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DeepSwitch - A Web-based Tool for the Introduction to Visual Analysis of Spatiotemporal Processes in Oceanographic Data

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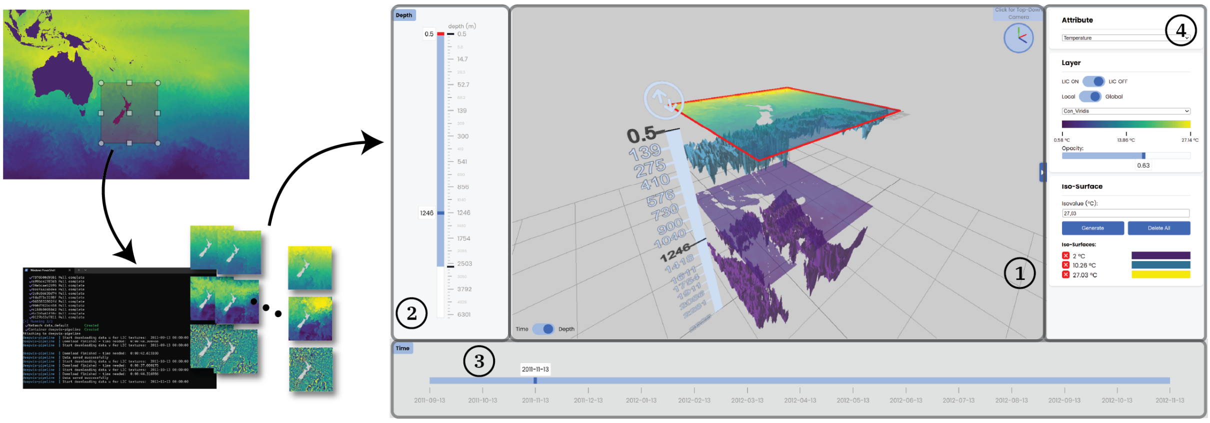

Figure 1: *The DeepSwitch workflow. Top left: Users define an area of interest within oceanographic data [MHH*21]. Bottom left: Time-dependent 3D data for the selected region is pulled from cloud storage and processed through containerized code. Right: Data is loaded into DeepSwitch. The main view (1) provides general interaction with data using a flexible space-time cube paradigm, where either time or ocean depth is fixed, while the other is mapped to the third visual dimension. Exploration is supported by adding slices (2) and isocontours, changing the data block (3), and controlling the visualization (4) to investigate both the spatial and temporal progression of quantities.*

Abstract

Oceanographic data comprises a multitude of information, such as concentrations of materials, temperature, or the movement of water over time. The interpretation and analysis of such data is useful for a large number of domains which all contribute to the understanding of dynamic environmental processes. Complex visual analysis applications are typically handcrafted for the needs of domain scientists and are thus powerful tools for experts, but often require a steep learning curve and involved setups. Visualization used for education and science communication on the other hand is often limited to simplistic 2D views, where temporal aspects are mainly communicated via flip-book animation or side-by-side comparisons, thus limiting the interactive exploration of data and ease of connecting temporal and spatial features. We present DeepSwitch - a web-based visual analysis tool tailored towards an accessible exploration of dynamic processes in oceanographic data. Its design is based on requirements that make it applicable to classroom environments and its central paradigm introduces a fast switch between fixed-time and fixed-depth representation of the data, aiming to minimize cognitive load while providing versatile exploration options for dynamic processes. We demonstrate its usefulness in two analysis scenarios and present preliminary feedback from teachers.

CCS Concepts

• ***Human-centered computing*** $\rightarrow$ ***Geographic visualization;***

1. Introduction

The ocean plays a fundamental role in sustaining and affecting life on Earth. Not only is it home to the majority of animal life, but due to its sheer size, its dynamic processes play a key role in atmospheric and environmental phenomena around the world [LLB15], from influencing weather patterns to regulating habitats, which is

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why fundamental basics of ocean dynamics are an essential part of most school curricula worldwide. Understanding these dynamic processes and the data describing them is essential for predicting environmental changes, protecting marine life, and understanding the complex links between phenomena. Given its relevance to society, various research teams and government agencies have decided to provide laypeople with access to such data through visual tools [BKY20]. Projects such as *Ocean Data View* [Sch15] or NASA's *Worldview* [NAS] provide web-based tools to explore quantities including temperature, salinity, or ocean currents over time through simple 2D visualizations. Interactive story-based websites, e.g., NASA's *Salinity Stories* [Sal], further connect the informative text with embedded visualizations. While these tools can be a good starting point to achieve an overview of the data, their workflows and features are often too restricted to efficiently analyze dynamic processes other than by reading line graphs or observing flip-book animations. While they represent one end of a spectrum, on the other end we find expert-oriented, hand-crafted, and feature-rich frameworks, which often require significant expertise, both in visualization literacy, as well as technical setup. This leaves a gap for applications that allow laypeople, especially students, to take the analysis a step further toward advanced analysis without requiring extensive training and technical knowledge.

To address this, in this work, we present DeepSwitch, an accessible web-based visual analysis tool, designed to provide an intuitive set of features on top of standard tools to explore dynamic oceanographic processes. To restrict the design space, we develop a set of requirements for our tool. These are based on insights and best practices provided by existing literature on oceanographic research and education studies, such that they are suitable for use by laypeople such as students and teachers alike. As a result, DeepSwitch is built around a dual-mode paradigm focused on effective analysis of dynamic processes through switching between spatial and temporal views. An intuitive and modern web-based interface acts as a starting point providing familiar interactions from existing 2D tools while offering seamless transition to 3D views based on the space-time cube paradigm, and the extraction of isocontours to provide a static view of spatial or temporal continuity. Data acquisition and processing are done using adaptable scripts within a Docker container to prevent excessive preparation steps. It can be accessed through a GUI to make it accessible to users without a technical background. We present example scenarios where interaction with data within DeepSwitch provides insights into dynamic oceanographic processes, that would have otherwise been challenging to achieve with other tools. Finally, we provide preliminary feedback from educators from various countries involved in teaching biological or environmental subjects on the usability of the tool in an educational context. The tool and its source code are publicly available at deepswitch-js.com.

2. Related Works

While our work is motivated by improving the visual analysis of oceanographic data in an educational context, research on the visualization of environmental and oceanographic processes has produced numerous contributions throughout the last decades. These range from ocean eddy analysis [RRHS17, BSAH17, LSB*17, FMKH*18] to uncertainty analysis in simulation outcomes [REGL24, RFA*22]. While Xie et al. [XLWD19] and Afzal et al. [AHG*19] provide an exhaustive review of works alongside a list of classifications and challenges, both do not touch upon their relevance in an education context, which is listed as one of the current challenges in the visual exploration of environmental data [HDB*17]. Thus, first, we want to briefly cover existing literature and applications that are relevant to our work, before we take a closer look at using visualization in the context of education of oceanographic contents.

Given its complexity in both, size and multidimensionality, the primary objective of several tools, such as the aforementioned web-based applications [Sal, NAS, Sch15], is to provide access to the data itself, as it typically requires a lot of storage and is updated regularly. Therefore, these are often limited to simple 2D spatial views, where dynamic processes can only be observed using flip-book animations if provided at all. On the other side of the spectrum, there are sophisticated visual analysis frameworks and workflows (see, e.g., [LCY*17, AGF*22]), often designed for expert users. As oceanographic data is inherently dynamic, several of these focus on temporal processes, such as the work of Kumar and Brooks [KB24], which provides oceanic experts with a collection of visual tools to find movement patterns of marine animals. The work by Nobre and Lex [NL15] allows users to create their own paths within oceanographic data to analyze multivariate properties along them to overcome the limitations of displaying multivariate data on 2D maps. Besides custom solutions, Jain et al. [JSS*25] present their plugin *pyParaOcean*, which integrated a collection of oceanographic visualization tools into the well-known visualization tool *ParaView* [AGL05]. Yet, all these tools are targeted toward experts who are expected to be familiar with many concepts and terminology used in the domain.

When reviewing the literature on designing visualization tools specifically for use in non-scientific contexts, most works focus either on the domain aspect or cover it from an educational standpoint. The work of Grainger et al. [GMB16] reviews relevant literature dealing with the visualization of environmental data for laypeople. They provide a list of guidelines, similar to Vavra et al. [VJWL*11] and more recently Lichtenwalner et al. [LHTM21], who define recommendations specifically targeted to the use of visualizations in science education. In a similar context, McElhaney et al. [MCCL15] analyze the effectiveness of dynamic visualizations on learning, and Krumhansl et al. [KBK*13] present a selection of findings and considerations when designing interfaces explicitly for the exploration of ocean data by students based on an exhaustive knowledge status report. It presents over 70 guidelines for interface and visualization tool developments.

In this work, our goal is to develop an application that lies in the gap between simple and accessible yet limited tools and more sophisticated visual exploration solutions. More precisely, we want users to be able to transition from the former toward the latter in a comprehensible way. To do so, we analyze the various recommendations and insights in the literature above to develop a set of requirements, which are presented in the following section.

3. Requirements

While the works discussed above may have slight differences in focus and domain, there are several overlaps within their recommendations and guidelines. We summarize them into six requirements for our tool, with the additional requirement of solving our primary goal of enabling students to explore dynamic processes in oceanographic data:

R1 Provide easy access to (prepared) data and visualization: Users should be able to easily access the data and its visualization without the need for database search queries, complicated or overly demanding setups, e.g., requiring large storage and powerful graphics hardware, or preprocessing steps. Accessibility should also be considered with classroom settings in mind, where certain access rights might be limited to teaching personnel or bandwidth might be limited.

R2 Reduce information & interaction to avoid overstimulation: To prevent cognitive overload, the amount of information presented at any given time should be limited. Expert terminology, complex interaction, advanced interfaces, and the number of complex visualizations should be reduced to a minimum. While this must not prohibit the opportunity to introduce means for deeper exploration when previous concepts are understood, the transition between different levels of complexity should be smooth and comprehensible.

R3 Engage users through collaboration, creation, and control: Studies indicate that learners have drastically improved learning rates when actively engaged with the matter. Thus, the tool should support inquiry-based learning processes, where users can actively explore their own questions, control the progression of information, and discuss their findings with peers. The option to moderate content helps to prevent frustration by getting lost in data. Engagement is also improved by adhering to established principles of good design and user experience.

R4 “Bridge to the familiar”: This phrase used within the knowledge report discussed by Krumhansl et al. [KBK*13] emphasizes the importance of connecting new tools with the knowledge and experiences users are likely to already have. Recognizing familiar visuals, interactions, and patterns eases the transition to novel concepts.

R5 Provide means to explore dynamic processes in oceanographic data: Ultimately, while all previous requirements can apply to various domains, the motivation behind this work is to enable novel users to visually explore dynamic processes within oceanographic data. This goal must be central to the design and functionality of our tool and supported by the previous requirements.

By addressing these requirements, we aim to develop an effective, engaging tool to introduce students to a meaningful exploration of oceanographic data.

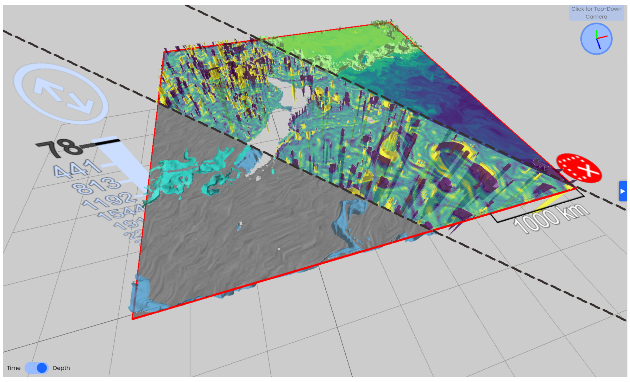

Figure 2: *DeepSwitch provides several visualization methods, including Line Integral Convolution (LIC) textures of the velocity (left), pseudo-color visualization of scalar quantities including temperature, salinity (right), and vorticity (center), and isocontours. Two of the three dimensions are always used to represent longitude and latitude, while the third dimension either represents ocean depth or time.*

4. DeepSwitch

As our application is designed to fulfill requirement **R5** specifically in classroom environments, the remaining requirements must be interpreted with both possible roles - teachers and students - in mind. While we primarily focused on creating an engaging tool for students to interact with data, providing teachers with easy access to the data and suitable preparation is essential to fulfill **R1**. Thus, alongside the main application, we provide an accessible containerized workflow. In the following, we present the design and features of both while referencing the requirements established in the previous section when appropriate.

Data Acquisition and Preparation

Existing tools typically either request data live from storage servers or require users to manually locate, acquire, process, and format datasets, which typically involves working with command-line tools, programming scripts, or specialized software. Especially for classroom settings, where students might have only access to low-cost hardware and limited bandwidth, the latter is a more reliable choice. As this can be cumbersome, especially for people lacking technical expertise, this represents a clear barrier. To address this, we provide a data acquisition and preparation workflow, designed such that non-technical users only have to choose the data they want to use, and the necessary steps are executed for them. Similar to Koenen et al. [KPGG24], we provide a Docker container, which executes the necessary steps to retrieve and process data of interest. Users, e.g., educators preparing the data for students, are only required to install and run the Docker software on their machine, which does not involve a complicated setup. Further, users do not directly interact with the container, but with a simple 2D GUI. First, they pick the start and end dates of the requested data from a list and enter the number of samples. Then, a 2D world map is displayed where a region of interest is selected by drawing a square and confirming their choice as shown left in Figure 1.

The container is currently configured to access OpenVisus data provided by the *2026 IEEE SciVis Contest*, which is an adapted version of the *Estimating the Circulation and Climate of the Ocean* (ECCO) LLC4320 simulation results using the MIT general circulation model (MITgcm) [MHH*21]. This constitutes sea-surface velocity, temperature, and water salinity for 90 depth levels in a 14-month global simulation of the ocean. After confirmation, the container is downloaded from Docker hub, and data is automatically downloaded and processed. This includes downsampling to a lower resolution, computing the vorticity magnitude based on the vector data, and saving the results to disk. During this process, the data is analyzed to correctly handle undefined data representing land mass, and optionally filtered for outliers based on their Z-score, thus supporting **R2**. Afterward, data is available locally, such that exploration can happen within a local network without the need for a fast and stable internet connection or large storage on the client device. It is also possible to host both this data and the application itself on a cloud server such that it is accessible through the internet. However, due to latency and bandwidth concerns, locally hosted data is often preferable, especially in educational settings. Note, that the container could be easily adapted to receive data from various other sources while obscuring these changes to the user.

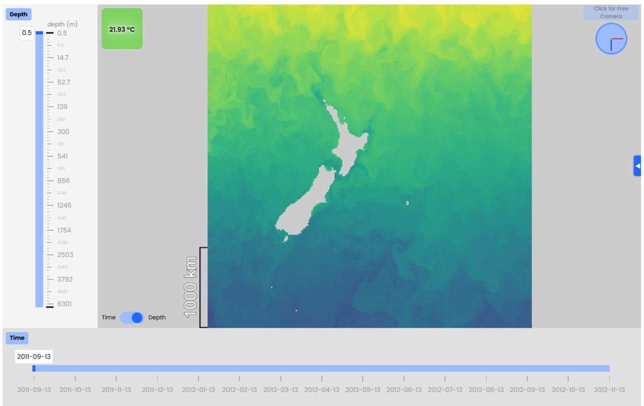

Figure 3: *The start of an exploration session: Similar to common online tools, users are presented with a map view of the selected region. Time and ocean depth can be changed with sliders and further information is hidden within a collapsed sidebar. The transition to a more complex analysis using a space-time cube metaphor is activated via button, or by moving the camera in the main view. This provides a smooth and traceable transition from 2D to 3D.*

The DeepSwitch Interface and Interaction Workflow

The central point of interaction with the oceanographic data is the DeepSwitch interface. Following requirements **R1**-**R4**, the application is realized as a modern, web-based 3D visualization tool, accessed via standard browsers on off-the-shelf hardware such as personal computers or tablets. It uses HTML and Javascript and its interface is divided into four elements, as shown in Figure 1.

Main View 1 - This view is the main place of interaction with representations of the data and several control elements. Rendering is provided using WebGL through Three.js and standard mouse controls allow users to rotate, translate, or zoom the view, as well as various standard interactions (**R2, R4**) while giving them control over the visuals (**R3**). Data does not need to be selected or loaded (**R1**) such that interaction can begin immediately. Following the concept of space-time cubes [Kra03], the visual dimensions in this 3D view always represent latitude, longitude, and a third dimension, either depth or time, which can be switched using a toggle. We call these states *space mode* and *time mode* respectively and refer to the data that can be explored in the main view as a *block*. Thus, a block always represents either the full spatial data of a selected time step or the progression of a selected depth slice over time. Attributes are represented as either color-coded slices, which can be added by clicking on the central axis, dense Line Integral Convolution (LIC) textures to represent vector data, or isocontours. This is indicated in Figure 2. Slices can be deleted and selected, and selected slices are marked with a red boundary. A toggle on the top right allows users to change between a 2D top view and the 3D view while simultaneously providing orientation (**R3**) by showing an axes widget common in 3D software. An info box appears when the mouse hovers over rendered slices, providing the current value and its mapping to color at that location, right-clicking saves this value for comparison or isocontour extraction.

Slice Control 2 - It consists of a single slider with range handles controlling the extent of the data in either time or space mapped to the third dimension in the main view. Tooltips indicate the value of slices and control their position in 3D space. Dragging a tooltip along the slider translates the corresponding slices accordingly, while the red color indicates a currently selected slice.

Block Control 3 - This element consists of a single slider that allows to change the block of data currently loaded into the main view. Slices and isocontours visible in the main view are solely based on the data currently loaded, therefore, limiting or extending the range would not change the visuals, thus this operation is not available in the Block control (**R2**).

Visualization Control 4 - This view provides controls over the visualization of selected data. Users can change the displayed attribute, the used color mapping by choosing a different color palette, and the transparency of slices with a slider. It further includes controls to add and remove isocontours. The view is collapsible and can be opened or closed on demand to reduce the number of visual elements (**R2**).

In the following, we describe a typical workflow with DeepSwitch. When starting the application, the user is presented with a top-down view of a single slice of data as shown in Figure 3. This is the shallowest ocean data close to the surface at the first available time step and thus similar to earth surface maps. A scalar attribute, e.g., temperature, is preselected and rendered using pseudo-coloring, and the Slice Control slider changes the depth, while the Block control changes the time of the data. The Visualization Control is collapsed. As such, the view and functionality are similar to existing online tools, e.g., NASA's Worldview [NAS], thus following (**R1**, **R2**, and **R4**). The transition to displaying data in 3 dimensions is simply achieved by either interacting with the view or pressing the orientation widget at the top. The application starts in space mode which maps the third dimension to ocean depth, similar to standard 3D models. Thus, a user can immediately make the intuitive connection between a rendered slice and its spatial relation within the data (**R4**). Clicking on the central axis visible in the main view adds additional slices, at the selected location, such that the space can be explored by adding multiple slices or altering their position using the Slice Control. The Visualization Control allows users to add and delete isocontours for user-defined isovalues, providing a better understanding of the distribution of values in space. The combination of slices and isovalues supports the understanding of this visualization method, thus improving visualization literacy for users. Using the Block Control changes the selected time sample of all slices, thus, users can gain an overview of the progression of attributes at different locations in space and time, following requirement **R5**. While animating content in that way can be engaging to students (**R3**) and is easy to follow (**R2**), it also introduces complexity, which might make it harder for non-experts to recognize patterns and understand dynamic processes. The works of McElhaney et al. [MCCL15] and Krumhansl et al. [KBK*13] both indicate that a powerful static representation might make it easier to grasp dynamic processes than using dynamic views. Based on this notion, we make use of the main view as a space-time cube. Using the terminology of Bach et al. [BDA*17], our tool provides both time- and space-cutting operations combined with 3D rendering and surface extraction. This means that, once the mode is changed to time mode, different slices represent different moments in time of the same depth, while the Block Control allows to change this depth. Now, isocontours can be used to show how selected values and their distributions change over time, using a single static view, which can support the extraction of interesting dynamic patterns. Yet, to ensure a smooth and comprehensive change from space to time mode, the change uses the currently selected slice as the intersection between space and time modes. This means, the currently selected slice will not change, thus providing orientation to the user.

Reiterating all requirements, the workflow illustrates how all requirements were taken into account: Easy access (**R1**) is granted through an accessible, web-based application that can be used immediately. Similarly, the containerized data acquisition pipeline makes the selection of data accessible to the educator. The application starts with reduced and familiar views and provides means to include more advanced visualization and analysis techniques step by step based on smooth and continuous increases in complexity, while always providing the means for users to find orientation if necessary (**R2**). Users can control the visualizations and views on their own, add and remove views, and explore the results of different settings, supported by the data selected by the teacher and potential additional information to moderate the exploration (**R3**). The interface and visualization choices are designed to follow current best practices of design and user experience by using common views and functionality, wherever possible (**R4**). This includes using the web browser as a common access point, imitating similar web-based tools at the beginning of a session, or using color maps specially designed to provide an intuitive interpretation of environmental data [STWB17]. Providing the means to explore the data in (animated) slices or isocontours using either space or time as the third visual dimension, provides a unique environment to explore dynamic oceanographic processes (**R5**).

5. Case Studies and Preliminary Feedback

To illustrate the effectiveness of our tool, we present two scenarios where DeepSwitch explores different aspects of ocean dynamics. For both cases, data was extracted using the containerized workflow described above. Further, we presented DeepSwitch to secondary school teachers in Germany and the Philippines, including both trainees and experienced educators, and gathered preliminary feedback.

Scenario 1: Shifting seahorse habitat near New Zealand The goal of this scenario is to understand how marine biology habitats are influenced by ocean dynamics and the main steps are displayed in Figure 4. The big-belly seahorse (Hippocampus abdominalis) is a common seahorse found in the oceans surrounding New Zealand. It resides in ocean depths from shallow waters up to approx. 104 meters and survives in temperatures between 8 °C and 24 °C. To explore the shift of the habitat over the seasons, students could start by visually exploring the temperatures close to the sea surface, over time. Data was prepared to show monthly samples over 14 months. Once a 3D view is used, they can use the Slice Control to limit the extent of the data to include only depths up to 112 meters, close to the maximum habitat depth. Adding two isosurfaces, one for 8 °C and one for 24 °C provides a spatial understanding of the habitat of these animals at a selected moment in time. The intersections with the slices show a strip-like area aligned horizontally with New Zealand. Now, changes to the habitat can either be explored by using the slider in Block control, which results in new isocontours, or by switching to time mode. Having the uppermost slice selected, switching to time mode reveals the motion of temperature boundaries over time, as the isocontours are directly recomputed for the same temperature values. Now, seasonal influence is clearly visible, as the temperature boundaries move north during the winter and return to the south in late summer. Changing the selected depth by using the Block Control reveals that these changes are less dramatic for deeper parts of the ocean. All these findings can be discussed within the class alongside other hypotheses,e.g., if this effect is solely produced by seasons or if currents might also play a role and tested within the tool.

Scenario 2: Ocean eddy analysis in the Mozambique Current In this scenario, we demonstrate how DeepSwitch can be used to test assumptions about phenomena described in the data. The exploration process is shown in Fig. 5. Movement of water in the ocean is typically described by vector fields and high absolute vorticity is an indicator of rotating motion. This is linked to a phenomenon called ocean eddies. A notorious location where such eddies appear is the Mozambique Channel between Madagascar and Mozambique. Locations and progressions of these can be observed in the 2D view supported by appropriate color maps. As eddies can form, merge, and dissipate over a shorter period, a time span of one month in the winter of 2011 was chosen with daily samples. When exploring vorticity at the sea surface, it appears that two eddies are merging as shown in the top row of Fig. 5. Right-clicking a texture

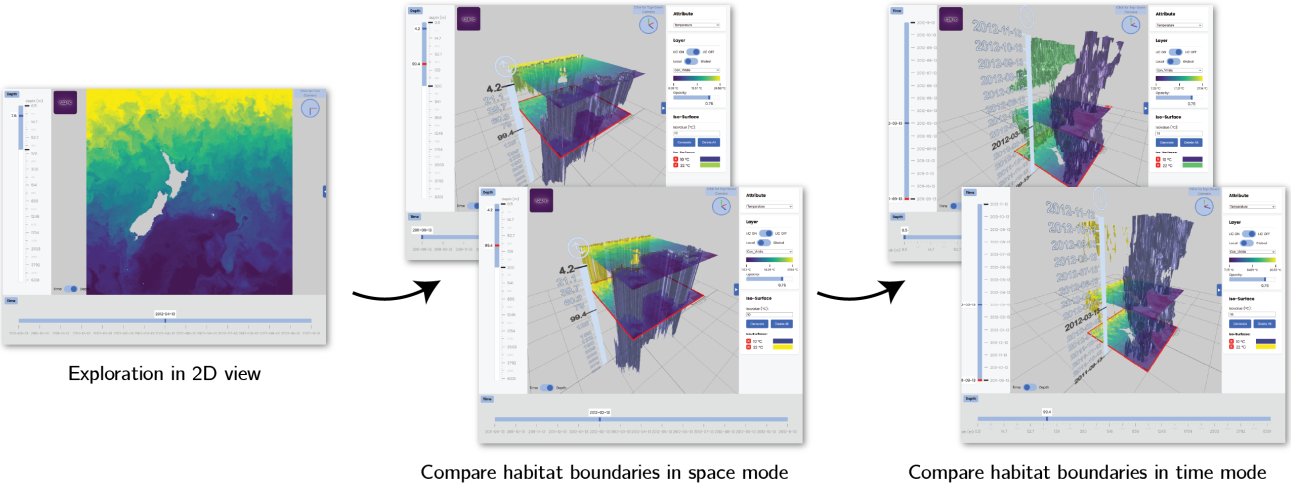

Figure 4: *Exploration scenario 1: Exploring the effect of ocean temperature dynamics on the possible habitats of big-belly seahorse populations. These habitats are restricted by ocean depth and temperature range. Left: Users gain an overview by analyzing the temperature indicated by the color in the 2D views. Time and depth are changed using the sliders. Center: The depth range is restricted using the Slice Control and isocontours show the spatial limits of a possible habitat for a given moment in time. The upper image shows a date in September, and the lower is in February. Right: The user can see the shift of these boundaries over time for selected depths, as indicated by the wave shape of the isocontour. Comparing different depths indicates that the shift is less prominent in deeper parts of the ocean.*

close to the center of a visible eddy allows users to identify interesting isovalues, and the corresponding contours in space mode show that they seem to reach deeper areas of the ocean. Switching into time mode, the shape of isocontours seems to confirm the assumption that two eddies indeed merge for a brief moment of time, before splitting again as shown left in Figure 5. However, when using the Block Control to change to a lower depth value of 473 meters, the contours do not merge at all but remain isolated structures over time. This, too, can be discussed within the class and connected to follow-up questions, e.g., the impact of eddies on salinity or temperature. This scenario illustrates, how users are able to explore interesting features they discover in the data solely based on visual cues and without comprehensive background knowledge about specific value ranges.

Preliminary Feedback from Teachers As our tool was primarily designed to transition from restricted 2D tools to more advanced visualization tools without being overwhelming, we reached out to a number of teachers involved in teaching biology in secondary schools. We received feedback from a total of four participants from the Philippines and Germany, whose experience ranged from trainees to seasoned educators with over 10 years of teaching experience. During informal interviews, we explained our motivation and design process and presented our tool with various scenarios. Afterward, participants were invited to freely interact with the tool themselves while vocalizing their thoughts. We asked them for an overview of how similar content would be taught in their classrooms and for general feedback on DeepSwitch, including its potential applications and limitations. While this cannot be considered a thorough user study, it provided valuable preliminary insights that are both promising and provide future directions for our work.

Overall, the feedback was predominantly positive and aligned well with the requirements we defined. Participants expressed strong interest in using the tool in their classes, particularly for project work or interdisciplinary themes. They especially mentioned the potential to support independent learning driven by the student's own curiosity. This is in contrast to current methods, which all participants noted as being restricted to books with 2D views showing overly simplified and idealized representations. However, teachers noted that while DeepSwitch could engage older students (grade 10 or above) effectively by providing a novel and engaging environment alongside the possibility of increasing complexity step by step, there were concerns about its complexity for younger and weaker students. However, this was also mentioned as providing potential for collaboration within the class to support one another. They provided potential features, such as exporting screenshots or 3D models or getting more control over the visibility of isocontours. Finally, they saw the importance of training educators to effectively incorporate the tool and discussed potential accessibility restrictions such as device compatibility and internet connectivity, which we included in our design considerations.

6. Conclusion and Future Work

In this work, we presented DeepSwitch, a novel web-based visual analysis tool, specifically designed to introduce students and non-experts to the visual exploration of dynamic processes in oceanographic data. We developed a containerized data acquisition workflow and web application based on requirements summarized from existing literature on the visualization of oceanographic data and teaching of environmental processes. DeepSwitch allows students to transition from known 2D tools to 3D exploration and more advanced visualization techniques while exploring dynamic processes

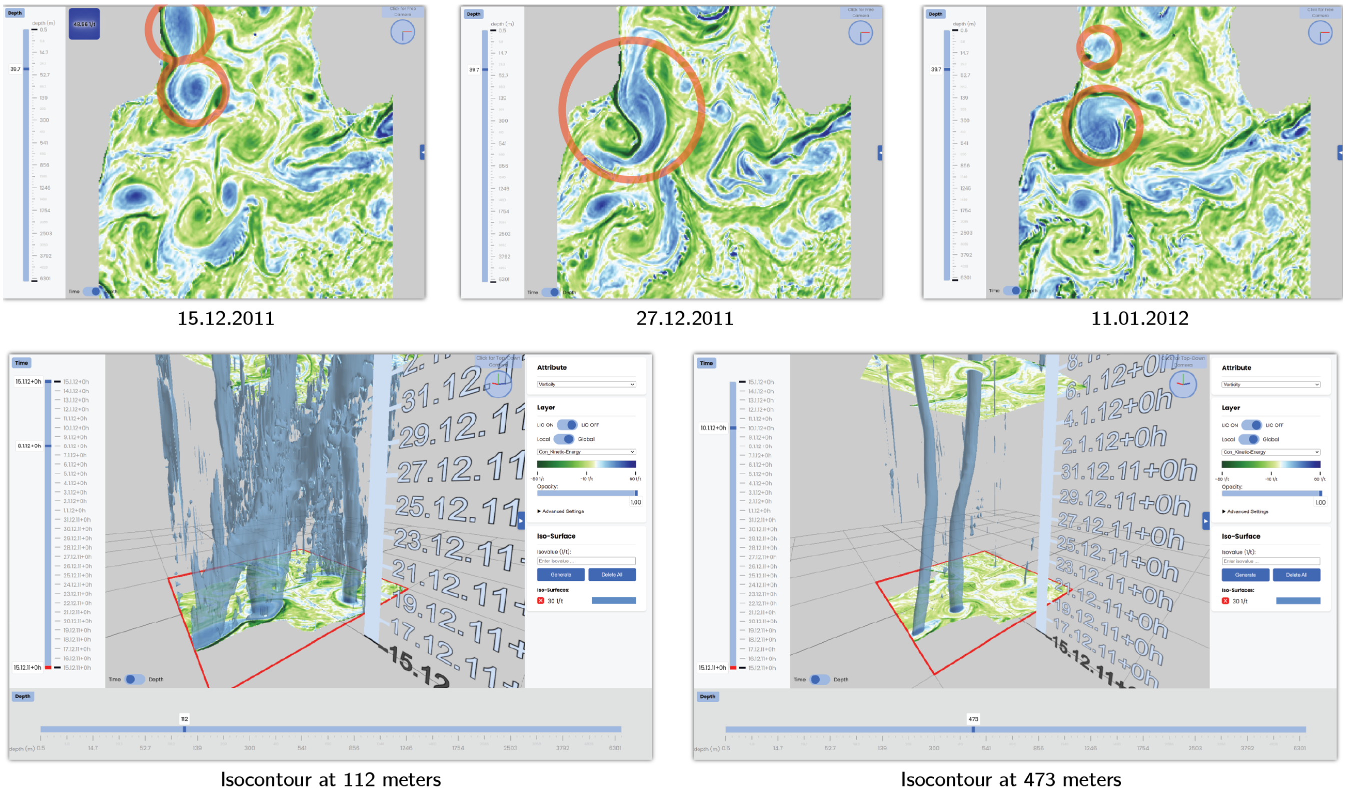

Figure 5: *Exploration scenario 2: Exploring the dynamics of ocean eddies over time for different ocean depths. Top row: Animation in the 2D view hints towards a possible merge event of two ocean eddies in the Mozambique Current. Bottom row: Comparing isocontours of high vorticity values for different ocean depths in time mode. The shape on the left indicates that two eddies merge over time and split apart again, while the two isolated tubes on the right indicate that, while the eddies come close, they never merge at depths around 473 meters.*

by building upon a space-time cube metaphor and a quick switch between time and space modes. This was demonstrated in two exploration scenarios and supported by preliminary feedback from teachers. Thus, we are optimistic that DeepSwitch can become a valuable tool within classrooms and for non-expert interaction with oceanographic data.

Naturally, a tool designed for entry-level visual analysis misses a lot of tools and powerful metaphors provided in other solutions and the insights gained within the presented scenarios can be reproduced using other visual analysis tools. However, a workflow within, e.g., ParaView, would require a substantial amount of steps of processing and remapping to achieve the same results, which cannot be expected from students and non-experts. On the contrary, we hope that our tool can motivate users to improve their visualization literacy and make the transition to more advanced tools easier. In the future, we hope to extend DeepSwitch in several ways. We plan to improve its stability and performance through continued developments, as well as user experience and accessibility through close collaboration with and iterative evaluation by educators. Integrating additional quantities, e.g., mode water regions [YIT*20], spatial features, and geological sights, such as volcanoes or faults might provide additional context to the data. Through modern web technologies, DeepSwitch could be extended to allow for the use of immersive visualization, e.g., being linked to live simulation data [KMKG25], providing additional novel interactions to users. While DeepSwitch was designed to be used in a classroom environment where mentoring and contextual information are provided by the teacher, it could easily be extended or embedded in more story-driven applications. Alternatively, additional tools for educators could be added to provide more central steering options. This could include the option to selectively control the applications on the student's devices from a central control application, guiding users through a shared exploration process, while only partially limiting students' individual interaction experience. Naturally, the tool could also be adapted for the use of a more advanced user group, such as undergraduate oceanography students, to provide a gateway visualization tool to more advanced visual analysis [RKO*20]. Finally, while DeepSwitch was designed with ocean data in mind, it is not limited to such data but can handle other time-dependent spatial data, too. However, it needs to be explored, whether the same requirements hold for different disciplines.

7. Acknowledgment

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