Status of the Seychelles Digital Ocean Atlas (SDOA) in 2023

Francis MARSAC[1] and Eric NOEL[2]

Abstract

A broad range of oceanographic and environmental conditions and processes influence marine ecosystems and fisheries. The Seychelles Digital Ocean Atlas (SDOA) is designed to provide to an easy access to information on the marine environment. The datasets associated to this first version include ocean numerical models (since 1993) and satellite sea colour (since 1997). An interactive web interface allows the user to generate maps, time series, transects, space-time and vertical plots of thirteen variables (seven physical and 5 biogeochemical variables, and the GEBCO seafloor topography) that are included in this version. The SDOA area stretches over an area of 5.2 million km² including the Seychelles Exclusive Economic Zone and neighbouring regions (5°N to 13°S, 41°E to 70°E). The SDOA system is flexible as it can easily include new variables (gridded or discrete) without huge development effort. The SDOA is also fully expandable to other regions, as the code and users interface can be applied to other NetCDF datasets generated specifically for other study areas. Eventually, the SDOA can provide useful information in a blue economy context.

1- Introduction

The Blue Economy Strategic Framework and Roadmap of Seychelles was released in 2018 with the objective of unlocking the potential of ocean natural resources in the EEZ. The founding document refers to seven key principles, including Research and Innovation to improve the knowledge of the marine space for management and technology-based economy. A survey of the existing knowledge resources covering the marine environment and the expectations of a range of local users and stakeholders pointed out the need to develop a dynamic atlas of the ocean conditions that could inform the management of fisheries and coastal marine protected areas, and appraise the climate-induced impacts on the coastal ecosystems.

The Seychelles Marine Spatial Plan Initiative coordinated by the Ministry of Agriculture, Climate Change and Environment (MACCE) and facilitated by The Nature Conservancy (TNC) has produced an atlas to assist with the implementation of the MSP in Seychelles (Smith et al, 2021). This atlas only includes "static" information such as maritime boundaries, maps of protected and high biodiversity areas, bathymetry, deep seafloor geomorphology, seagrass density, distribution of wetlands and mangroves (https://seymsp.com/outputs/atlas/). Therefore, the SDOA can be considered as a useful complement to the MSP atlas by providing "dynamic" layers at high spatial resolution, analysing status and trends of the ocean conditions from 1993 to present, with monthly updates.

A project call (FSPI: Solidarity Fund for Innovative Projects) released by the French Ministry of European and Foreign Affairs in 2020 to support the Blue Economy in the Southwestern Indian Ocean, was the opportunity to start the SDOA project, in the framework of the Blue Economy Year 2021-2022 of the Indian Ocean Commission.

The objectives and insights on the very first stages of the SDOA were presented at the WPDCS17 in 2021 (Marsac and Noel, 2021). The SDOA was developed over an area of 5.2 million km² including the Seychelles Exclusive Economic Zone and neighbouring regions:5°N to 13°S, 41°E to 70°E (Fig. 1). In this paper, we provide more details on the progress of the project, which has generated the first version of the web application in 2023.

[1] MARBEC, IRD, Centre Ifremer, Avenue Jean Monnet, 34203 Sète, France (email : francis.marsac@ird.fr)
[2] SPACE Ltd, Huteau Lane, Victoria, Mahe, Seychelles (www.space95.sc)

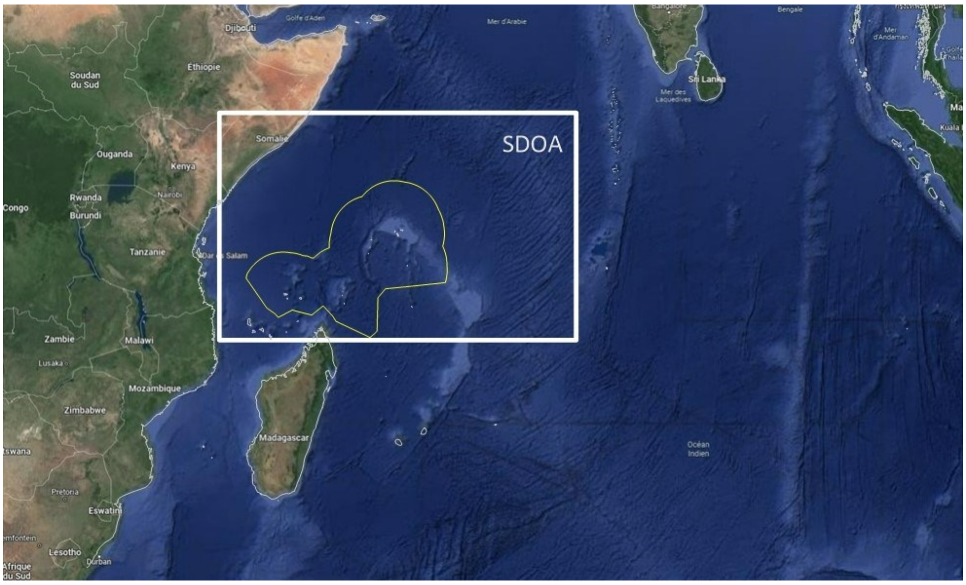


Fig. 1 – Boundaries of the SDOA box in the West Indian Ocean. The yellow line indicates the Seychelles EEZ boundary.

The data cover the deep sea and the shallow waters over the banks, shown in light grey (Fig. 2).

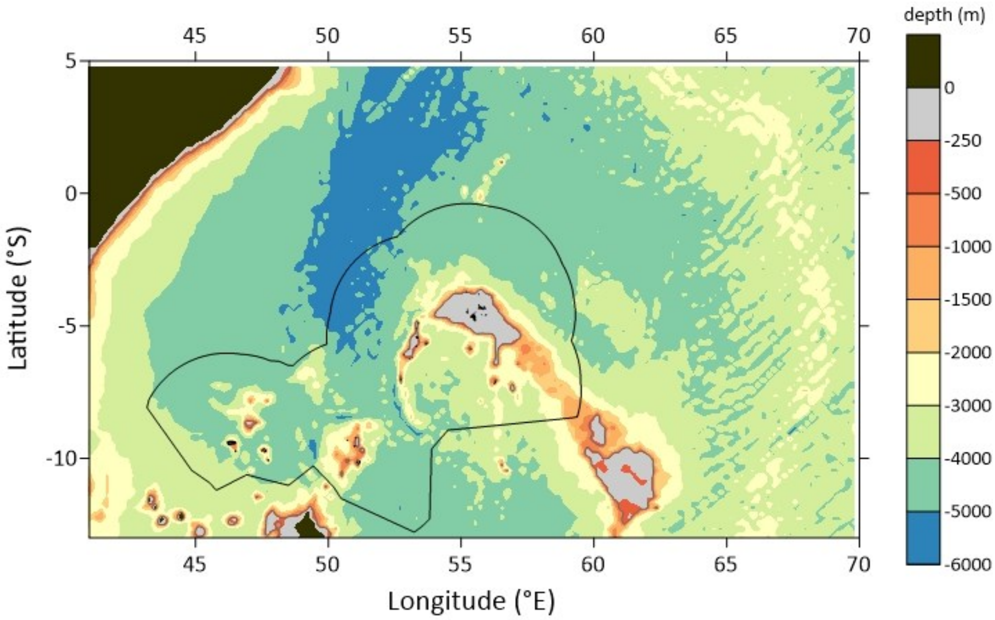


Fig. 2 – Seafloor topography in the SDOA area

2- Methodology

The SDOA is a Shiny app developed by the two authors. Shiny is an open source R package that provides an elegant and powerful web framework for building web applications using R. An interactive web application can then be developed without requiring HTML, CSS, or JavaScript knowledge (extracted from the RStudio web page).

2.1 General overview of the SDOA application

A schematic of the app is given in Fig.3. The SDOA includes datasets extracted from the European Copernicus Marine service (see 2.2) for the study area. R scripts embedded in the Shiny interface perform the various tasks corresponding to the user's queries. The Shiny interface display the results of the query (maps, line plots) on the user's device (computer, tablet, mobile phone). In parallel, the details on the user (sign-up information) are stored in a backend application that is accessible by the system and data administrator only. This is used to track the activity on the SDOA pages, and to measure the interest by different categories of users. A "feedback page" is also connected to the backend to collect the expectations or bug reports from the users, in order to fix or identify new potential products to incorporate in the further versions of the SDOA. The app is hosted on a THREDDS data server on the web.

The procedure to update the datasets on a monthly basis is described in the left part of the schematic (Fig.3), and this is performed by the data administrator. The newly released information from the source (Copernicus) is processed by specific R scripts (so-called Calc scripts) to generate the new datasets that are later transferred to the cloud server. All datasets are coded in NetCDF (Network Common Data Form), a binary format that is platform-independent and self-describing (with header and file metadata in the form of name/value attributes). NetCDF is an international standard in scientific data exchange among climate and ocean data centers.

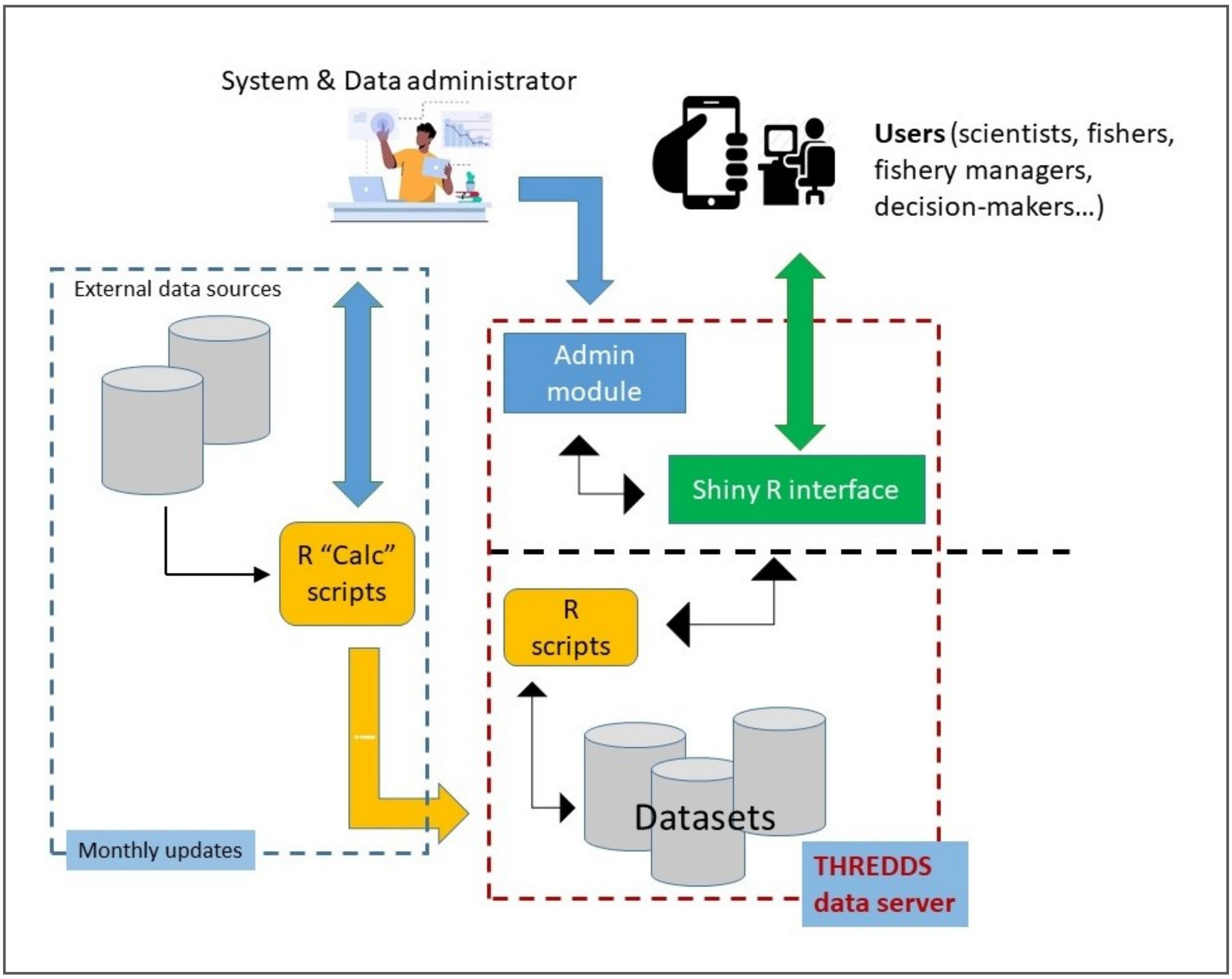


Fig. 3 – Schematic of the SDOA application

2.2 Data description

A full description of the datasets is given in Table 1. The seafloor topography, initially the ETOPO1 Global relief model, as presented at the WPDCS17 meeting, has now been updated to GEBCO (GEBCO_2022 Grid) with a higher spatial resolution (450 m at the equator instead of 1852 m).

The twelve other variables belong to two categories, physical (blue) and biogeochemical (green) ocean.

- **Physical ocean variables** (spatial resolution of ~9 km at the equator)
  - Temperature, salinity, current (with zonal *u* and meridional *v* components), all ocean numeric model products, along 34 depth levels (surface to 763 m);
  - Mixed layer depth, defined as the depth where the seawater density difference compared to the density at 10 m is 0.01 $kg.m^{-3}$
  - 20°C isothermal depth, i.e. the depth of the 20°C isotherm in the water column. It usually defines the core of the thermocline in the tropical ocean. This variable is calculated by interpolating the modelled temperature at depth using a Calc R script, keeping the same spatial resolution as its source file;
  - The vertical current shear (*K*) is the log-transformed integration of changes in velocity and direction in the water column, from surface to 200 m (the maximum depth for most of the longline operations in Seychelles), calculated by a Calc R script from the modelled *u* and *v* components at depth :

    $$K = \log\left(\frac{\int_0^z \left\|\frac{\partial \vec{u}}{\partial z}\right\| \mathrm{d}z}{Z}\right)$$

    with Z being the maximum depth scanned (200 m), and $\vec{u}$ the horizontal current vector. The spatial resolution is identical to that of the source file
  - The sea level anomaly (SLA), a satellite-based product from merged altimetry sensors that describes the deviations of the sea level height to the geoid. The sea level anomalies describe the vertical movements (upwelling or downwelling) and the geostrophic current. Unlike the other physical variables, the SLA is at a spatial resolution of 25 km.
- **Biogeochemical variables** (spatial resolution of ~25 km at the equator)
  - Dissolved oxygen (DO) concentration, a model product, along 34 levels, from surface down to 763 m;
  - The depth of the 2.5 ml/L DO concentration, in the upper 150 m of the ocean. This specific concentration is defined in relation to critical DO level for surface dwelling tunas such as skipjack This variable is derived by interpolation between the modelled DO at depth using a Calc R script, keeping the same spatial resolution as its source file;
  - The depth of the maximum fluorescence (Fmax) which indicates the depth of highest phytoplankton biomass. This is a derived variable calculated by a Calc R script from the modelled chlorophyll at depth;
  - The integrated chlorophyll content, obtained by summing the chlorophyll concentration at all levels from surface to 300 m. This is a derived variable calculated by a Calc R script from the modelled chlorophyll at depth;
  - The surface chlorophyll content, a satellite-based product (level L4) resulting from the merging of several ocean colour sensors, which is a proxy of the phytoplankton richness within the first meters of the ocean. Unlike the other biogeochemical products, the spatial resolution is 4 km. The images may contain blank areas where clouds have been persistent over the time window of the composite (here, 1 month).

In terms of time coverage, the models datasets start in January 1993. The period 1993-2020 is the result of reanalyses (eddy-resolving global ocean simulations – GLORYS12-V1), a product named GLOBAL_REANALYSIS_PHY_001_030. The Forecast period starts in January 2021, with files using different forcing compared to reanalysis (GLOBAL_ANALYSIS_FORECAST_PHY_001_024). These two datasets are quite consistent as they are both data-assimilated products. However, the data assimilation scheme is slightly different. Therefore, time series plots overlapping the pre and post-2020 periods may show some disruptions at the transition between 2020 and 2021.

The biogeochemical datasets have a similar time and product partitioning: GLOBAL_REANALYSIS_BIO_001_029 and GLOBAL_ANALYSIS_FORECAST_BIO_001_028 for reanalysis and forecast, respectively. The Forecast dataset is updated monthly in the SDOA when new monthly files become available on the CMEMS server. Unlike the physical ocean dataset, the BIO reanalysis product (1993-2020) which uses the PISCES biogeochemical model (included in the NEMO modelling platform), does not assimilate data. The BIO forecast product is somewhat different as it does assimilate satellite chlorophyll data and uses a different atmospheric forcing compared to the reanalysis product. Therefore, time plots encompassing the two periods, pre and post 2020, will show some disruptions at the transition between 2020 and 2021.

The satellite-based products have a different time coverage. The surface chlorophyll content dataset starts in September 1997 (with the SeaWifs data). The satellite altimetry products started in 1992; however, the period covered in the SDOA begins in April 2019.

The temporal resolution of the products is the month except the altimetry products, which are daily.

Table 1 – Specifications of the current SDOA datasets

Variable	Depth range	Spatial resolution	Timeframe	Source	Product name
Temperature	0–763 m (34 levels)	1/12 degree (~9 km)	January 1993 To Present (monthly)	Model (CMEMS)	*PHYsical files :* Reanalysis: GLOBAL_REANALYSIS_PHY_001_030 Forecast : GLOBAL_ANALYSIS_FORECAST_PHY_001_024
Salinity					
Current (zonal u and meridional v)					
Mixed layer depth	1 layer				
Dissolved oxygen	0-763 m (34 levels)	¼ degree (~25 km)			*BIOgeochemical files :* Reanalysis : GLOBAL_REANALYSIS_BIO_001_029 Forecast : GLOBAL_ANALYSIS_FORECAST_BIO_001_028
20°C isothermal depth	1 layer	1/12 degree (~9 km)			Calculated from PHY source files: reanalysis & forecast
Vertical Current shear	1 layer				Calculated from PHY source files: reanalysis & forecast
Depth of 2.5 ml DO (in the upper 150 m)	1 layer	¼ degree (~25 km)			Calculated from BIO source files: reanalysis & forecast
Depth of Fmax	1 layer				Calculated from BIO source files: reanalysis & forecast
Integrated Chlorophyll content 0-300m	1 layer				Calculated from BIO source files: reanalysis & forecast
Surface chlorophyll content	1 layer (surface)	4 x 4 km	Sept 1997 to present (monthly)	Satellite merged products	OCEANCOLOUR_GLO_BGC_L4_MY_009_104
Sea level anomaly	1 layer (surface)	¼ degree (~25 km)	April 2019 to present (daily)	Merged altimetry products	SEALEVEL_GLO_PHY_L4_NRT_OBSERVATIONS_008_046
Seafloor topography	1 layer	15 arc-second (~450 m at the equator)	n.a	Measured and estimated seafloor topography	GEBCO 2022

Climatological fields are required to calculate anomalies for each variable, at each depth level. The monthly climatology (mean over 1993-2016) for the reanalysis datasets of temperature, salinity, *u* and *v* of current and mixed layer depth were downloaded from CMEMS. Calc R scripts calculated the climatology for the other variables of the reanalysis period over the same reference period. As for the Forecast datasets, which exhibit differences with the reanalysis datasets, a specific climatology was used and was calculated over 2019-2021. Eventually, monthly anomaly datasets were generated by subtracting the monthly climatology to the analysed month. Anomalies for the reanalysis datasets used the 1993-2016 climatology, whilst those for the forecast datasets used the 2019-2021 climatology.

The monthly climatology of the surface chlorophyll content was calculated over the period 2000-2019. No climatology was calculated for the sea level anomaly dataset.

3- Maps and plots produced by the app

The atlas is accessible through a web site embedded in the Shiny environment: www.marineatlas.sc

When accessing the app for the first time, a user must create an account (i.e. register) with a login and password and indicates the category he belongs to: scientist, fisheries company manager, fisherman, fisheries administration, student (Fig. 4). This information is only used to compute statistics on the professional sectors using the SDOA. The registration to SDOA is free. Once registered, each user enters with a sign-in page, where login and password only are required. The home page allows a choice between four types of plots: map, line plots, Hovmoller plot or vertical profiles. Each type of plot has specific forms with drop-down lists to generate a query that will produce a particular map or plot. Each set of selections made in the form activates a command line in R-Shiny to display the requested plot. The plots can be saved in standard image formats, or exported as data files, that can be read and used by other software (e.g. Excel).

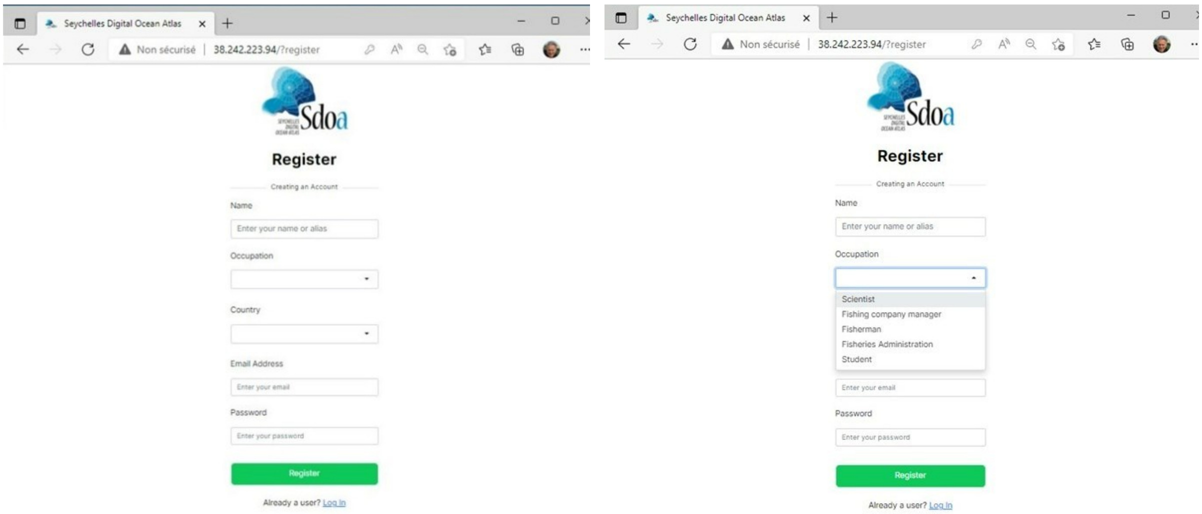


Fig. 4 – SDOA registration page (when accessing the for the first time)

3.1 The MAP page

The result of the query is a map of a given variable (or its anomaly), at a given depth and for a given month (or day for the sea level anomaly). A map can be produced for the whole area of SDOA, or inside a smaller area. The boundaries of the reduced area can be defined interactively by drawing a box on the map, or by entering extreme latitudes and longitudes manually.

Presently, the app can display maps for a given year/month (button "monthly"), or monthly climatology. It is also possible to display "computed maps" allowing *1)* to map the difference between two month-years defined by the user, or *2)* to map the average conditions for a given month over a period (years) defined by the user. Screen shots are shown in Annex 1. For each of those maps, it is possible to overlay the EEZ boundary by checking a box in the menu.

Eventually, a fourth option allows the user to create a bathymetric map, displaying all available depth range or a restricted range of isobaths

The sequence of operations must follow an order when making a query (otherwise issues may arise):

- Select "whole area" or "Smaller area"
- Select a variable through the drop-down list, and a depth level. Depth level is only requested for the multilayer variables such as "Temperature", Salinity", "Current", "Dissolved oxygen"

- Select a map type
- Input the year and month using the drop-down list
- Check the “EEZ boundary” box if this information needs to be added to the map
- The anomaly field of the selected variable can be generated by checking the “Anomaly” box

The map will be generated in real time and can be exported in various image formats by the Export button

3.2 <u>The LINE PLOT page</u>

Three types of line plots can be selected with a radio button: time series, longitude or latitude transect.

Time series plot

Firstly, a location has to be selected interactively on the Google map, using the locator icon on the map  or by entering coordinates manually. The exact latitude and longitude coordinates are displayed in the text box. Secondly, a variable must be selected and a depth level (if relevant). Thirdly, a start and end date of the time series must be defined from the drop-down list. By checking the “Anomaly” box, the anomaly series of that variable will be displayed. Once the time series produced, the data can be exported in two ways: *1)* Summary Stat will give the statistics associated to the time series: mean, standard deviation, minimum and maximum values, median, 25 and 75% quartile, coefficient of variation; *2)* Summary report will give the data that make the plot. These different outputs can be in .csv or .txt formats. Examples of time series plots are given in Annex 2.

Longitude transect

Firstly, a horizontal line (across longitudes) indicating the transect must be drawn from the map with two clicks (start and end of the transect), using the tool located at the top right corner of the Google map. A double click validates the line drawn on the map. Alternatively, coordinates can be entered in the text box. Secondly, a variable must be selected and a depth level (if relevant). By checking the “Anomaly” box, the anomaly series of that variable will be displayed. Thirdly, a date (year and month) must be selected from the drop-down list. Once the transect is displayed, the data can be exported in two ways: *1)* Summary Stat will give the statistics associated to the transect: mean, standard deviation, minimum and maximum values, median, 25 and 75% quartile, coefficient of variation; *2)* Summary report will give the data that make the plot. These different outputs can selected in .csv or .txt formats. Examples of time series plots are given in Annex 2.

Latitude transect

Firstly, a vertical line (across latitudes) indicating the transect must be drawn from the map with two clicks (start and end of the transect), using the tool located at the top right corner of the Google map. A double click validates the line drawn on the map. The rest of the procedure is similar to the longitude transect. Examples of time series plots are given in Annex 2.

3.3 The HOVMOLLER PLOT page

A Hovmoller plot is a space-time diagram. The app offers two options: longitude-time and latitude time. In the first case, the longitude is along the x-axis and the time (months) are along the y-axis. In the second case, the latitude is along the y-axis and the time along the x-axis.

Once the type of plot selected (by longitude of by latitude), a box area (generally a thin elongated rectangle) can be drawn by using the box tool in the upper right corner of the Google map. For a longitude-time plot, the box must be in the horizontal direction; for latitude-time plots, the direction is vertical. Longitudes and latitudes of the selected area are displayed in the text box. Secondly, select a variable and a depth level if relevant). The “Anomaly” box can be checked in that selection too. Thirdly, select the start and end years of the plot from a drop down list. The Hovmoller diagram will be displayed. The plot can be exported in various image formats.

Examples of Hovmoller plots in longitude and latitude are shown in Annex 3.

3.4 The VERTICAL PROFILE page

A vertical profile plot describes the variation of a variable with depth. The user starts by selecting a location with the locator icon at the top right corner of the Google map. Latitude and longitude of the point are displayed in the text box. Secondly, select a variable among three: temperature, salinity and dissolved oxygen. Thirdly select the upper and lower bounds of the profile to be plotted (generally, a profile starts at the surface, 0 m for upper selection). Then select a date (year and month) from a drop-down list. Finally, four options are offered to incorporate (or not) other profiles in the analysis: “None” means that only the profile at the selected location will be plotted; the three other options are to plot the range of all profiles located within a radius of 25, 50 or 100 km, around the selected location. This is useful to indicate whether a strong spatial variability is associated to that particular location. The plot can finally be exported in various image formats.

Examples of vertical profile plots are shown in Annex 4.

4- SDOA home page

General information about the SDOA, the partnership, the project itself and the database can be found in the home page of the app. One important tag is the “Feedback”, where the users can express their feeling and expectations about the app, and report bugs. A name and an email address must be associated to the feedback report.

5- Conclusion

The development of an electronic atlas of oceanic data for the Seychelles EEZ through a user-friendly web interface paves the road for integrating a wider range of information for the benefit of fisheries management, conservation purposes and more generally, in marine spatial planning (MSP). Easy and free access to oceanographic data contributes to deliver advice and services to stakeholders of the marine domain.

The current version of the SDOA may be extended to integrate more ocean or biological variables, depending on the feedback from the various users. The atlas was released only recently, so it is a bit premature to measure its impact among the users.

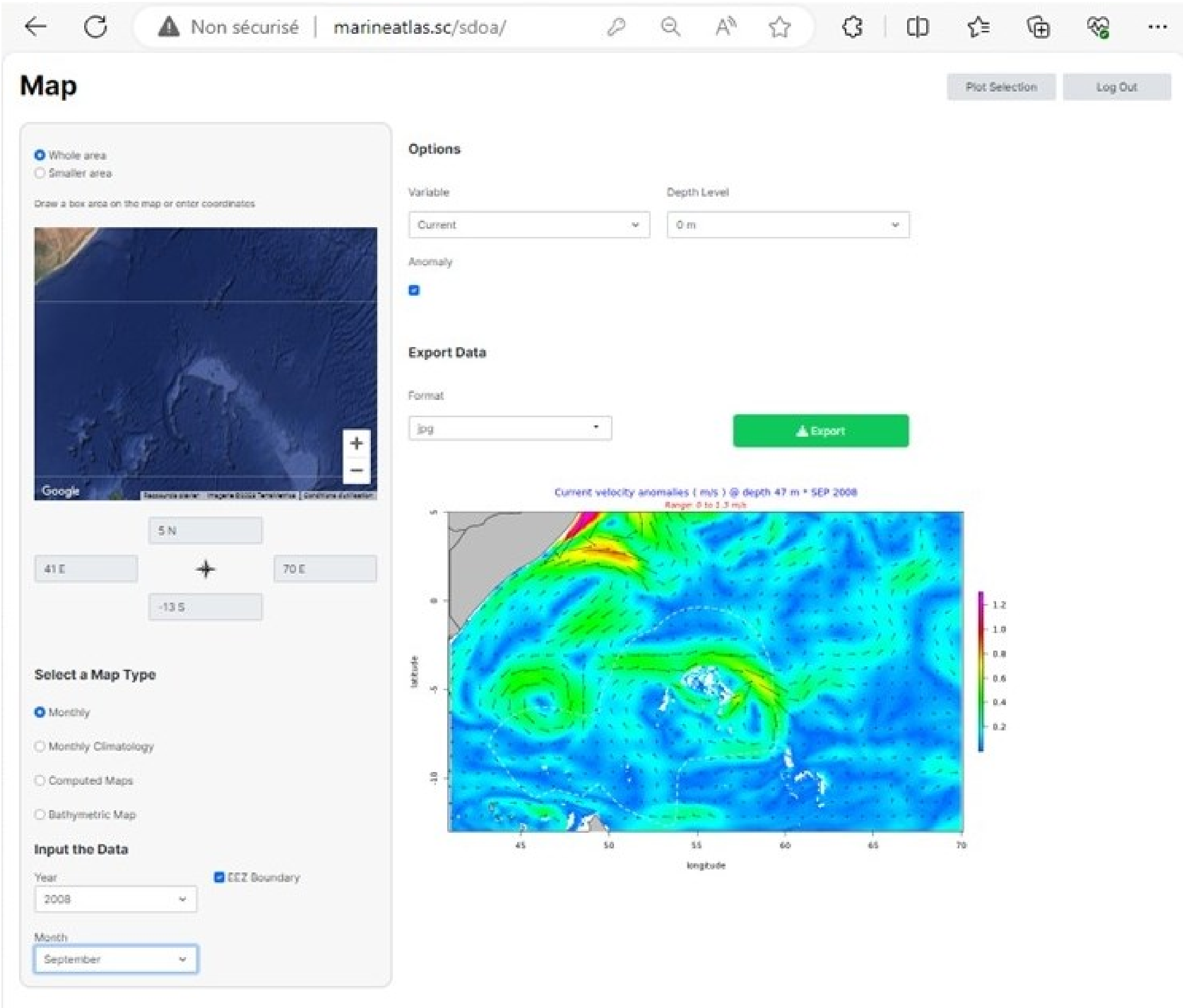
In the IOTC framework, a spatial extension of the current atlas could be considered. However, there are costs associated to the extension and the maintenance of the atlas, and technicalities about the server (and domain) which must be discussed further, should particular interest be raised in the IOTC community.

References

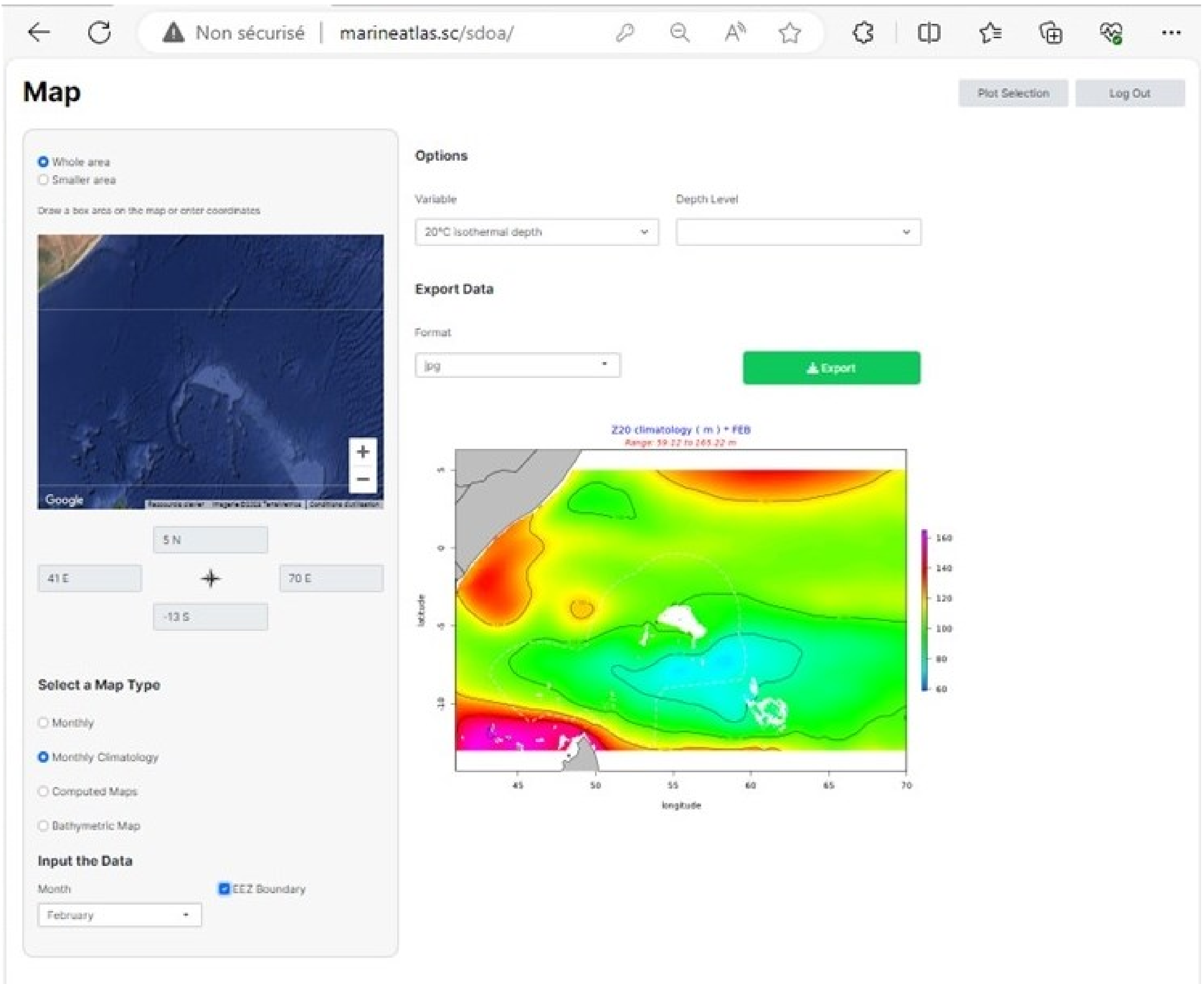
Marsac, F. and Noel, E. (2023). Development of an online ocean digital atlas for the Seychelles EEZ and neighbouring ocean regions. IOTC-2021-WPDCS17-22, 12p.

Smith, J.L., R.Tingey and H.E. Sims (2021). Seychelles Marine Spatial Plan Atlas. Developed by The Nature Conservancy for the Seychelles MSP Initiative. Unpublished maps accessed at www.seymsp.com

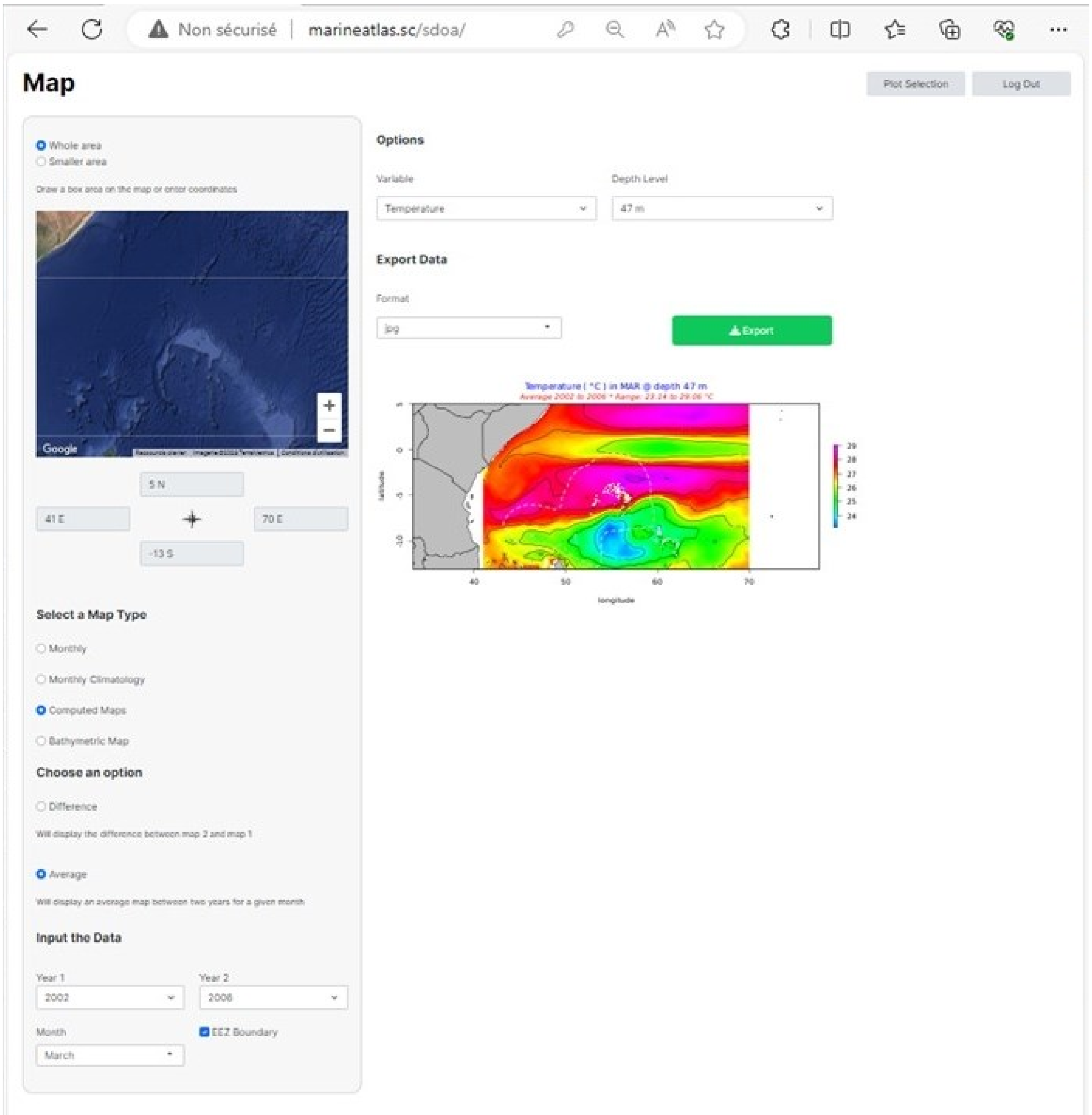
ANNEX 1 – MAP page



Map of the surface current velocity and direction in September 2008

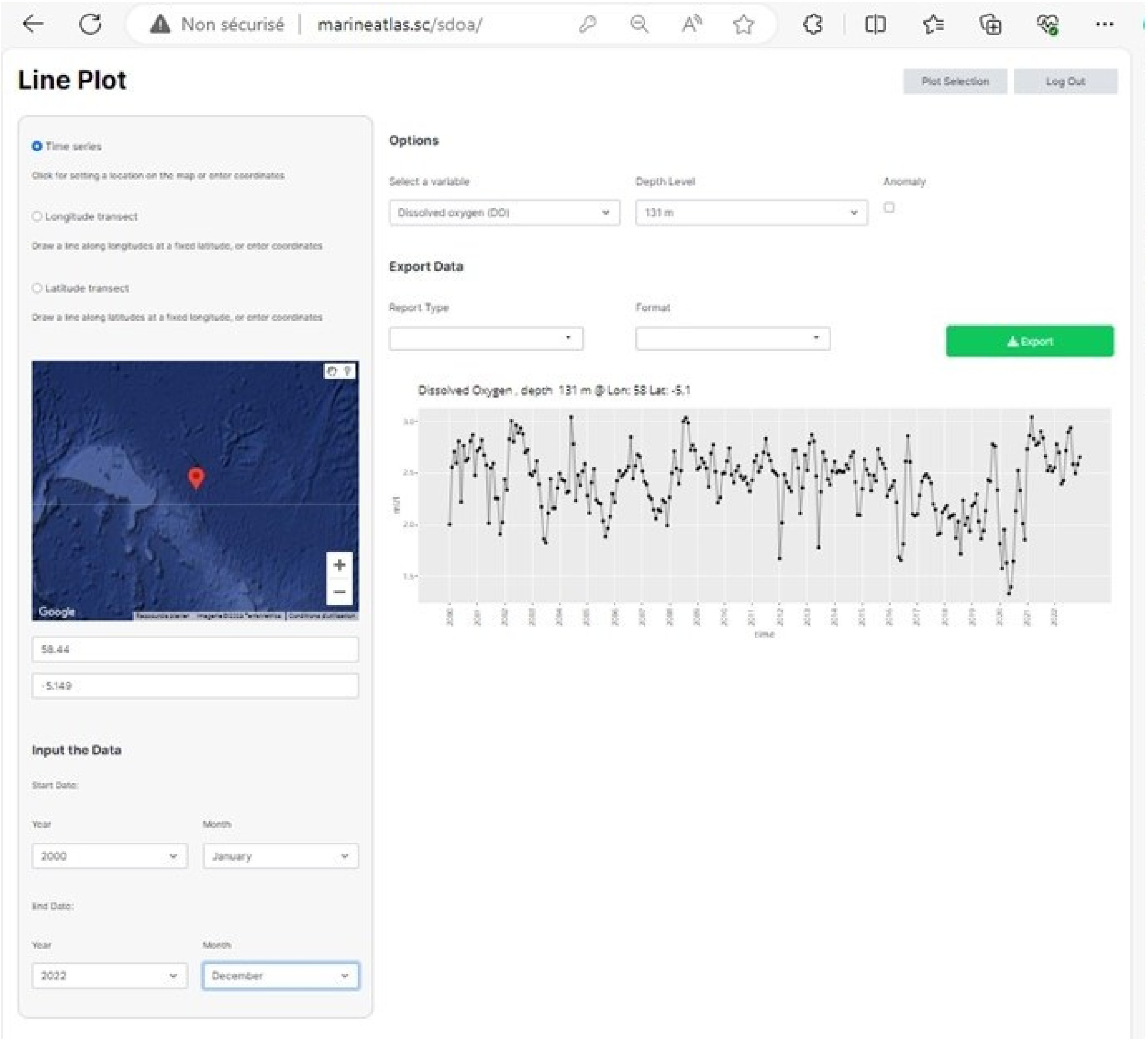


Climatological map of the 20°C isothermal depth in February

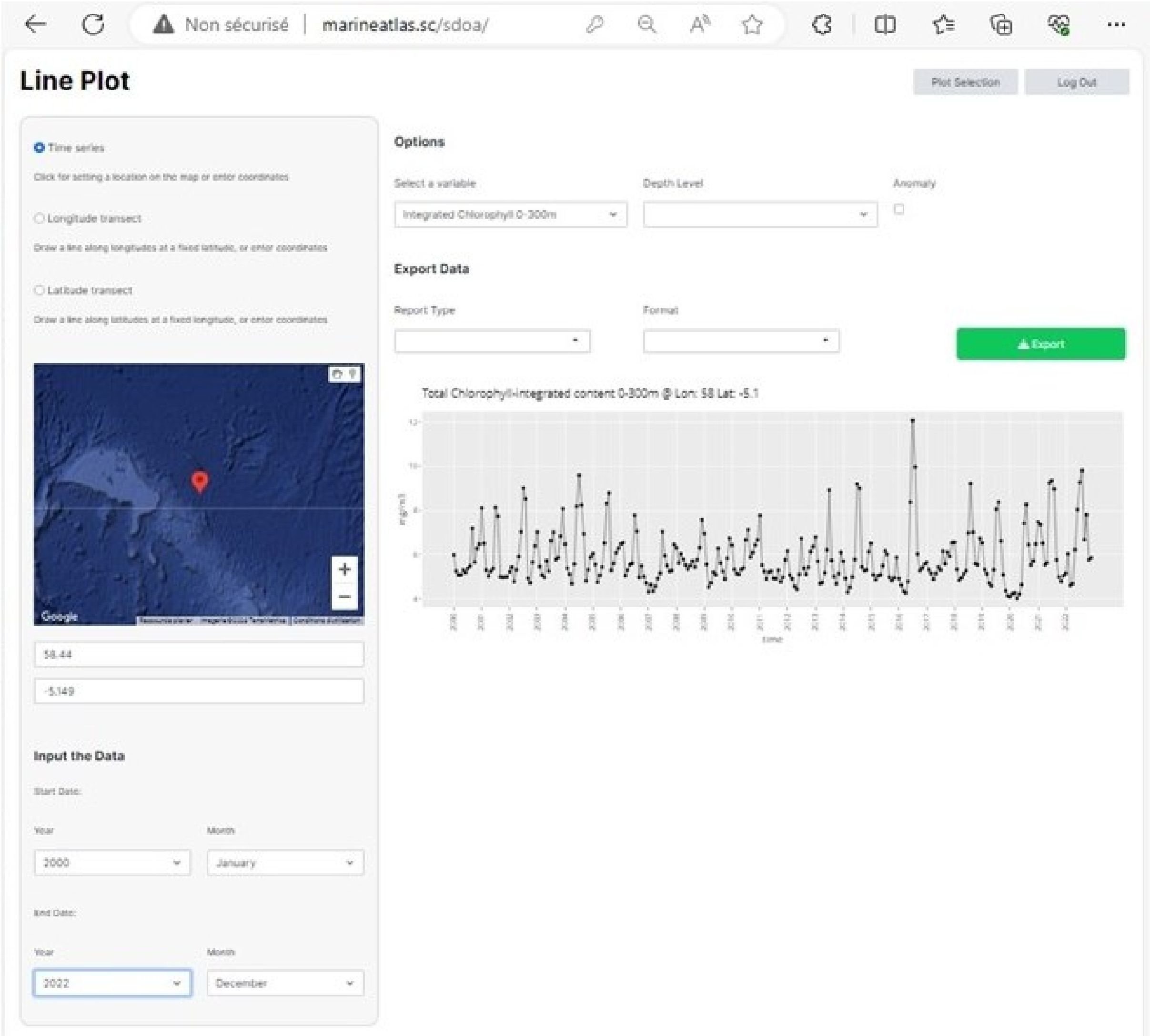


Map of the average temperature at 47 m in March, from 2002 to 2006

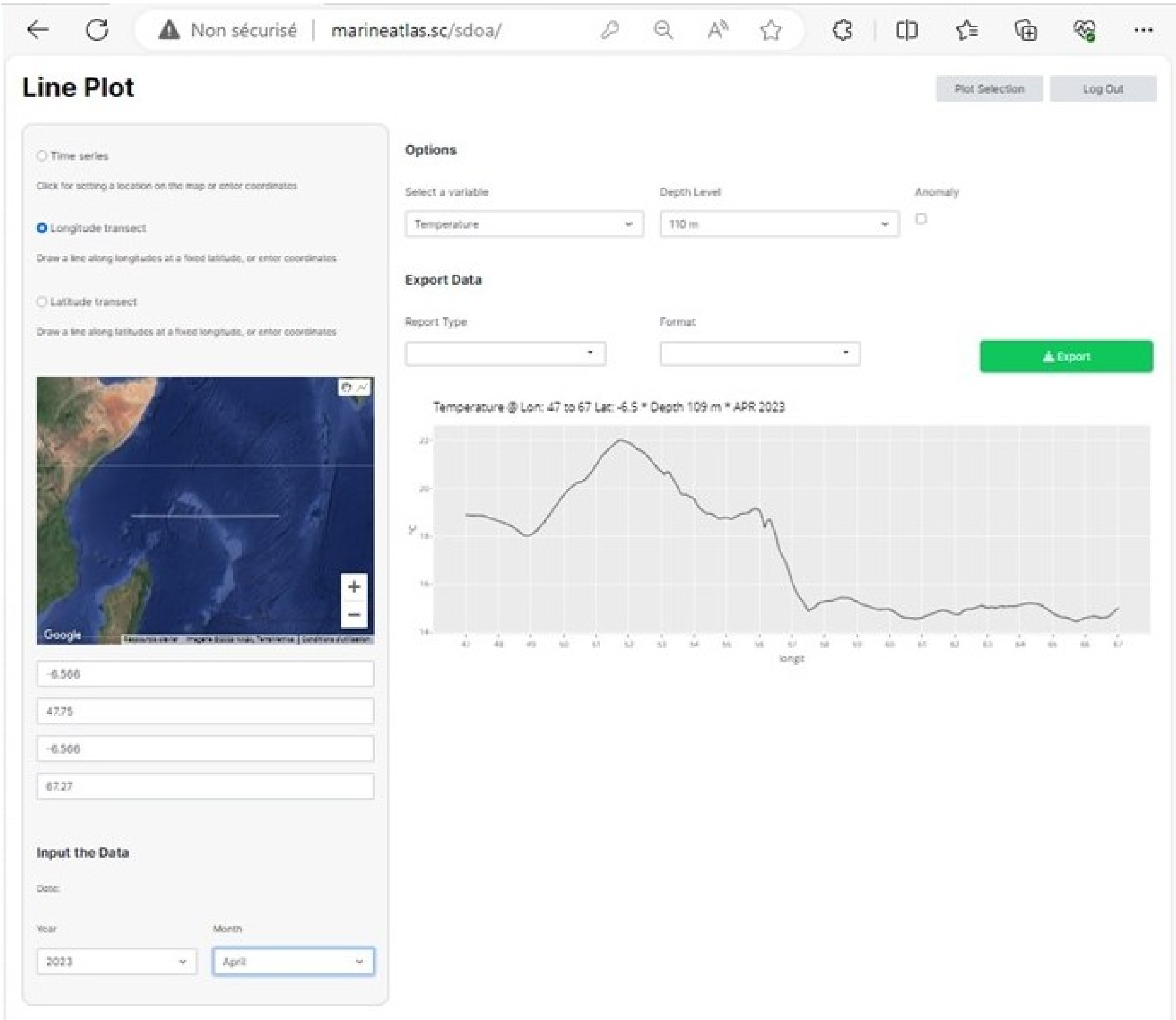
ANNEX 2 – LINE PLOTS



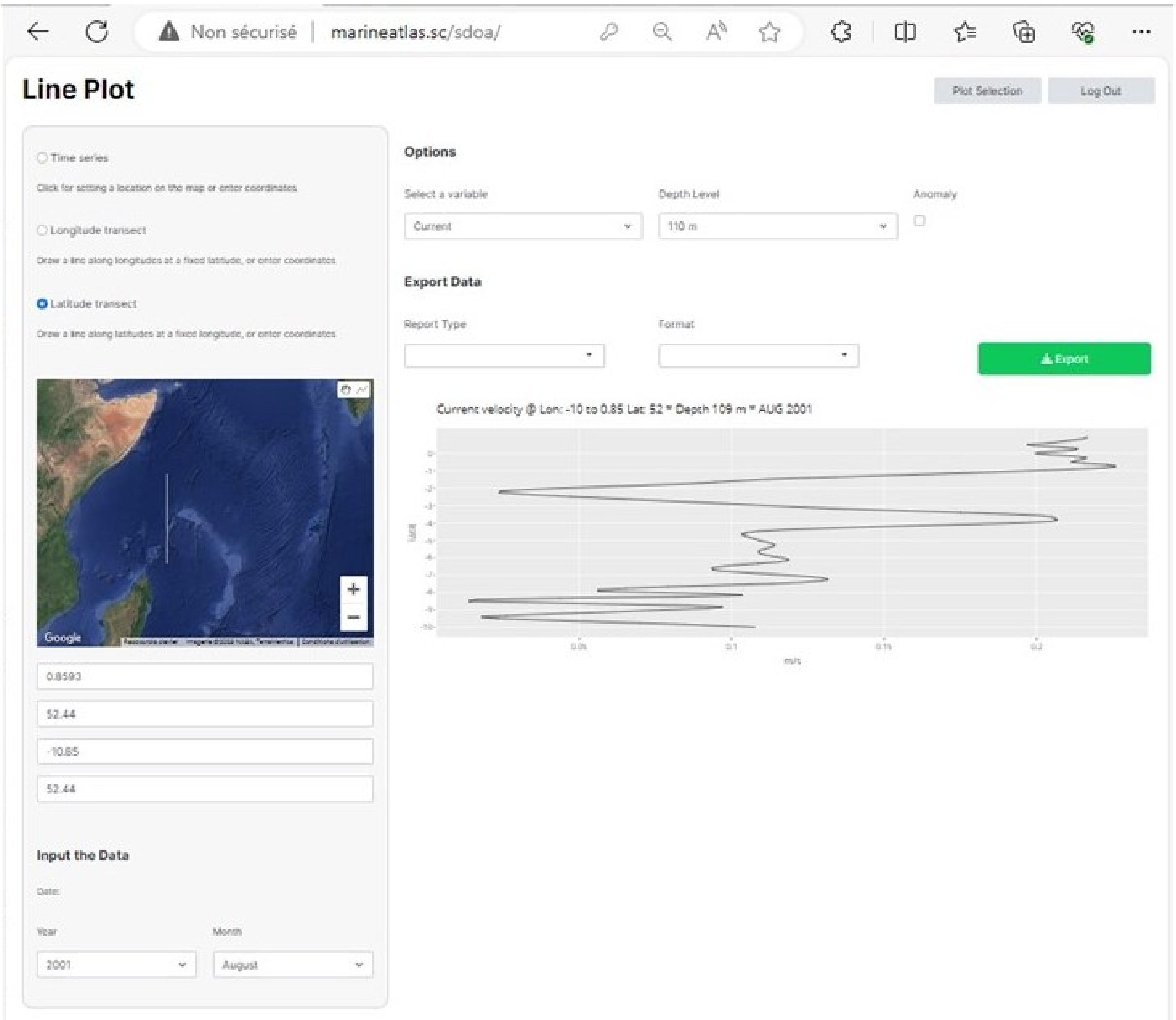
Time series of dissolved oxygen at 131 m from Jan 2000 to December 2022



Time series of the integrated chlorophyll content from January 2000 to December 2022

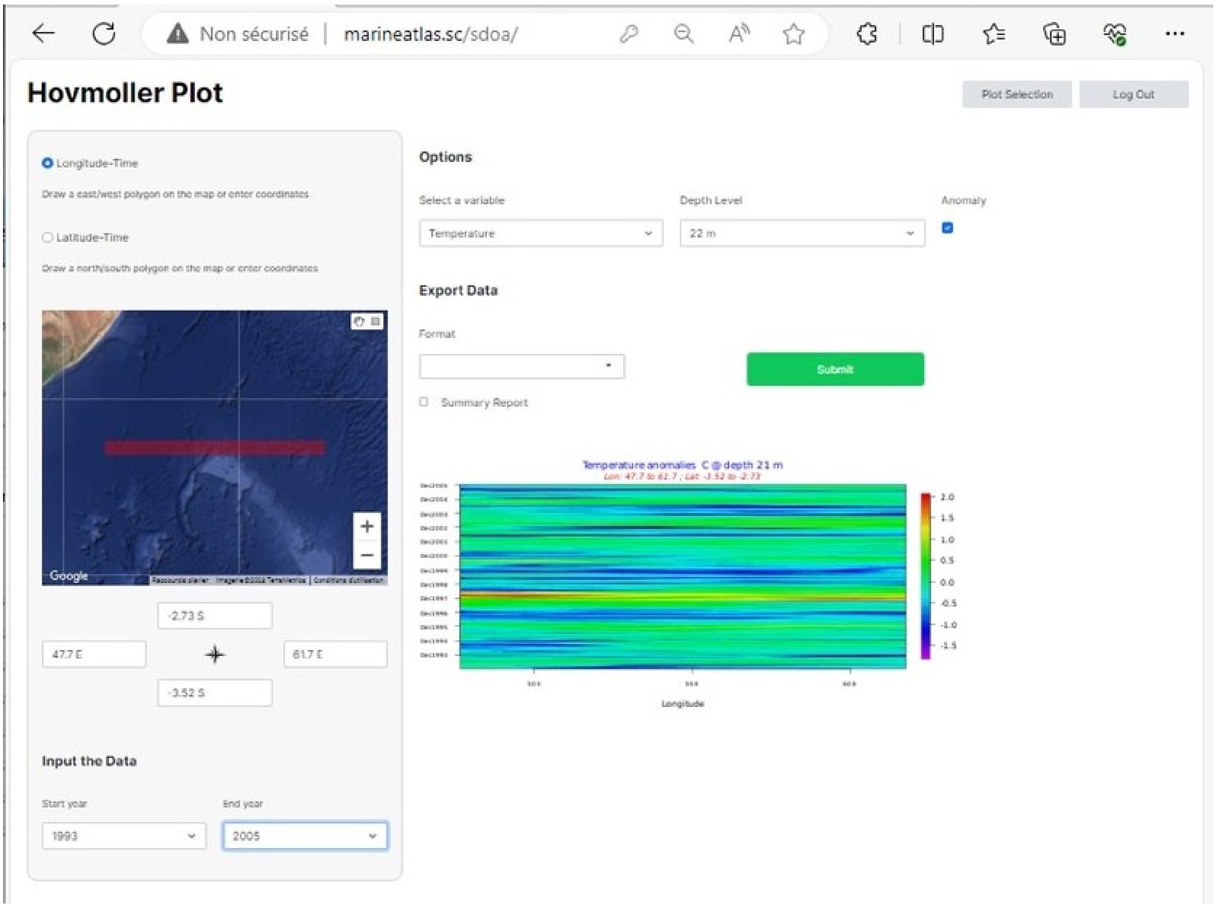


Longitudinal transect of temperature at 110 m in April 2023

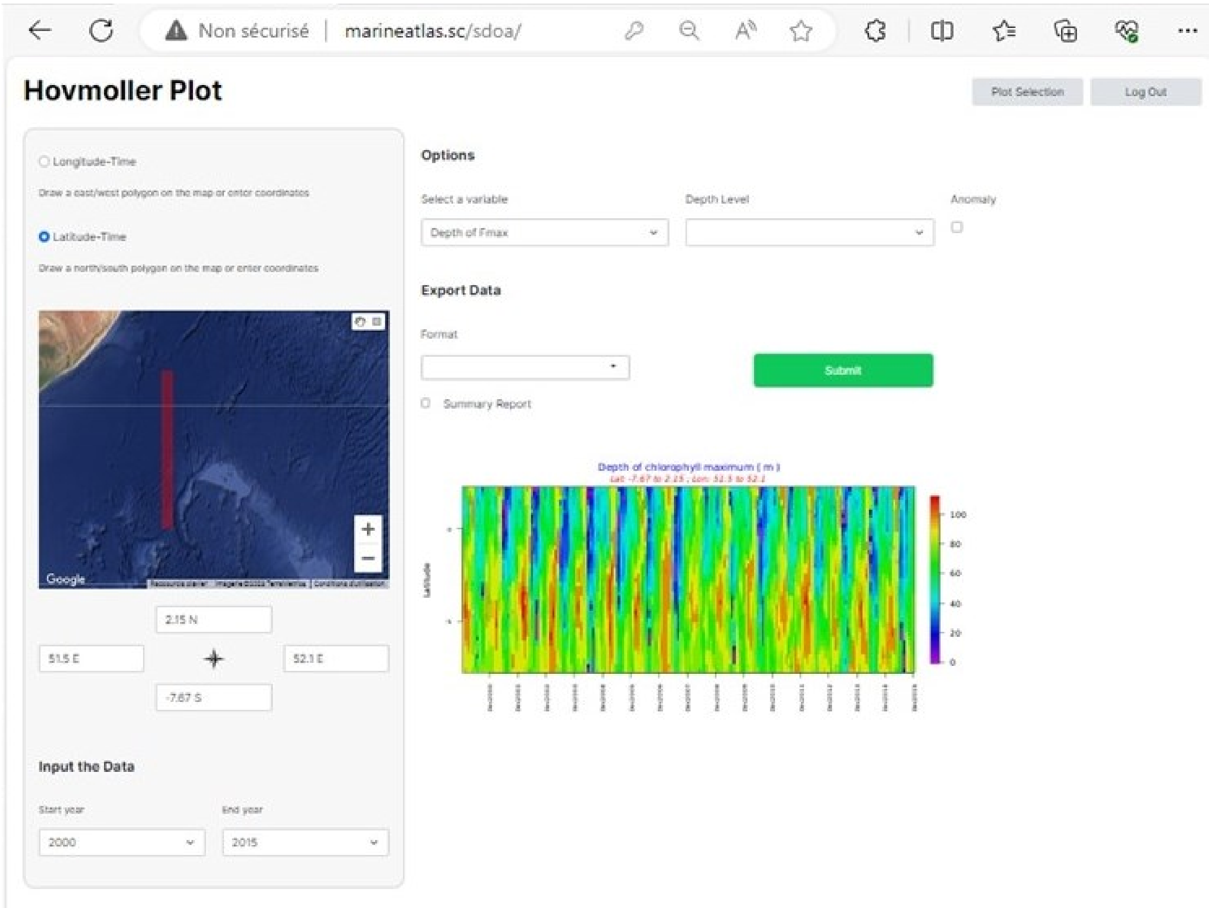


Latitudinal transect of current velocity at 110 m in August 2001

ANNEX 3 – HOVMOLLER PLOT

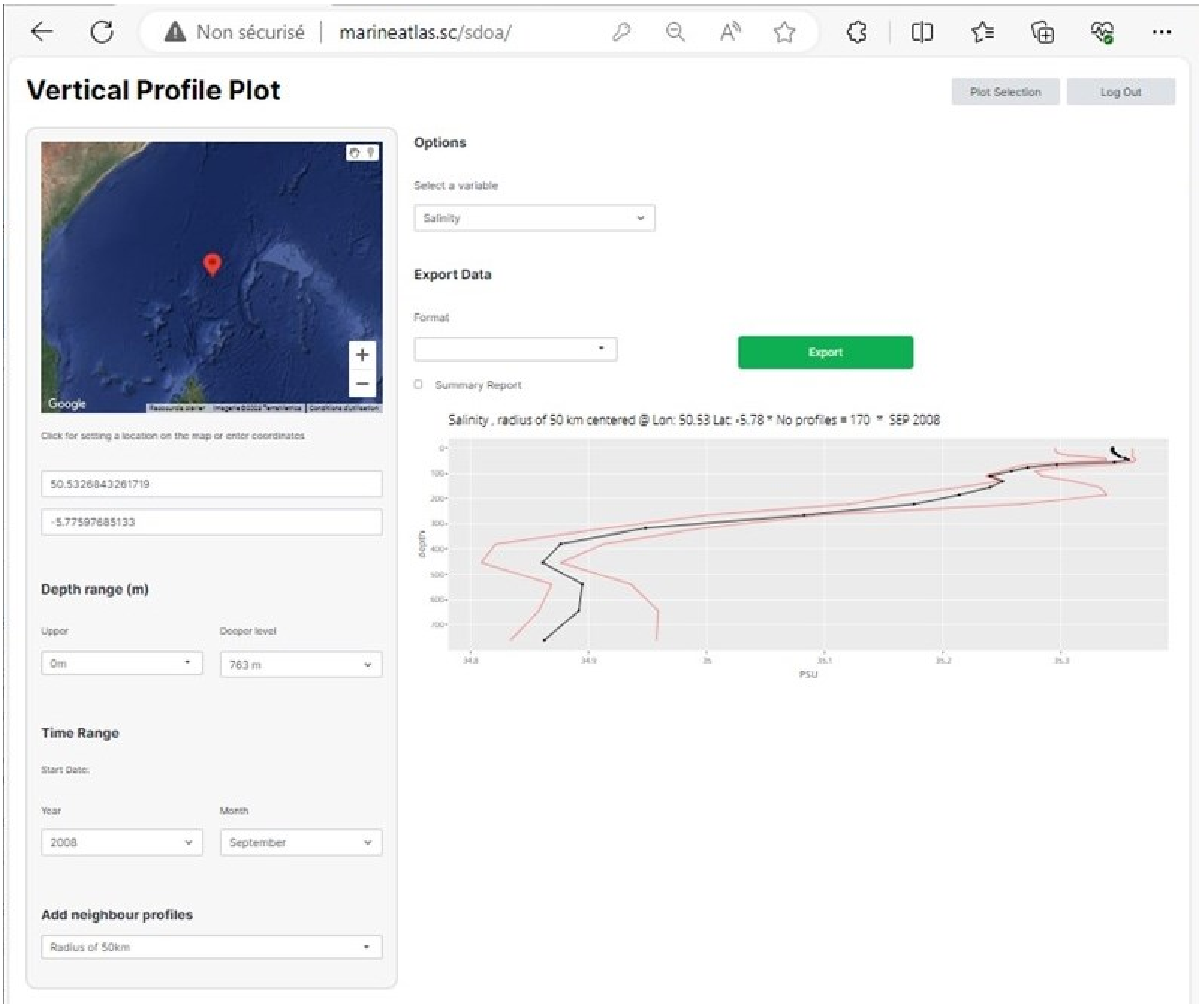


Longitude-time Hovmoller plot of temperature anomalies at 22 m from 1993 to 2005



Latitude-time Hovmoller plot of the depth of maximum chlorophyll from 2000 to 2015

ANNEX 4 – VERTICAL PLOT



Vertical profile of dissolved oxygen in September 2008, combining all profiles in a radius of 50 km around the selected position