Proposal of an online digital ocean atlas for the Indian Ocean and a dedicated IOTC webpage on climate change and its impacts 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 monthly maps, time series, transects, space-time plots (hovmoller) and vertical profiles, from a set of 18 physical and biogeochemical oceanic variables, from surface to 763 m 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. In this paper, we also suggest guidelines for the development of an ocean-climate web page on the IOTC web site, to present indicators and trends on the ocean and climate, and provide educational materials in relation to climate change in the Indian Ocean. Those suggestions for the atlas and the web page must be discussed by the WPEB to define a roadmap 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. 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 though 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, the Commission adopted Res 24/01 (a revision of the former Res 22/01) to support further research to assess the actual and potential 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 initiates the scoping study requested by the SC, by proposing a design of an online and interactive atlas covering the whole Indian Ocean (from the atlas project developed for Seychelles) and some ideas for the ocean-climate web page for the IOTC. This proposal is meant to be discussed during this WPEB session to draw a road map for a better understanding of climate change effects on tuna fisheries and its implication for the conservation and management of tuna stocks.

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 millions Km². Details on the SDOA can

be found in Marsac & Noel (2021, 2023). The different steps to be discussed and agreed are presented hereafter.

2.1 Objectives

Based on Res 24/01, the IODA should provide relevant information on the status of the ocean and its past and ongoing trend in order to support scientific research into the relationship between climate change, tuna fisheries, tuna stocks, bycatch and pelagic ecosystem to which tuna depend on.

Therefore, the atlas project should include:

i) Creating datasets of oceanic products covering the Indian Ocean at the highest possible spatial resolution;
ii) Setting up 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) Developing scripts and a web-based application with a user-friendly interface to select ocean variables to be plotted, either though maps or other types of graphs, 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.

Complementing the atlas project, as reminded in Res 24/01, users' training sessions and capacity-building programs to improve climate change science and the understanding of climate change impacts on tuna stocks should also be organised.

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 (optional)
- Plot a section along a transect (drawn interactively on the map)
- Plot a time-series (and produce associated statistics) at a given location
- Plot a time series (and produce associated statistics) in a given polygon drawn 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 animated maps along a range or months/years

Data export
- Export selected data to text files (.txt, .csv) and to "shape" files compatible with GIS software
- Export maps in various image formats (jpg, png…)
- Export animations in 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 the language selected for coding the application. The frond-end user interface is developed in Shiny, a R package designed to build interactive web apps straight from R (https://shiny.rstudio.com/)

iv) The site administration backend, which generates statistics on users, is coded in PHP. The meta-database containing the available products used by the IODA is a SQL relational database. The backend portal will also provide login access, permission control, audit log, administrative and management reports as requested by the project's administrator.

2.4 Geographical boundaries

The atlas should cover the whole area of competence of the IOTC (Fig 1). The blue-shaded area indicates the two FAO areas 51 and 57 that correspond to the IOTC area. The red polygon is the area selected for the IODA.

It is noted that the northern boundary (25°N) does not include 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 belonging to the FAO area 71 (Western Pacific). Finally, the southern boundary of the IODA at 50°S is intermediate between the southernmost latitudes of Area 51 (45°S) and Area 57 (55°S).

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 would 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/).

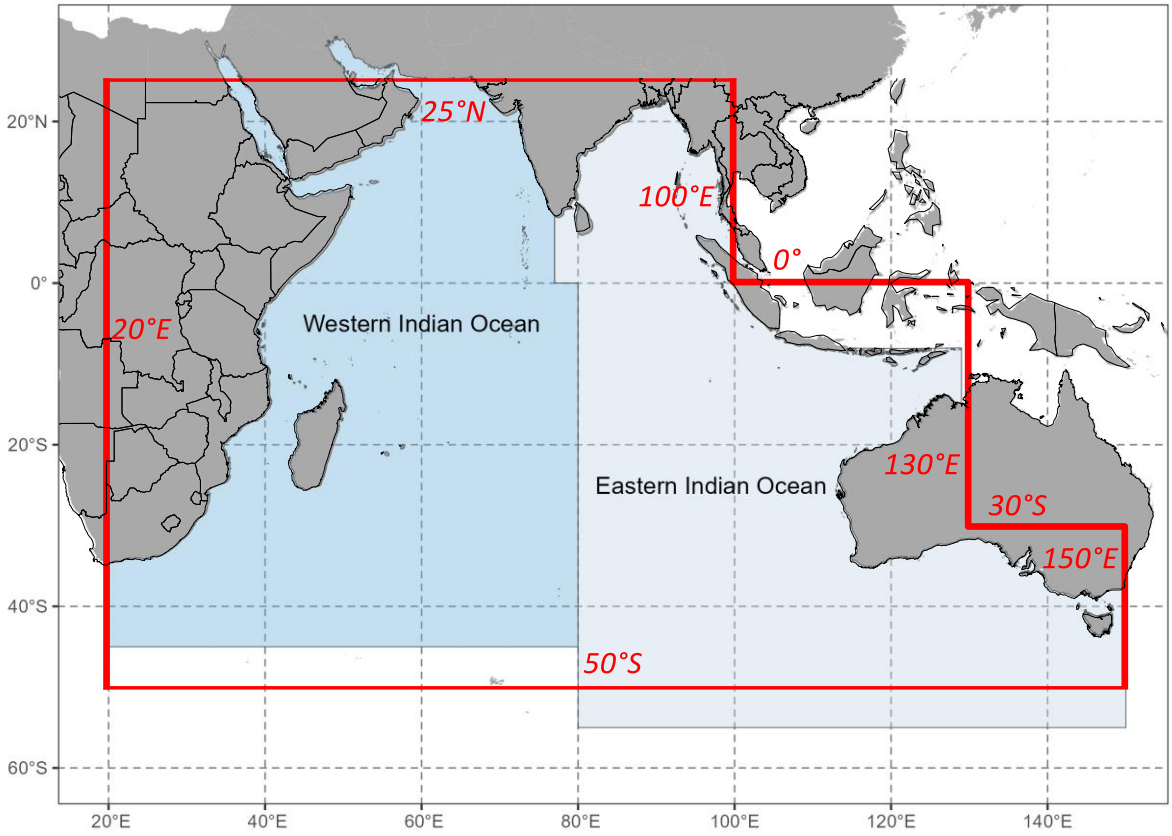

Figure 1 – Proposed geographical boundaries of the Indian Ocean Digital Atlas

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, from which only six 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 sea water (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 from the CMEMS portal, using specific scripts that are run by the maintenance team each time a new month is loaded in the database. The SDOA includes 5 derived variables, which 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 metrics 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) for shallow longline sets, and 0-450 m (SH450) for deep longline sets;
- 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 include climatological fields and anomaly fields. Therefore, there will be 3 datasets for each variable in the IODA.

A seafloor topography is also 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 more 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.

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 (50°S to 25°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 original datasets 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 34 depth levels, including their anomalies and climatological fields. The 3dim files correspond to variables with *lat x lon x depth* along time. The other category (onelayer 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 34 levels is 1.3 Terabytes for 32 years of archive (1993-2024), considering that the datasets will grow by 41.5 Gigabytes each year.

Table 1 – Size of the IODA datasets with 18 variables and 34 depth levels

(Size in Kb)

3dim files (by year)	standard	ano	Clim 1993-2016	Clim 2021-2023	Total IOTC area
t	2 240 364	2 240 364	2 240 364	2 240 364	8 961 456
s	2 240 364	2 240 364	2 240 364	2 240 364	8 961 456
u	2 240 364	2 240 364	2 240 364	2 240 364	8 961 456
v	2 240 364	2 240 364	2 240 364	2 240 364	8 961 456
do	249 962	249 962	249 962	249 962	999 848
npp	249 962	249 962	249 962	249 962	999 848
ph	249 962	249 962	249 962	249 962	999 848
chl0-300	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	10 548 406	10 335 058	10 335 058	10 335 058	41 553 580
Total 1993-2024	337 548 992	330 721 856	330 721 856	330 721 856	1 329 714 560
GEBCO	1 097 264				1 097 264
Total incl. GEBCO	338 646 256	330 721 856	330 721 856	330 721 856	1 330 811 824
Shiny server	100 000				
Total space requested					**1 330 911 824**

An alternative scenario to reduce the storage size is to remove several levels of the mixed layer separated by short intervals. The proposal is to keep the following depth levels in the datasets:

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

Retaining these 19 levels, the size of the datasets would then be 780 Gigabytes, a 41% reduction compared to the 34-levels scenario, with annual growth of 24.3 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.

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 at the WPEB.

Table 2 – Size of the IODA datasets with 18 variables and 19 depth levels

(Size in Kb)

3dim files	standard	ano	Clim 1993-2016	Clim 2021-2023	total IOTC
t	1 251 600	1 251 600	1 251 600	1 251 600	5 006 400
s	1 251 600	1 251 600	1 251 600	1 251 600	5 006 400
u	1 251 600	1 251 600	1 251 600	1 251 600	5 006 400
v	1 251 600	1 251 600	1 251 600	1 251 600	5 006 400
do	139 723	139 723	139 723	139 723	558 892
npp	139 723	139 723	139 723	139 723	558 892
ph	139 723	139 723	139 723	139 723	558 892
chl0-300	119 189				119 189
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	6 168 474	6 049 285	6 049 285	6 049 285	24 316 329
Total 1993-2024	197 391 162	193 577 120	193 577 120	193 577 120	778 122 522
GEBCO	1 097 264				1 097 264
Total incl. GEBCO	198 488 426	193 577 120	193 577 120	193 577 120	779 219 786
Shiny server	100 000				
Total space requested					**779 319 786**

Several examples of maps, time plots, hovmoller and vertical plots for the IODA are given 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.

3. Climate change indicators and impacts on tuna fisheries

The setting up of a web page dedicated to the ocean-climate under iotc.org is also a project that needs reflection. Obviously, this web page will have links to the online atlas, but it should also present indicators that can be helpful to understand climate trends in the Indian Ocean and potential impacts on tuna fisheries.

There are many web pages worldwide with climate information; then the goal of the IOTC ocean-climate web page would be to filter and gather the information relevant to the Indian Ocean. A first proposal was presented at the 14th session of the WPDCS, in 2018 (Marsac, 2018) and this can be a starting point for a group discussion. Potentially, the web page could include:

- Links to the most recent literature on climate change and variability in the IO
- Time series of the most popular climate indicators (e.g. Southern Oscillation Index, Indian Ocean Dipole Mode Index, …) updated monthly
- A portal to the most relevant datasets (not included in the atlas) for ocean observations (winds, drifters, world ocean atlas…), ocean models (Global Ocean Data Assimilated System -GODAS- of the NOAA), and remote sensing (ocean colour, sea surface temperature, altimetry).
- Static pages summarizing spatial patterns for several key parameters (results of PCA/ Empirical Orthogonal Functions, and climatology)
- Educational resources on climate change impacts specifically for the Indian Ocean (sea level rise, heat waves) and relationships to tuna ecology and fisheries

The Secretariat of the IOTC will need to be assisted by a few volunteers among the CPCs scientific community to update the contents of the different sections of the web page. Resources and inputs into this project need to be well assessed, as reminded in the WPDCS 14 report:

> *The WPDCS **NOTED** the need to find a balance between the efforts required by the IOTC Secretariat to successfully manage this additional information and the benefits provided to the Scientific community, and **SUGGESTED** that a scoping study focusing on the availability of the information, the format used for its dissemination and the potential for an automated update of the presented information be explored (Para 183).*

4. Conclusion

The development of a digital online ocean atlas for the Indian Ocean, and a dedicated ocean-climate web page are concrete objectives 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 WPEB to devise a consolidated project (with 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.

The ocean-climate web page will need discussions (during the WPEB session and during the weeks after) to agree on the different topics that should be included in this web page. It will also need an approval by the FAO headquarters should this web page be part of the IOTC web site. So, we can consider this web page initiative will take more time to kick off than the IODA project.

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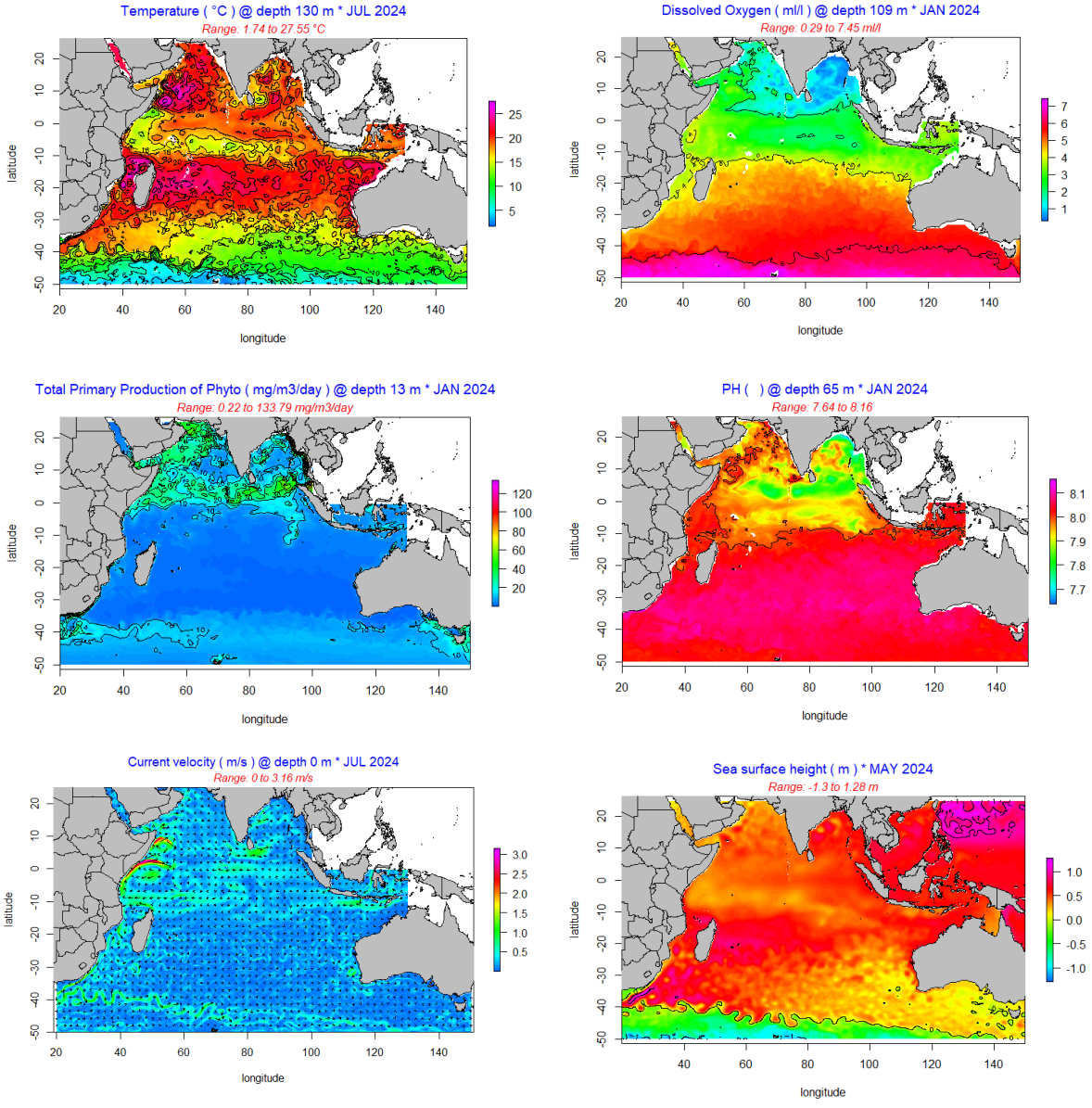
APPENDIX

Examples of plots of several variables for the IODA

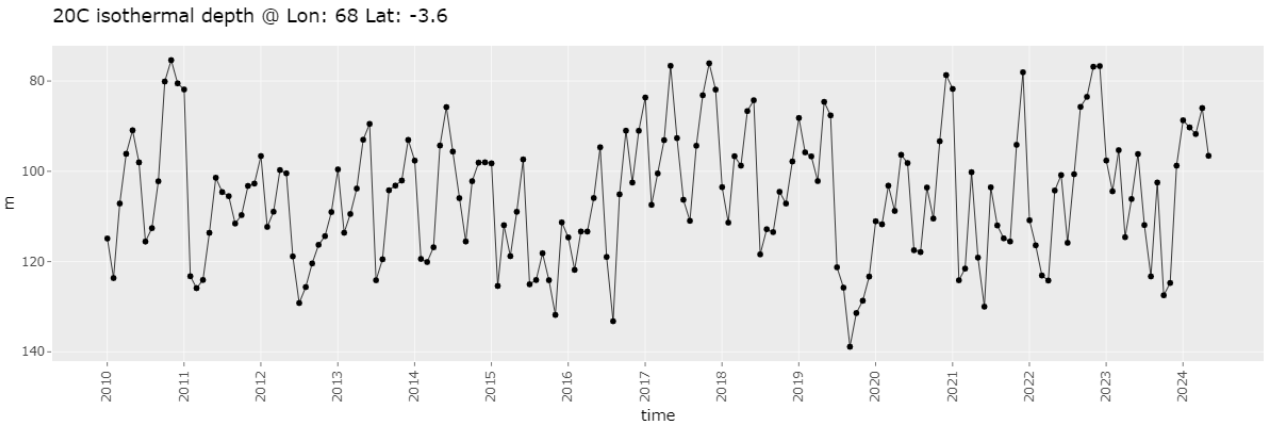
The IODA would include several categories of plots: Maps, Line plots (time series, transects), Hovmoller plots and Vertical plots. Examples are given hereafter.

1) MAPS



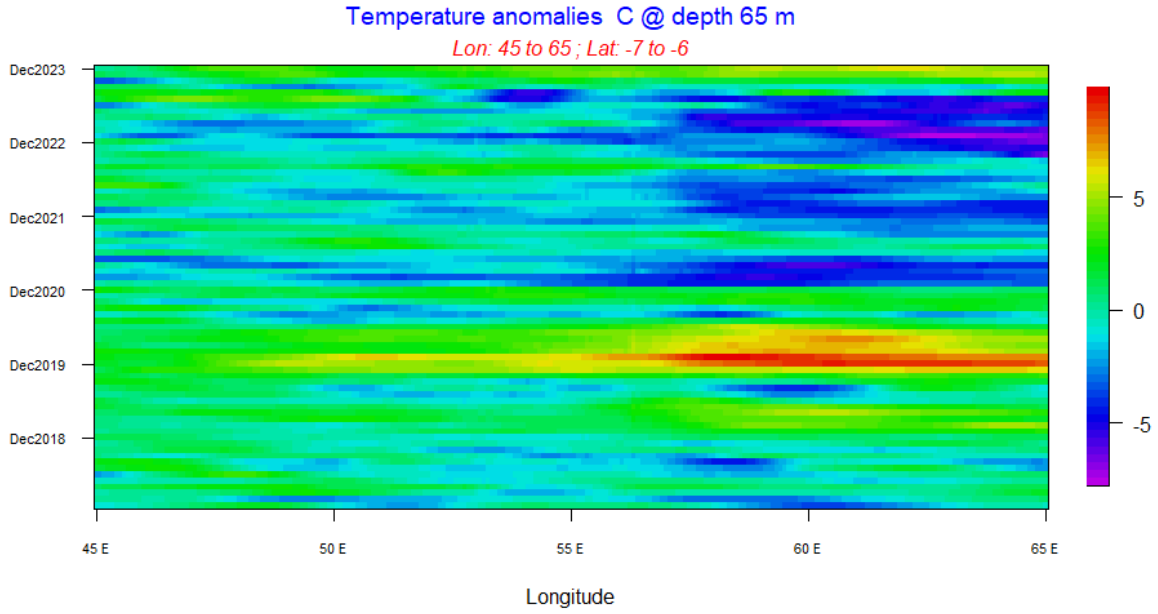
Maps of several variables extracted from provisional IODA datasets

2) TIME SERIES

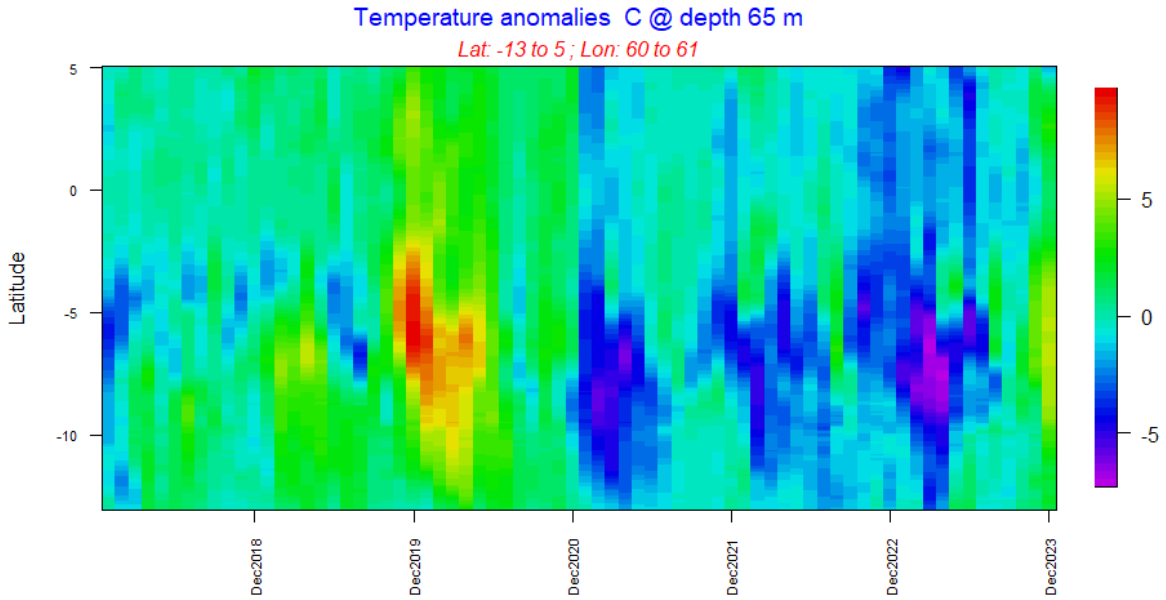


Time series of the 20°C isothermal depth, Jan 2010 to May 2024,
at longitude 68°E and latitude 3.6°S

3) HOVMOLLER PLOT

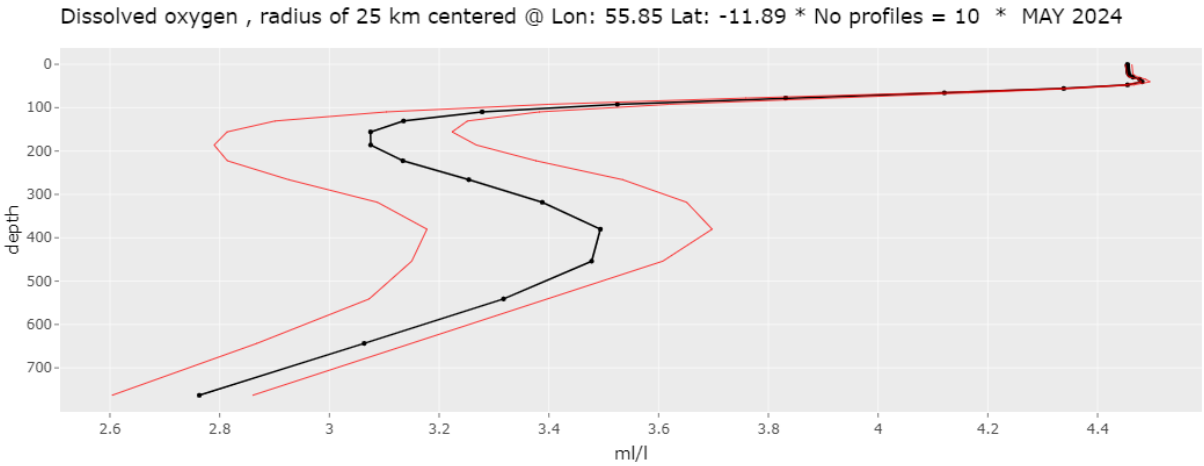


Distribution of temperature anomalies at 65 m from 45°E to 65°E in the latitudinal belt 6°S-7°S,
2018 to 2023.



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)