Proposal of an online digital ocean atlas for the Indian Ocean as a tool to study the impacts of climate change and variability on tuna fisheries

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Abstract

Resolution 24/01 of the IOTC, adopted at the 28th session of the Commission, calls for a better integration of ocean and climate change information in the development of conservation and management measures. In this context, a design for a digital ocean atlas for the area of competence of the IOTC (IODA) is proposed. The atlas would produce interactively maps, time series, transects, space-time plots (hovmoller) and vertical profiles, from a set of 18 physical and biogeochemical oceanic variables, from surface to 900 m in depth. Different options are discussed on the required datasets to optimize the disk space. The Fisheries and Aquatic Resource Department of Sri Lanka is candidate to support hosting the server and deploying IT team, to perform the maintenance of the system and to have IODA running routinely. These suggestions must be discussed at the current session of the WPTT26 to devise on a roadmap for the atlas, in accordance with Res 24/01.

1. Introduction

The digital ocean atlas for Seychelles (SDOA) was presented at the 19th session of the Working Party on Data Collection and Statistics, in December 2023. The relevance of such a tool for the IOTC in the context of Res 22/01 was emphasized by the WPDCS. At its 26th session, the Scientific Committee noted the potential of the SDOA to provide detailed ocean-climate information and considered the resources needed to develop online indicators for the whole Indian Ocean. The SC also "endorsed the implementation of a scoping study to further develop all presented indicators, possibly through an online atlas, and devise the most effective ways to present these to the SC and its Working Parties" (para 140, SC Report). Finally, at its 28th session, in May 2024, the Commission adopted Res 24/01 (a revision of the former Res 22/01) to support further research to assess the impacts of climate change in IOTC fisheries. The Commission specifically tasked the WPEB to include climate change as a standing agenda item of its regular meeting, and the IOTC Secretariat to develop and keep up to date a dedicated IOTC webpage on climate change and its impacts on IOTC fisheries.

This paper is a step in the scoping study requested by the SC, however limited here to the online interactive atlas covering the whole Indian. This atlas can be seen as a tool to assist the scientific community in developing studies on the impacts of climate change and variability on tuna stocks and fisheries. A first version of this proposal was presented and discussed during the WPEB20 (9-13 September 2024). This paper is an updated version taking stock of several comments made at the WPEB20, with the expectation that other inputs from the WPTT would be included in the atlas proposal.

2. Technical design of an online atlas for the Indian Ocean

The approach proposed for the Indian Ocean Digital Atlas (IODA) is based on the experience acquired with the Seychelles Digital Ocean Atlas (SDOA), a project developed from 2021 to 2023, covering the Seychelles EEZ and its neighbouring waters, over an area of 5 million km². Details on the SDOA can be found in Marsac & Noel (2021, 2023). The different elements to be discussed about the IODA are presented hereafter.

2.1 Objectives

In the line of Res 24/01, the IODA should provide relevant information on the status of the ocean and its past and on-going trends in order to support scientific research on the relationships between climate change, tuna fisheries, tuna stocks, bycatch and pelagic ecosystem to which tuna depend on.

Therefore, the atlas project should include:

i) Datasets of oceanic products covering the Indian Ocean at the highest possible spatial resolution;
ii) A dedicated THREDDS data server (Unidata | THREDDS Data Server (TDS) (ucar.edu)) hosting the atlas datasets and using a variety of remote data access protocols;
iii) Specific scripts and a web-based application with a user-friendly interface to visualize a selection of ocean variables, either though maps, time series or other types of plots, exported to standard formats, and to calculate derived products (anomalies and general statistics);
iv) Definition and implementation of comprehensive system and data maintenance protocols;
v) Developing and maintaining data sharing SOPs (standards of procedures);
vi) Training a technical team in the server hosting site to ensure the maintenance of the atlas and to update of the datasets.

Res 24/01 emphasizes the necessity to develop capacity building programs. The atlas project would therefore include training sessions in the use of the atlas. In addition, capacity-building activities to improve the understanding of climate science and its implications on tuna stocks and tuna fisheries management could also be developed.

2.2 Possible products of the IODA

The following products are proposed:

System administration

• Contain an audit trail of all operations conducted in the system

Maps and plots

• View a map for a given ocean variable at a selected time and depth over the whole ocean (standard) or in smaller user-defined areas

• Overlay EEZ contours on any map

• Overlay additional layers of information (i.e. fisheries, biological data) on the maps of physical and biogeochemical variables

• Plot a section along a transect (drawn interactively on the map)

• Plot a time-series (with associated statistics) at a given location

• Plot a time series (with associated statistics) in a given polygon on the map

• Plot space-time diagram (Hovmoller plot) i.e. with a spatial dimension on one axis and a time dimension on the other axis

• Plot a vertical profile over the whole depth range at any location on the map

Animations

• Create and play animated maps along a range or months/years

Data export

• Export of products to text files (.txt, .csv) and to "shape" files compatible with GIS software

• Export maps in various image formats (jpg, png…)

• Export animated GIF images

Summaries

• Produce statistics summary reports (mean, average, standard deviation, minimum, maximum, coefficient of variation, median, quartiles) for the selected variables and plots.

2.3 Data standards and coding language

In order to conform to international standards, the following requirements are proposed for the file formats, database management system, and for the programming language of the application:

i) The data files are in Network Common Data Form (NetCDF) format and follow the CF-1.4 convention. NetCDF is a standard for the exchange of scientific data in binary format that are platform-independent and self-describing (files contain a header and file metadata in the form of name/value attributes). See https://www.unidata.ucar.edu/software/netcdf/ for more information)

ii) Data are available through a THREDDS Data Server (TDS), which is a web server providing metadata and data access for scientific datasets, using OPeNDAP (Open-source Project for a Network Data Access Protocol), Open Geospatial Consortium (OGC), Web Map Service (WMS) and Web Coverage Service (WCS), Hypertext Transfer Protocol (HTTP), and other remote data access protocols. See https://www.unidata.ucar.edu/software/tds/current/ for more information.

iii) R (R Core Team, 2023) is a language and environment for statistical computing and graphics. R is the language selected for coding the application. Like the SDOA, the frond-end web app will be built using the Shiny Framework which uses R as a programming language (https://shiny.rstudio.com/)

iv) The site administration backend of the SDOA, which generates statistics on access and use of the app, relies on multiple frameworks, including PHP for the admin panel, Node.js with Express for the APIs, and MariaDB for the database. The backend structure for the IODA may consider using either Node.js (similar to the SDOA) or Rust with the Axum framework. PostgreSQL will be used as the database instead of MariaDB.

2.4 Geographical boundaries

The atlas will cover the whole area of competence of the IOTC (Fig. 1). The blue-shaded area indicates the two FAO areas 51 and 57 defining the IOTC area. The red polygon bounds the area selected for the IODA.

The selected northern boundary at 30°N includes the Persian Gulf and the northern Red Sea. Moreover, the delineation along straight latitudes and longitudes leads to the inclusion in the IODA of part of the Indonesian waters North of Java belonging to the FAO area 71 (Western Pacific). Finally, the southern boundary of the IODA at 45°S is an extension to the East of the southernmost latitudes of area 51. Very few catches of IOTC species are reported south of 45°S, hence this boundary for the atlas.

2.5 Source of the ocean products

It is proposed to use the ocean products assembled and disseminated by the European Copernicus Marine Service (CMEMS). The IODA will include products from a range of data-assimilated ocean models and satellite products. The CMEMS provides free, regular and systematic authoritative information on the state of the Blue (physical), White (sea ice) and Green (biogeochemical) ocean, on a global and regional scale. Scientists, policy makers, fisheries managers, stakeholders of the civil society can access and use the data and services for marine policy implementation and to support blue growth and scientific innovation (https://marine.copernicus.eu/).

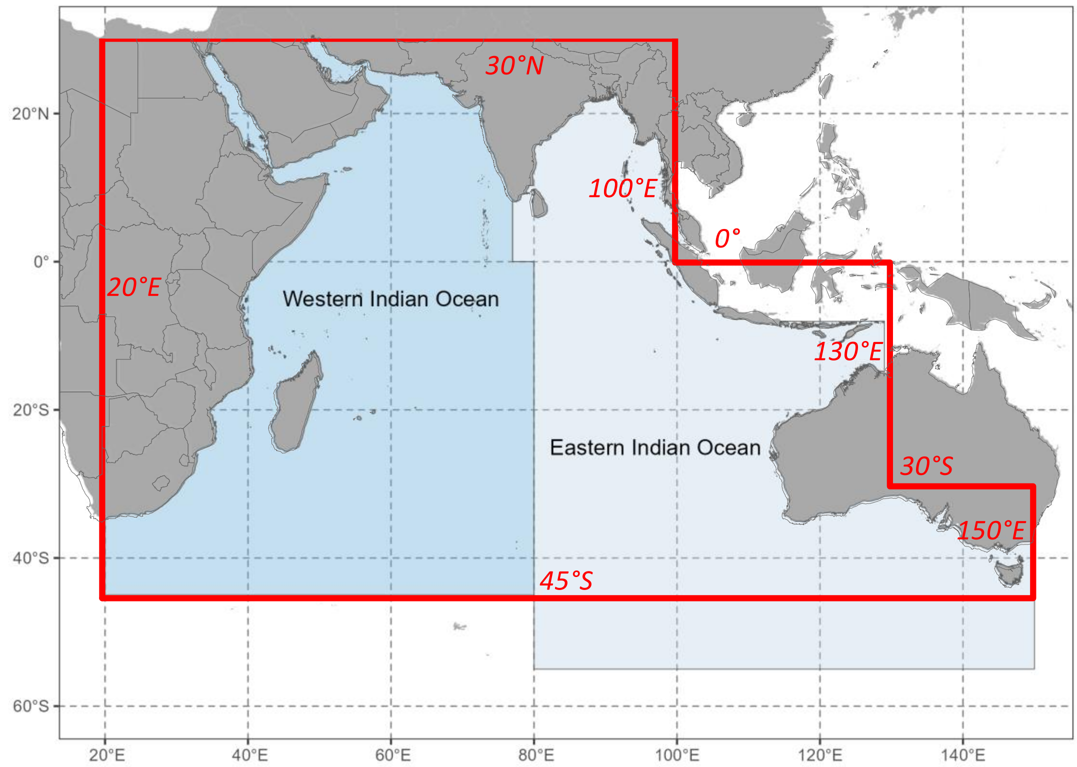

Figure 1 – Proposed geographical boundaries of the Indian Ocean Digital Atlas (IODA)

2.6 Ocean variables

The CMEMS ocean physics ("blue ocean") in reanalysis and forecast numerical models includes 25 variables. Not all these variables are appropriate for the IODA. We consider here a selection of six variables to be included in the atlas:

Ocean physics variables at CMEMS (numerical models)	
Relevant to IODA	**Not relevant to IODA**
Sea water potential temperature (T)	Sea water potential temperature at sea floor
Sea water salinity (S)	Sea water potential salinity at sea floor
Sea surface height above geoid (SSH)	Sea surface wave stokes drift x velocity
Eastward sea water velocity (U)	Sea surface wave stokes drift y velocity
Northward sea water velocity (V)	Upward sea water velocity
Ocean mixed layer thickness defined by sigma theta (MLD)	Surface sea water x velocity
	Surface sea water y velocity
	Surface sea water x velocity due to tide
	Surface sea water y velocity due to tide
	Products related to ice (9)
	Seafloor depth below geoid

The CMEMS ocean biogeochemistry ("green ocean") includes 13 variables from numerical models and satellite observations. Only six of them are considered relevant to the IODA:

Ocean biogeochemistry variables at CMEMS (numerical models and satellite observations)	
Relevant to IODA	**Not relevant to IODA**
Mass concentration of chlorophyll a in the water colum (CHL)	Mole concentration of phytoplankton expressed as carbon in sea water
Net primary production of biomass expressed as carbon per unit volume in sea water (NPP)	Mole concentration of nitrate in sea water
Mole concentration of dissolved molecular oxygen in sea water (DO)	Mole concentration of phosphate in sea water
Sea water pH reported on total scale (PH)	Mole concentration of silicate in sea water
Surface partial pressure of carbon dioxide in sea water (spCO2)	Mole concentration of dissolved iron in sea water
Surface chlorophyll content (CHLsat)	Mole concentration of dissolved inorganic carbon in sea water
	Sea water alkalinity expressed as mole equivalent
	Volume attenuation coefficient of downwelling radiative flux in sea water

Derived variables of interest for tuna fisheries can be computed from the variables downloaded on the CMEMS portal, using specific scripts run by the maintenance team each time a new month is available in the Copernicus products database. The SDOA includes 5 derived variables, which are not directly available in the Copernicus products, but are computed specifically by specific scripts by the maintenance team. These derived variables could also form part of the IODA:

- 20°C isothermal depth: a proxy of the mean depth of the thermocline (Z20);
- vertical current shear: a metric of turbulence caused by currents in the water column, which longline catchability can be related to. It can be calculated across two depth ranges, 0-130 m (SH130) and 0-450 m (SH450) for shallow and deep longline sets, respectively;
- depth of the 2.5 ml/l dissolved oxygen concentration: a proxy of the lower depth of the optimal habitat for tuna;
- depth of Fmax (maximum fluorescence): a proxy of biological productivity in stratified water column, with oligotrophic status linked to deep chlorophyll maximum (DCM or Fmax);
- integrated chlorophyll content in the upper 300 m: an overall indicator of the ocean biological productivity calculated from the vertical distribution of CHL.

For each variable selected, the atlas will also include climatological fields and anomaly fields (difference of a month with its climatological mean). Therefore, the IODA would contain 3 datasets for each of the variables.

A seafloor topography will also be included in the atlas, using the GEBCO latest release (GEBCO, 2024)

2.7 Spatial and temporal resolution

The ocean products listed in para 2.6 are available on hourly, daily and monthly basis. In line with the SDOA, we propose to use the monthly datasets only, which are appropriate to serve the objectives of the atlas. The datasets are available since January 1993. In December 2024, the datasets will span over 32 years without gaps. There was a comment at the WPEB20 that a monthly basis might not be the most appropriate for all fisheries, and that a shorter time scale, such as the week, could be considered. This option would necessitate a significant amount of work to generate weekly datasets from daily datasets and would also have a cost in terms in disk storage on the server. Nevertheless, this remains an option to be discussed.

The spatial resolution of the ocean physics datasets is 1/12° which makes 8 km at the equator. The spatial resolution of the ocean biogeochemistry datasets is ¼° which makes 25 km at the equator. The equirectangular projection used introduces a slight deformation which remains acceptable until the 45th parallel in latitude.

In the proposed boundaries of the IODA, the ocean physics datasets would have 1561 grid cells in longitude (20°E to 150°E) and 901 grid cells in latitude (45°S to 30°N), making a matrix of 1 406 461 cells for each datasets and month. For the ocean biogeochemistry, the matrix would include 521 grid cells in longitude and 301 grid cells in latitude, making a total of 156 821 grid cells per dataset and month.

In the vertical dimension, the Copernicus datasets in full contain 50 levels ranging from 0 to 5500 meters. In the SDOA, only 34 levels were selected, from 0 to 763 m, which spans the depth range used by the fishing gears. The interval between levels is not regular, the smallest intervals (1 to 8 meters) are concentrated in the upper mixed layer (0-55 m), then intervals increase with depth.

2.8 Data storage and required disk space

Data storage must be considered with caution as there is a cost associated to data storage. Moreover, too large datasets can lengthen the processing time of data at each query. Then we have to be parsimonious when designing the final structure of the atlas. Table 1 shows the size of the datasets in the scenario with 18 variables (12 + 6 derived) and 35 depth levels (0 to 902 m[1]), including their anomalies and climatological fields. The *3dim* files correspond to variables with *lat x lon x depth* along time. The other category (*one-layer files*) are those characterized by a single value at each *lat x lon* grid cell along time (e.g. depth of 20°C). The size of the datasets with 35 depth levels is close to 710 gigabytes for 32 years of archive data (1993-2024), considering that the datasets will grow by 43 gigabytes each year.

Table 1 – Size of the IODA datasets with 18 variables and 35 depth levels (0-902 m)

(Size in Kb) 35 levels

3dim files	standard	anomalies	Clim 1993-2016	Clim 2021-2023	**Total IOTC area**
t	2 306 257	2 306 257	2 306 257	2 306 257	9 225 028
s	2 306 257	2 306 257	2 306 257	2 306 257	9 225 028
u	2 306 257	2 306 257	2 306 257	2 306 257	9 225 028
v	2 306 257	2 306 257	2 306 257	2 306 257	9 225 028
do	257 314	257 314	257 314	257 314	1 029 255
npp	257 314	257 314	257 314	257 314	1 029 255
ph	257 314	257 314	257 314	257 314	1 029 255
chl (0-300m)	213 348				213 348
One-layer files by year					
mld	66 120	66 120	66 120	66 120	264 480
z20	66 120	66 120	66 120	66 120	264 480
sh130	66 120	66 120	66 120	66 120	264 480
sh450	66 120	66 120	66 120	66 120	264 480
ssh	66 120	66 120	66 120	66 120	264 480
chlsat	263 604	263 604	263 604	263 604	1 054 416
intChl	7 378	7 378	7 378	7 378	29 512
fmax	7 378	7 378	7 378	7 378	29 512
ox25	7 378	7 378	7 378	7 378	29 512
spco2	7 378	7 378	7 378	7 378	29 512
Total by year	10 834 034	10 620 686	10 620 686	10 620 686	42 696 091
Total 1993-2024	346 689 079	339 861 943	10 620 686	10 620 686	707 792 393
GEBCO	1 097 264				1 097 264
Total incl. GEBCO	347 786 343	339 861 943	10 620 686	10 620 686	708 889 657
Shiny server	100 000				
Total space requested					**708 989 657**

[1] The depth of 902 m was defined after discussions at the WPEB, to cover the vertical movements of swordfish

An alternative scenario to reduce the storage size is to remove several levels of the mixed layer separated by short intervals, where variations between levels are very small. Then, we propose to keep a selection of 20 depth levels in the datasets:

0, 10, 25, 40, 56, 78, 92, 110, 130, 156, 186, 222, 266, 318, 380, 454, 541, 644, 763, 902 m

With 20 depth levels, the size of the datasets would be 430 gigabytes, a 40% reduction compared to the 35-levels scenario, with annual growth of 26 gigabytes (Table 2). We consider that the removal of 15 levels will not affect substantially an accurate description of the water column and the objectives of the atlas. Therefore, this option could be considered as a trade-off allowing substantial information at a lower storage cost.

Table 2 – Size of the IODA datasets with 18 variables and 20 depth levels (0 to 902 m)

(Size in Kb) 20 levels

3dim files	standard	anomalies	Clim 1993-2016	Clim 2021-2023	**Total IOTC area**
t	1 318 591	1 318 591	1 318 591	1 318 591	5 274 364
s	1 318 591	1 318 591	1 318 591	1 318 591	5 274 364
u	1 318 591	1 318 591	1 318 591	1 318 591	5 274 364
v	1 318 591	1 318 591	1 318 591	1 318 591	5 274 364
do	147 045	147 045	147 045	147 045	588 180
npp	147 045	147 045	147 045	147 045	588 180
ph	147 045	147 045	147 045	147 045	588 180
chl (0-300m)	213 204	213 204	213 204	213 204	852 816
One-layer files by year					
mld	65 959	65 959	65 959	65 959	263 836
z20	65 959	65 959	65 959	65 959	263 836
sh130	65 959	65 959	65 959	65 959	263 836
sh450	65 959	65 959	65 959	65 959	263 836
ssh	65 959	65 959	65 959	65 959	263 836
chlsat	263 302	263 302	263 302	263 302	1 053 208
intChl	7 375	7 375	7 375	7 375	29 500
fmax	7 375	7 375	7 375	7 375	29 500
ox25	7 375	7 375	7 375	7 375	29 500
spco2	7 375	7 375	7 375	7 375	29 500
Total by year	6 551 300	6 551 300	6 551 300	6 551 300	26 205 200
Total 1993-2024	209 641 600	209 641 600	6 551 300	6 551 300	432 385 800
GEBCO	1 097 264				1 097 264
Total incl. GEBCO	210 738 864	209 641 600	6 551 300	6 551 300	433 483 064
Shiny server	100 000				
Total space requested					**433 583 064**

Should the size of the datasets need to be reduced further, another scenario would be to remove variables that are thought of less interest for IOTC tuna fisheries, but this should be discussed and agreed by the group.

Several examples of maps, time plots, hovmoller and vertical plots for the IODA are presented in the Appendix.

2.9 A site for the IODA server

The most convenient option would be that one CPC of the IOTC hosts the server and performs the routine checks as well as the maintenance of the atlas when it goes online. Indeed, this requires that IT staff is available and has the required skills at one national institution of the CPC, especially the set up and functioning of a THREDDS server.

At the 19th session of the WPDCS, Sri Lanka has expressed interest to host and maintain the atlas server. There is a possibility to deploy IT team of Fisheries and Aquatic Resource Department of Sri Lanka to maintain the system and the hosting could be covered for a prescribe period with supportive eternal funds available for the implementation of fisheries management systems in Sri Lanka.

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3. Conclusion and way forward

The development of a digital online ocean atlas for the Indian Ocean is a concrete objective in the context of Res 24/01. The atlas project (IODA) would benefit from a previous experience in a smaller area, the western Indian Ocean around Seychelles, which provides the ground to scale up the Seychelles atlas (SDOA) to the Indian Ocean atlas (IODA). The scoping study requested by the SC has been initiated in this paper, however the options detailed here need to be further discussed by the WPTT (and ultimately by the WPDCS) to devise a consolidated project (with terms of reference and budget) at the upcoming SC. It is also understood that one CPC will have to engage by providing the technical environment to host the atlas server, and the human resources to run it on a routine basis. Sri Lanka is expressing interest into this endeavour.

References

GEBCO (2024). Global ocean & land terrain models. Gridded Bathymetry Data. Retrieved from https://www.gebco.net/data_and_products/gridded_bathymetry_data. (Accessed August 2024)

Marsac, F. (2018). Proposal for the development of an ocean-climate web page for the IOTC. IOTC-2018-WPDCS14-36, 9p.

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

Marsac, F. and Noel, E. (2023). Status of the Seychelles Digital Ocean Atlas (SDOA) in 2023. IOTC-2023-WPDCS19-33, 18p.

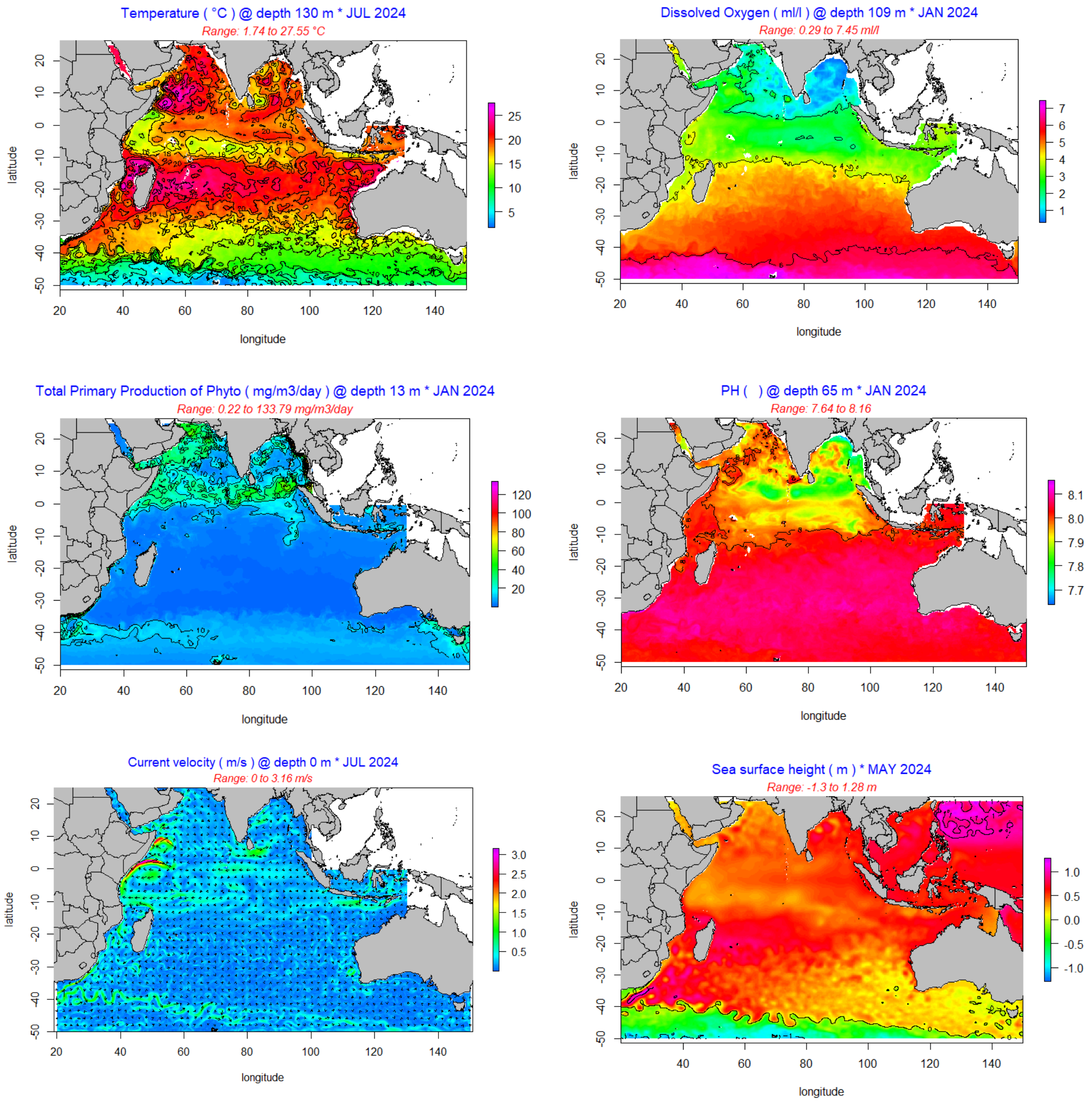
R Core Team (2023). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

APPENDIX

Examples of plots of several variables for the IODA

The IODA would include several categories of plots: Maps, Line plots (time series, transects), Hovmoller plots and Vertical plots. Examples are given hereafter.

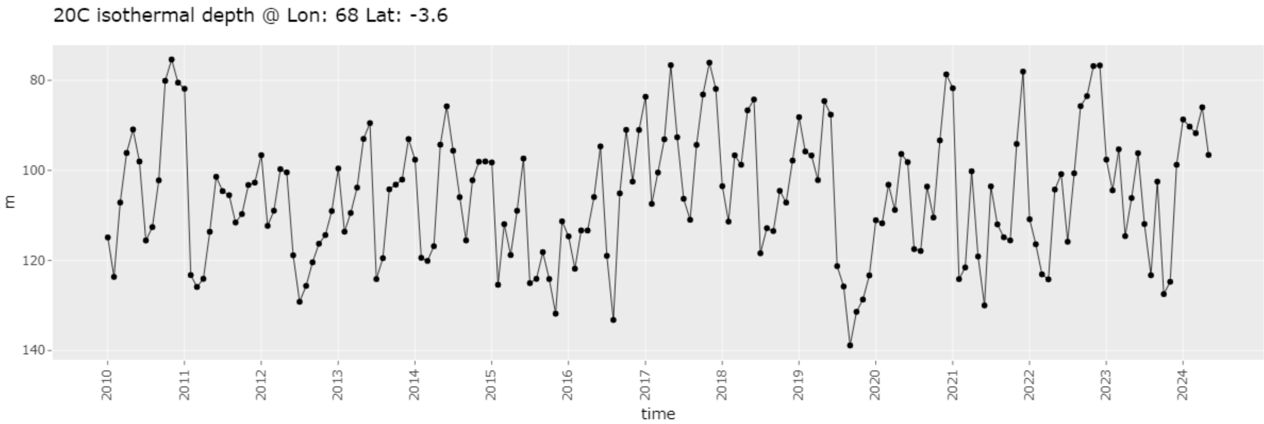
1) MAPS



Maps of several variables extracted from provisional IODA datasets

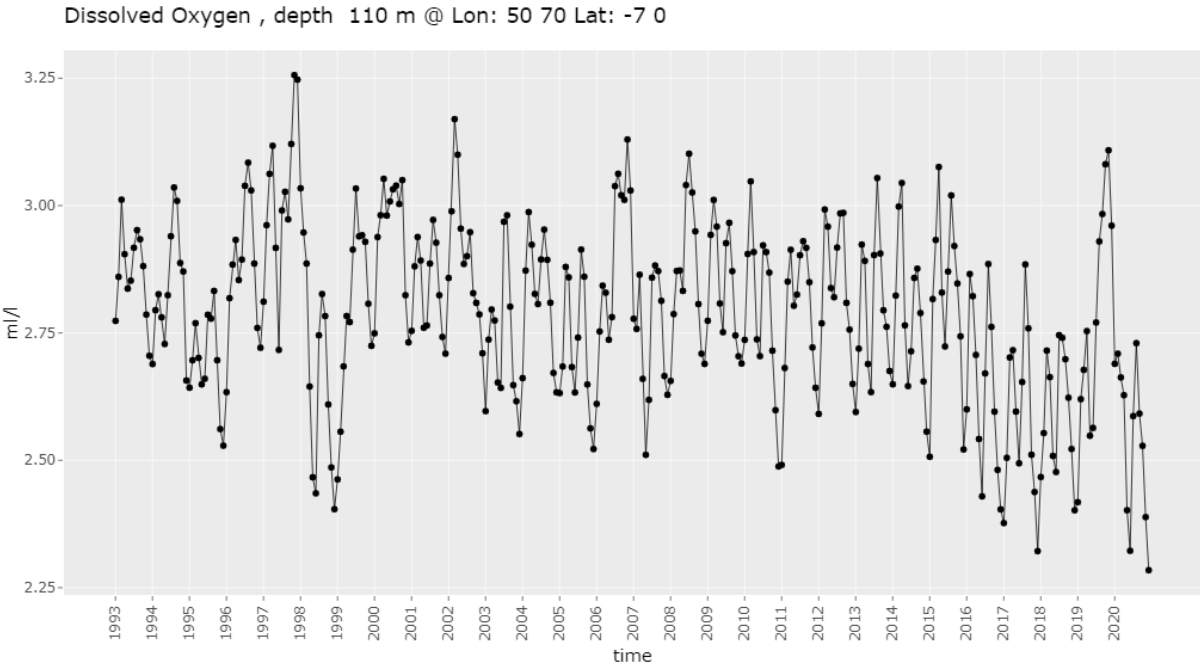
2) TIME SERIES

At a given location:



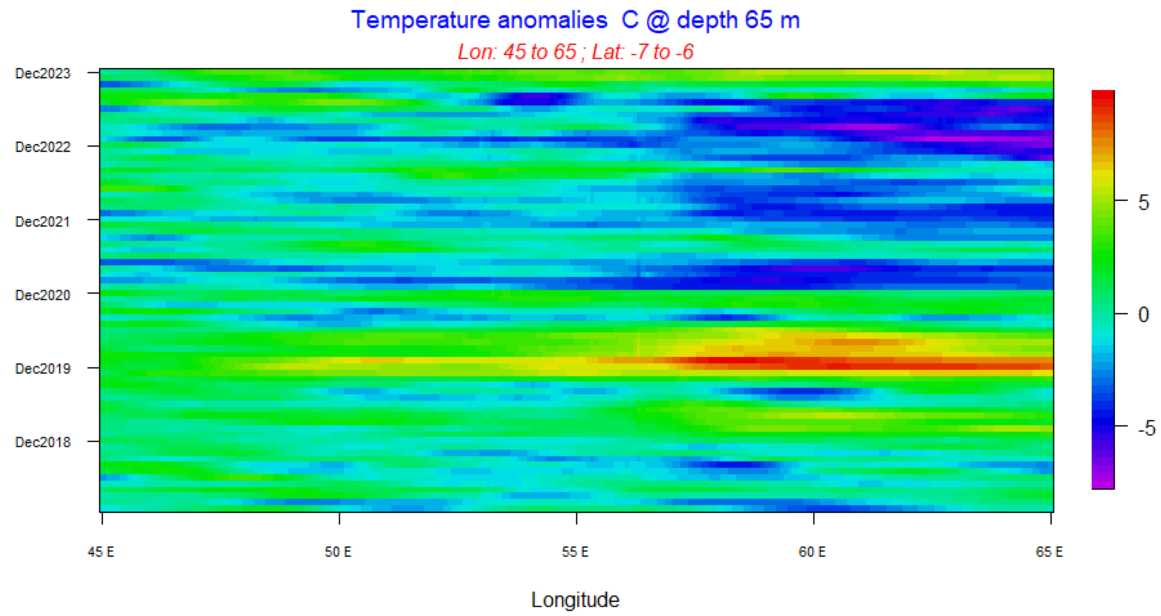
Time series of the 20°C isothermal depth, Jan 2010 to May 2024,
at longitude 68°E and latitude 3.6°S

Mean inside a polygon:

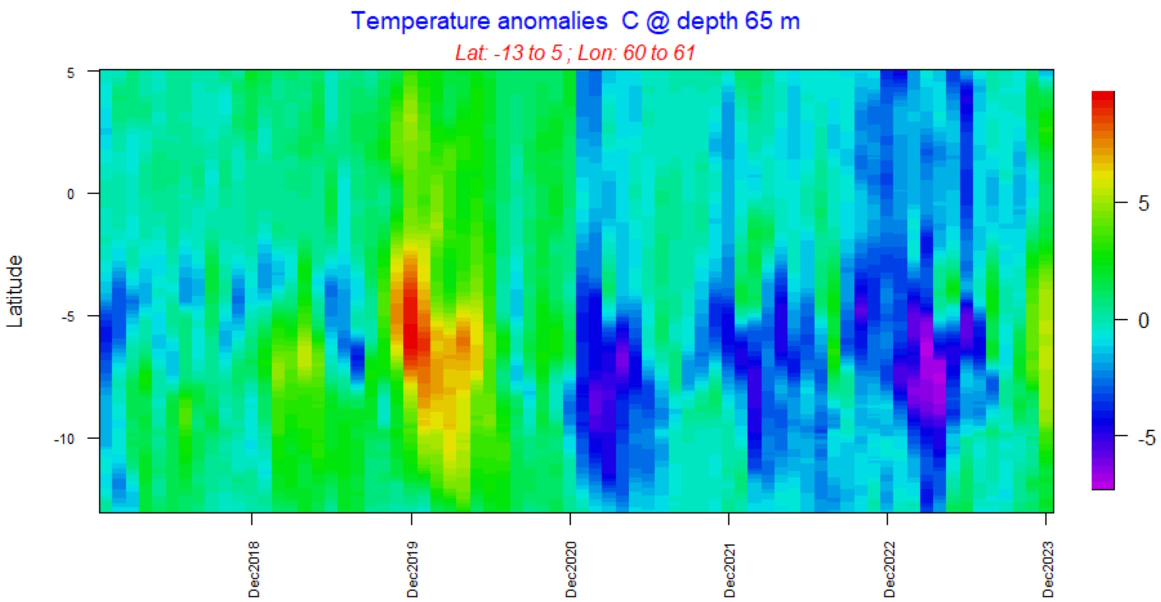


Time series of the dissolved oxygen at 110 m, Jan 1993 to December 2020,
between 50°E-70°3 and 0°-7°S

3) HOVMOLLER PLOT

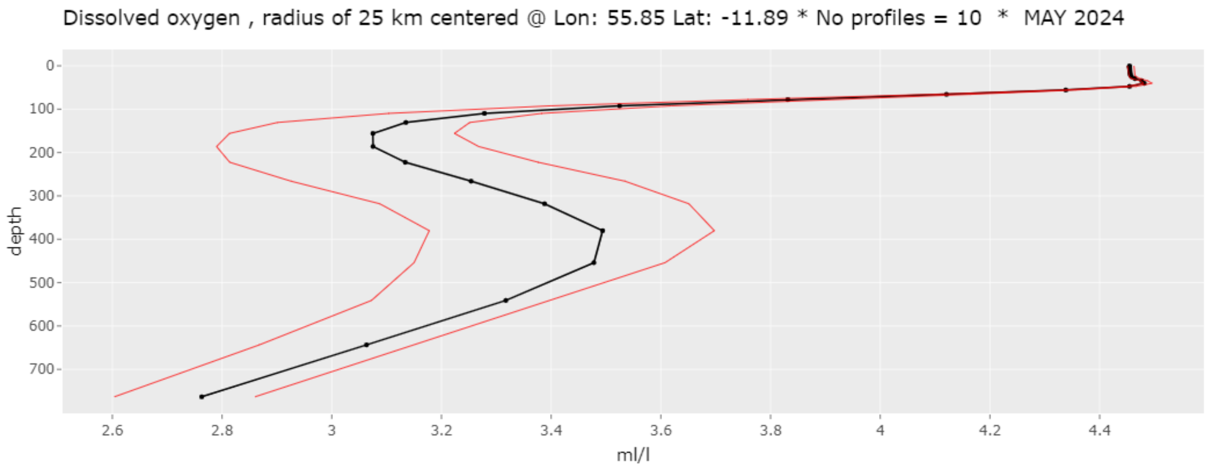


Distribution of temperature anomalies at 65 m from 45°E to 65°E in the latitudinal belt 6°S-7°S, 2018 to 2023.



Distribution of temperature anomalies at 65 m, from 5°N to 13°S in the longitudinal belt 60°E to 61°E, 2018 to 2023.

4) VERTICAL PLOT



Vertical profile of dissolved oxygen, at 55.85°E and 11.89°S, May 2024, with ranges of values in a radius of 25 km around the location (red line)