Food and Agriculture Organization of the United Nations

Indian Ocean Tuna Commission
Commission des Thons de l'Ocean Indien
iotc ctoi

[IOTC-2026-WPDCS22-16]

Explore ocean patterns and trends at your fingertips with the newly released Indian Ocean Digital Atlas (IODA)

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Purpose, expectation and action intended

The development of a digital and interactive atlas to monitor ocean and climate conditions in the Indian Ocean (IODA) was commissioned by the IOTC in 2026, in line with Res 25/01. This working paper provides an overview of the atlas and describes its functionalities.

Discussions

The paper informs meeting participants of the release of the first version of IODA and promotes its use by the scientific community for fisheries and environmental research. Following the presentation, the floor will be open for questions, clarifications and suggestions regarding IODA.

Feedback

Comments and suggestions received from WPDCS22 participants will be collated with those received from the past IOTC Working Parties of the year (WPEB22 & WPTT28). The combined feedback will be used to inform discussions on the way forward, including potential improvements to IODA, at the Scientific Committee meeting in December 2026.

Conclusion

The paper seeks confirmation that IODA meets the expectation of IOTC scientists and can facilitate the incorporation of environmental and oceanographic data into their research activities.

Recommendation

The paper is to seek endorsement of the datasets and methods implemented in IODA

Decisions

The paper is to seek approval on the current version of IODA and endorsement of the review through the SC Working Parties.

Abstract

The **IODA** is a newly developed digital platform that integrates oceanographic data from data-assimilative models and satellite observations with advanced visualisation tools into a single operational system. The platform provides free access to more than thirty years of environmental observations describing the physical and biological state of the Indian Ocean. Updated monthly, IODA enables users to explore ocean variability, identify long-term trends, and analyse the effects of climate variability and climate change on marine ecosystems and ocean-based activities. In this paper, we present the datasets and main features of the atlas. This paper documents the achievements of the project in relation to its Terms of Reference and aims to foster ownership and uptake of the atlas within the IOTC scientific community.

1. Introduction

The Indian Ocean Digital Atlas (IODA) was developed in response to the request made in IOTC Resolution 24/01, subsequently superseded by Resolution 25/01, for tools providing the IOTC Scientific Committee with easy access to oceanographic and climate data, thereby facilitating the integration of such information into the development of management measures for IOTC fisheries.

Climate change is transforming the physical structure and functioning of the Indian Ocean at an unprecedented pace. Understanding these changes requires continuous access to reliable environmental information over long time periods. Although large quantities of oceanographic data are now available from international observation programmes, these data remain fragmented across multiple repositories and often require substantial technical expertise to access and interpret.

IODA addresses this gap by integrating multiple datasets into a harmonised database supported by an intuitive visualisation interface accessible to both specialists and non-specialists. The atlas has been designed to enable users to explore oceanographic data across three spatial dimensions (longitude, latitude and depth) and through time, on a monthly basis since 1993, in the simplest possible way. IODA was developed between March and August 2026 by the authors of this paper. The Terms of Reference for the project are provided in *Annex 1*. A series of presentations has been planned for several IOTC Working Parties in 2026—WPEB22, WPTT28 and WPDCS22—to obtain feedback ahead of the final discussion on IODA at the Scientific Committee meeting in December 2026.

Initially developed under the auspices of the IOTC to strengthen ecosystem-based fisheries management, IODA has evolved into a multidisciplinary platform with applications extending well beyond fisheries. The system is now fully operational. A full description of IODA is provided in the following sections.

2. Platform capabilities

IODA currently contains twenty key ocean variables describing the marine environment, down to 900 metres depth for some of them. The database covers the entire area of competence of the IOTC, approximately 70 million km² (Fig. 1) at spatial resolutions of 4, 12 and 25 km, depending on the variables. The Western Pacific waters stretching north and east of Indonesia have been removed from the atlas. Monthly updates ensure that users always have access to the most recent available observations while maintaining a continuous historical record extending back to 1993.

The platform allows users to:

- visualise present ocean conditions;
- analyse long-term environmental trends;
- detect marine anomalies and extreme events;
- compare present observations with historical conditions;
- download figures and maps suitable for scientific publications and technical reports.

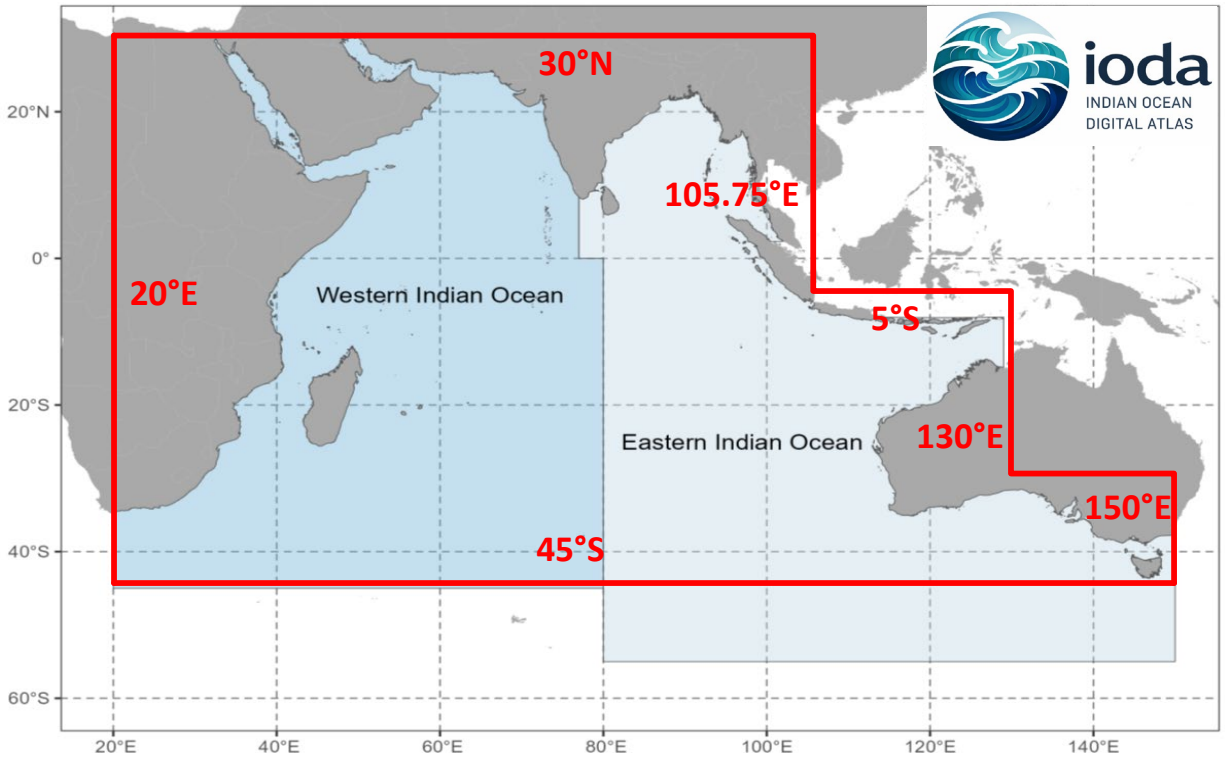


Figure 1 – IODA spatial coverage (red boundaries) on top of the IOTC area of competence (blue shaded)

3. Datasets description

IODA includes eight ocean physical variables, eight biogeochemical variables, and four climatic indices.

The **physical variables** (Table 1) are available at two different spatial resolutions, 8 km (1/12°) and 12 km (1/8°). The left panel lists the six variables directly sourced from the European Copernicus Marine Service (https://marine.copernicus.eu). The right panel lists additional variables derived by the authors specifically for IODA from the core Copernicus datasets. The products consist of outputs from data-assimilative ocean models, downloaded for the IOTC area of competence

Ocean physics variables
1/12 deg (~9-km) grid - numerical models
1. Sea water potential temperature (T)
2. Sea water salinity (S)
3- Eastward sea water velocity (U)
4- Northward sea water velocity (V)
5- Ocean mixed layer thickness (MLD)
1/8 deg (~12-km) grid - satellite obs
6 - Sea level anomalies (SLA)

Ocean physics derived variables (from numerical models)
1. 20°C isothermal depth (Z20)
2. Vertical current shear (SH130 & SH450)

Table 1 – Ocean physical variables managed by IODA. Left: Copernicus products, right: derived variables

For the **biogeochemical variables**, the spatial resolution is 25 km (1/4°) for data from coupled ocean models, and 4 km (1/24°) for *Level 4* sea colour (Chlorophyll-a) composites derived from satellite observations. In Table 2, the left panel lists the variables directly sourced from the Copernicus Marine Service, whereas the right panel lists the derived variables created by the authors from the original products shown in the left panel.

Ocean biogeochemistry variables
1/4 deg (~25km) grid - numerical models
1. Mass concentration of chlorophyll-a in sea water (CHL)
2. Net primary production of biomass (NPP)
3. Mole concentration of dissolved molecular oxygen (DO)
4. Sea water pH reported on total scale (PH)
1/24 deg (~4km) grid - satellite obs
5. Surface chlorophyll content (CHLsat)

Ocean biogeochemistry derived variables (from numerical models)
1. Depth of the 2.5 ml/l dissolved oxygen concentration
2. Depth of the maximum fluorescence (Fmax)
3. Integrated chlorophyll content in the upper 300 m

Table 2 – Ocean biogeochemical variables managed by IODA. Left: Copernicus products; right: derived variables

Climatic indices form the third data component of IODA. Four indices with long-term time series have been included to track large-scale oscillations in the ocean–climate system:

- the **Dipole Mode Index** (DMI), an indicator of the Indian Ocean Dipole based on temperature anomalies (1870 to present).
- the **Southern Oscillation Index**, an indicator of the El-Niño Southern Oscillation (ENSO) and a predictor of global scale climate variability (1866 to present).
- the **Multivariate ENSO index** (MEI.v2), another indicator of ENSO that combines five variables (1979 to present).
- the **Niño-4 index**, based on temperature anomalies in the central equatorial Pacific and also related to the ENSO cycle (1870 to present).

The last data component, the **seafloor topography**, will be added to the database in 2027. These data originate from the GEBCO 2026 database. With a spatial resolution of 463m (15 arcs-second), the Indian Ocean portion of the dataset is very large (> 1 GB) and specific processing is therefore required to manage this data efficiently.

Except for the climatic indices which are provided in CSV text format, the datafiles were created using the Network Common Data Form (NetCDF; Unidata, DOI:10.5065/D6H70CW6). They are organised by variable and year. Each variable also includes anomalies (difference from the climatology) and climatology (calculated over 1993-2016). The variables are also organised into two categories: **three-dimensional** (longitude, latitude and depth), and **single layer** (one value per longitude/latitude grid cell). The 3D files include 20 depth levels[1], from the surface to 900 m. The overall size of the dataset is approximately 250 GB for the period from January 1993 to December 2025. The database is expected to grow by approximately 10 GB per year. Variables and their characteristics for each data component are summarised in Table 3.

The overall size of the database is relatively compact considering the amount of information stored. This is primarily due to the nature of NetCDF files. We have further reduced the storage requirements by converting real values to integers without loss of accuracy, using the offset and scale-factor parameters included in the NetCDF headers. Given

[1] 0, 10, 25, 40, 56, 78, 92, 110, 130, 156, 186, 222, 266, 318, 380, 454, 541, 644, 763 and 902 m

the number of grid cells—up to 28 million cells per month for the ocean physical variables with 20 depth levels—this transformation was necessary and has greatly reduced the initial size of the datasets.

Another advantage of this data compression is that it speeds up reading data by the application. The core datasets(left panels in Table 1 and 2) were downloaded using Python scripts from the Copernicus data centre (THREDDS server). The scripts were executed in the Jupyter lab environment, using the *copernicusmarine* library. These scripts will need to be run by the data manager whenever the datasets need to be updated, on a monthly basis.

	Variable	Depth range	Start year	Source	Spatial resolution	Product ID
PHYSICAL	Temperature Salinity Current	0-902 m (20 levels)	1993 - Jan	Ocean model	0.083° x 0.083° (~8km)	GLOBAL_MULTIYEAR_PHY_001_03
	Sea level anomaly	single-layer	1993 - Jan	Satellite altimeter	0.125° x 0.125° (~12km)	SEALEVEL_GLO_PHY_L4_MY_008_047
	Mixed layer depth Thermocline depth Current shear 0-130m Current shear 0-450m	single-layer	1993 - Jan	Ocean model Derived Derived Derived	0.083° x 0.083°	GLOBAL_MULTIYEAR_PHY_001_03
BIOGEOCHEMICAL	Depth of 2.5 ml/l DO	single-layer	1993 - Jan	Derived	0.25° x 0.25°	GLOBAL_MULTIYEAR_BGC_001_029
	Dissolved oxygen Chlorophyll-a Net Primary Prod pH	0-902 m (20 levels)	1993 - Jan	Ocean model	0.25° x 0.25° (~25km)	
	Surface chlorophyll	single-layer	1997 - Sep	Satellite obs.	4 x 4 km	OCEANCOLOUR_GLO_BGC_L4_MY_009_104
	Fmax depth Integrated chl content		1993 - Jan 1993 - Jan	Derived Derived	0.25° x 0.25°	GLOBAL_MULTIYEAR_BGC_001_029
CLIMATE	Dipole mode index Southern oscillation Index Multivariate ENSO index Nino-4 index	single-layer	1870 - Jan 1866 - Jan 1979 - Jan 1870 - Jan	Observations	n/a	n/a
BATHY	Seafloor bathymetry	single-layer	n/a	Composite	~ 500 m	GEBCO 2026 Grid (Sub-ice topo/bathy)

Table 3 –IODA datasets summary, with depth range, period covered, source, spatial resolution and product reference

4. The IODA application

IODA is implemented as a multi-component web system:

- a public R Shiny atlas for interactive maps, time series, transects, Hovmöller diagrams, depth profiles, exports, account access, and saved plots;
- a Bun/Elysia backend API with PostgreSQL for authentication, plot-option catalogues, admin operations, audit-supported metadata, contact messages, and saved-plot artefact storage;
- a TanStack Start/React admin portal for internal management of users, variables, datasets, plot options, THREDDS metadata, settings, audit logs, contact messages, and operational dashboard views;
- filesystem-backed NetCDF data storage used by the Shiny runtime;
- a THREDDS Data Server exposing the published NetCDF database through catalogue browsing, HTTP file access, OPeNDAP, and NetCDF Subset Service.

4.1 – IODA thematic products

IODA allows the exploration of ocean data through four types of products: (1) Maps, (2) Time & Space profiles, (3) Hovmöller Diagrams and (4) Depth Profiles. These products are powered by 30 scripts written in R (R Core Team, 2025) and incorporated into a Shiny (Chang et al, 2026) application which provides the user interface. The four IODA thematic

products are accessible directly from the IODA home page, as shown in Fig. 2. Screenshots of the application are presented in *Annex 2.*

MAPS - Generates maps of a specific variable (including anomalies and climatology) over the whole ocean or within user-defined areas, including user-controlled overlays. For the 3-dimensional files, the depth level must be indicated. The range of values displayed on the map can be set either in automated or customized mode (especially if several maps must be compared, using the same colour palette). The catalogue includes:

- map of a specific year and month (or month only for a climatology map);
- computed maps (2 types): i) difference between two maps of two different years-months; ii) average over a range of years-months;
- animated maps: creates a sequence of maps between two dates (year-month), animates the sequence in a loop in the viewing window of the atlas, and generates an animated GIF that can be run outside IODA if needed;
- GEBCO bathymetry, to display the depths of the seabed (not fully implemented yet).

It is also possible to add layers (overlays) to the maps, such as:

- contours and labels for the displayed variable;
- EEZ boundaries;
- External data (columnar text file created by the user, space delimited, tab-delimited of csv formats), containing at least longitude and latitude at each row, and optionally, a value associated to Lon and Lat. In that latter case, a circle of size proportional to the value is plotted instead of a simple point.

For each map, general statistics are calculated and can be exported. The user can also save the maps in image formats, and export the map data. Export formats are CSV, XLSX, JSON, and tabular (latitudes in rows and longitudes in columns).

TIME & SPACE PROFILES – Display time series and transects of variables and anomalies across longitudes or latitudes.

Time series: the user selects a location (with a pointer) or a box area (drawing a rectangular selection) on an inset map, then the starting and ending dates (year-month). When a box area is selected, the median value (line) and the 25th and 75th percentile (shaded area) of the time series are displayed, whereas only a line is plotted for a single location. The plot can be saved in image format, and the general statistics as well as the values of the time series can be exported in various formats (CSV, XLSX, JSON).

Climate indices: No area selection is requested as the indices apply to the whole ocean. The design of the plot (type and style) can be customised. There are two possible types, raw series or smoothed by a 5-month moving average; and two styles, line only or coloured field areas (above and below the baseline). The figure can be saved and the data can be exported in various formats, same as above.

Transects: The user draws a horizontal line (for longitude) or a vertical line (for latitude) in the inset map, defining the transect along which the values of the selected variable will be plotted. The general statistics as well as the values of the transects can be exported. The figure can be saved and the data can be exported in various formats, same as above.

HOVMÖLLER DIAGRAMS – Space time coloured fields for a variable or its anomaly, either in longitude or in latitude. It is a common way of plotting environmental data to highlight the behaviour of waves and cycles.

The user can draw a rectangle (in longitude or in latitude) in the inset map, where the data will be averaged and displayed for each month at each grid point, forming a continuous field of values just like a map. Longitudinal Hovmöller diagrams have the longitude along the X axis and the time along the Y axis, whereas Latitudinal diagrams have the latitude in the Y axis and the time on the X axis. The plot can be saved and data exported in the tabular format.

DEPTH PROFILES – Draws the profile of a variable or its anomaly versus depth.

The user selects a location in the inset map. The vertical profile will be plotted in a range of depth (from surface to X, with X being defined by the user). Optionally, the envelope of the profiles located in the neighbour grids, at distances of 25, 50 and 100 km around the selected location, can also be plotted. The figure can be saved and the profile values be exported in CSV format.

4.2 – Other elements of the home page

About- describes the content of the atlas and the various data sources, including their DOIs. References needed to cite IODA are also provided.

Contact –opens a form through which users can report specific requests, comments or bugs. A reply will be sent to the user.

Account – is created at the first login. Users are required to register by providing a username, password, email address, professional sector, and country of origin. Registration is free but mandatory to use the atlas. Plots saved within IODA (using the *Save* button at the bottom of plots) can be accessed in the "Plots" folder associated with the user's account, thereby creating an image repository that can be built up over successive sessions.

Notifications –opens a window displaying information about the software, data updates, and various topics.

User Manual –a link to download the IODA user manual

4.3 – Documentation files

Contextual help is provided on each thematic page of the atlas though the ? icon. This provides a brief description of each thematic page and its associated functionalities

We plan to produce short videos describing how to use each component of IODA. They will be released online in 2027.

5. Maintenance

5.1 – Hosting and management of the App and data on a public server

During the IODA development phase (March–August 2026), the App was hosted on a test server only accessible to the developers. Although the server had limited storage capacity, it was sufficient to test the different stages of development using a subset of the datasets. Once the App had been completed and thoroughly tested, a permanent hosting solution was required to make the platform publicly accessible.

In March 2026, we contacted the Department of Information Communication Technology (DICT) of Seychelles to assess its willingness to host the IODA on a public server. Several meetings were subsequently held to discuss the technical and operational requirements. The feedback from the Government of Seychelles was very positive, and we have since worked closely with the DICT team to finalise the technical arrangements. A dedicated domain name has been created (**ioda-atlas.gov.sc**), and the different components of the IODA App have been transferred to the national server.

The DICT team will monitor the functioning of the App and undertake the necessary actions to ensure the continuity and reliability of the IODA service.

5.2 – Data updates

In October 2026, the IODA database has been updated up to August 2026. There is currently a delay at the production centre (Copernicus marine Service) in releasing the latest model outputs, as these products need to be processed and validated upstream before becoming available to public.

Updating the database is a recurring process that is carried out on a monthly basis, as soon as the latest available ocean model outputs become accessible. Dedicated Python scripts are used to download the original datasets from the

Copernicus repository. The data integration into the IODA is performed through dedicated R scripts, each script processing a specific variable. Presently, this procedure requires manual intervention. We therefore aim to improve and automate this process in order to reduce the time required for each update and ensure a more robust and error-free workflow.

We are currently developing a Shiny App that will integrate the entire database update process. The App will sequentially call and execute the different scripts required to process the datasets and generate the final files for integration into the IODA.

The Seychelles Fisheries Authority has kindly offered to take responsibility for the regular data update service. We are grateful to this organisation for its commitment to maintaining this important component of the IODA.

6. Feedback received from previous Working Parties

IODA was presented at WPEB22 and WPTT28. A few suggestions were received after the presentation and the training session that was organised in the margin of the WPEB22 meeting.

The first suggestion was to include shape files among the overlays (presently limited to contours, EEZ boundaries and text files). For instance, these shapefiles could delineate the EBSAs[2], ISRAs[3], IMMAs[4] and MPAs set for the Indian Ocean.

The second suggestion would be to incorporate the metadata in each export of data from IODA. The floor remains open for other suggestions and ideas.

7. Conclusion

This document has presented an application designed to facilitate access to and processing of oceanographic data relevant to the stock assessment of IOTC tuna species, in accordance with the Terms of Reference established for this Atlas project. We hope that this new platform will stimulate scientific research into the relationships between climate change and tuna fisheries in the Indian Ocean.

Although the current version already provides most of the variables and visualisation tools required for ecological research, participants are invited to provide feedback on the functionality of the application and, where appropriate, to suggest new features that could be incorporated into a future version. Requirements may differ among Working Parties, and it will therefore be important to compile and synthesise the suggestions from the different Working Parties at the next IOTC Scientific Committee meeting. This will help determine whether improvements to IODA are needed and, if so, establish priorities and timelines for their implementation.

References

R Core Team (2025). _R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Chang W, Cheng J, Allaire J, Sievert C, Schloerke B, Aden-Buie G, Xie Y, Allen J, McPherson J, Dipert A, Borges B (2026). *shiny: Web Application Framework for R*. R package version 1.14.0.9000, https://github.com/rstudio/shiny.

[2] Ecologically or Biologically Significant Marine Areas (Convention on Biological Diversity)
[3] Important Shark and Ray Areas (IUCN)
[4] Important Marine Mammal Areas (IUCN)

Annex 1

Terms of Reference of the project

Based on Res 25/01 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.

The different phases to be undertaken in the IODA development are as follows:

1. Creating datasets of oceanic products covering the Indian Ocean at the highest possible spatial resolution;
2. 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);
3. Set- 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;
4. Description and implementation of comprehensive system and data maintenance protocols;
5. Developing and maintaining data sharing SOPs (standards of procedures)
6. Contain an audit trail of all operations conducted in the system
7. Training a technical team in the server hosting site to ensure the maintenance of the atlas and to update of the datasets.

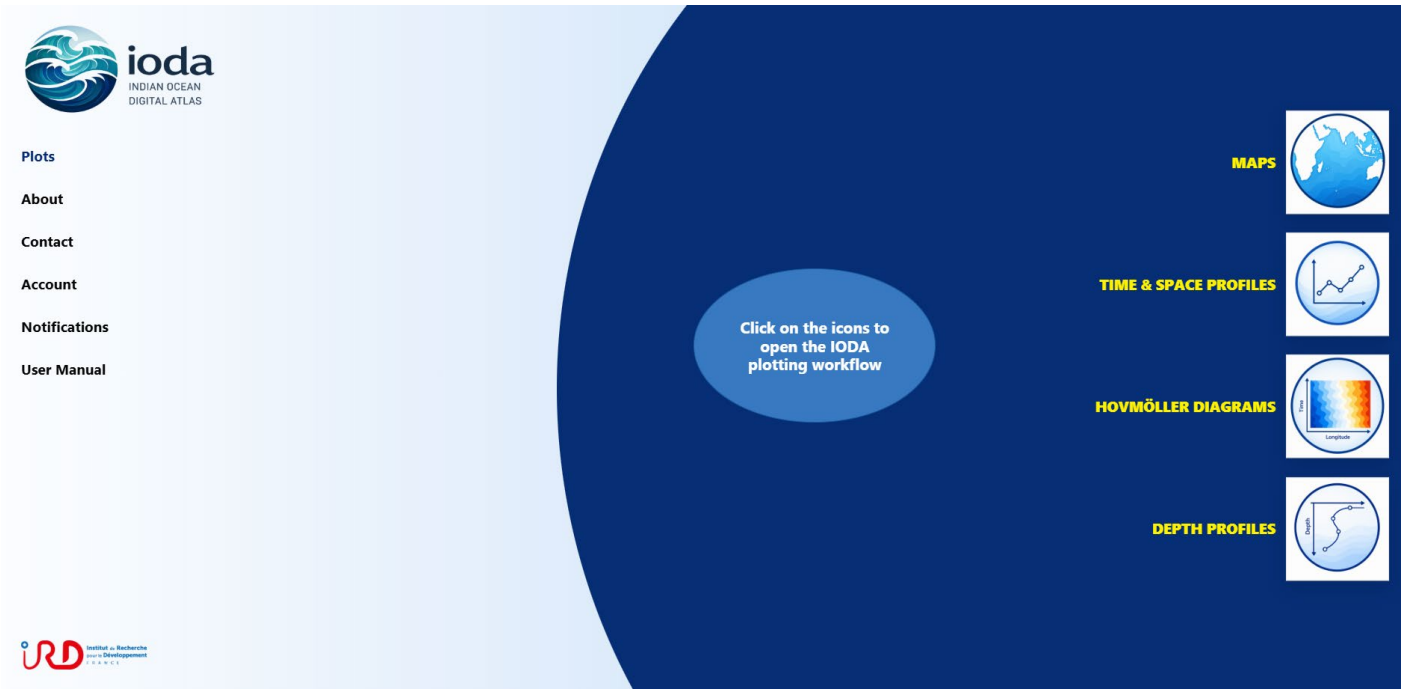
The following specific products are proposed:

- 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 (Hovmöller 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
- Create user-defined animated maps along a range or months/years
- 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
- Produce statistics summary reports (mean, average, standard deviation, minimum, maximum, coefficient of variation, median, quartiles) for the selected variables and plots.

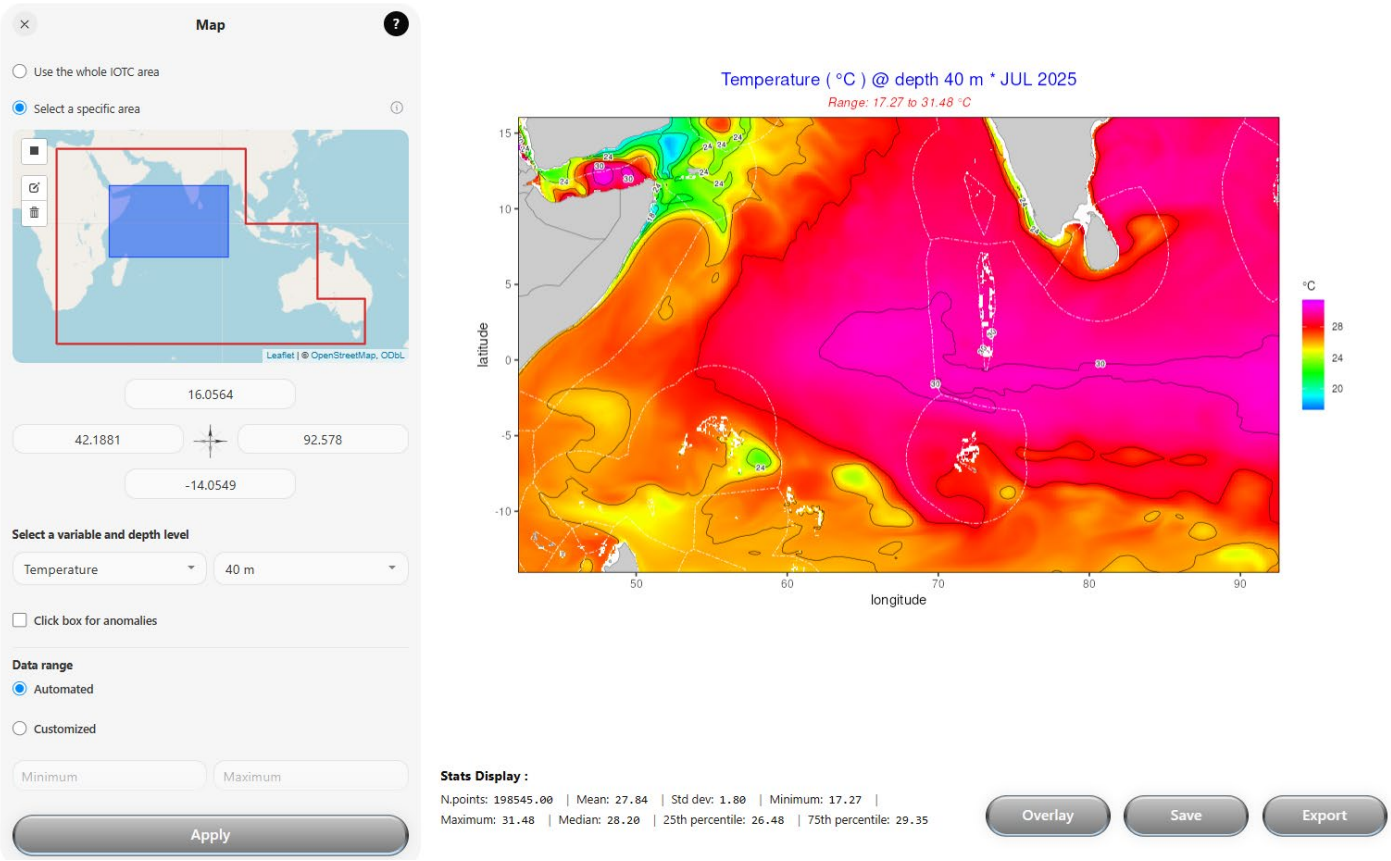
Annex 2

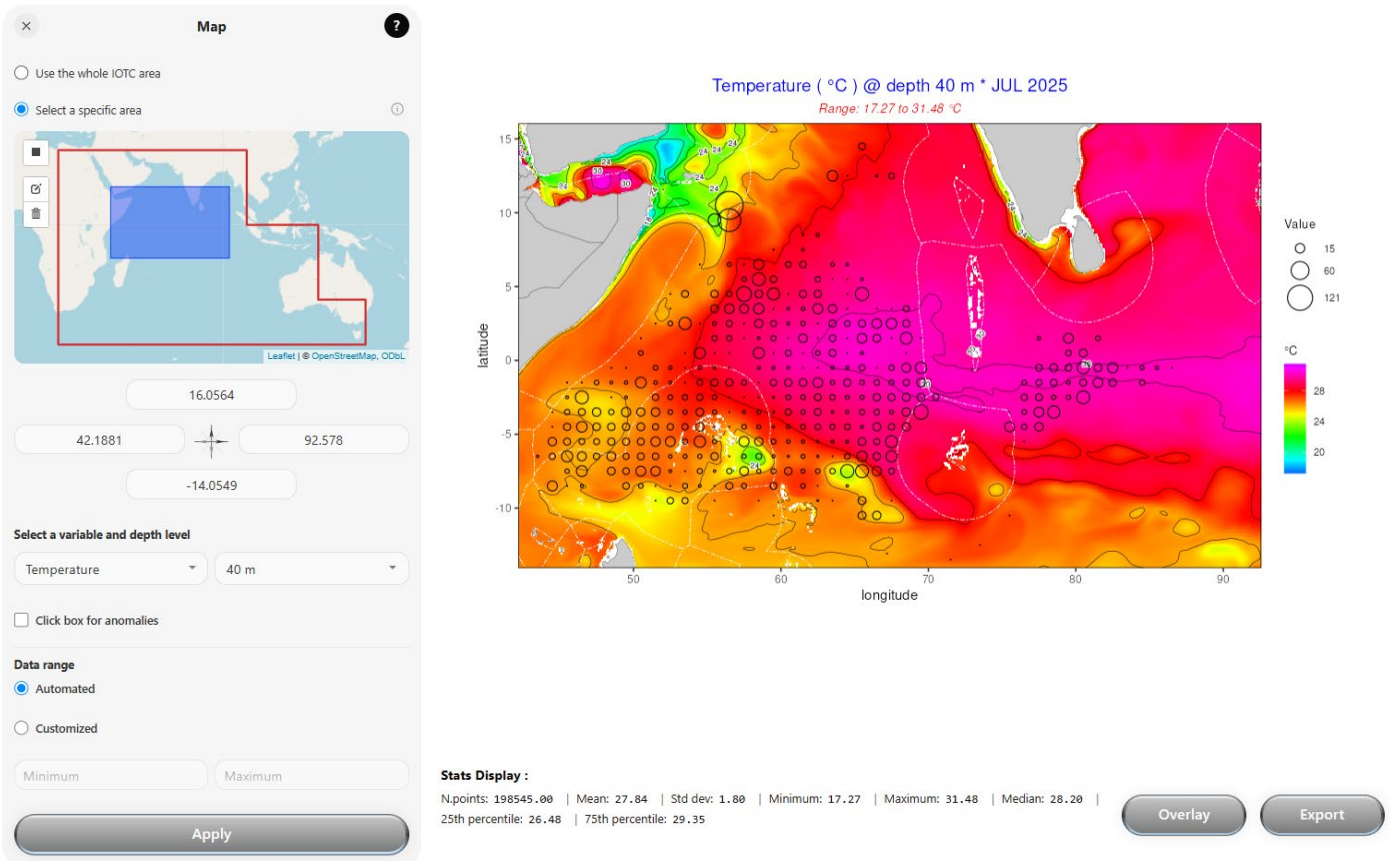
Screenshots of the IODA App

(examples)

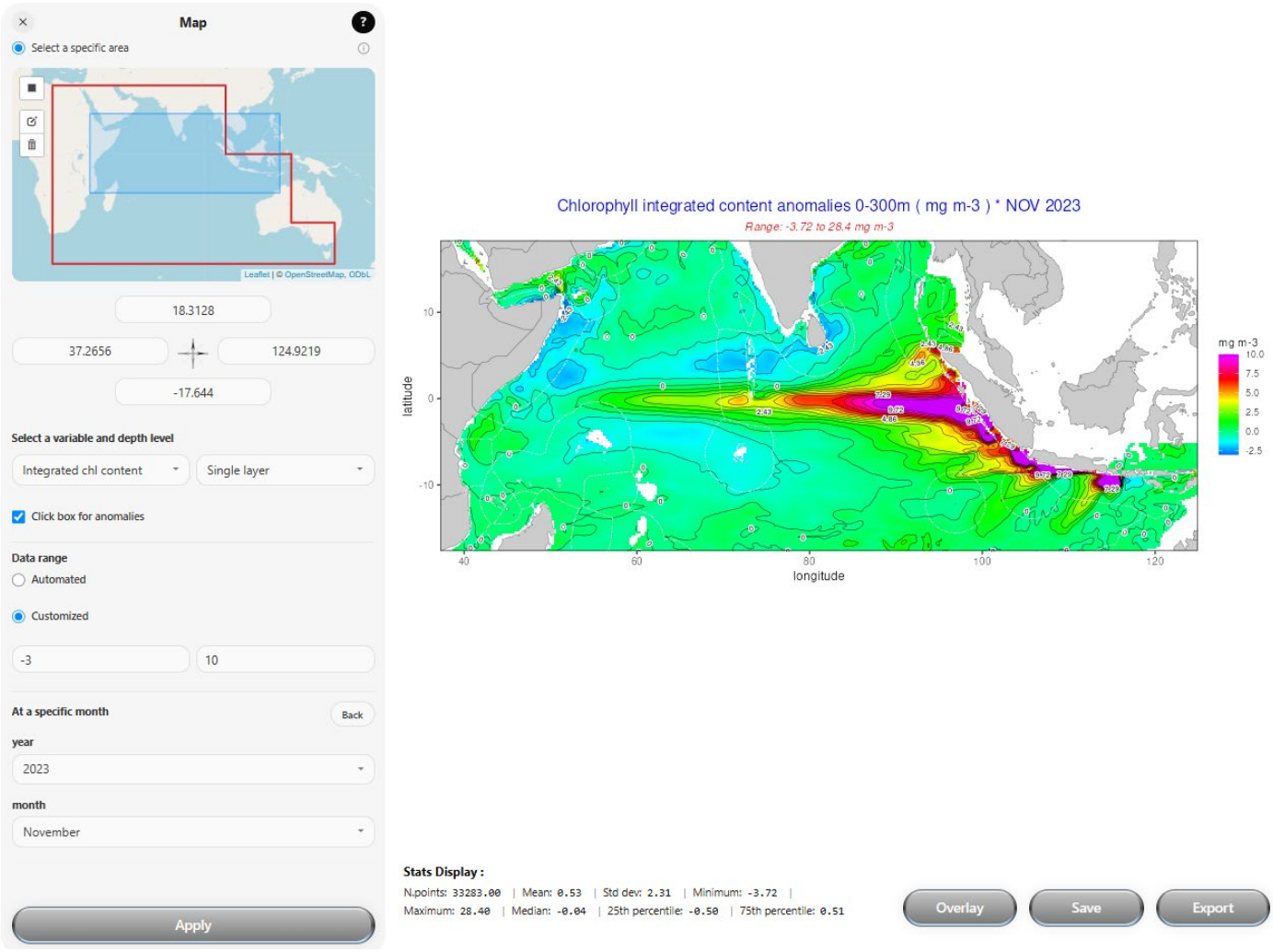


IODA home page

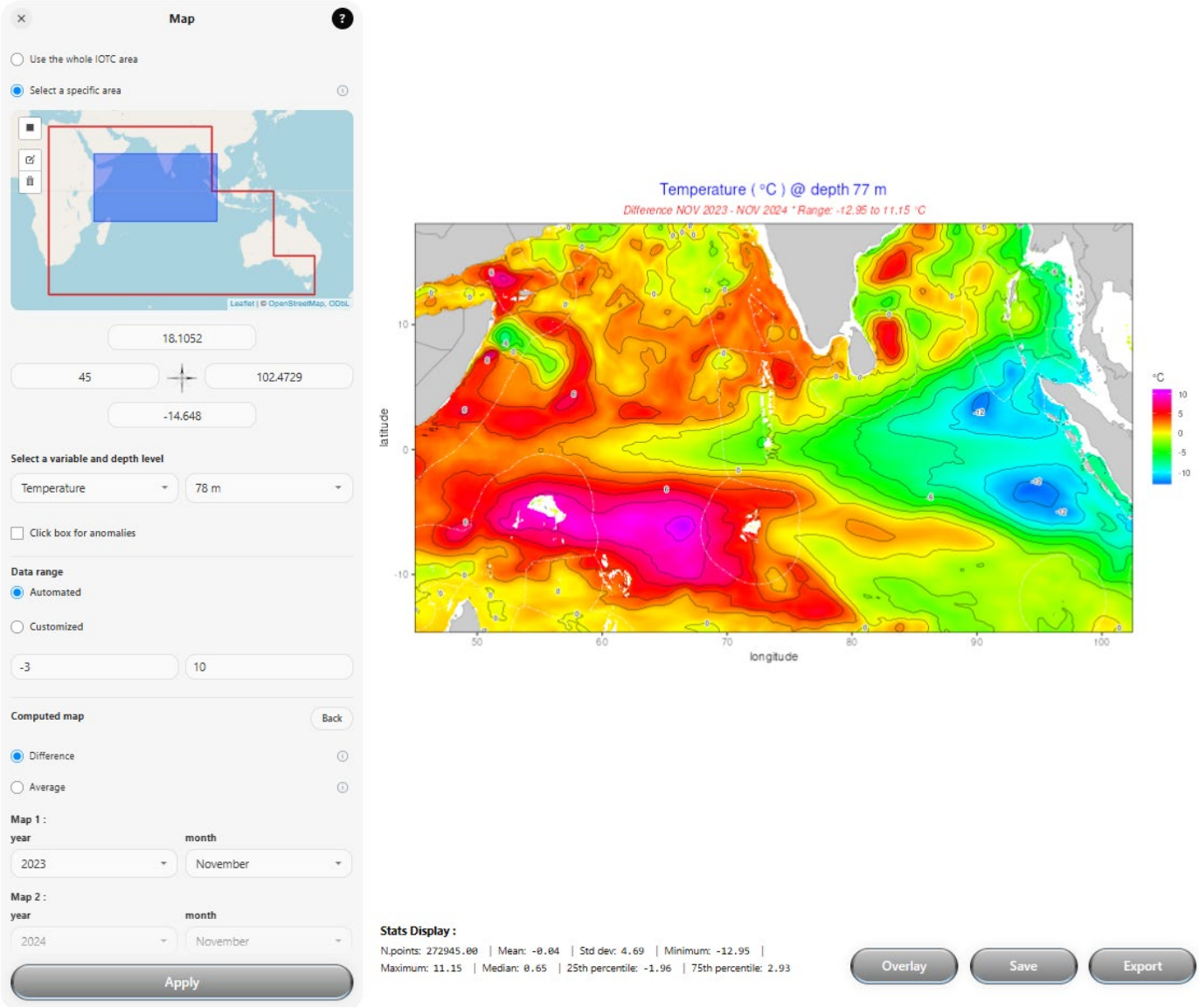




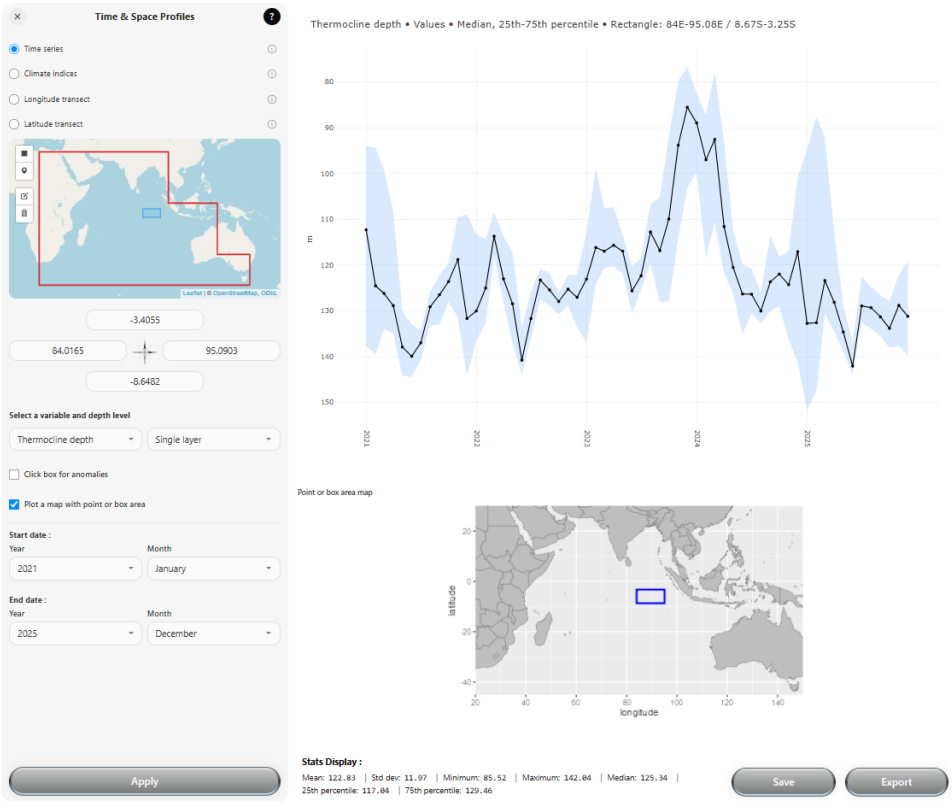
Temperature map (40 m depth) in July 2025, with EEZ boundaries (top) and catch data overlaid (bottom)



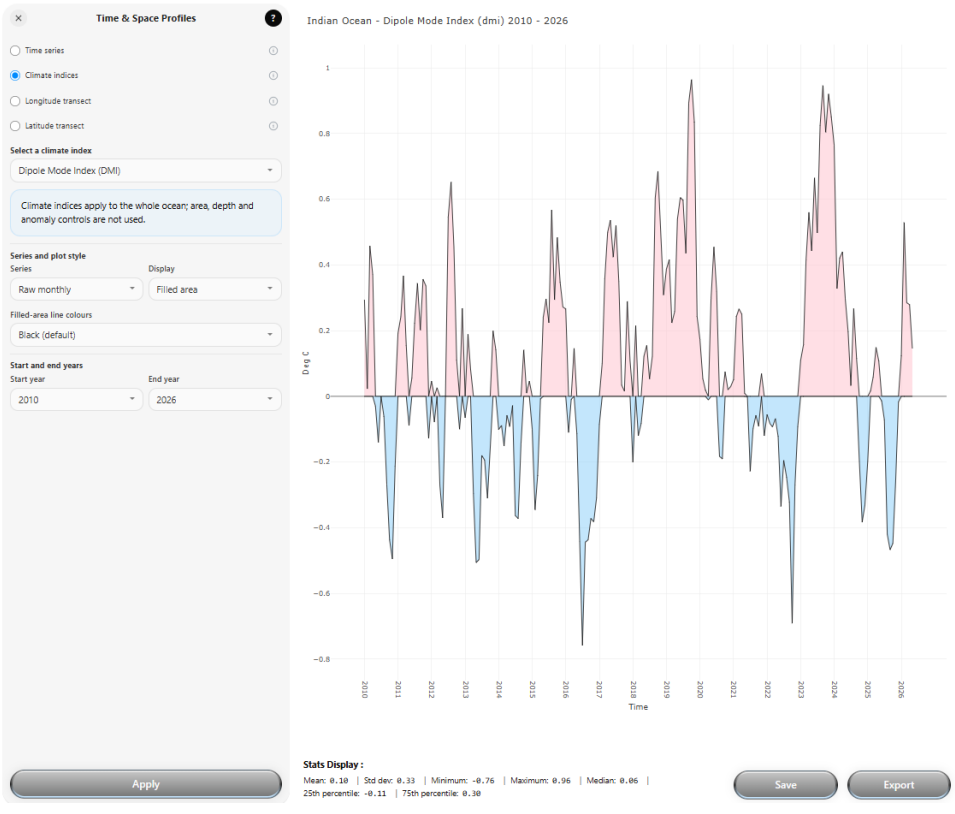
Anomalies of the integrated chlorophyll content in Nov 2023 in the equatorial Indian Ocean. The 2023 positive dipole is well depicted with enhanced chlorophyll production (> 10 mg m^{-3} above normal) in the Eastern Indian Ocean (red shaded); and reduced Chl production in the Western part (blue shaded). In the left pane, the anomaly box was checked and the data range was customized between -3 and +10 to enhance the contrast in the features.



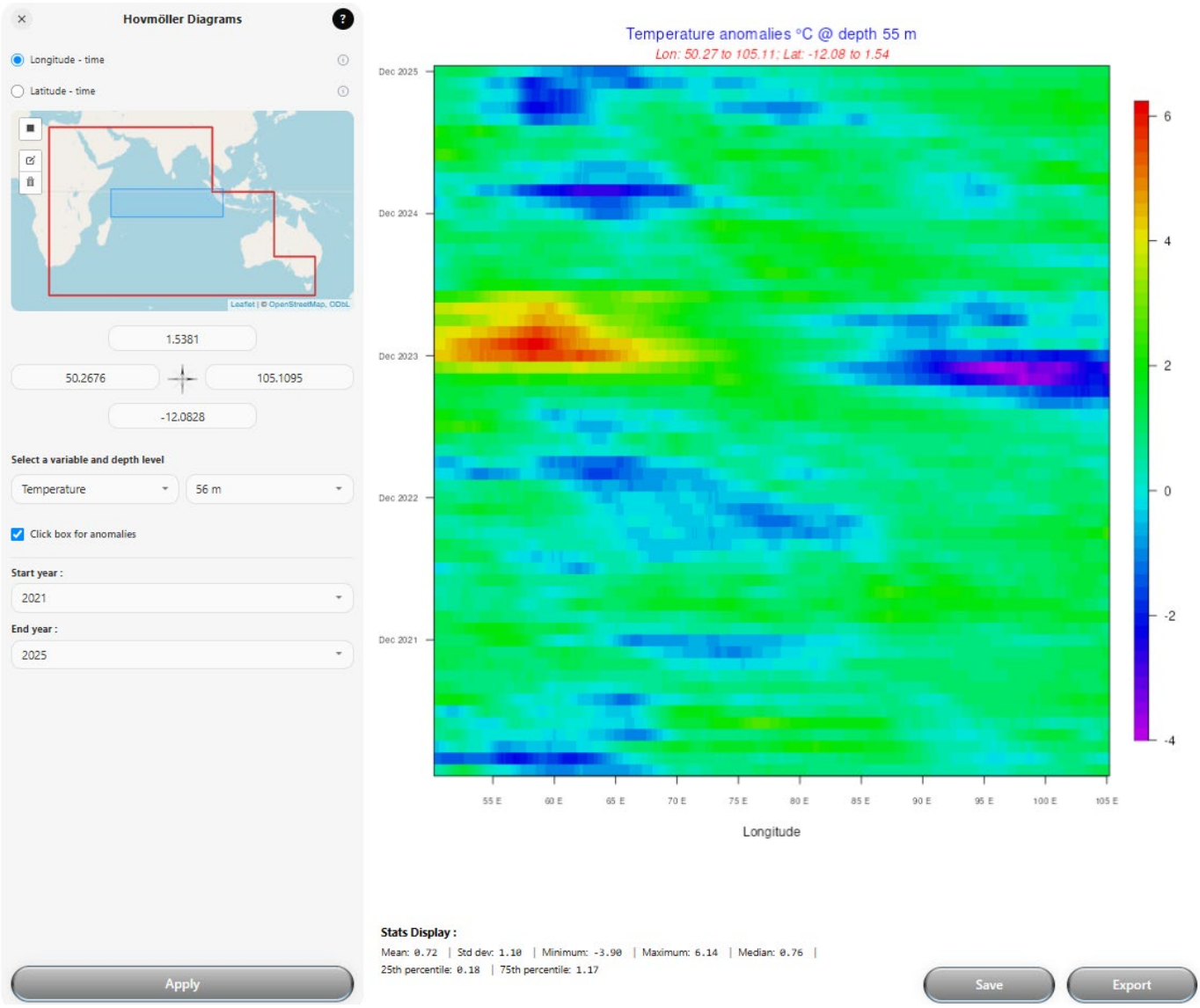
Difference in temperature at 78 m between Nov 2023 and Nov 2024. During the 2023 positive dipole, the temperature was up to 12°C cooler in the Eastern Indian Ocean and up to 10°C warmer in the Western part compared to one year later, when the dipole was negative. The strong difference in temperature at that depth reflects an intense deepening (in the West) or shoaling (in the East) of the thermocline



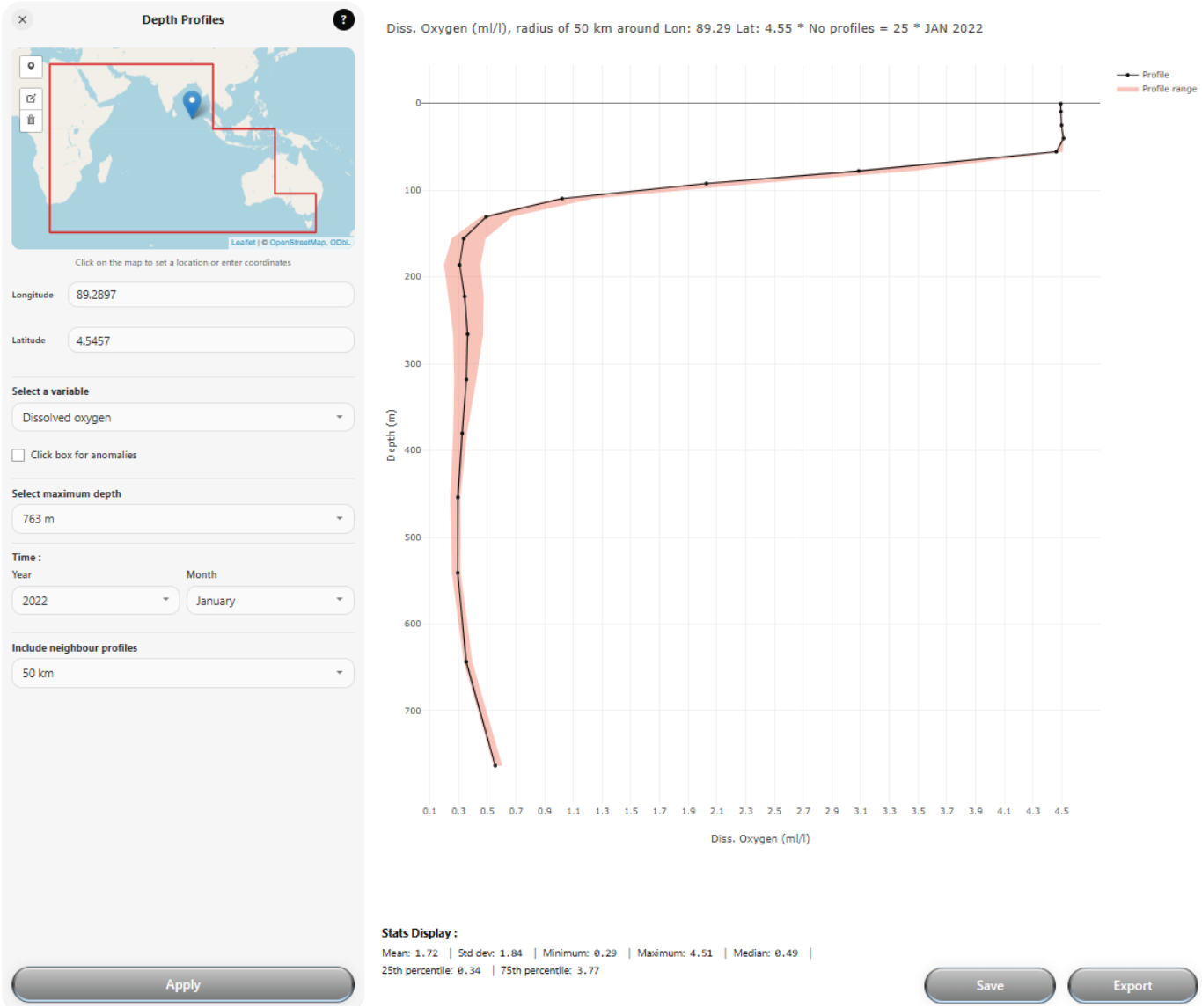
Time series 2021-2026 of the depth of thermocline in a selected sub-area



Time series of the Dipole mode Index, 2010-2026



Longitudinal Hovmöller diagram of temperature anomalies at 56 m from 2021 to 2025, in the user-defined area



Depth profile of dissolved oxygen in Jan 2022, in the Southern Bay of Bengal (80°E, 5°N), with indication of the variability in oxygen-at-depth in a radius of 50 km round the selected location, as indicated in the left pane.