Acronyms

CRS	Coordinate Reference System
EFH	Essential Fish Habitat
GIS	Geographic Information System
NOAA	National Oceanic and Atmospheric Administration
SST	Sea Surface Temperature
SWH	Significant Wave Height

Table of contents

1. INTRODUCTION 7

1.1. SCOPE OF THE DOCUMENT 7
1.2. CONTEXT 7
1.3. OBJECTIVES OF THE COPERNICUS MARINE DATA 4 OCEAN HEALTH WORKSHOP 8

2. COPERNICUS MARINE SERVICE PRODUCTS, CONTEXTUAL INFORMATION AND GIS TOOL 9

2.1. COPERNICUS MARINE SERVICE PRODUCTS USED IN THIS TRAINING 9
2.1.1. General information 9
2.1.2. Example: How to download data from the Copernicus Marine Service? 9
2.2. ADDITIONAL CONTEXTUAL INFORMATION 12
2.2.1. Essential Fish Habitat of the Gulf of Mexico GIS data 12
2.3. QGIS SOFTWARE 12
2.3.1. Installation of QGIS 12
2.3.2. Presentation of the NETCDF2GIS plugin in QGIS 12
2.3.3. Installation of the NETCDF2GIS plugin 12

3. PREPARE THE QGIS PROJECT AND LOAD THE DATA 15

3.1. OPEN QGIS AND CREATE A NEW EMPTY PROJECT 15
3.2. ADD BACKGROUND LAYERS 15

4. MAPPING OF THE COPERNICUS MARINE SERVICE PRODUCTS 17

4.1. SIGNIFICANT WAVE HEIGHT FIELD TO IDENTIFY HURRICANE MICHAEL 18
4.1.1. Map the variable 18
4.1.2. Change the style of one layer 19
4.1.3. Identify the Hurricane Michael trajectory using the SWH field 21
4.2. WIND VECTOR FIELD IN THE GULF OF MEXICO 26
4.2.1. Compute and display wind vector field 26
4.3. IMPACT OF HURRICANE ON OCEAN HEALTH 30
4.3.1. Sea water potential temperature 30
4.3.2. Influence of sea water temperature on Essential Fish Habitat 31

5. CONCLUSION 36

1. Introduction

1.1. Scope of the document

This document describes the different steps of the Copernicus Marine Service GIS training for Ocean Health. It is complementary to the tutorial videos available here.

1.2. Context

Hurricane Michael, a Category 5 storm, made landfall on October 10, 2018, near Mexico Beach, Florida. It was the first Category 5 hurricane to strike the contiguous United States since Andrew in 1992. Michael brought catastrophic winds, reaching sustained speeds of 260 km/h, and generated a storm surge of up to 4 meters, causing widespread devastation across the Florida Panhandle and into the south-eastern U.S. The hurricane resulted in severe economic losses and at least 74 fatalities.

Hurricanes like Michael significantly impact ocean health. They drive powerful mixing of the upper ocean layers, bringing cooler, nutrient-rich waters from the depths to the surface, often causing sea surface temperature (SST) to drop in the storm's wake. This mixing can temporarily benefit marine ecosystems by enhancing phytoplankton growth, which serves as the basis of the ocean food web. However, prolonged or intense hurricane activity can disrupt ecosystems, leading to physical destruction of coral reefs, displacement of marine organisms, and hypoxia in coastal regions due to excess nutrient runoff and reduced oxygen levels. Understanding these dynamics is vital to assessing the broader ecological consequences of such extreme weather events.

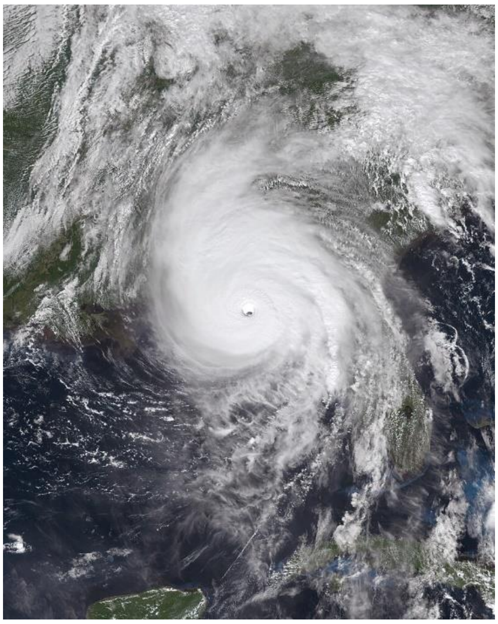


Figure 1: Hurricane Michael captured on the afternoon of October 10, 2018, making landfall in the Florida Panhandle. Credit: https://registry.opendata.aws/collab/noaa/.

In this context, the operational, precise and reliable Copernicus Marine Service products for Ocean Health 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 Ocean Health 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 netcdf2qgis

1.3. Objectives of the Copernicus Marine Data 4 Ocean Health 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 2.3.3 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 various types of Copernicus Marine Service products for Ocean Health in QGIS;
- Create maps out of these products' variables;
- Analyse the SWH induced by Hurricane Michael;
- Follow the storm trajectory by spotting the areas of maximum significant wave height (SWH) and export this trajectory as a new shapefile layer;
- Follow the wind strength and direction in the hurricane and check how they match the areas of maximum wave height;
- Work with external layers;
- Filter data by condition;
- Work with raster layer calculator;
- Import layers through external link.

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 Ocean Health, we will focus on Hurricane Michael and its impact on ocean ecosystems, using the following products:

- **GLOBAL_MULTIYEAR_WAV_001_032:** Global wave reanalysis describing past sea states since the 1980s is based on the MFWAM model. Average wave quantities derived from this wave spectrum such as the SWH (significant wave height) or the average wave period are delivered on a regular 1/5° grid with a 3h time step. The product is available here. The characteristics of this product are the following:
  - Spatial resolution: 0.2° × 0.2°
  - Temporal resolution: hourly, monthly
  - Download hourly product for the period from October 6 to October 12, 2018.
- **WIND_GLO_PHY_L4_MY_012_006:** Global Ocean Hourly Reprocessed Sea Surface Wind and Stress from Scatterometer and Model contain hourly Level-4 sea surface wind at 0.125 and 0.25 degrees horizontal spatial resolution. The product is available here. The characteristics of this product are the following:
  - Spatial resolution: 0.125° × 0.125°
  - Temporal resolution: hourly
  - Download hourly product for the period from October 6 to October 12, 2018.
- **GLOBAL_MULTIYEAR_PHY_001_030:** Global Ocean Physics Reanalysis 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, monthly
  - Download daily product for the period from October 1 to October 17, 2018.

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 a 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 Physics Reanalysis (GLOBAL_MULTIYEAR_PHY_001_030) daily sea water potential temperature variable:

- First, go to the Copernicus Marine Data Store and register or log in to your existing account.

- Then, in *Filters* tab type 'temperature', click on the Global Ocean Physics Reanalysis product (Figure 2) and choose *Data access* tab in the menu on the left.

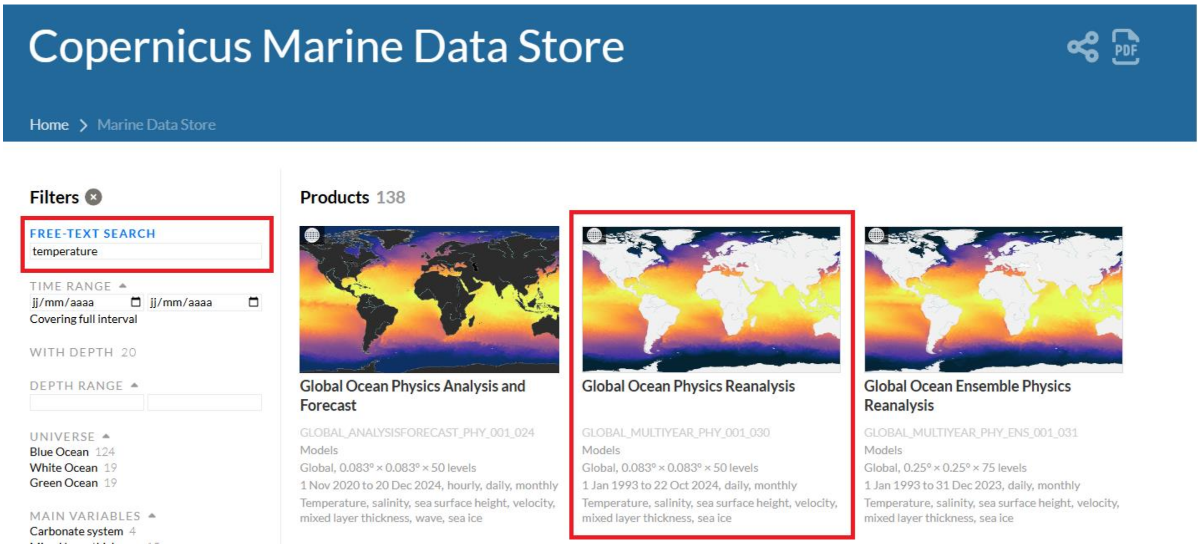


Figure 2: Filter by keyword and select Global Ocean Physics Reanalysis product.

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

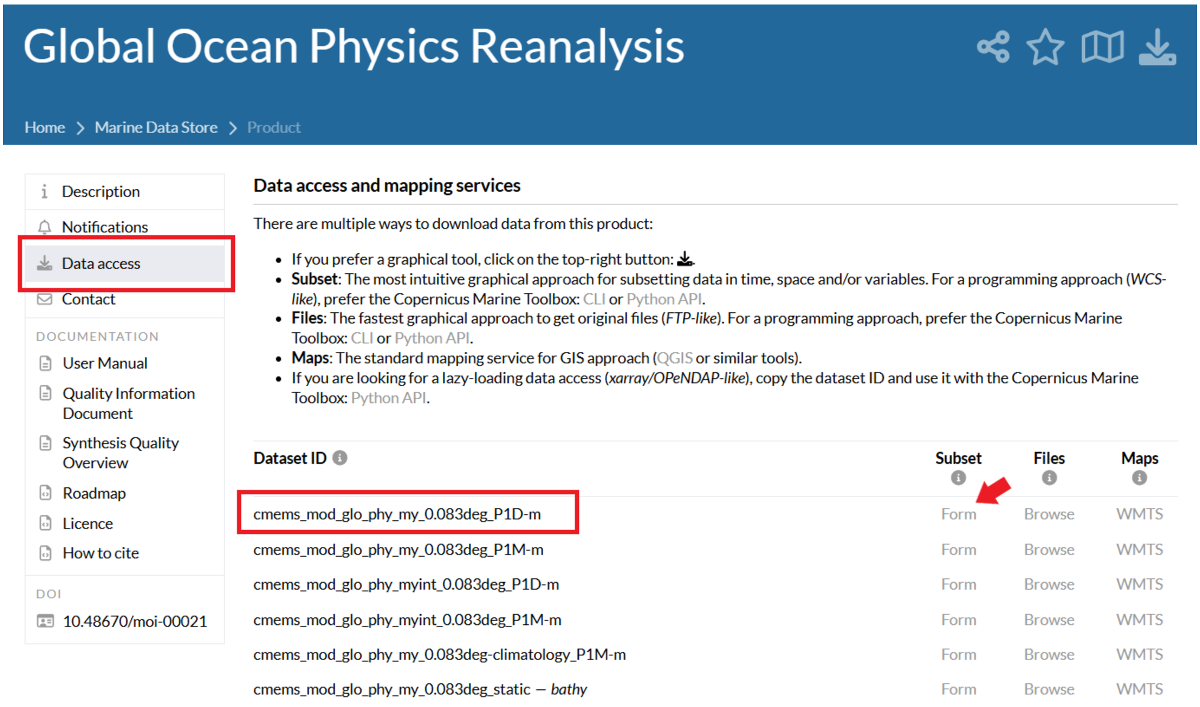


Figure 3: Select the product.

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

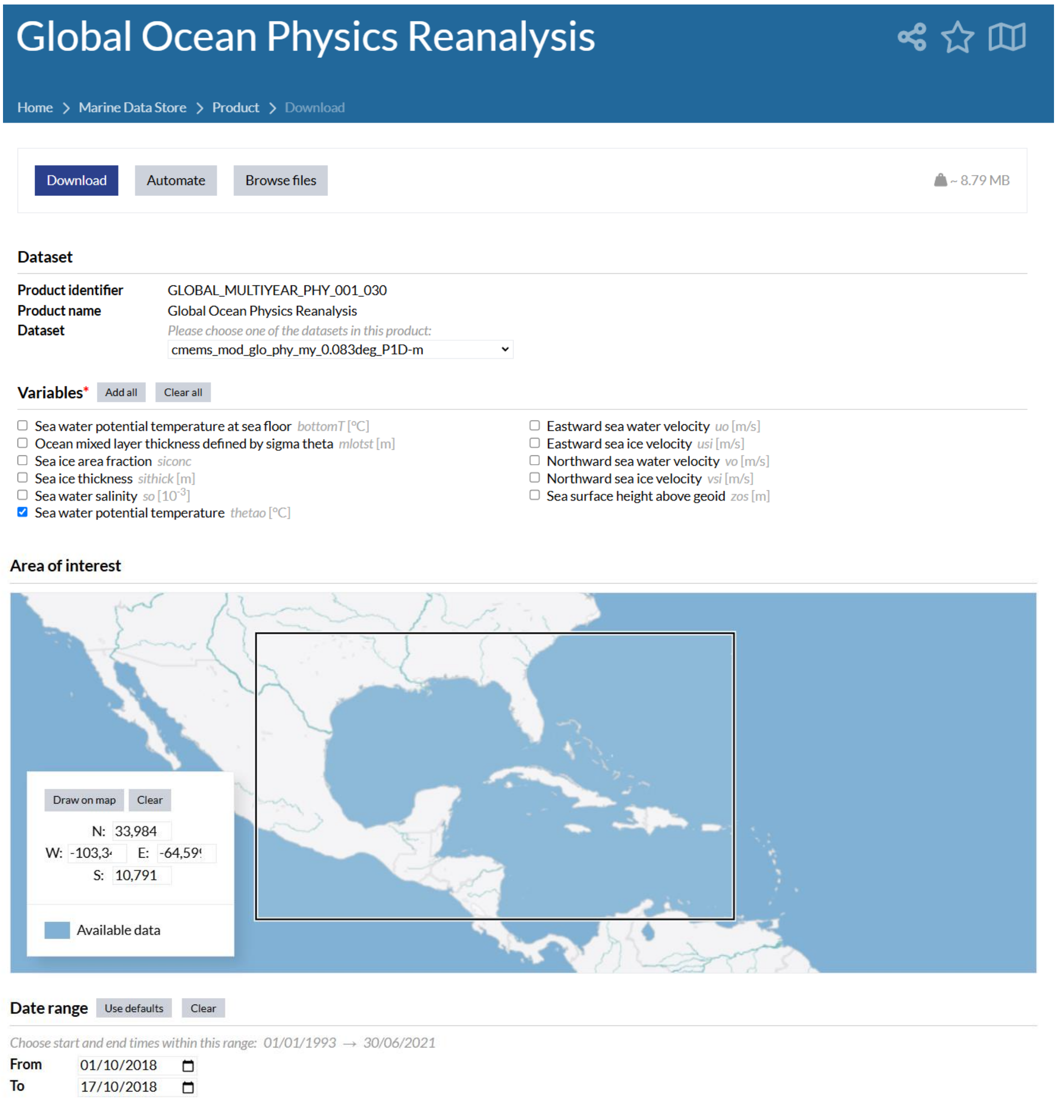


Figure 4: Product spatial and temporal extents to download.

- 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 daily sea water potential temperature variable.

HINT: *For greater convenience, each NetCDF file downloaded from the Copernicus Marine Service has been renamed. For example, this global ocean physics reanalysis product containing sea water potential temperature variable has been renamed as follows:* **cmems_mod_glo_sst_d.nc**. *We will refer to these files as such in the rest of the document.*

2.2. Additional contextual information

2.2.1. Essential Fish Habitat of the Gulf of Mexico GIS data

For one of the exercises, we will use .shp file of polygon representing Essential Fish Habitat in the Gulf of Mexico. This database is made available by the NOAA.

2.3. QGIS Software

2.3.1. 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.

2.3.2. Presentation of the NETCDF2GIS plugin in QGIS

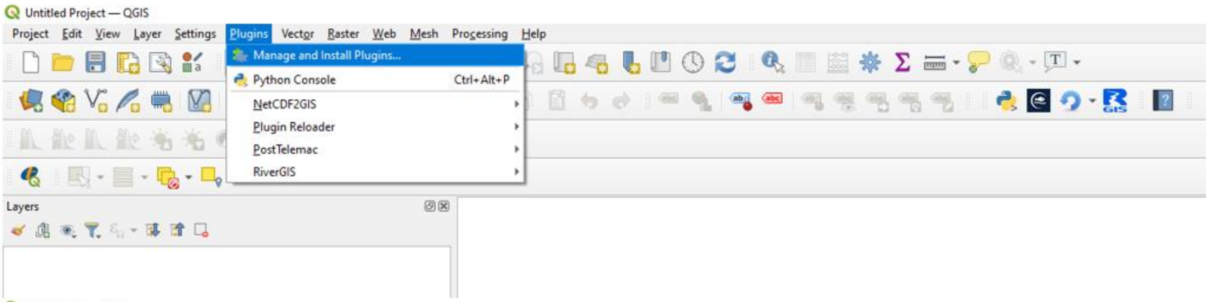
As previously mentioned, the Copernicus Marine Service products are provided in NetCDF format, which can be directly ingested by QGIS using the **OsGeo gdal** library. However, the automatic ingestion available by default on QGIS is not always ideal to handle multidimensional products. Therefore, in 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.

2.3.3. Installation of the NETCDF2GIS plugin

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

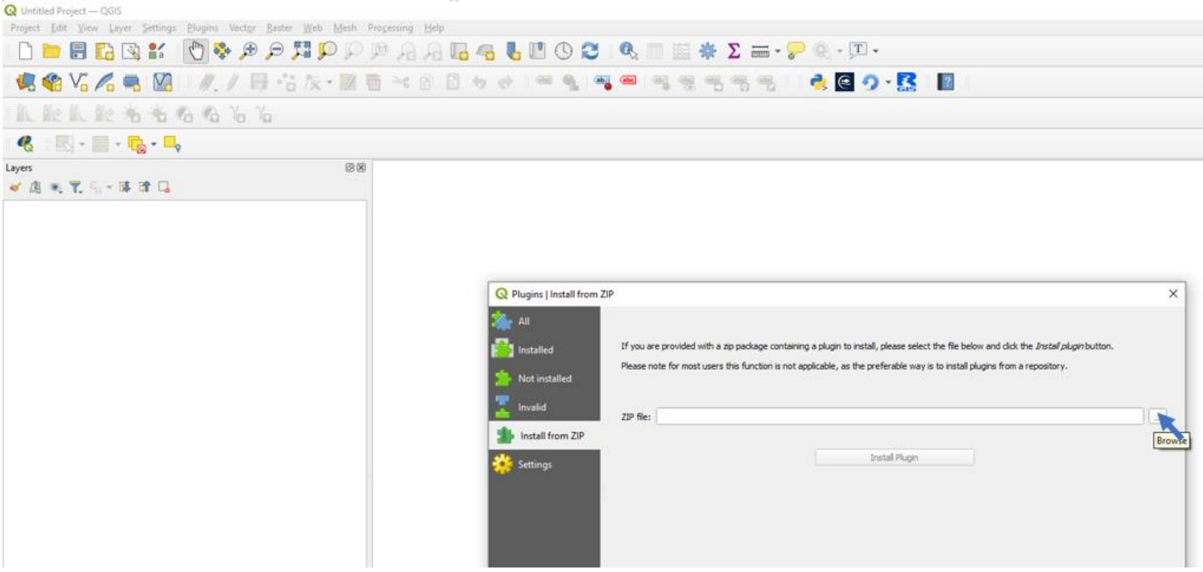
Open the QGIS software and click on **Plugins > Manage and install Plugins** (Figure 6: **step 1**). Click on the **Install from ZIP** tab and browse to the NETCDF2GIS.zip location (Figure 6: **step 2**). Once selected, click on **Install Plugin** (Figure 6: **step 3**) and the NETCDF2GIS icon will appear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

1



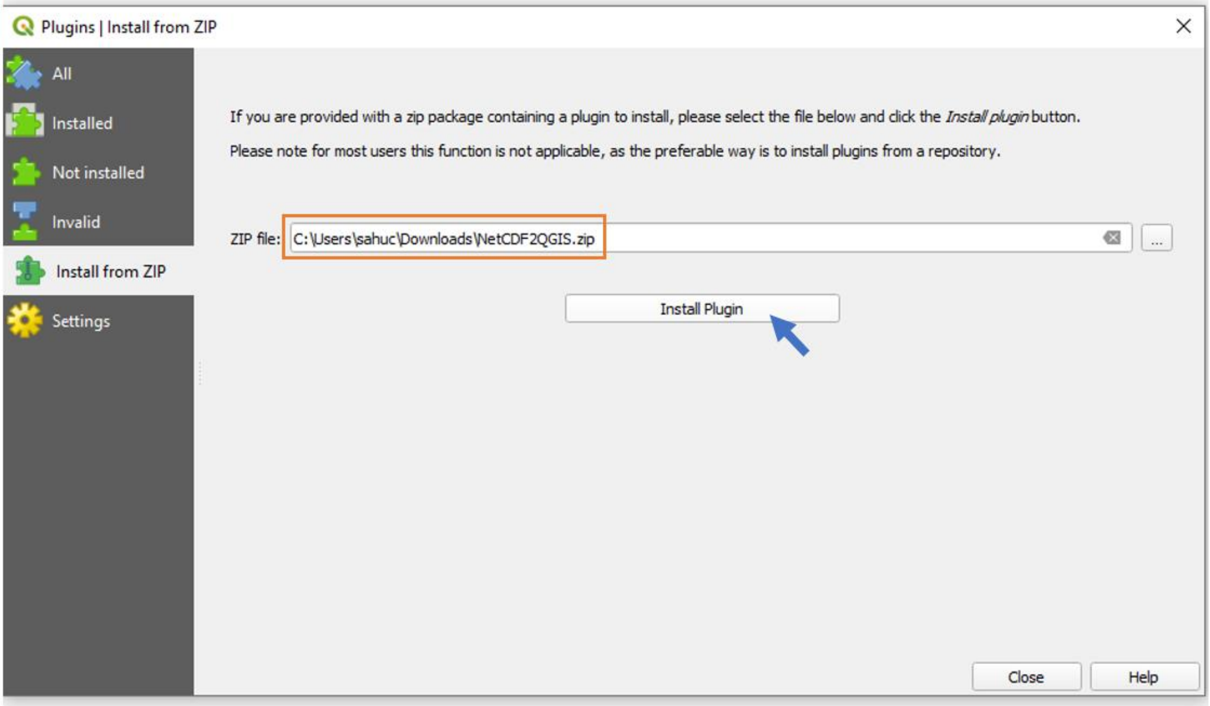
Untitled Project — QGIS
Project Edit View Layer Settings Plugins Vector Raster Web Mesh Processing Help
Manage and Install Plugins...
Python Console Ctrl+Alt+P
NetCDF2GIS
Plugin Reloader
PostTelemac
RiverGIS
Layers

2



Untitled Project — QGIS
Layers
Plugins | Install from ZIP
All
Installed
Not installed
Invalid
Install from ZIP
Settings
ZIP file:
Browse
Install Plugin

3



Plugins | Install from ZIP
All
Installed
Not installed
Invalid
Install from ZIP
Settings
If you are provided with a zip package containing a plugin to install, please select the file below and click the Install plugin button.
Please note for most users this function is not applicable, as the preferable way is to install plugins from a repository.
ZIP file: C:\Users\sahuc\Downloads\NetCDF2QGIS.zip
...
Install Plugin
Close
Help

4

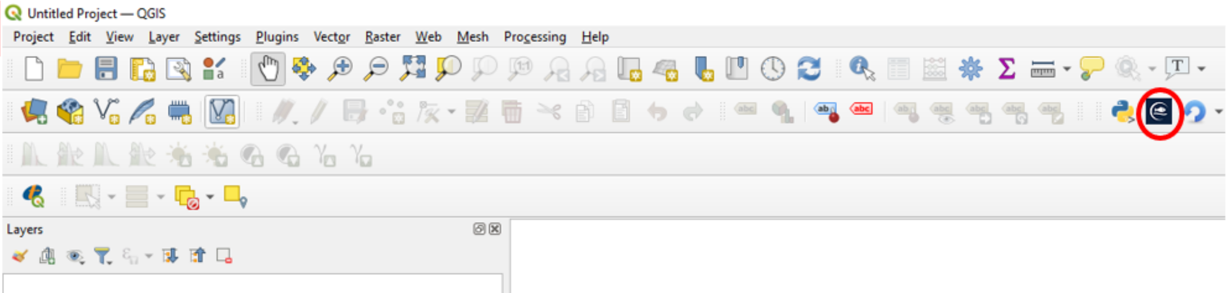


Figure 6: NETCDF2GIS plugin installation steps.

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).

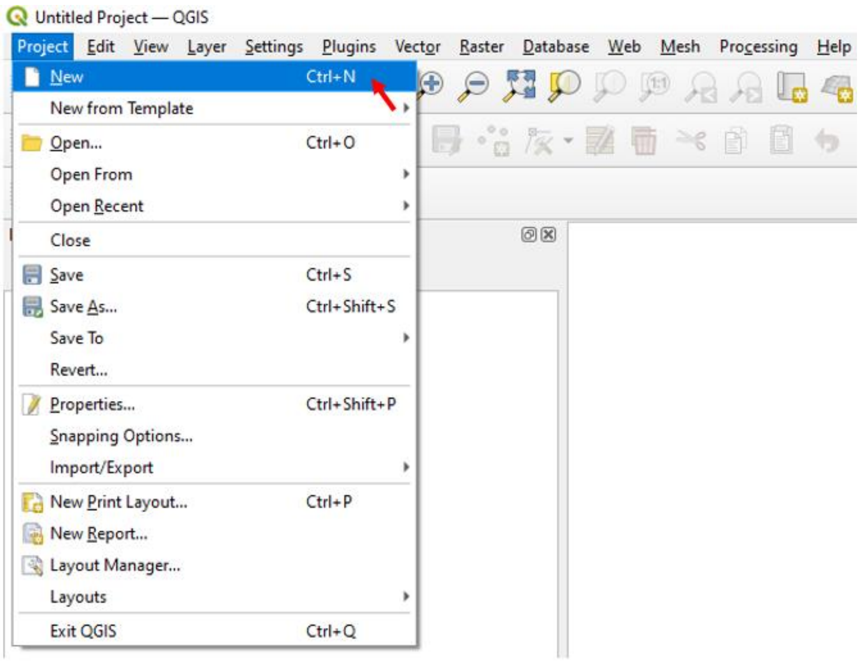


Figure 7: Create a new project on QGIS.

3.2. Add background layers

For the background layer 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. You will find some of them below. 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**

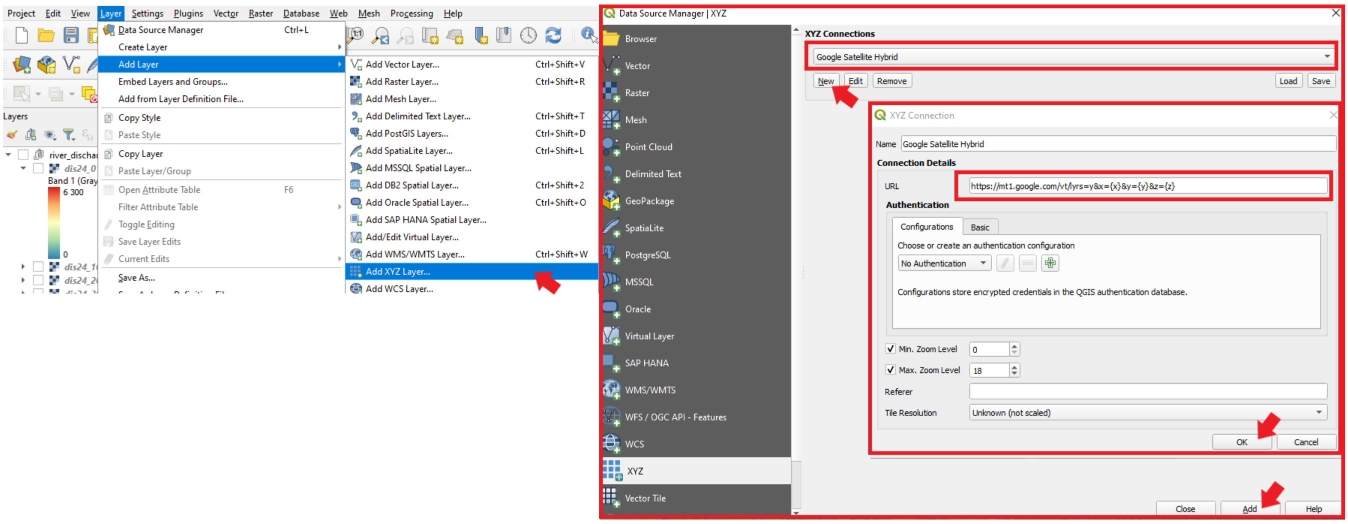


Figure 8: Add Google satellite view as background.

We will now have a background like the following:

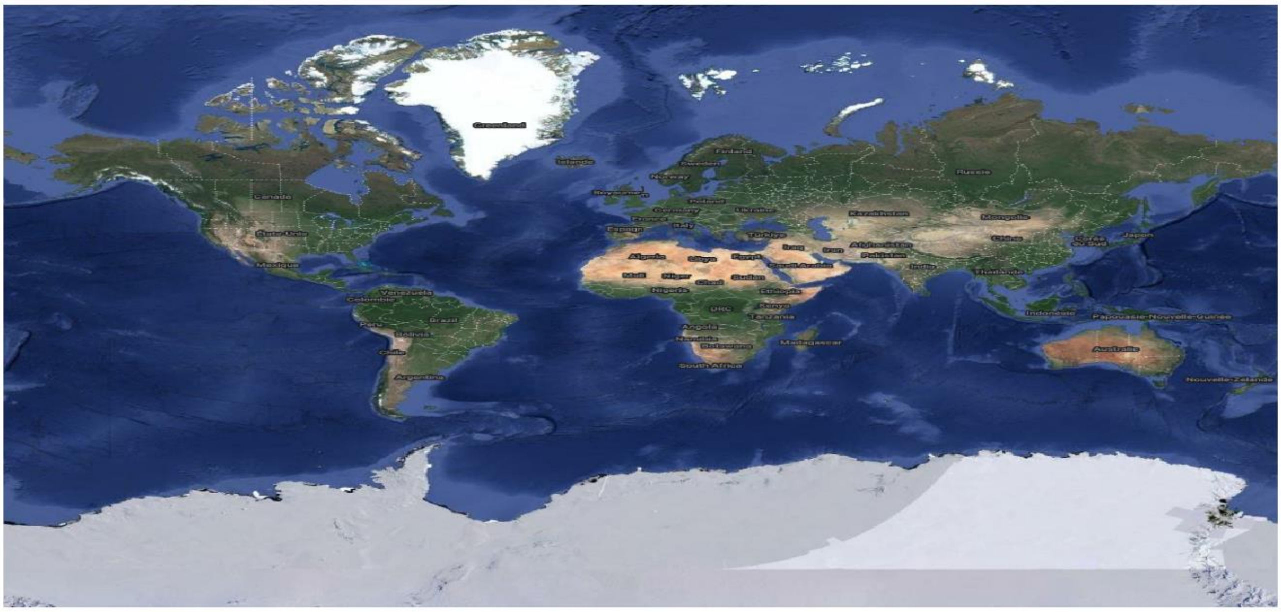


Figure 9: Background Layer.

4. Mapping of the Copernicus Marine Service Products

Now that we have set a CRS and a map background, we are going to import the Copernicus Marine Service products in our QGIS project. After opening the CMEMS plugin (in §3.1), 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.

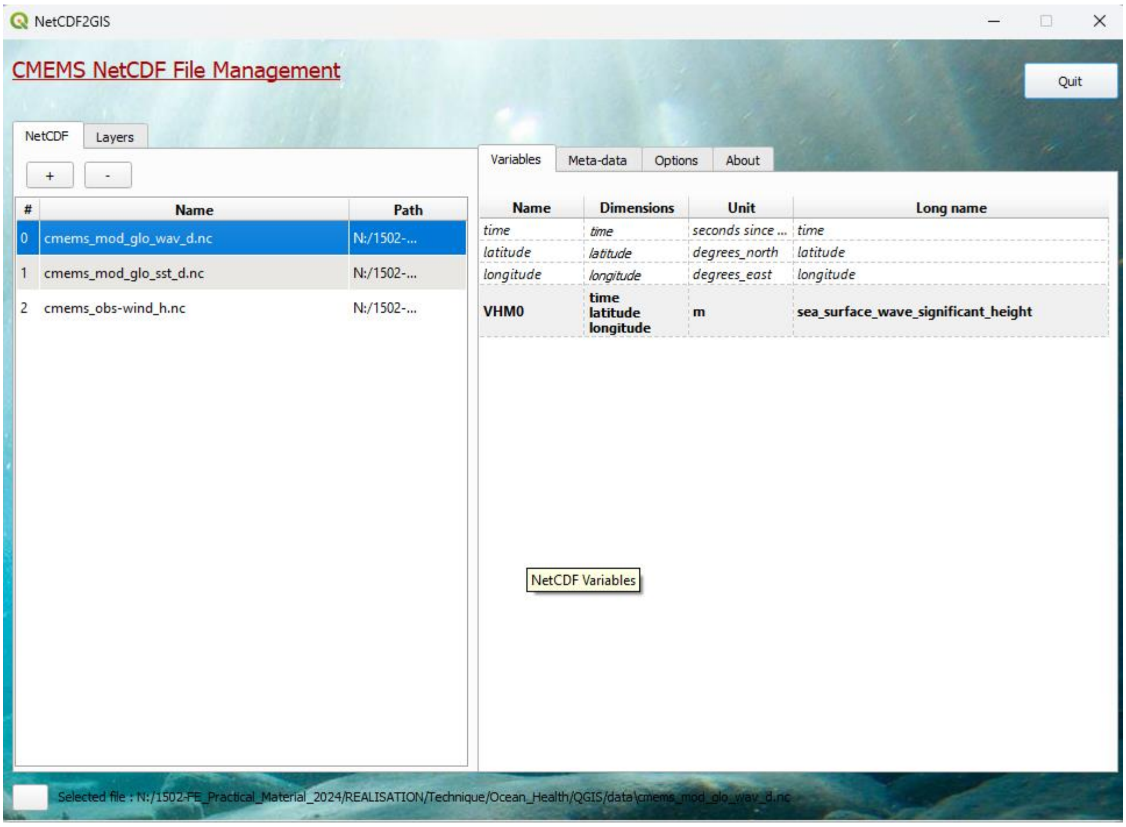


Figure 10: NETCDF2GIS plugin – loading NetCDF data.

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_wav_d.nc** in section 4.1;
- **cmems_obs-wind_h.nc** in section 4.2;
- **cmems_mod_glo_sst_d.nc** in section 4.3.

The NetCDF files have been renamed with convenient extension after their download from the Copernicus Marine Service platform.

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

- Significant wave height (reanalysis model product) in part 4.1: **VHM0** (m);

- Wind speed (reprocessed model product): eastward and northward components in part 4.2: **eastward_wind, northward_wind** (m/s):
- Sea water potential temperature (reanalysis model product) in part 4.3: **thetao** (°C).

4.1. Significant wave height field to identify Hurricane Michael

4.1.1. Map the variable

For our first product exploration, we will display the significant wave height from the Global Ocean Waves Reanalysis model product of the Copernicus Marine Service on a 3-hour basis.

First, add the NetCDF file containing the GLOBAL_MULTIYEAR_WAV_001_032 product from October 7^{h}, 15:00 to October 10, 21:00 to the NETCDF2GIS plugin:

- **First check the metadata of the product to find additional information**
- **On the variable panel, select the VHM0 (Significant wave height) variable**
- **Right click on it and select the sequence layer function (top of Figure 11)**
- **Select the timeframes of your variable from 7/10/2018, 15:00 to 10/10/2018, 21:00:**
  - **Click on the first timeframe you want to select, then CTRL on your keyboard and select the timeframes one by one, or**
  - **It is also possible to select all layers between those two dates (select the first date, press Shift on your keyboard and select the last date (while keeping Shift pressed))**
- **Set Group to VHM0**
- **Set Frequency 0.2 s**
- **Click on Start (Figure 11).**

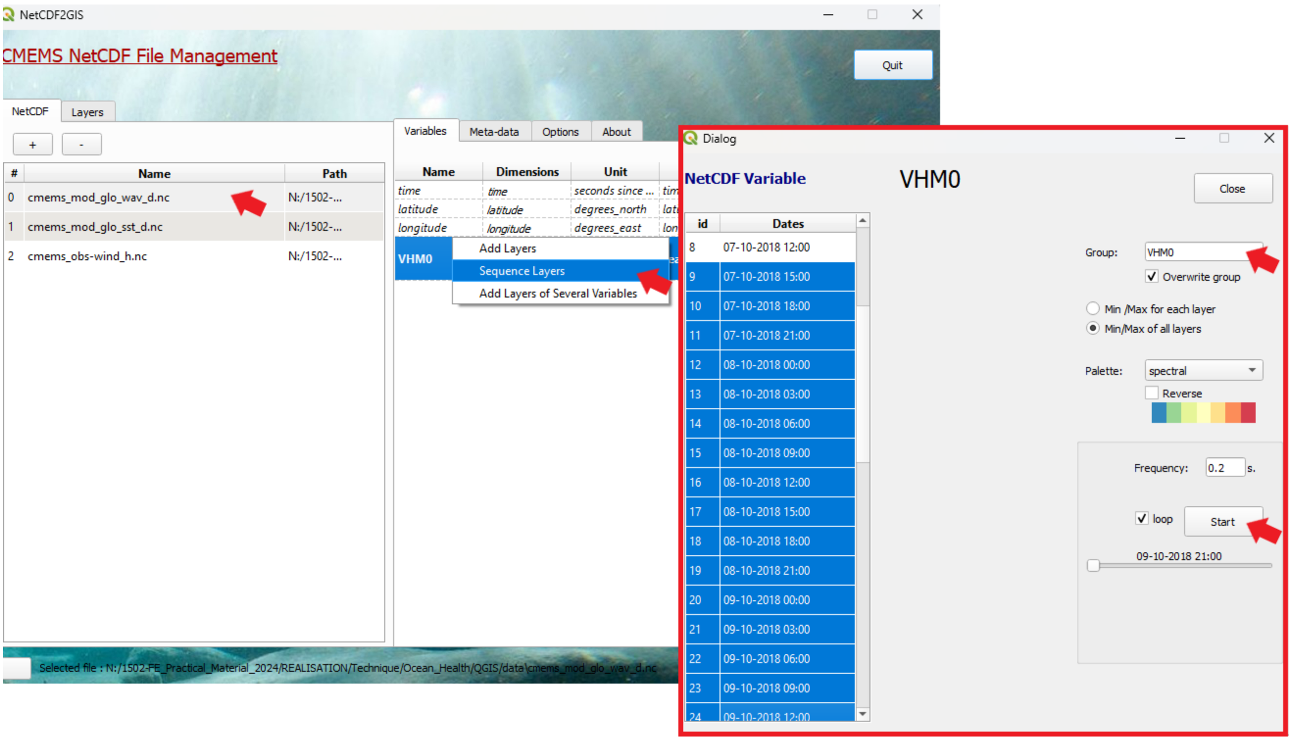


Figure 11: Sequence the Significant wave height.

The significant wave height layers from October 7, 15:00 to October 10, 21:00 (every 3 hours) are now scrolling on your main QGIS window (Figure 12). You can then **click on Stop and Close** on the dialog box of the NETCDF2GIS software to stop the animation. These timeframes are now added to your project.

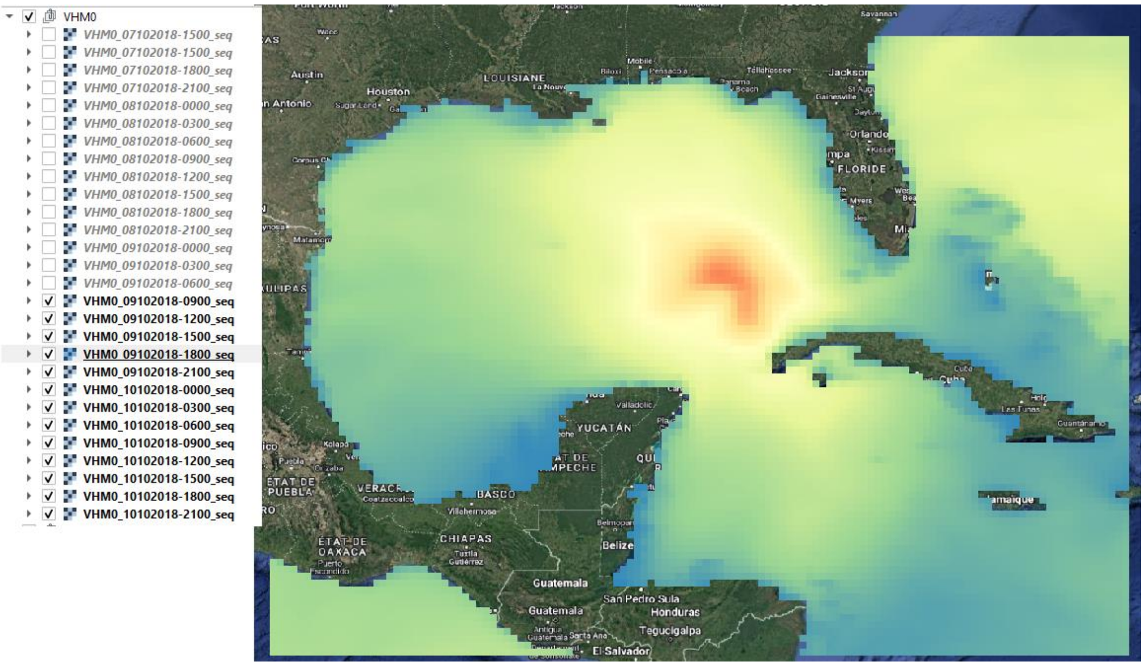


Figure 12: Sequence significant wave height layers.

4.1.2. Change the style of one layer

We are now going to tune the value range and colour palette of the significant wave height layers and apply this style to every timeframe loaded in the project.

- **Double click on the VHM0_07102018-1500_seq layer to open Properties**
- **In Symbology, set the minimum/maximum value for the significant wave height: [0 to 7m]**
- **Ensure that the palette is 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 13).**

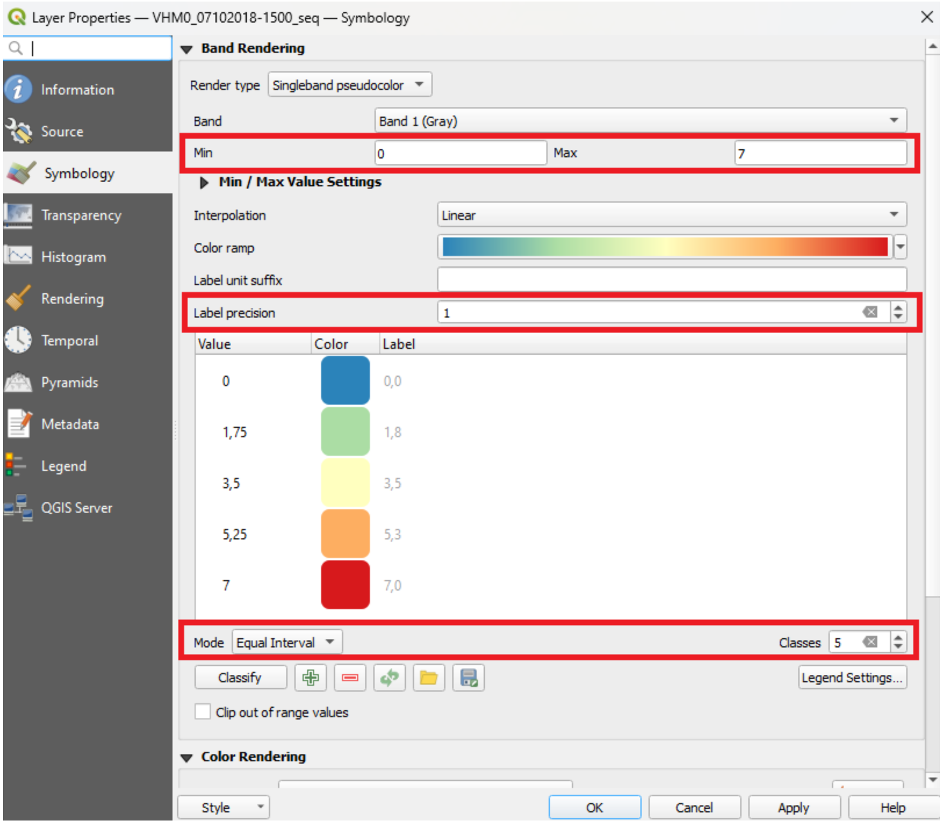


Figure 13: Change the style of the SWH layer.

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

- **Right click on the VHM0_07102018-1500_seq layer > Style > Copy style**
- **Select all the other significant wave height layers (with Shift key) and Paste style (Figure 14).**

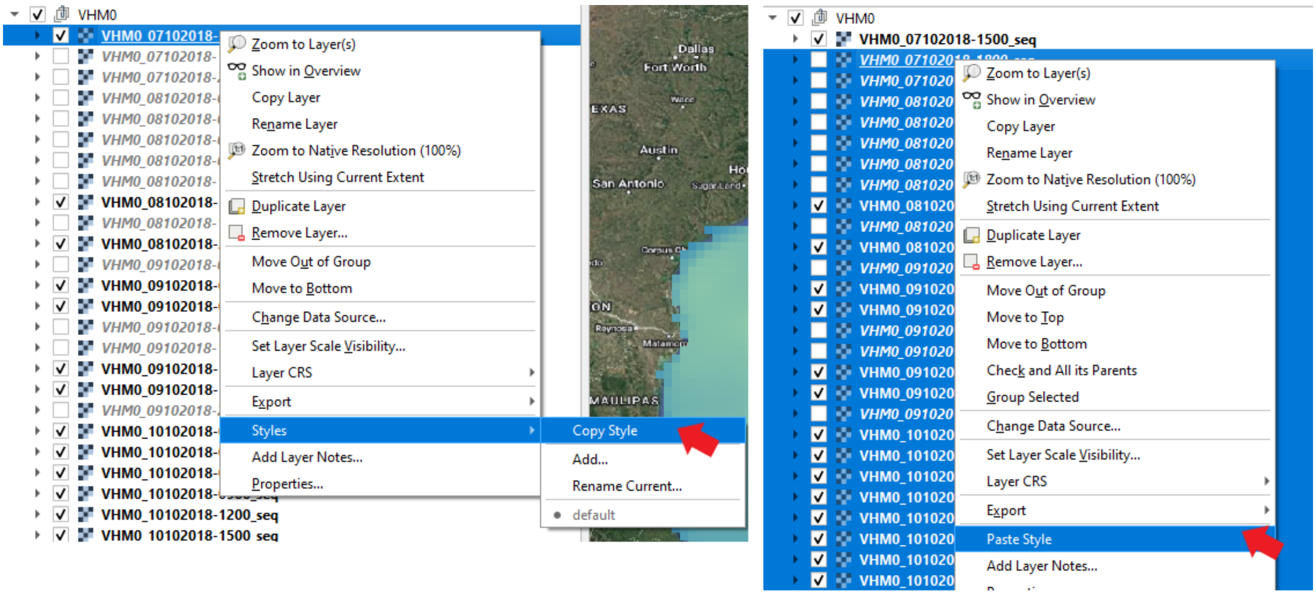


Figure 14: Copy Style from a layer and paste it onto other layers.

Then, you can activate and deactivate each layer, and see how the significant wave height maximum evolves with time in the Gulf of Mexico. The formation of Hurricane Michael is easily recognizable with SWH values building up throughout the time (Figure 15). These characteristics will help us to spot the hurricane trajectory in the following part of this training.

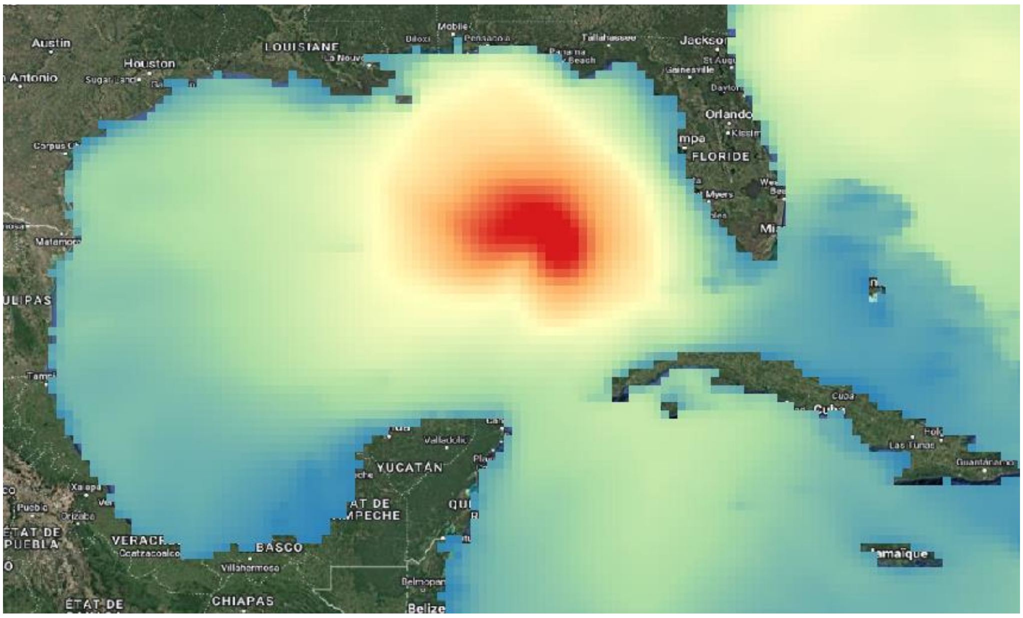


Figure 15: SWH (in meters) on October 9, 2018, 21:00.

4.1.3. Identify the Hurricane Michael trajectory using the SWH field

This part will teach you how to create a new shapefile layer where we can add the position of the center of the hurricane, approximately, between October 7, 15:00 and October 10, 21:00.

4.1.3.1. Create New Shapefile layer

To do so, we first need to create a New Shapefile layer:

- **Click on Layer > create Layer > New Shapefile layer**
- **Change the File name to Michael_path.shp**
- **Make sure the geometry type is set to point and then click on OK (Figure 16)**

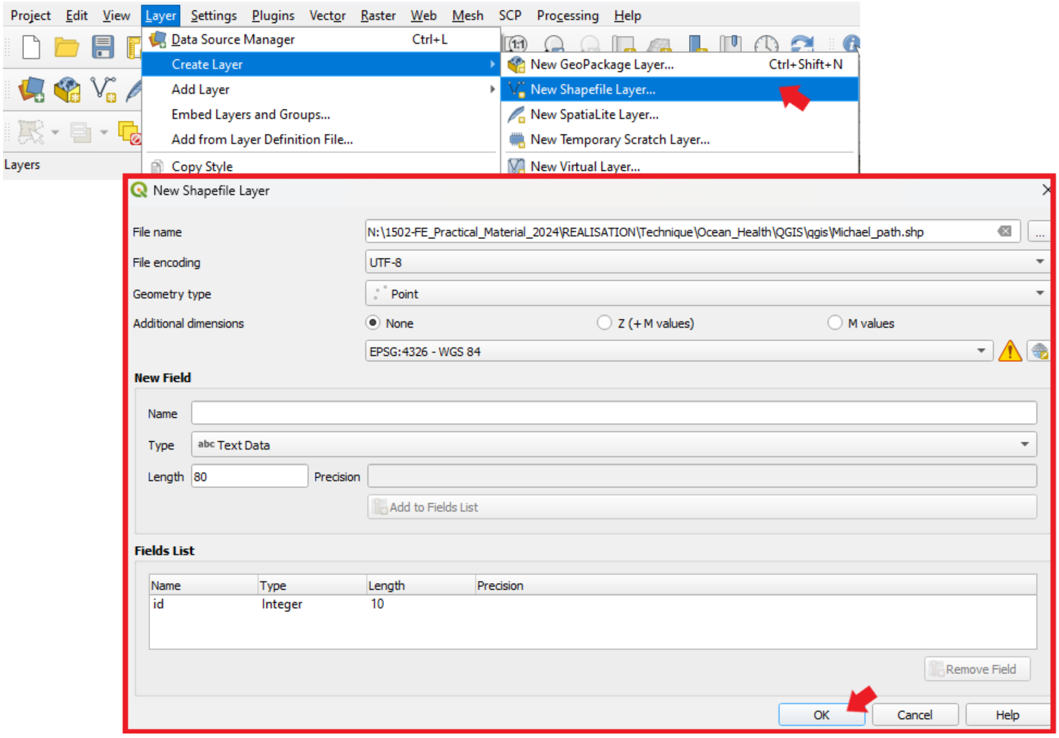


Figure 16: Create a new shapefile layer.

4.1.3.2. Add positions

Is it now time to add point features to this new layer:

- **Toggle to editing mode:** 
- **Select the Add point feature function:** 

Now, let's scroll over **VHM0** and pin a point at the center of the SWH maximum area for selected time steps to spot the hurricane's trajectory. To speed up the process, we are going to use only 15:00 and 03:00 timeframes for each loaded date:

- **Activate the VHM0_07102018-1500_seq layer (if not already activated). On the Michael_path layer, pin the center of the SWH maximum area. Set index to 0 and click on OK**
- **Activate the next time step SWH layer and pin again the position of the hurricane center. Increment the index and click on OK (Figure 17)**
- **Repeat the operation for the following time steps**
- **Once the successive positions of the hurricane have been spotted for each SWH layer, close the Editing mode and Save the modifications brought to the layer (Figure 17)**

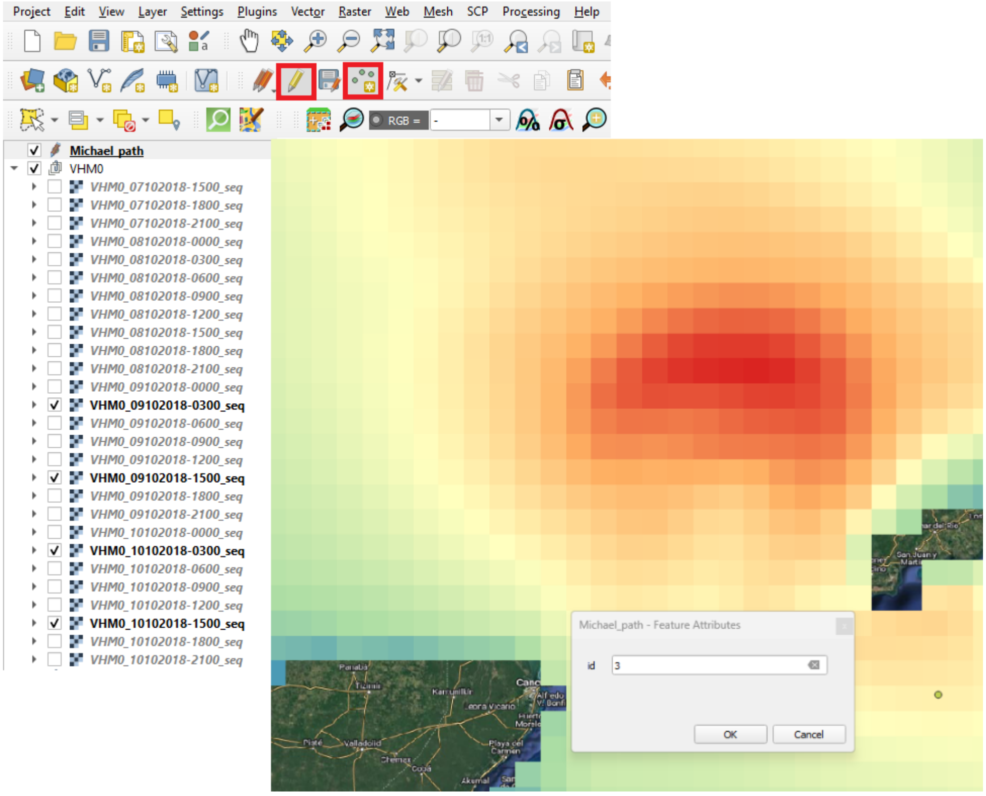


Figure 17: Spot the possible hurricane centre according to SWH maximum.

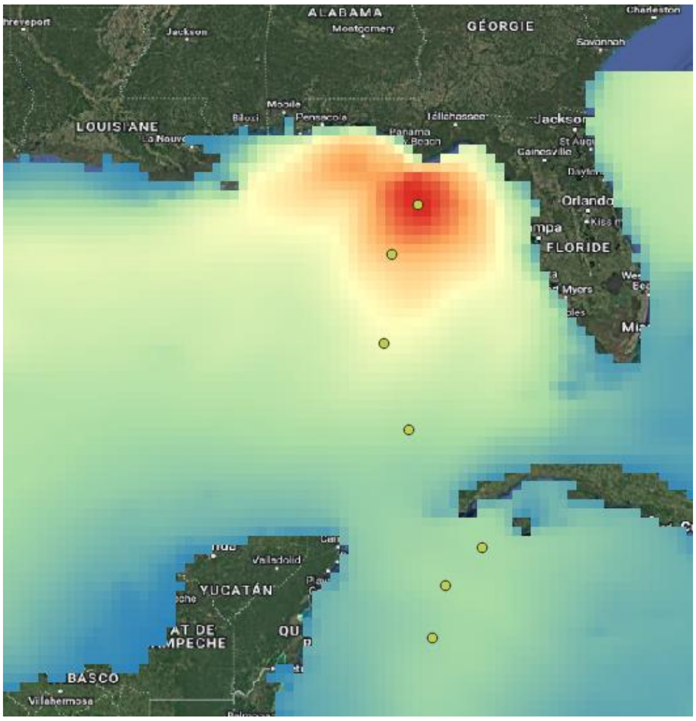


Figure 18: Michael_path is now completely filled with the hurricane potential position every 12 hours from October 7 to 10, 2018.

4.1.3.3. Add a date attribute to the position shapefile

Now, we will access the Attributes of our Michael_path shapefile and add the dates corresponding to each potential position of Hurricane Michael:

- **Right click on the Michael_path layer > Open attribute table**
- **Toggle to editing mode and add a field to the table of attributes:**
  - **Name this new field “Date” with Type: Date**
  - **Click on OK**
- **Make sure to select the Date field and in ε copy and paste the following expression (Figure 19):**
  - ***make_datetime(2018,10,7,15,0,0)+make_interval(hours:=id*12)***
  - **It will add the date in a datetime format for each point:**
    - *2018-10-07 for id=0*
    - *2018-10-07T15:00 + 1*12hours = 2018-10-08 id=1 etc*
  - **Hit Update all**
- **Then close the Editing mode and the Attribute table of the Michael_path layer**

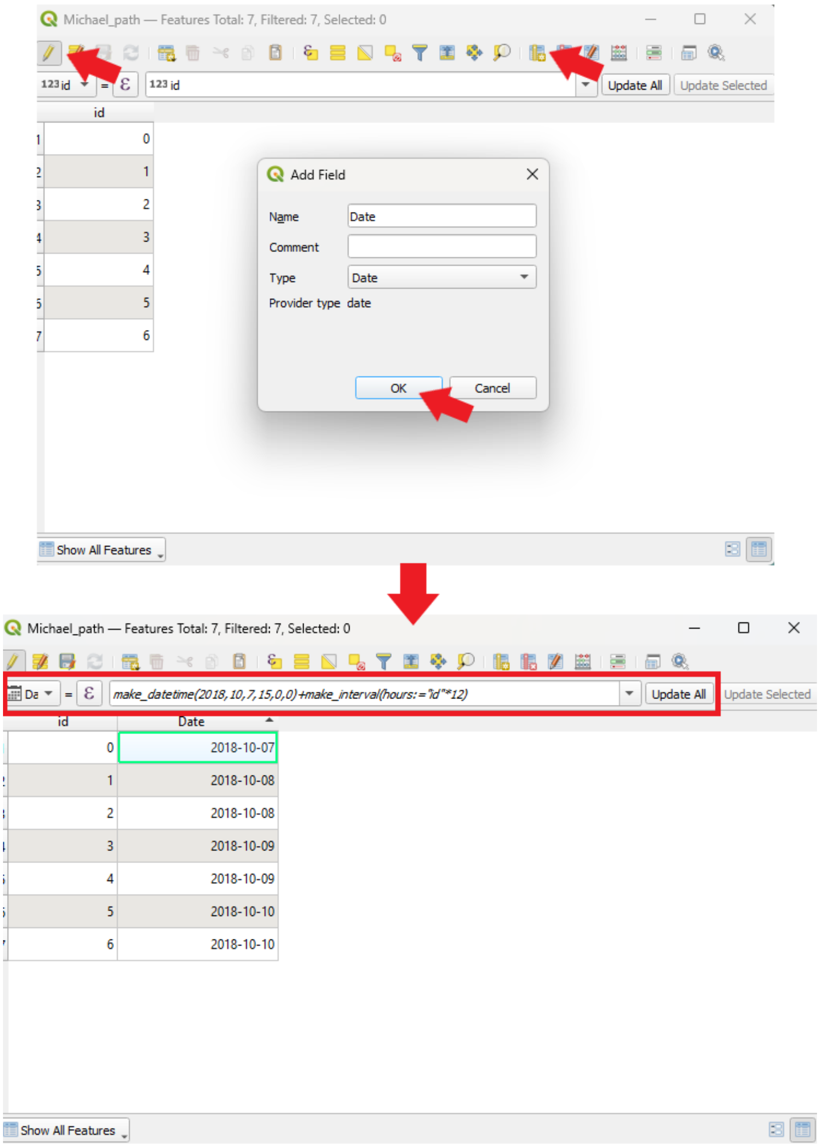


Figure 19: Add “Date” field to the attribute table and fill it with the dates corresponding to each spot of the hurricane trajectory.

Each position now corresponds to a date and we end up with a shapefile defining the hurricane successive positions every 12 hours from October 7 to 10, 2018.

4.1.3.4. Tune Michael_path layer

Once this "Date" attribute has been added to the Michael_path shapefile layer, we will use this information to label its potential trajectory.

To do so:

- **Right click on the Michael_path layer and open Properties**
- **Select Labels > Single Labels (Figure 20):**
- **Set the Value to the Date field**
- **Change the Labels background by ticking the Draw background box and set a white background (Figure 20)**
- **Click on Apply and close the layer properties**

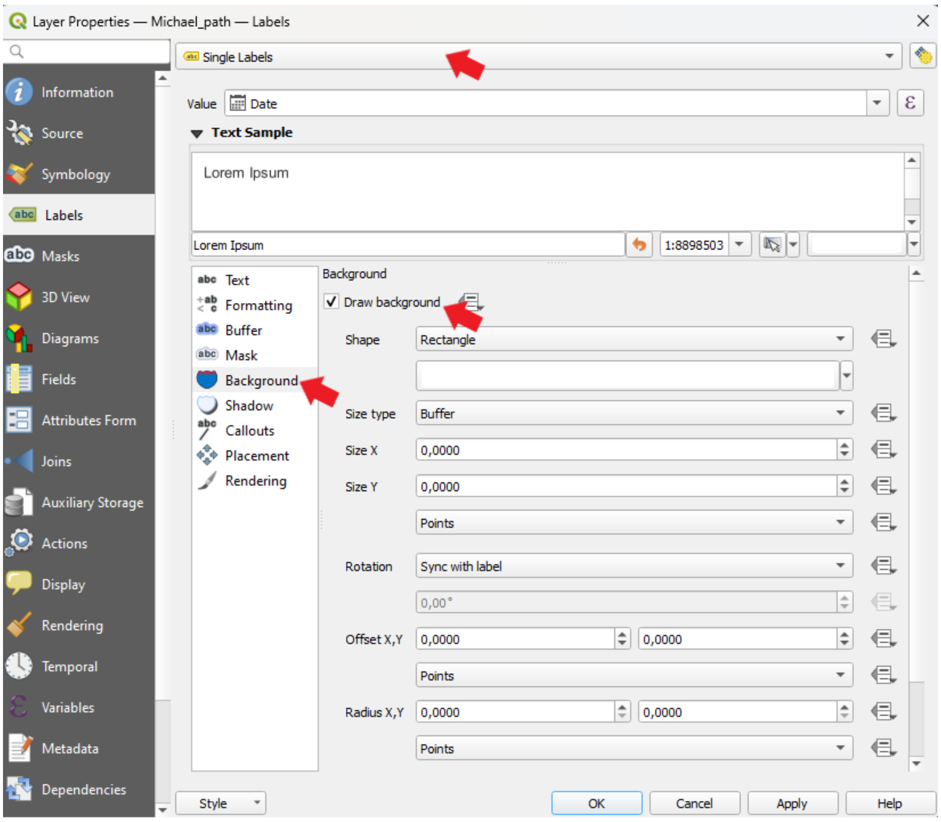


Figure 20: Set labels.

You can see that the potential Hurricane Michael trajectory is now labelled with the different timesteps of the significant wave height layers we used to spot the hurricane center (Figure 21).

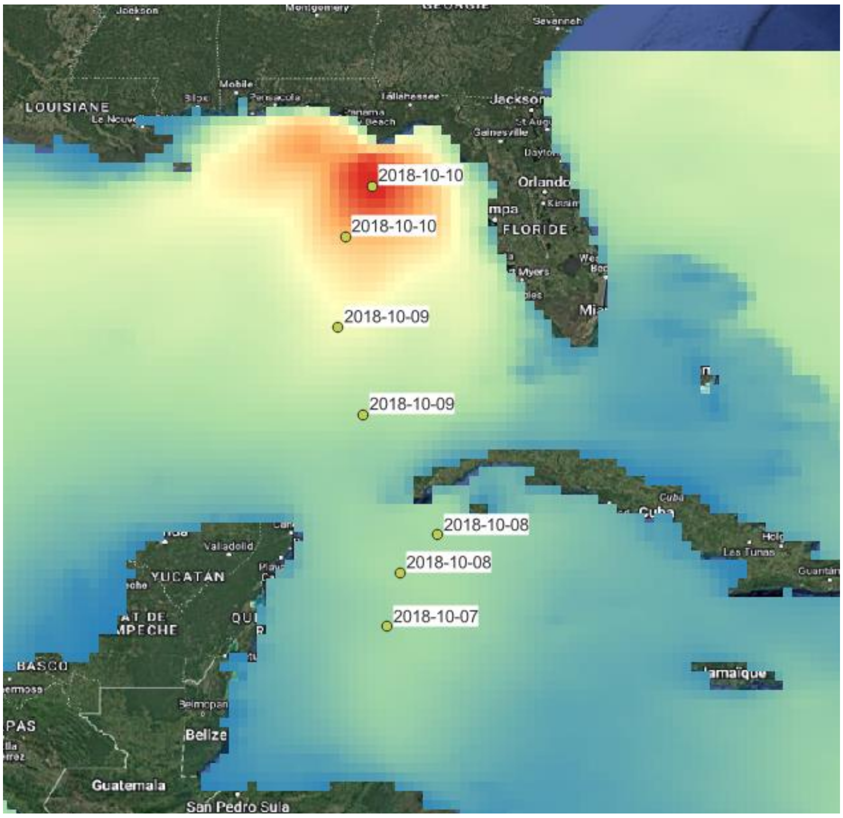


Figure 21: Hurricane Michael potential trajectory.

4.2. Wind vector field in the Gulf of Mexico

In this part, we will verify that the trajectory defined from the SWH products agrees with the wind fields available in the Copernicus Marine Service products for the same timeframe.

4.2.1. Compute and display wind 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 wind field** (and any other vector field using its two components u and v, or norm and direction) with the NETCDF2GIS plugin.

4.2.1.1. Load the scalar components of the vector field

First, you need to load each component of the vector field as a single layer (respectively **eastward_wind** and **northward_wind**).

- **Click on the satellite observation NetCDF file containing the x and y wind velocity variables (components of the vector field you want to display)**
- **Right click on the eastward_wind variable**
- **Click on Add Layers of Several Variables**
- **In the pop-up window, choose eastward_wind and northward_wind 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 October 10, 03:00 in one of the windows (as an example, you can choose any other date). The same timeframe will be automatically chosen for the second variable**
- **Click on Add and Close (Figure 22)**
- **Both windows will close and the two variables will be added to your project**

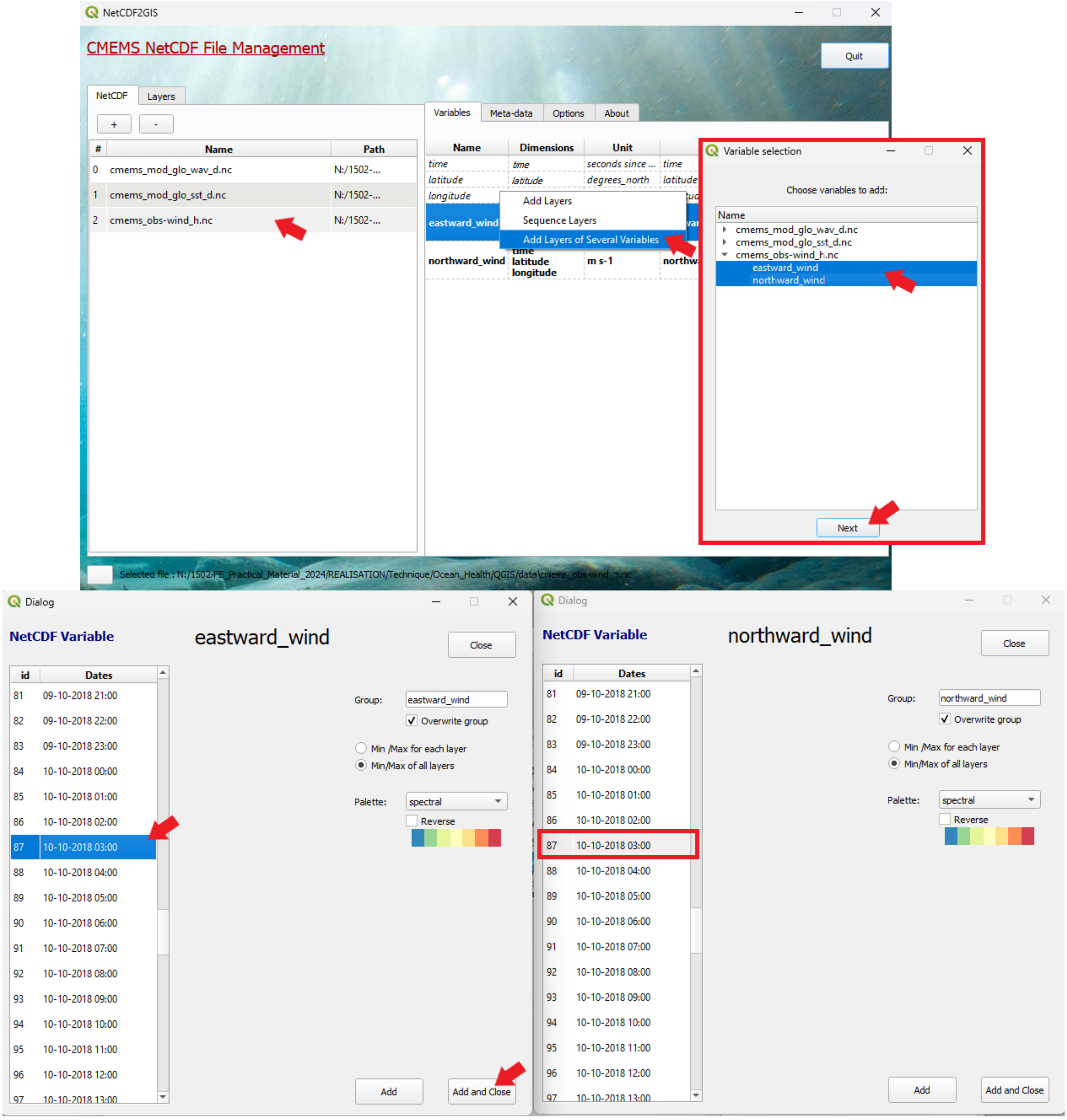


Figure 22: Select the wind components.

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

4.2.1.2. Compute wind 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 wind speed vector field: eastward_wind and northward_wind (hold the Ctrl key of your keyboard)**
- **Right click on the layers**
- **Click on the Vectorize function (Figure 23)**
- **Select the layers corresponding to the x and y axes of your vector field (respectively eastward_wind and northward_wind)**
- **Select the convention of the directions of the vector field: Wind/waves**
- ***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 x3.***
- **Select the output directory and name of the vector field layer: wind_10102018.gml (Figure 23)**
- **Hit Vectorize and Close**

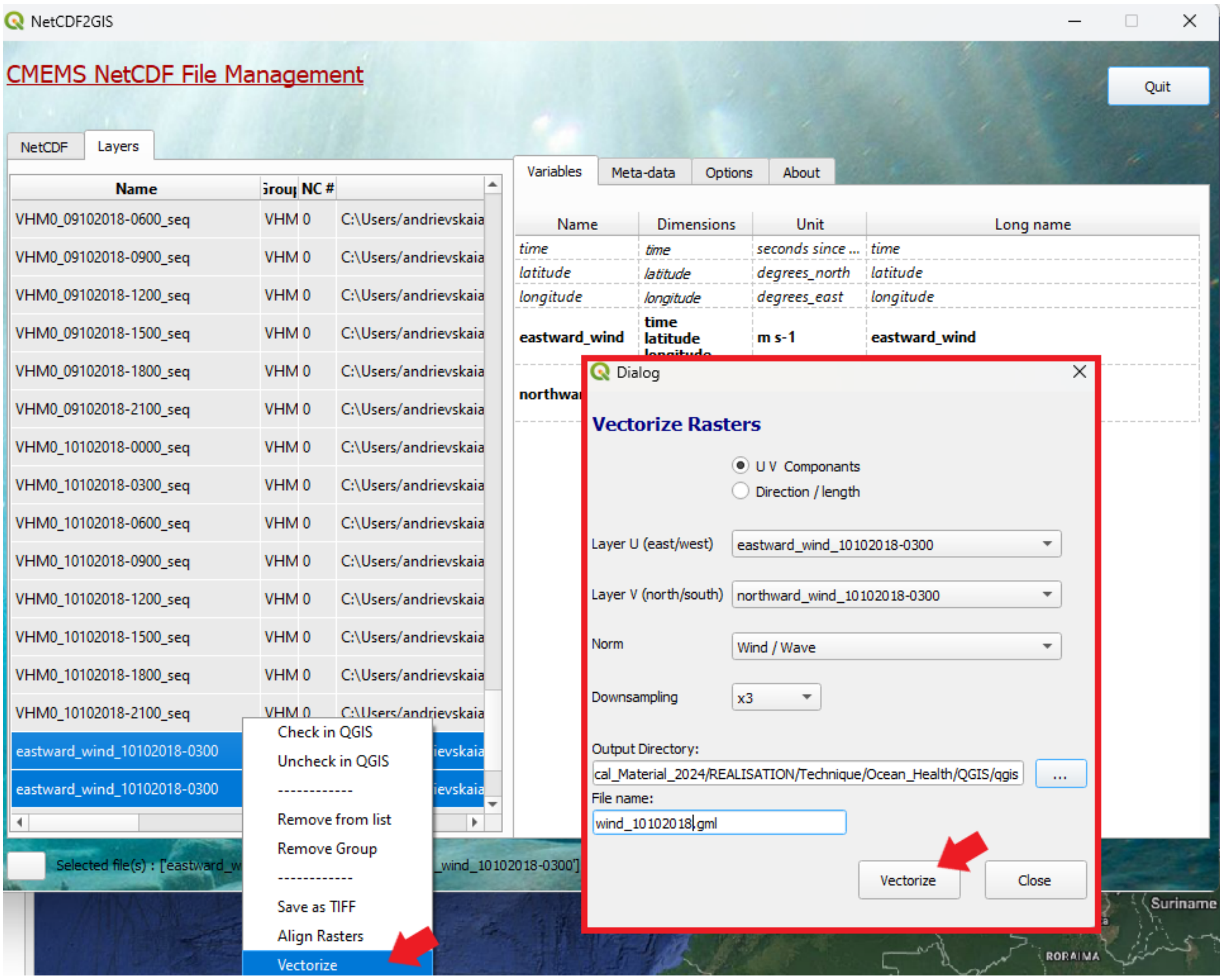


Figure 23: Apply the Vectorize function to the eastward_wind and northward_wind variables, wind speed vector field components.

You just plotted the wind speed vector field corresponding to October 10, 2018 at 03:00. We will adjust the style for this vector field:

- **Right click on the wind_10102018.gml layer > Open Properties**
- **From the Symbology panel, change colour ramp to Magma**
- **Invert it from light to dark**
- **Reduce Classes number to 7**
- **Click on Apply and Ok**

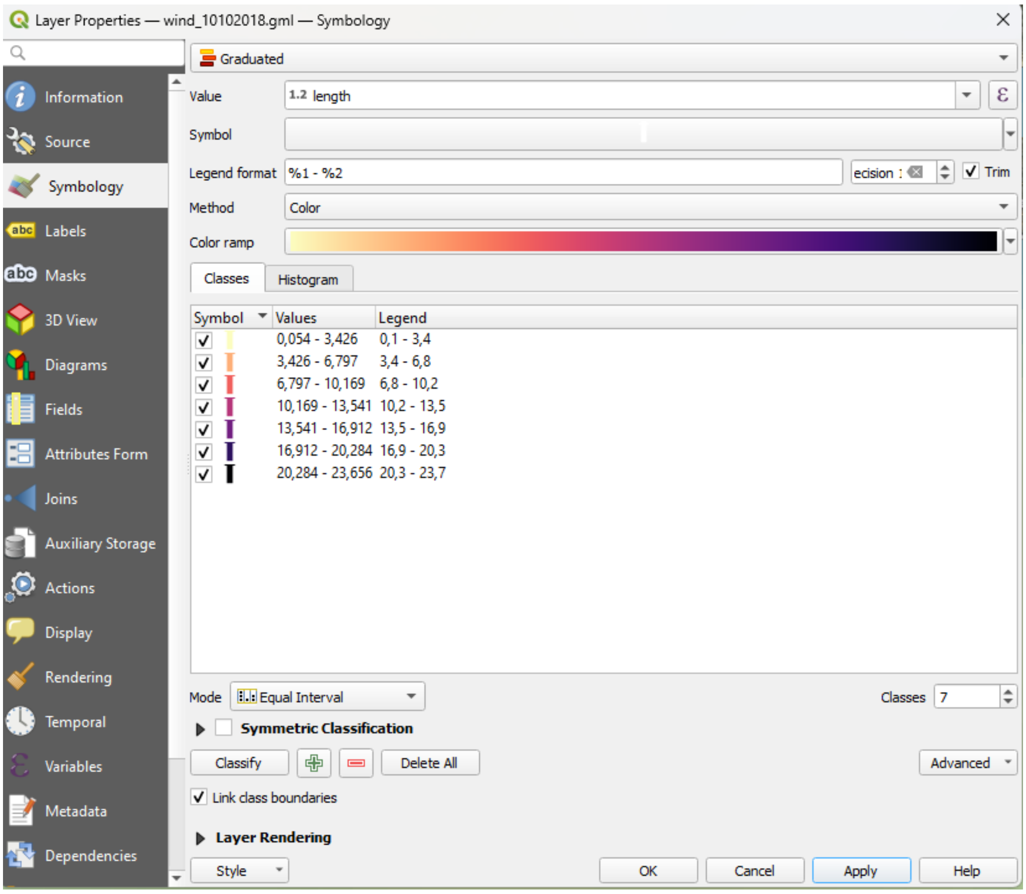


Figure 24: Tune style for the wind speed vector field.

By superimposing this wind vector field with the SWH from October 10, 03:00, we can clearly see the matching patterns of the wind direction and waves propagation (Figure 25).

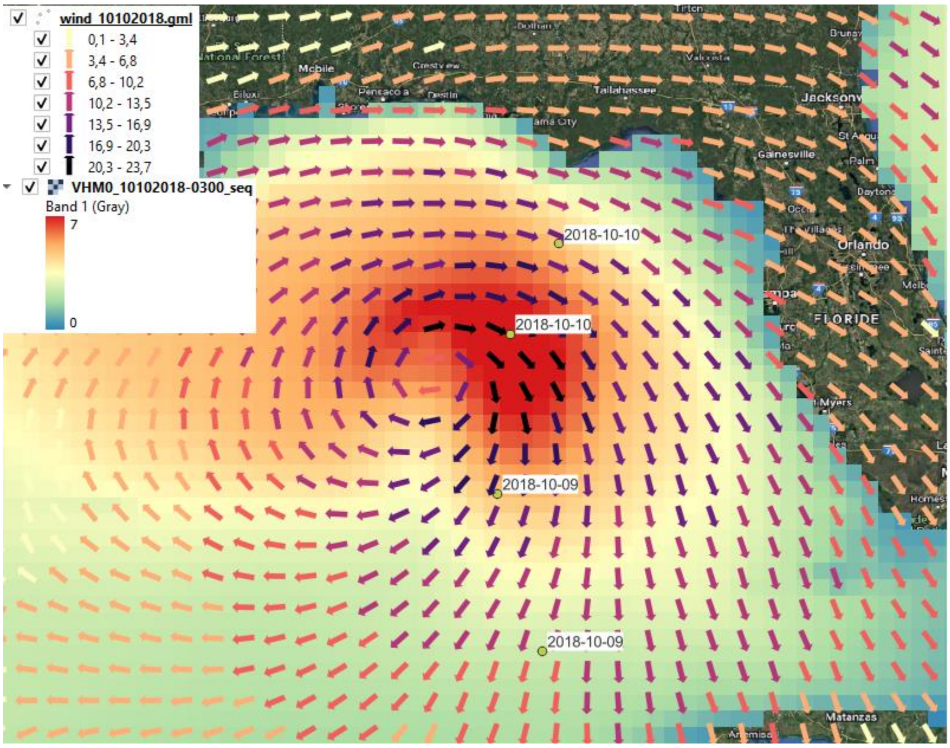


Figure 25: Wind vector field and SWH on October 10, 2018 at 03:00.

4.3. Impact of Hurricane on Ocean Health

In this part, we will study how hurricanes can potentially impact the marine ecosystems. We will focus on the sea water potential temperature variable before, during and after the Hurricane Michael.

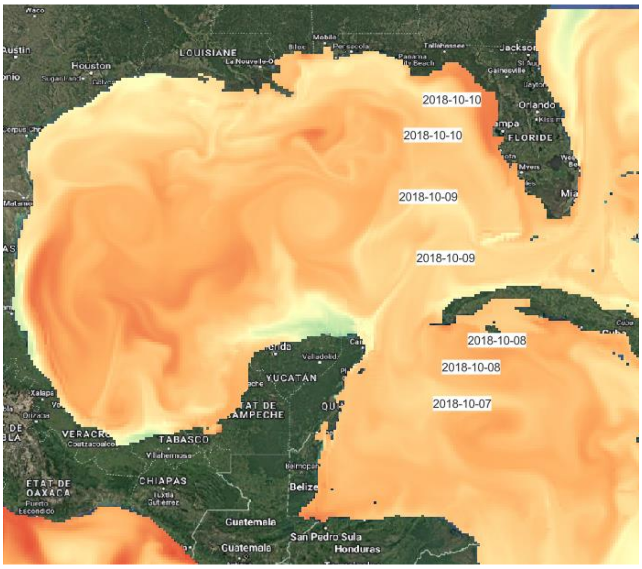
4.3.1. Sea water potential temperature

First, we will import three timeframes of the sea water potential temperature variable from GLOBAL_MULTIYEAR_PHY_001_030 product: before the hurricane on October 1, during the hurricane on October 10, and after the hurricane on October 13. We already learned how to do so in section 4.1.1.

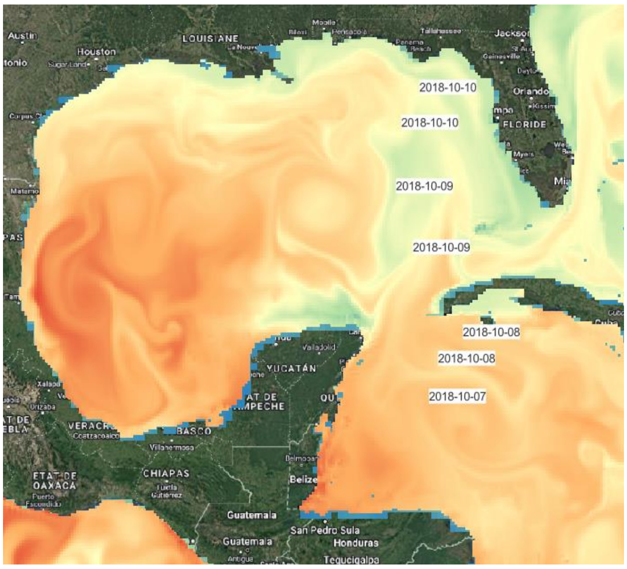
When the three timeframes are added to the project, you can repeat the procedure from section 4.1.2and change the style of the new layers with the following settings:

- **In Symbology, set the minimum/maximum value: [26 to 31]**
- **Ensure that the palette is 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**

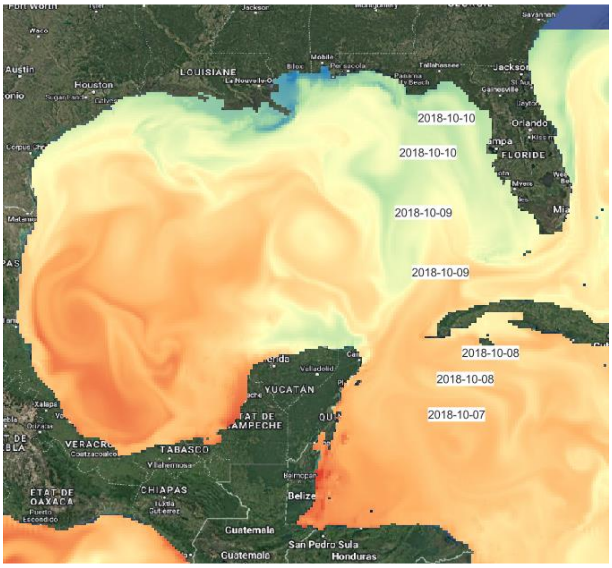
The result should look like as follows:



a) Sea water potential temperature on October 1



b) Sea water potential temperature on October 10



c) Sea water potential temperature on October 13

Figure 26: Sea water potential temperature before, during, and after Hurricane Michael.

We can see that as the hurricane moves inland, the sea water temperature slightly decreases, which might occur due to mixing of deeper, cooler waters with surface waters although it is also important to note that, overall, sea water can start cooling down due to the natural shift of seasons. In addition, we can spot a drastic sea water temperature drop off the Mississippi/Louisiana coast. This phenomenon could potentially be attributed to increased river discharge, triggered by heavy rainfall associated with Hurricane Michael.

4.3.2. Influence of sea water temperature on Essential Fish Habitat

In order to see how such phenomena as hurricanes can affect the ocean health, we will look into the effects of hurricane-induced changes in sea water temperature on the Essential Fish Habitat (EFH) in the Gulf of Mexico. Essential fish habitat includes coral reefs, kelp forests, bays, wetlands, rivers, and even areas of the deep ocean that are necessary for fish reproduction, growth, feeding, and shelter. Marine fish could not survive without these vital, healthy habitats.

4.3.2.1. Import layer

First, we will import an external layer described in section 2.2.1 to our project: simply drag and drop the provided file from where it is located on your computer to the QGIS project. It should look like the following:

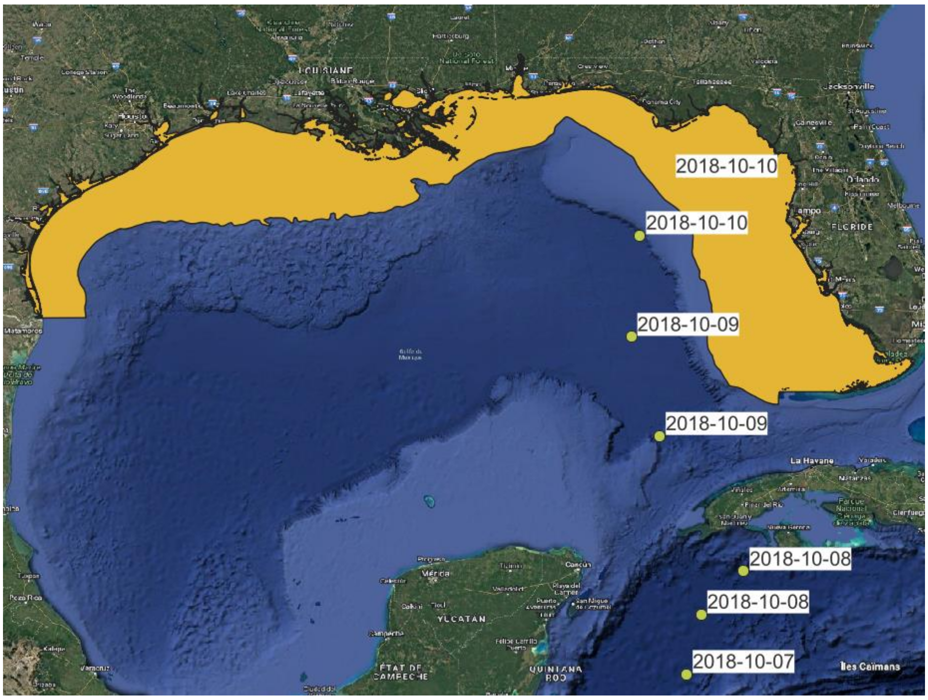


Figure 27: Polygon of Essential Fish Habitat in the Gulf of Mexico.

Before moving to the next step, we will apply the *Fix geometries function* to this polygon layer to avoid errors and geometric incompatibilities in the following steps:

- **Open the Processing > Toolbox and look for the Fix geometries function**
- **Double click to open it:**
  - **Set the *ReefFish_EFH_GOM* layer as Input layer**
- **Click on Run and Close**

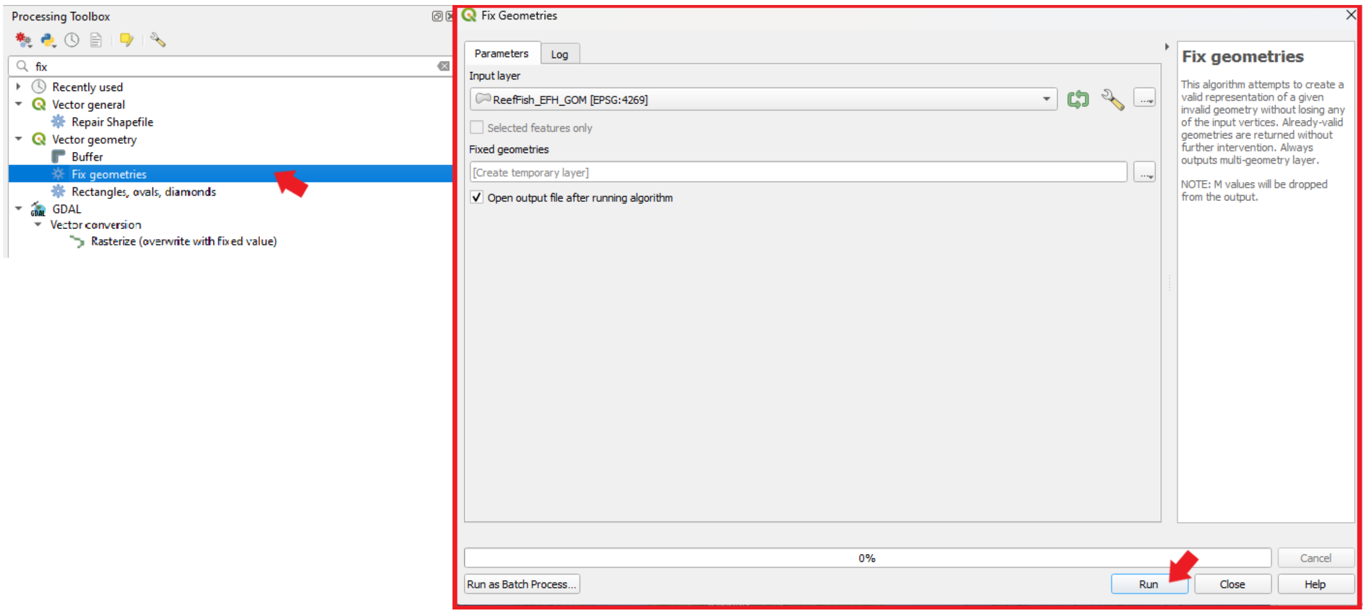


Figure 28: Apply the Fix geometries function.

4.3.2.2. Clip raster by polygon

Let's now look at the essential fish habitat zone: we will clip the three sea-water temperature raster layers according to the imported polygon:

- **Open Raster > Extraction > Clip Raster by Mask Layer (Figure 29)**
- **Select Input Layer: thetao_01102018-0000_0.49 layer**
- **Select Mask layer: Fixed geometries**
- **Select Input SCR: 4326**
- **Tick the box "Keep resolution of input raster"**
- **Set the name to cropped_01102018**
- **Repeat with the other two layers**

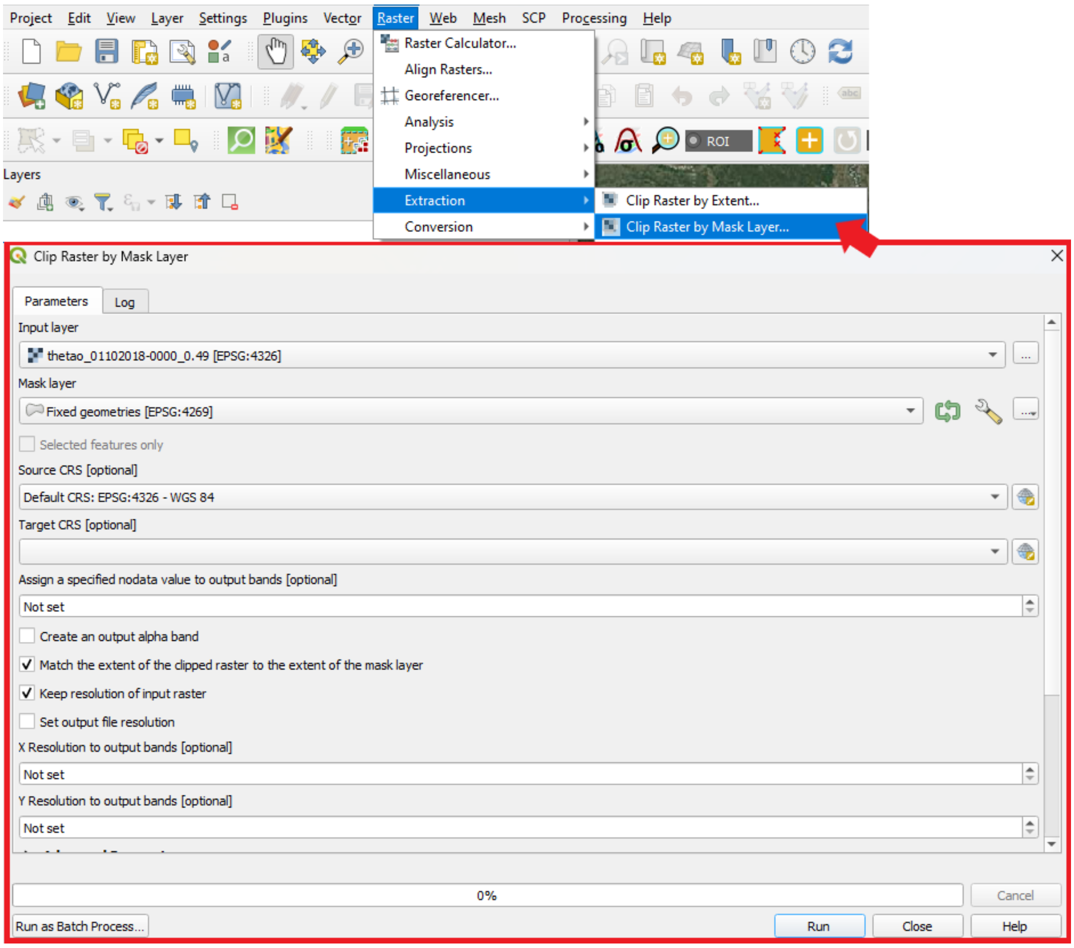
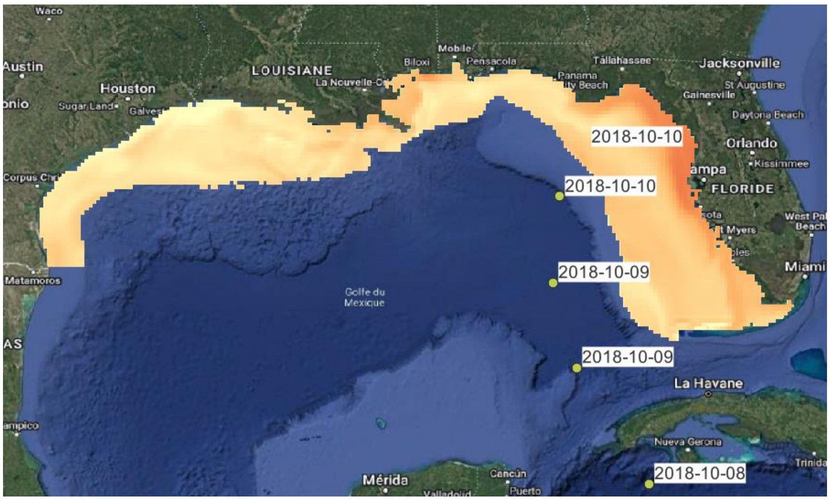
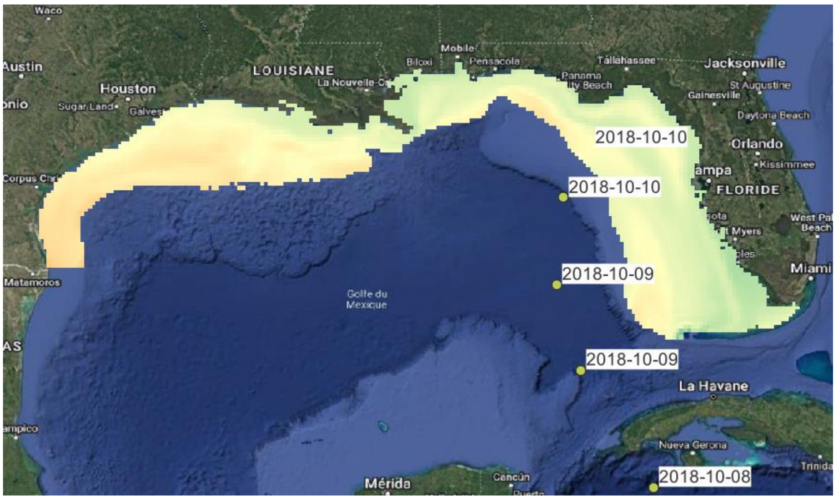


Figure 29: Clip Raster by Mask layer tool.

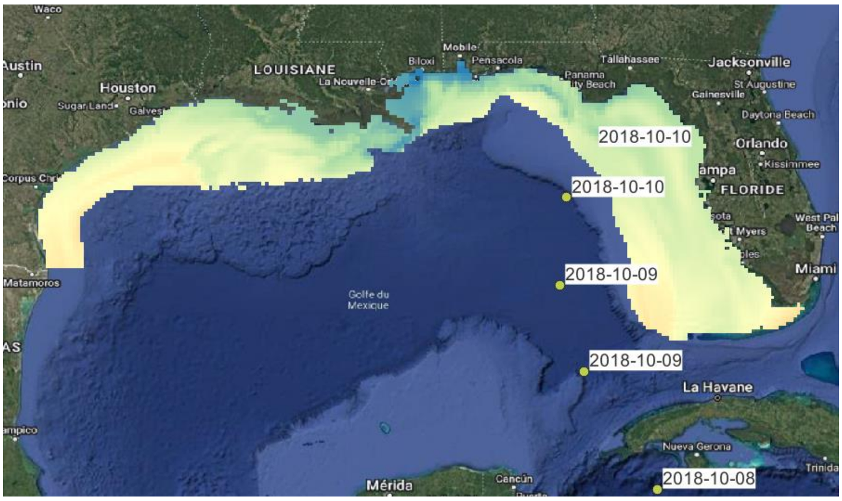
Adjust style of obtained layers by coping-pasting the style from **thetao_01102018-0000_0.49** layer. Below are the results of the performed procedure:



a) October 1



b) October 10



c) October 13

Figure 30: Sea water temperature cropped according to the essential fish habitat zone.

From this figure we can see the evolution of the sea water temperature for the zone of interest.

4.3.2.3. Calculate statistics

Additionally, to quantify this evolution, we can use Zonal statistics tool – it will allow us to calculate mean, min and max of sea water temperature over the region:

- **Processing > Toolbox > Search for Zonal statistics function (Figure 31)**
- **Input layer: Fixed geometries**
- **Raster layer: cropped_01102018**
- **Statistic: Mean, Min, Max**
- **Output layer: stats_01102018**
- **Click on Run and Close**
- **Repeat for other two dates**

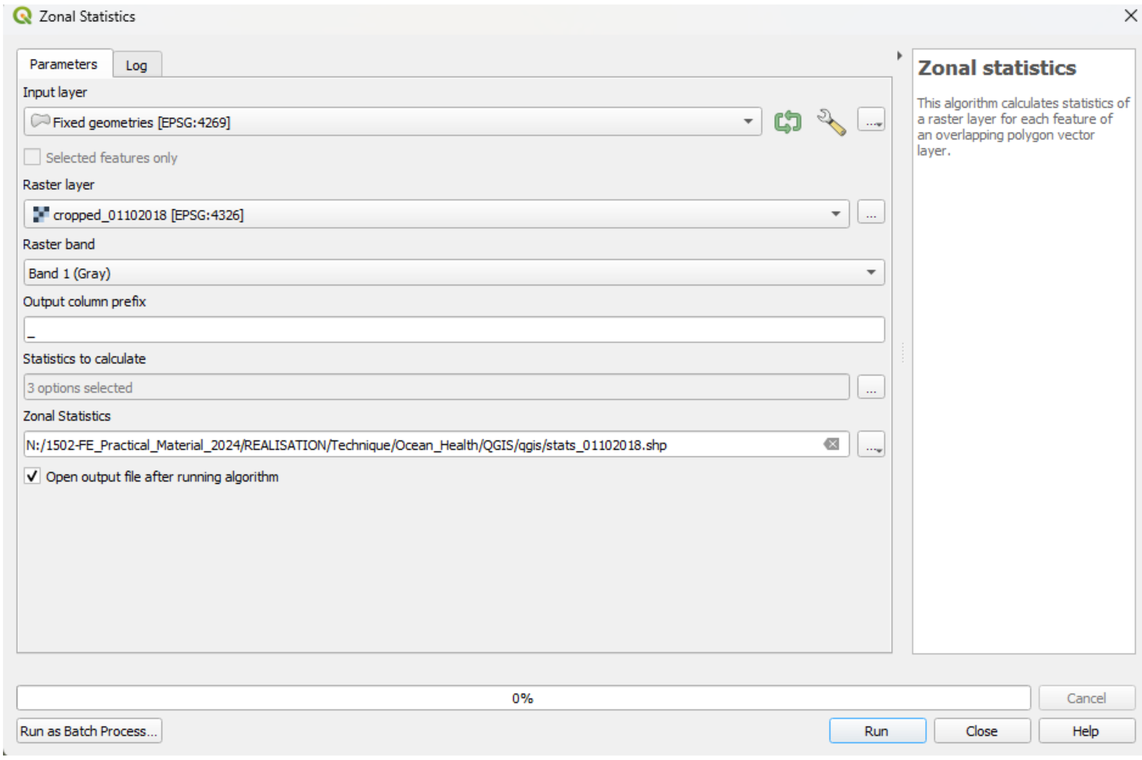


Figure 31: Zonal statistics tool.

As a result, three new polygon layers will be added to the project. If you right click on each of them and open Attribute Table, you will see the calculated statistics (see below).

_mean	_min	_max
29,14916099313...	28,31565284729...	30,18851280212...

a) October 1

_mean	_min	_max
28,32439120009...	26,85955429077...	29,34547042846...

b) October 10

_mean	_min	_max
27,93974976331...	25,62245559692...	29,03564643859...

c) October 13

Figure 32: Sea water temperature statistics for the EFH zone before, during, and after the hurricane.

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 Ocean Health. It enabled us to display raster variables in order to see their evolution. We learned how to create new geometries, add positions to them and tune their representation. We also worked with scalar components of the vector field. Additionally, we saw how to import external shapefile layer, use it to crop raster layers, and calculate such statistics as mean, min, max.

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.