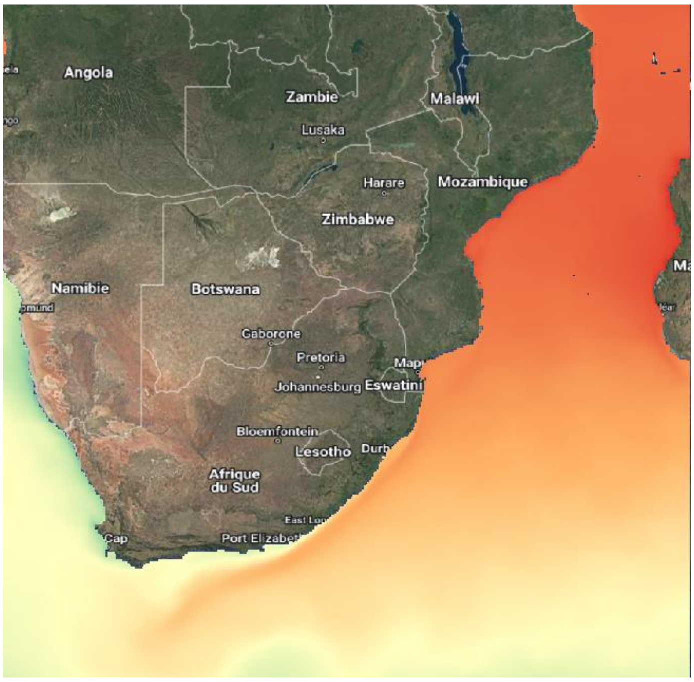


Figure 28: February climatology (2000-2019).

Now, we have our February mean sea water temperature for the period of 2000-2019! As it was mentioned, you can play with the other data and calculate climatology for other months.

4.3.3. Calculate sea water temperature anomaly

As we have both the climatology data and the event data, we can now proceed to sea water temperature anomaly calculation. For this, we will use Raster calculator function once again:

- **Open the Processing Toolbox > search for Raster Calculator**
- **In the function window:**
    - **Set the expression as follows:**
      "thetao_01022020-0000_0.49@1" - "climatology_feb@1"
      (or set it manually by choosing the layers in the Layers window on the left)
    - **Reference layer: *thetao_01022000-0000_0.49***
    - **Output CRS: EPSG:4326**
    - **Save to file *temp_anomaly_feb.tif***
- **Click on Run and Close**

Adjust the layer's style by tunning the settings as follows:

- **In Symbology, choose Render type: Singleband pseudocolor**
- **Set the minimum/maximum value for sea water temperature anomaly: [-3 to 3]**
- **Set the palette as RdBu (under All Color Ramps)**
- **By right clicking on the colour ramp, invert the colour bar from blue to red**
- **Set the label precision to 1**
- **Set the Mode to Equal interval and define the number of classes to 7**
- **Click on Apply and OK (Figure 29)**

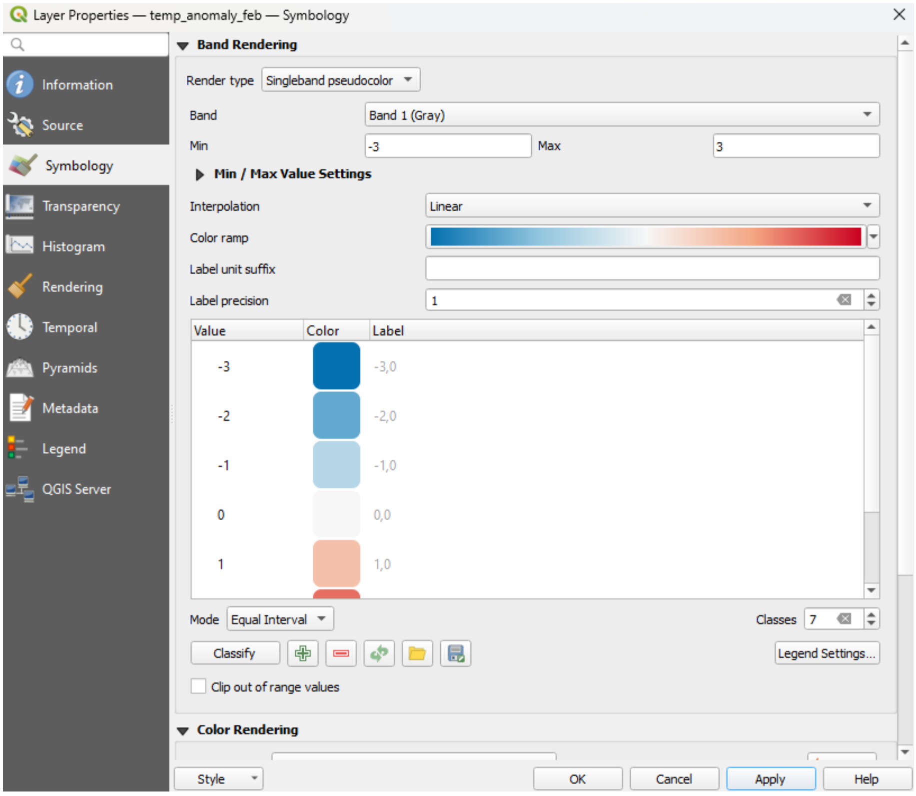


Figure 29: Tune the layer style.

As a result, the following layer will be produced:

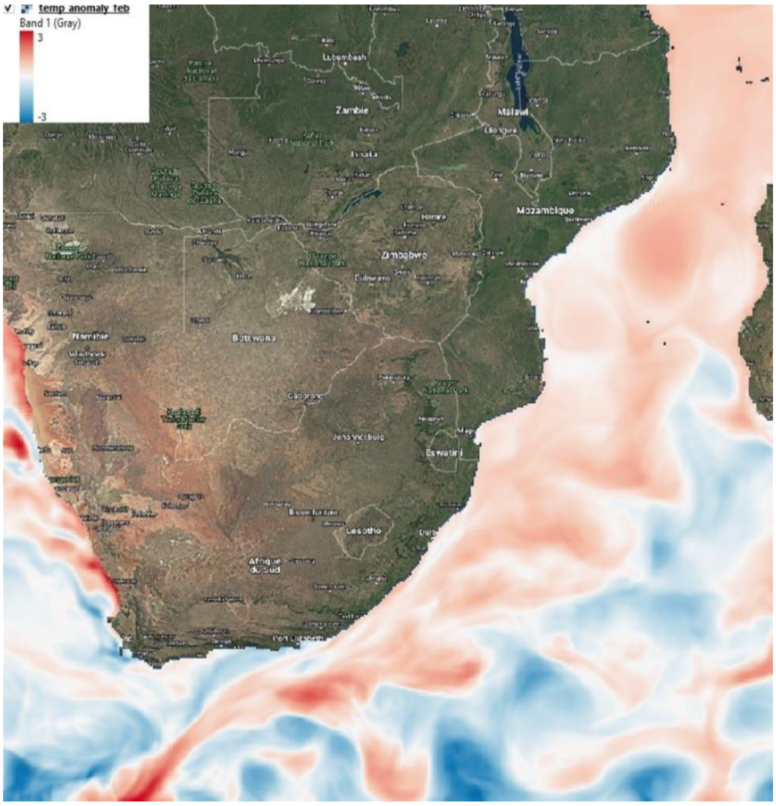


Figure 30: Sea water temperature anomaly for the month of February.

As observed in the figure above, the majority of the Agulhas Current region appears in various shades of red, with particularly intense red patches near the southern tip. These colour patterns indicate that sea surface temperatures in this area were significantly higher than the long-term climatological average. The presence of these warm anomalies suggests that the region experienced unusually elevated temperatures, which could be associated with a marine heatwave event.

4.4. Agulhas Current vector field

In this part, we will see how to plot current vector field in order to see the way warm water spreads during the MHW.

4.4.1. Compute and display current vector field

As a special function exists in the NETCDF2GIS plugin to easily display a vector field in QGIS, the following part of the demonstration explains how to map **the speed and direction of a current field** (and any other vector field using its two components u and v, or norm and direction) with the NETCDF2GIS plugin.

4.4.1.1. Load the scalar components of the vector field

First, you need to load each component of the vector field as a single layer (respectively **uo (eastward_sea_water_velocity)** and **vo (northward_ ea_water_velocity)**).

- **Click on the NetCDF file containing the x and y current velocity variables (components of the vector field you want to display)**
- **Right click on the uo (eastward_sea_water_velocity variable)**
- **Click on Add Layers of Several Variables**
- **In the pop-up window, choose uo and vo variables by clicking on them in the drop-down menu, click Next**
- **Two separate windows for both variables will open**

- **Select the timeframe corresponding to February 2020 in one of the windows (as an example to illustrate the spreading of warm water during the peak of MHW, you can choose any other date). The same timeframe will be automatically chosen for the second variable**
- **Click on Add and Close (Figure 31)**
- **Both windows will close and the two variables will be added to your project**

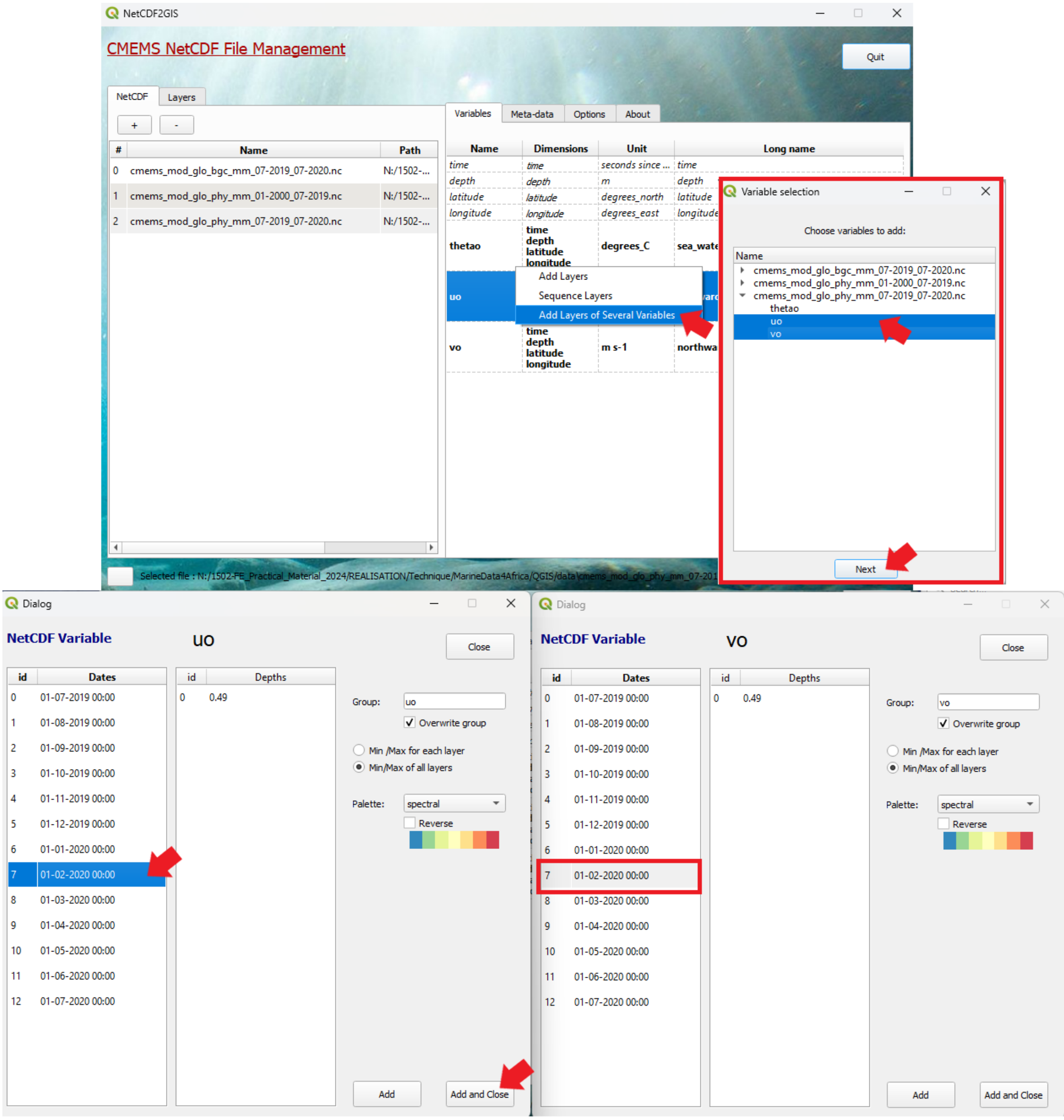


Figure 31: Select the vector field components.

After doing so, the ***uo*** and the ***vo*** variable layers should appear in the Layer tab of the NETCDF2GIS plugin and in your QGIS project. As we want to display the current vector field, you can uncheck the uo and vo groups in the QGIS window.

4.4.1.2. Compute current vector field using the NETCDF2GIS plugin

Now, in the **Layer tab** of the NETCDF2GIS plugin:

- **Select the two layers corresponding to the two components of the current speed vector field: uo and vo (hold the Ctrl key of your keyboard)**
- **Right click on the layers**
- **Click on the Vectorize function (Figure 32)**
- **Select the layers corresponding to the x and y axes of your vector field (respectively uo and vo)**
- **Select the convention of the directions of the vector field: Current**
- ***The downsampling factor is an option which allows you to make the display less busy by representing only one vector out of 10 (if = x10). Here we will apply a downsampling factor of x5.***
- **Select the output directory and name of the vector field layer: current_022020.gml (Figure 32)**
- **Hit Vectorize and Close**

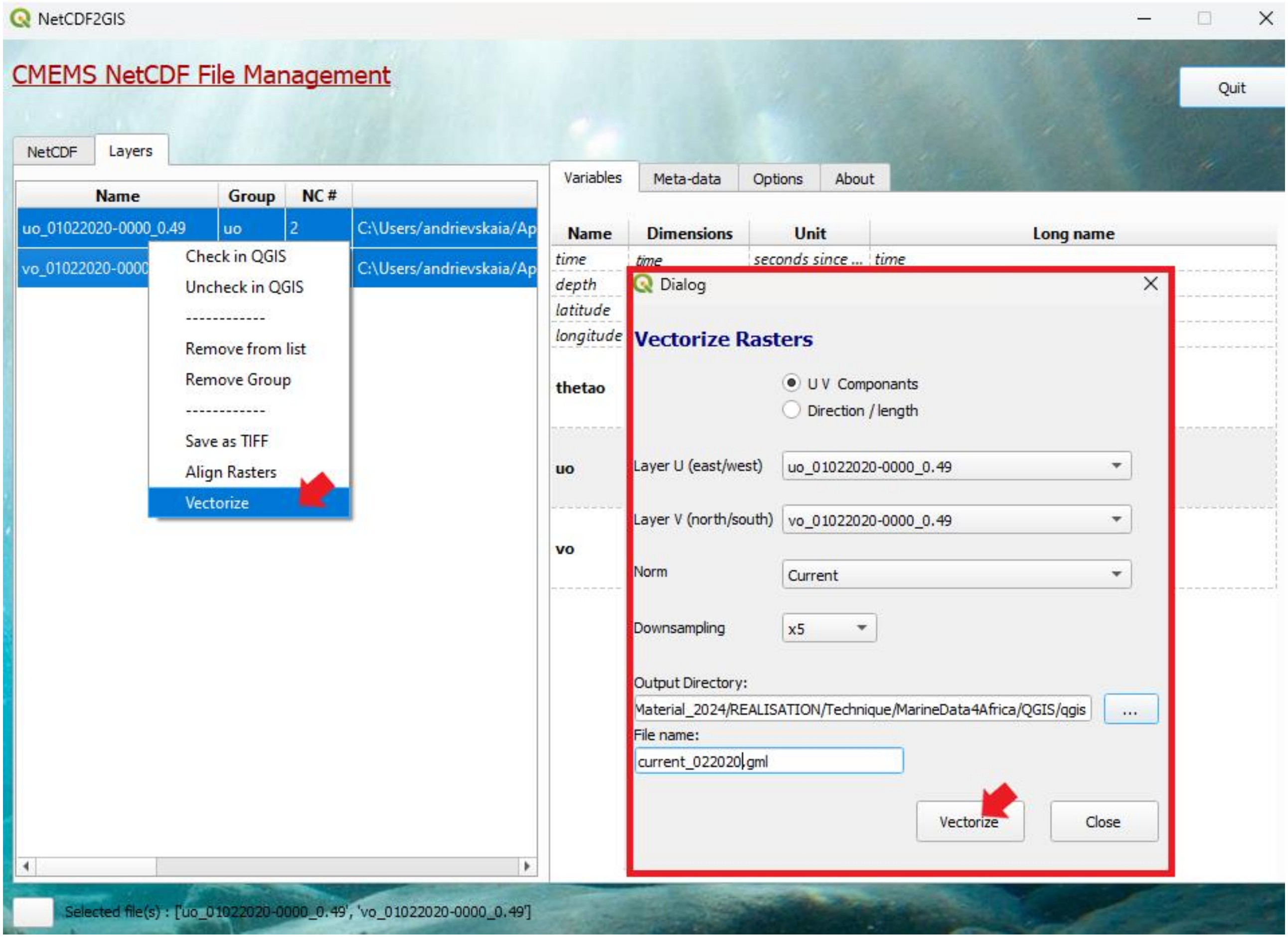


Figure 32: Apply the Vectorize function to vector field components.

You just plotted the current speed vector field corresponding to February 2020. By superimposing this current vector field with the sea water temperature from February 2020, we can clearly see the matching patterns: the Agulhas Current flows from north-east to south-west, bringing the warm water along (Figure 33).

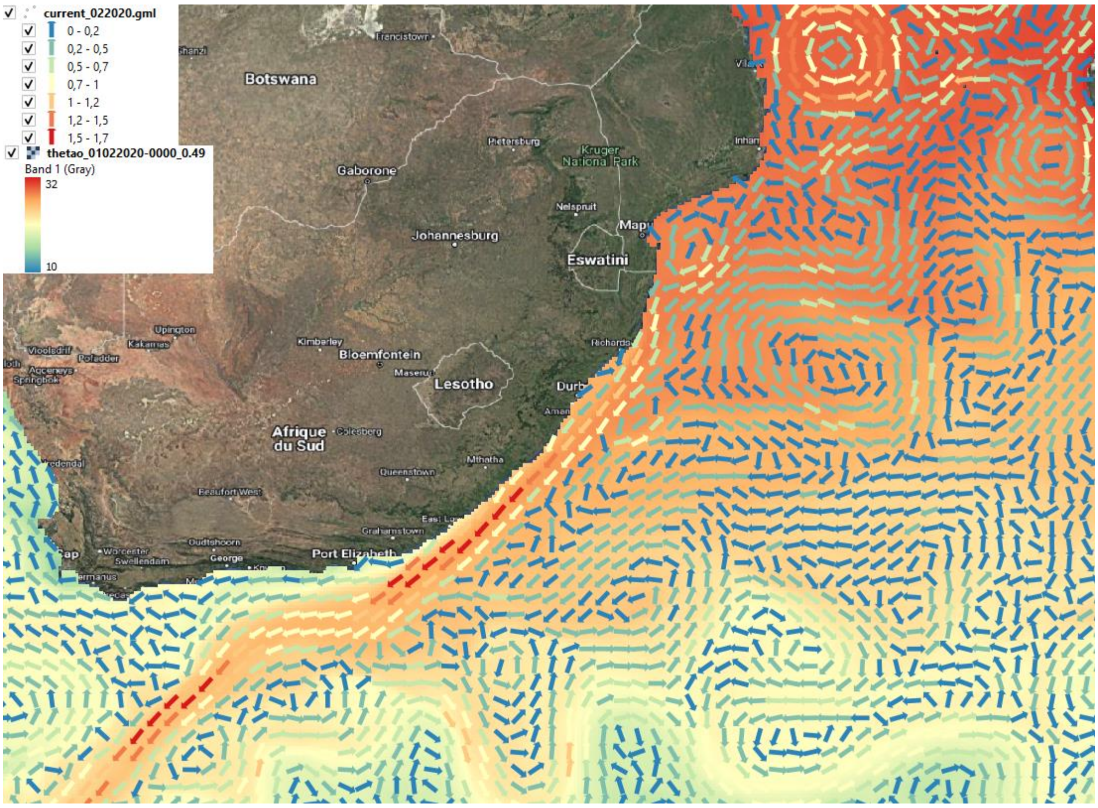


Figure 33: Current vector field and sea water temperature in February 2020, during the peak of MHW.

5. Conclusion

In this training, we used the NETCDF2GIS plugin (developed by NOVELTIS for the QGIS open-source GIS tool) to handle and visualize Copernicus Marine Service products for Africa. It enabled us to display raster variables, and compute contour lines and polygons in order to conditionally filter them to see their evolution. We learned how to calculate climatology from the historical data and use it to calculate sea water temperature anomaly. Additionally, we saw how to compute current vector field from its directional components.

This scenario is workable with other Copernicus Marine Service products, other periods and other areas of interest. Feel free to visit the Copernicus Marine Service portal and download other data to map them on QGIS.