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OCEANVIZIO: A Dynamic and Scalable Visualization Tool for Comprehensive Analysis of Ocean Parameters

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ABSTRACT

Understanding the ocean is crucial for scientific, environmental, and commercial applications. OCEANVIZIO is a dynamic and scalable tool that makes possible comprehensive examination of ocean parameters using real-time/in-situ data and sophisticated analytics. It offers features that are both customizable and interactive for a thorough understanding of the ocean. The paper describes the development of a novel tool for visualizing ocean parameters with unique and adaptive features. OCEANVIZIO incorporates the 2D and 3D visualization of ocean parameters and can depict a variety of ocean phenomena, including eddies and water masses. It is also capable of handling different types of data and formats. The tool also incorporates overlays, statistical analysis, multivariate analysis, and a cruise planner which can be used for challenging research and planning tasks. The tool's efficacy is illustrated by including the architecture, functionalities, and potential applications along with case studies, thus demonstrating its effectiveness in enhancing oceanographic research and decision-making processes.

Keywords: Ocean parameters; Visualization; Cruise planner; Water masses; Ocean Eddies; Multivariate analysis

1. INTRODUCTION

The ocean, covering over 70 % of the Earth's surface, plays a vital role in global climate regulation, biodiversity maintenance, and sustenance of life on earth[1-2]. For several scientific fields, including oceanography, climate science, marine biology, and environmental research, monitoring the ocean's characteristics and comprehending its dynamics are essential. Technology has made it possible to gather enormous volumes of oceanographic data from a variety of sources over the last few decades, which includes satellites, buoys, ships, and autonomous underwater vehicles. However, there are numerous obstacles for analysis, interpretation, and visualization owing to massive volume, heterogeneity and complexity in these data. The dynamic nature of ocean data can be challenging for traditional static visualization techniques to handle, and they frequently fall short of offering a thorough understanding of the complex patterns and processes found there[3].

Visual analysis has emerged as a promising approach for understanding complex ocean processes. Historically, scientific visualization has been successful in ocean science for displaying results[4]. Tools like MATLAB, IDL, AVS, and SURFER have generated various plots and animations but often struggled with integrating multiple interactions and quantitative analysis, failing to meet domain-specific demands. Tools like VisTrails[5] also face challenges in interactively exploring visual scenarios or performing complex queries. In recent years, SeaVizKit[6] is an interactive tool designed to handle multivariate oceanographic datasets and to visualize complex ocean data, making it easier to analyze patterns and trends in marine environments. OFExplorer[7], an integrated system for interactive visual analysis of sea-surface temperature fronts near the China Sea. The tool uses satellite data and adjustable temperature gradient thresholds to identify and evaluate ocean fronts in real-time. However, it is realized that there is no single visualization tool, that accommodates all the different types of visualization techniques and tools for ocean parameters and ocean phenomena.

To address these issues, the goal of this work is to create a scalable and dynamic ocean parameters visualization tool, OCEANVIZIO, that will make it easier to analyze and explore oceanographic data in-depth. With the use of cutting-edge data processing methods, interactive visualization tools like python, and scalable computing infrastructure, OCEANVIZIO seeks to give scientists, researchers, and decision-makers a user-friendly platform for visualizing, analyzing, and interpreting intricate oceanographic datasets. This tool also aims to develop interdisciplinary collaboration in ocean science and related fields thus improving our understanding of ocean dynamics and promote informed decision-making through a combination of creative visualization approaches, real-time data integration, and user-friendly interfaces.

The paper is structured as follows: Section 2 gives the various data sources and formats. Section 2 provides a detailed description of the proposed methodology. Section 3 explores

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the different case studies to prove the efficacy of the tool. The conclusion of the work is briefed in Section 5.

2. METHODOLOGY

This section details the methodology behind OCEANVIZIO. A general architecture encompassing the different features of OCEANVIZIO is given in Section 2.1A detailed description of the data sources and conversion is given in Section 2.2. The different visualization features supported by OCEANVIZIO is detailed in Section 2.3. Section 2.4 describes the comprehensive analysis features supported in OCEANVIZIO Section 2.5 briefs about the Cruise Planner in OCEANVIZIO.

2.1 System Architecture

The architecture of OCEANVIZIO is depicted in Table 1. OCEANVIZIO's architecture guarantees smooth data conversion and integration from multiple sources, enabling a dynamic and scalable framework for thorough analysis of ocean parameters. Both observed and derived parameters are covered by OCEANVIZIO through parameter computation module; visualization options include, 2D plots, 3D plots, 4D volumes and overlays. Ocean phenomena like eddies [8] and water mass [9] can also be visualized though OCEANVIZIO when provided with the appropriate and relevant data. The analysis module provides options for basic, advanced, and multivariate statistical analysis. The utility, viz., cruise planner has tools like a ship track planner, ship-to-ship experiment planning tool, a ship time calculator, and a report generator. All of these features of OCEANVIZIO combine to provide a comprehensive suite intended for effective oceanographic analysis.

Table 1. Architecture of OCEANVIZIO

Cruise planner					
Ship track planner	Ship to ship experiment	Ship time calculator	Report generator		
Analysis					
Basic statistical analysis	Advanced statistical analysis	Multivariate analysis			
Visualization					
2D maps	3D plots	4D volumes	Overlays	Eddies	Water mass
Parameter computation					
Observed parameters	Derived parameters				
Data conversions					
Data sources					

2.2 Data Sources and Conversion

Various oceanographic data sources are accessible for utilization within OCEANVIZIO for analytical purposes. The data sources in the tool are stored as files. The tool is intentionally designed to avoid using an RDBMS for data storage, opting instead for a file-based approach to ensure ease of storage and to enable the tool to function seamlessly across different environments without reliance on a database management system. A summary of them is provided as follows.

2.2.1 Satellite Data

Satellite data from SeaWiFS (Sea-Viewing Wide Field-of-View Sensor)[10] which is used to capture ocean color and chlorophyll concentration, MODIS (Moderate Resolution Imaging Spectro radiometer)[11] for sea surface temperature (SST) and ocean color, Jason-3 for sea surface height (SSH), wave heights, and wind speed, and Sentinel-3[12] for SST, SSH, and ocean color. These satellites monitor primary productivity, phytoplankton blooms, ocean circulation, climate impacts, and marine environment dynamics.

2.2.2 In-Situ Data

Different types of In-situ data is supported by OCEANVIZIO It includes Argo floats, part of the Array for Real-time Geostrophic Oceanography (Argo)[13], which measure temperature, salinity, and pressure profiles from the surface to 2000 mtr depth, and Bio-Argo floats which measures biogeochemical parameters such as dissolved oxygen, chlorophyll, and nitrate. OCEANVIZIO can also accommodate data from Drifting buoys, ship-based observations and CTD sensors.

2.2.3 Model Data

Model data supported by OCEANVIZIO includes Modular Ocean Model (MOM)[14] and Nucleus for European Modelling of the Ocean (NEMO)[15], Reanalysis data, combining historical observations and models to detail ocean states over time, offers datasets in ASCII, NetCDF, and CSV formats, is also supported by OCEANVIZIO. World Ocean Data, including the World Ocean Database (WOD), provides comprehensive oceanographic data, supporting research into ocean conditions and climate variability, available through repositories and platforms such as NOAA (National Oceanic and Atmospheric Administration)[16], Copernicus Marine Environment Monitoring Service (CMEMS)[17], and the British Oceanographic Data Centre (BODC)[18] can also be imported into OCEANVIZIO successfully.

The raw data from these diverse sources often come in various formats and resolutions. OceanVizio employs several steps to convert and standardize these datasets. Data conversion from NetCDF to ASCII and vice-versa, Binary to ASCII and vice-versa is supported in the tool. The above said feature is incorporated into the tool considering the "familiarity range" of an end user, which points to the level of easiness and confidence that a user has when utilizing OCEANVIZIO.

2.3 Visualization Tools

The visualization tools in OCEANVIZIO are designed to be interactive and user-friendly, allowing different data formats. Users can easily switch between different visualization types, adjust parameters, and apply filters to focus on specific aspects of the spatial data. The platform also supports exporting visualizations in various formats, thus enabling users to incorporate them into image, document, web and video formats. By providing a comprehensive suite of visualization tools, OCEANVIZIO empowers researchers, policymakers, and other stakeholders to effectively analyze and interpret complex oceanographic data, facilitating informed decision-making and advancing our understanding of the ocean. A summary of the visualization technique is provided.

2.3.1 2D Plots

2D plot are one of the fundamental visualization tools in OCEANVIZIO, providing a straightforward powerful means of representing spatial data. These maps display various ocean parameters, such as sea surface temperature, salinity, and chlorophyll concentration, over a two-dimensional plane representing the ocean surface. The different 2D plots supported by OCEANVIZIO include location map, profile plot (single and multiple), bunch plot, scatter plot, section plot, contour map and color map. Users can easily navigate through different regions, zooming in and out to examine specific areas of interest. The color gradients and contour lines on these maps allow for quick visual interpretation of data patterns and trends.

2.3.2 3D Plots

3D Plots in OCEANVIZIO take visualization to the next level by adding depth to the data representation, offering a more immersive view of ocean parameters. These plots are particularly useful for visualizing subsurface data such as temperature and salinity profiles obtained from CTD or Argo floats. By incorporating the depth dimension, users can explore vertical structures and layers within the ocean, which are crucial for understanding ocean stratification and mixing processes. The interactive features of 3D plots, such as rotation, zooming, and slicing, allow users to view the data from different angles and perspectives, enhancing the overall analysis.

2.3.3 4D Volume Plots

4D Volumes extend the capabilities of 3D Plots by adding the dimension of time, thus creating a dynamic representation of how ocean parameters evolve over space and time. This type of visualization is essential for studying complex oceanographic processes that vary both temporally and spatially. The 4D volumes provide a comprehensive understanding of temporal trends and patterns.

2.3.4 Overlays

Overlays in OCEANVIZIO allow for the combination of multiple data layers on a single map or plot, providing a multifaceted view of the ocean environment. This feature is particularly useful for correlating different oceanographic parameters and identifying relationships between them. The basic visualization maps available in the Overlays module include color maps, contour maps, vector plot, stream plot, rose plot, stick plot, which can be overlaid one above the other as per the user requirement. Options are provided in OCEANVIZIO to customize and adjust the transparency and color schemes of each layer thus ensuring that the overlays are clear and informative.

2.3.5 Eddies

Ocean phenomena like eddies can be detected and tracked in OCEANVIZIO Two kinds of traditional algorithms, viz, Okubo-Weiss and Winding Angle method are built-in modules in OCEANVIZIO. A thorough analysis of parameters associated with eddies are also available in the tool.

2.3.6 Water Mass

Yet another ocean phenomena supported by OCEANVIZIO is identification of water mass through T-S plots., as different water masses in the ocean have characteristic temperature and salinity signatures. Standard water masses and customized water masses can be identified in OCEANVIZIO.

2.4 Analysis

The Analysis module of OCEANVIZIO provides both basic and advanced statistical summaries. Advanced statistical analysis includes probability density functions, linear and spatial trends, lead-lag correlation and lead-lag regression. OCEANVIZIO also supports a robust suite of multivariate analysis tools to enhance oceanographic research. These include Fast Fourier Transformation (FFT) for frequency analysis, Empirical Orthogonal Function (EOF) for identifying spatial patterns, and Partial and Multiple Correlation for examining relationships between variables. Partial and Multiple Regression provides insights into how variables influence each other, while Power Spectrum analysis helps in understanding the distribution of energy across frequencies.

2.5 Cruise Planner

Cruise Planner is an advanced module in the OCEANVIZIO software designed for oceanography sampling. It focuses on designing precise tracks and identifying optimal sampling locations. This module helps researchers map out specific routes for their vessel to follow during the expedition. It also identifies strategic sampling sites based on research objectives and prior oceanographic data. The cruise planner in OCEANVIZIO consists of four key options. These options include Ship Track Planner, Ship to Ship Experiment, Ship Time Calculator, and Report Generator. The Ship Track Planner is used to prepare tracks and sampling points in the ocean. It allows researchers to create detailed plans for their sampling activities.

The two ship experiment option is used to prepare tracks for two ships. This is particularly useful for coordinated sampling efforts involving multiple vessels. The Ship Time Calculator is another important feature. It is used to calculate the ship survey time using spatial locations, ship speed, and the ship's staying time in the sampling region. This helps in accurately estimating the duration of the research expedition. Finally, the Report Generator is used to make detailed reports of research surveys. It compiles all the collected data and observations into comprehensive documents. These reports are essential for analyzing and sharing the results of the expedition. By using the Cruise Planner module, researchers can ensure systematic and efficient oceanographic sampling. It provides the tools needed to plan, execute, and document their research activities. The module helps in optimizing the use of research vessels and resources. It enhances the accuracy and reliability of the sampling process.

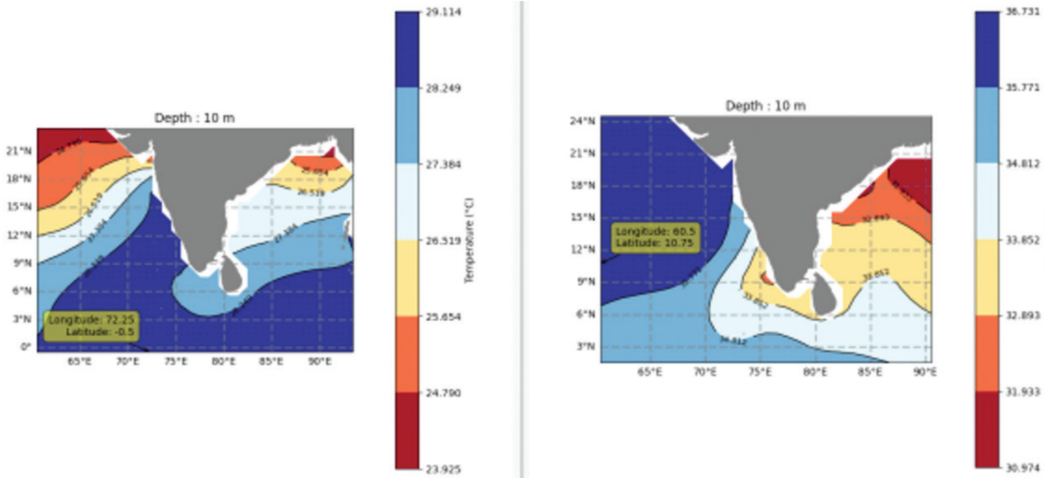

Figure 1. Color maps of SST and salinity.

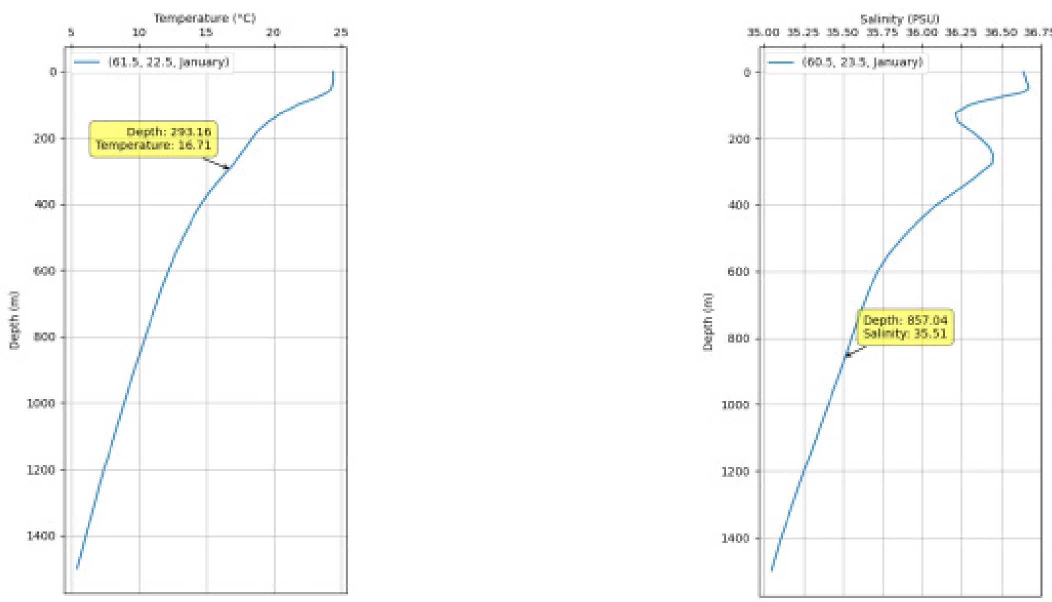

Figure 2. Profile plots of SST and salinity.

Hence, to summarize the OCEANVIZIO stands out from similar tools through its unique features, including dynamic 4D visualizations that enable seamless spatiotemporal analysis. Its platform independence, achieved by avoiding reliance on RDBMS or specific server configurations, ensures portability and ease of use across diverse environments. The tool is highly customizable, allowing researchers to integrate additional datasets or algorithms, and it is scalable to handle datasets of various sizes efficiently.

3. CASE STUDIES

This section describes the different use cases demonstrating the effectiveness of the tool in different scenarios. The implementation of the tool is done inthe open-source language, Python.

3.1 Case Study 1: Visualization and Analysis of Ocean Parameters

The case study focuses on analyzing the variability of sea surface temperature (SST) and salinity in Indian Ocean

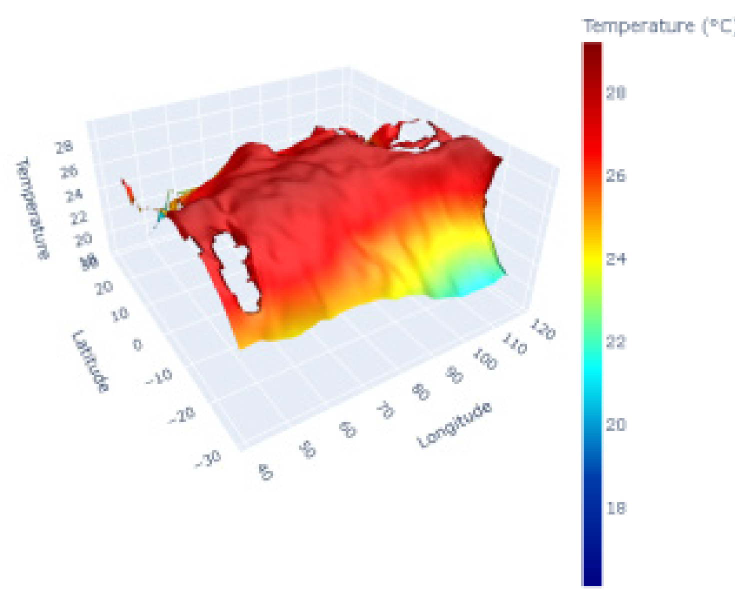

Figure 3. 3D plot of SST.

using OCEANVIZIO. Data is imported into OCEANVIZIO and converted into NetCDF format. SST and salinity are the observed parameters. Visualization tools included 2D maps like color maps are visualized as shown in Fig. 1. It is observed that when temperature increases, the evaporation rates are enhanced, causing dissolved salts to remain and consequently increasing salinity, particularly in warm and shallow regions as depicted in the figure. The profile plots are also depicted in Fig. 2. The 3D plots of SST reveal deeper temperature structures as shown in Fig. 3. Plotting SST as a 3D plot enhances visual interpretability by emphasizing spatial temperature gradients and patterns, even though the depth axis does not represent actual depth. This approach is useful for improving engagement and providing an intuitive representation, especially for educational or non-specialist audiences.

Fast Fourier Transformation (FFT) in OCEANVIZIO is used to analyze seasonal cycles in SST as shown in Fig. 4. The FFT analysis reveals a dominant periodic component in the temperature data around the frequency of 0.1, which is more likely to map to the monthly variability of temperature patterns. Additionally, the presence of noise and minor peaks in FFT suggests the presence of other less dominant cycles or random variations. The phase spectrum shows significant phase shifts at the dominant frequency, with more random phase variations at other frequencies. This indicates a strong seasonal pattern in the monthly temperature data, alongside other minor or random variations. The gaps in the data are filled through interpolation techniques. The FFT toolbox depicted in Fig. 4 shows the location (latitude and longitude), depth and parameter in consideration.

Multiple correlation examined the relationship between SST and salinity and identified a significant correlation as shown in Fig. 5. It is noted from the plots that the contour plot delineates the spatial distribution of the multiple correlation among density, salinity, and temperature at a depth of 98 mtr. The highest correlation values are localized in a central region, indicating strong interactions among these variables in this area. Conversely, peripheral regions exhibit lower correlation values, suggesting weaker interdependencies among the variables in these zones.

The above case study demonstrates the effectiveness of OCEANVIZIO in analyzing oceanographic data, providing valuable insights into seasonal and spatial variability in the Indian Ocean.

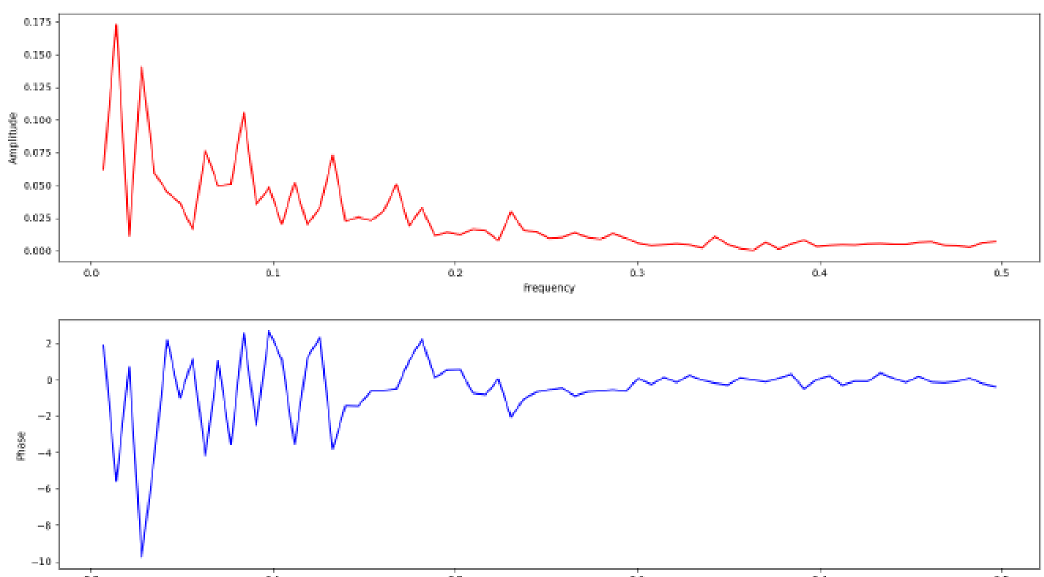

Figure 4. Fast fourier transform of SST.

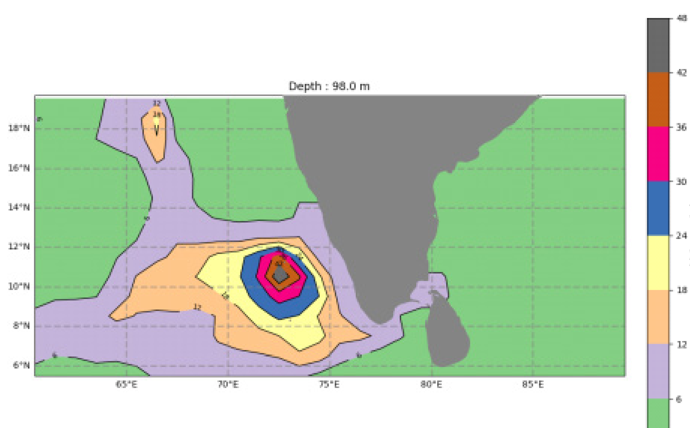

Figure 5. Multiple correlation between SST and salinity.

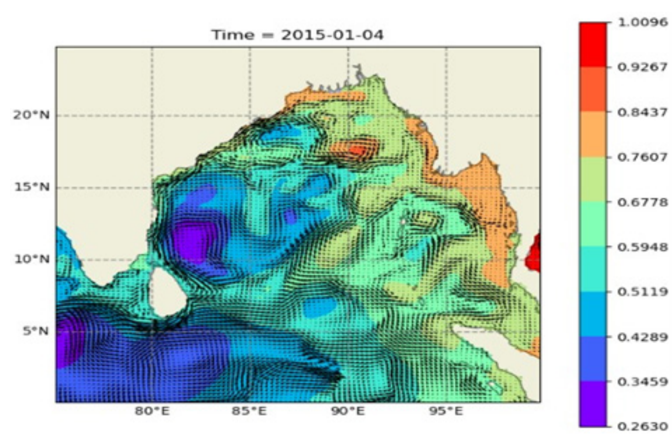

Figure 6. Overlay of geostrophic current over SSH.

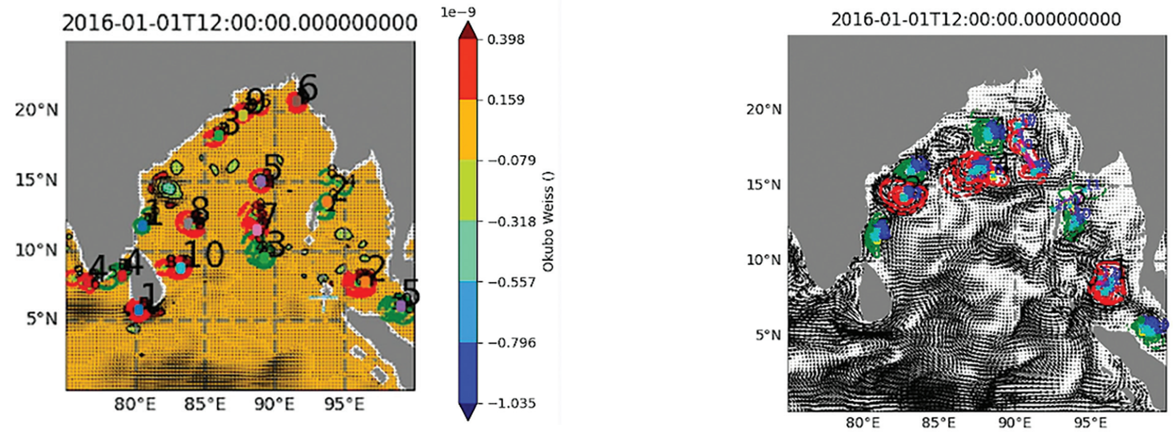

Figure 7. Eddy detection using okubo weiss method and winding angle method.

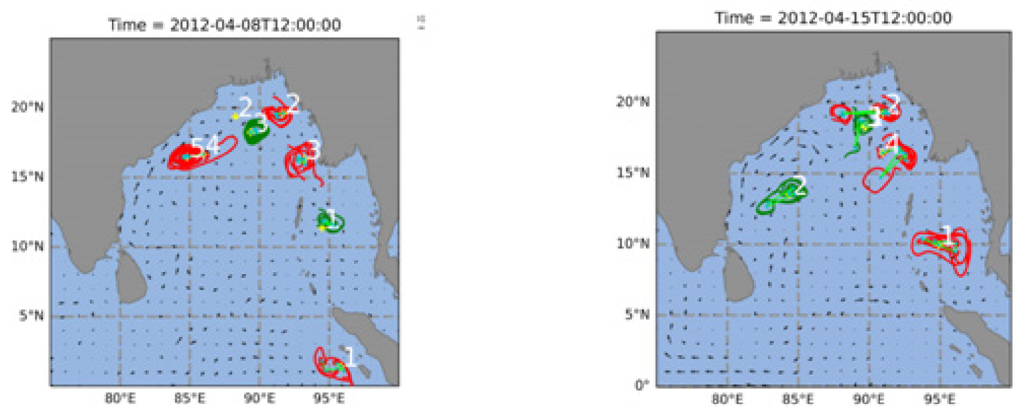

Figure 8. Eddy Tracking for a particular time period.

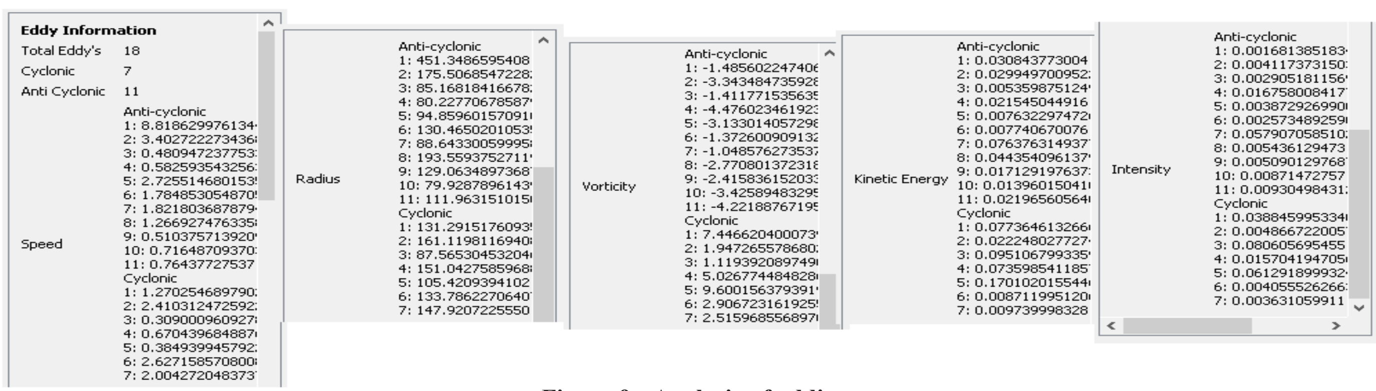

Figure 9. Analysis of eddies.

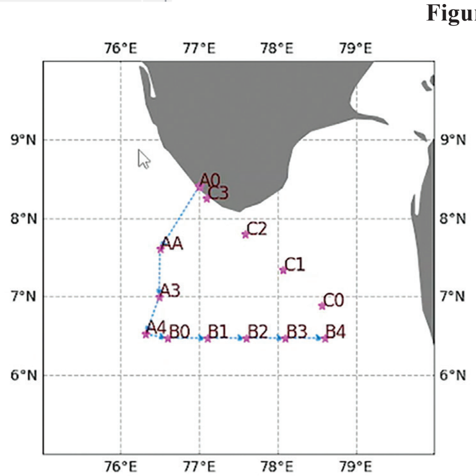

Figure 10. Multiple ship tracks identified in cruise planner.

3.2 Case Study 2: Analysis of Ocean Eddies Using OCEANVIZIO

The case study focuses on analyzing ocean eddies in the Indian Ocean using OCEANVIZIO, with a specific emphasis on their detection and characteristics. Data were collected from satellite altimetry missions that provide high-resolution sea surface height (SSH) data, which is in NetCDF format. From the SSH data, the geostrophic current data is derived and is imported into OCEANVIZIO. The overlay of geostrophic current over SSH data is depicted in Fig. 7 which is obtained from OCEANVIZIO. The eddies detected using Okubo Weiss method and Winding Angle method are illustrated from OCEANVIZIO in Fig. 8. The eddies are classified into different types (e.g., cyclonic and anticyclonic) based on their

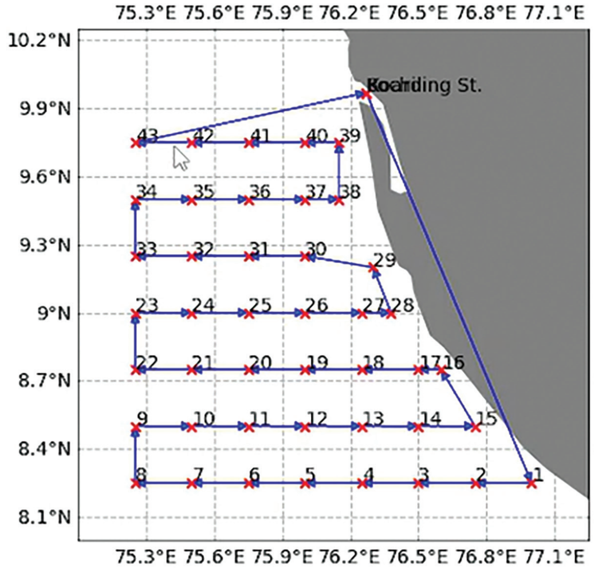

Figure 11. Ship time calculator.

rotational direction and size, which are marked as green and red, respectively in the tool's interface. The detected eddies are to be tracked at different time periods and are as depicted in Fig. 9.

The analysis of eddies is also available in OCEANVIZIO, which can be viewed as shown in Fig. 10 or can be imported as a separate file. This case study demonstrates OCEANVIZIO's capability to analyze and visualize ocean eddies effectively, providing valuable insights into their formation, characteristics, and ecological impacts. Future research could expand on these findings to explore broader oceanic regions and long-term trends in eddy dynamics.

3.3 Case Study 3: Cruise Planner Using OCEANVIZIO

The case study focuses on the components of Cruise planner in OCEANVIZIO. The Cruise Planner has options for planning ship tracks as shown in Fig. 10. The figure depicts multiple tracks for the ship and the details of the stations as well. The track shows the sampling points also. The duration of the research expedition station-wise is shown in Ship Time Calculator as shown in Fig. 11.

4. CONCLUSIONS

This research paper presents the development of a novel ocean parameters visualisation tool called OCEANVIZIO intended to improve the analysis and exploration of oceanic data. The dynamic and scalable property of the proposed tool facilitate the visualisation of diverse ocean phenomena, including water masses and eddy, and also provides the 2D and 3D visualizations. Its extensive features, such as overlays, statistical analysis, multivariate analysis, and a cruise planner, along with its capacity to handle a wide variety of data types and formats, make it an effective tool for intricate planning and research projects.

With the use of interactive visualisation tools like Python, scalable computing infrastructure, and state-of-the-art data processing techniques, OCEANVIZIO aims to provide scientists, researchers, and decision-makers with an easy-to-use platform for visualising, analysing, and interpreting complex oceanographic datasets. Along with enhancing the ocean dynamics, this tool aims to foster interdisciplinary collaboration in the fields of ocean science and related ones. It also facilitates informed decision-making by combining innovative visualisation techniques, real-time data integration, and user-friendly interfaces. The paper also shows the efficacy of the tool through case studies. The case studies demonstrated how the tool's clear and intuitive visualisations of important ocean metrics might improve decision-making processes. This visualisation tool covers a broad range of scientific, environmental, and commercial applications in addition to facilitating improved understanding and analysis of ocean data.

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In the current study, he is involved in review and supervision.