Real-time Immersive VR Visualization of Ocean Climate Data

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Figure 1. Example views of the VR environment landscape showing the textured topography (left and right image) and HDRI sky dome (middle and right image) and the dynamic ocean surface with Gerstner waves (left and middle image)

Abstract
Virtual Reality is expanding rapidly in many academic and industry areas as an important tool to represent 3D objects, while graphics hardware is becoming increasingly accessible. Conforming to these trends, we present an immersive VR environment created to help earth scientists and other users to visualize and study ocean simulation data and processes. Besides scientific exploration, we hope our environment will become a helpful tool in education and outreach.

Index Terms: Data visualization—Ocean salinity—Ocean temperature—Virtual reality

1. INTRODUCTION

Due to rapid technological development, virtual reality (VR) is becoming an accessible and important tool for many applications in science and industry. Being immersed in a 3D environment that enables direct interaction with the presented climate phenomenon, offers a wider and more profound result in the exploration and learning process than the usual 2D or pseudo 3D models on monitor devices. A variety of VR implementations-related work can be found in recent research. Helbig et al. [1] proposed a system that integrates heterogenous atmospheric model data in a stereoscopic VR environment. Kolb et al. [2] present a proof of concept project regarding the use of immersive VR in climate sciences, that allows the visualization and exploration of terrain and accumulated precipitation data. The VR environment presented in this work combines a 1-year MITgcm simulation [3, 4] with daily temporal resolution and 3km spatial resolution, with a bathymetry digital elevation model in order to visualize the evolution of Northeast Atlantic eddies enclosed by warm and salty Mediterranean Water.

2. ENVIRONMENT IMPLEMENTATION AND DESIGN

2.1 The Visualized Phenomenon

The study of the dynamical processes involving the Mediterranean Water is important since this water mass plays an essential role in the ocean's thermohaline circulation and thus in regulating the World's climate. The mean state and variability of the circulation of Mediterranean Water is still unclear. Due to the spatial scales at which the relevant related phenomena occur, the explicit representation of the Mediterranean Water in climate models is poor and therefore needs to rely on parameterizations. In fact, climate models still do not parameterise correctly the small-scale features of the Mediterranean Water outflow in the Atlantic, namely the anticyclonic eddies of Mediterranean Water origin ("meddies") and the boundary intensified undercurrent, which transports Mediterranean Water along the Iberian continental slope. Therefore, high-resolution simulations like the one presented here are needed to study the physics of those processes.

The high rate of evaporation in the Mediterranean Sea leads to a significantly larger salinity in that basin when compared with the Atlantic. The salty and relatively warm Mediterranean Water flows through the Strait of Gibraltar and afterwards along the Iberian Peninsula into the Northeast Atlantic. The generation of meddies takes place at an intermediate depth (800-1200m) along the path of the Mediterranean Water undercurrent and seems to be more frequent at places along the Iberian Peninsula, like the Portimão Canyon, off Cape St. Vincent, at the Estremadura Promontory and off Cape Finisterre. In those places, abrupt changes in bathymetry affect the undercurrent stability promoting the flow separation in capes [8], baroclinic instabilities [9], intermittence of the undercurrent transport and topographic effects in canyons [10, 7].

The visualized simulation presents one year of the evolution of meddies close to the generation regions along the Iberian slope. Meddies are shown wandering through the ocean while rotating clockwise and enclosing the salty and warm water, mantaining those properties over long periods of time. During their movement, fast, rich and complex interactions take place between the meddies themselves, between meddies and other, counterclockwise rotating (cyclonic) eddies and between eddies and the boundary current. Due to these interactions, meddies modify their translation direction, sometimes start to wobble and can eventually lose their stability and be destroyed.

In order to carry out a visualization of this phenomenon, we selected from the MITgcm data set a region between longitude -23 to -1 degrees east, and latitude 31 to 47 degrees north. We combined this with a more ample topography and bathymetry region from the one degree GEBCO's gridded bathymetric data set [5], where we selected -30 to 0 longitude degrees east and 25 to 50 latitude degrees north.

2.2 Environment Development

The process of modeling and building the virtual environment is as follows: we imported the raw data sets in the 3D procedural modeling software HoudiniFX. The visual representation of

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the meddies structures was carried out with the help of isosurfaces. In order to represent the clockwise rotating meddies, we extracted a relative vorticity isosurface at values -0.15 (shown in violet in Figure 2) while the counterclockwise rotating meddies are represented by an isosurface of the same variable at value 0.1 (shown in green in Figure 2). The warm and salty Mediterranean Water eddies were represented with a salinity isosurface at value 36.3 that was coloured by temperature.
This initial step was followed by data refinement consisting of area size-based removal of small noisy features and polygon count reduction with the help of a feature-preserving algorithm. The bathymetry was modeled with the help of a height field based on the height values stored in the GEBCO elevation model. Furthermore, height layers and mask layers were used to establish height-based dry land (fields, hills, mountains) and ocean floor components, as a preprocessing step allowing height-dependent texturing.
Both 3D data sets were then translated in the Unreal Engine 4 (UE4) game engine. We strove to create a realistic, visually compelling environment. The scene illumination was set up with the help of a directional light and a sky dome mesh textured with a High Dynamic Range Image (Figure 1). The topography data was textured according to the aforementioned height layers with physically-based materials. We applied a Fresnel transparency shader to the salinity isosurface, in order to highlight the lenticular shape and filaments' silhouette of the meddies and allow the visibility of the interacting vorticity isosurfaces (Figure 2). The UE4 Community Free Ocean Project libraries [6] were used for creating a dynamic ocean surface with Gerstner waves (Figure 1). The under-water environment was created with the help of a water physics volume with a buoyancy and water friction component that enabled the implementation of a swim-like user motion. In order to ensure a good visibility of the simulation, we established an active perimeter, corresponding to the bounding box of the MITgcm simulation data. The user is enabled to play the simulation only when situated within the limits of this active perimeter. We activated UE4's World Composition feature, a crucial tool for the real-time display of large-scale terrains, which allows the import and tiling of landscapes that have greater dimensions than the default maximum size of 20x20 km. We also enabled the World Origin Rebasing, which resets the origin of the coordinate system depending on the current position of the user. Enabling this feature avoids negative and unstable effects for objects that are placed more than 5 km away from the world origin.

2.3 Motion Control and User Interaction

We used an Oculus Rift Touch HMD and decided to keep the motion controls lightweight and mirrored, in order to facilitate for users the focus on the simulation data and possibly unfamiliar swim-like motion. On dry land users can move around with the help of head movements and thumbstick navigation. In the water environment users can direct their swim-like motion similarly, with an additional ascending/descending motion component. While located in the active perimeter, the users are able to start and stop playing the simulation with the trigger button.
We included a heads-up display (HUD) that contains a circular widget informing the user about the simulation time progress, a colour legend and a real-time sliding map with the user position marked, in order to enhance the users' geographic orientation awareness (Figure 2, lower image and Figure 3). The background image of the map was obtained in the game engine during an initial development step with the help of a camera that captured an orthographic view from above of the scene and rendered it to a texture render target. The texture was first exported as an image then imported in the project where it's centred in real-time around the user position. In order to further facilitate the understanding of the geographical spatial extent, we added to the corners of the active perimeter information about the corresponding longitude, latitude and depth, with the

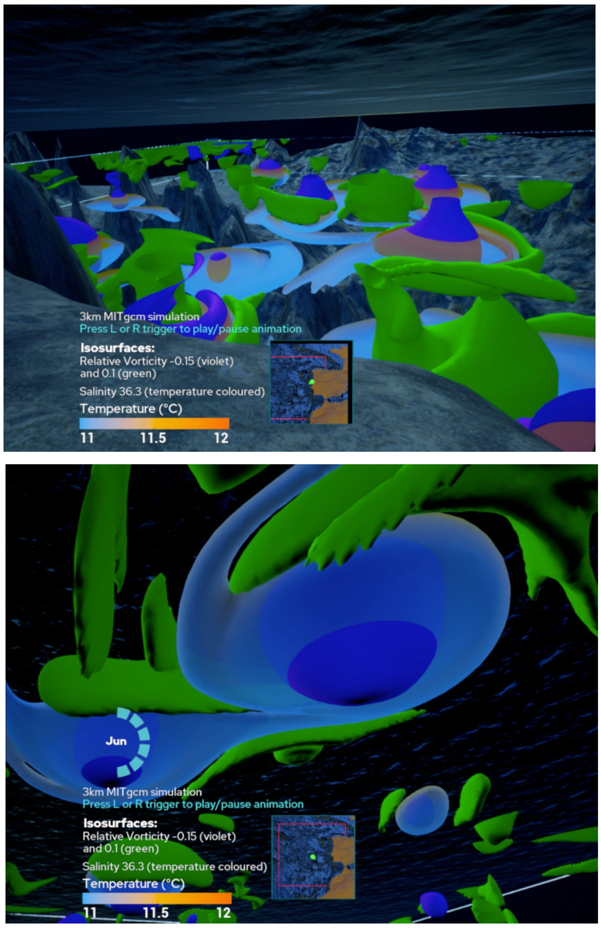

Figure 2. Two views showing the eddies' isosurfaces (with Fresnel transparency applied to the salinity isosurface) and the heads-up display

text panels rendered dynamically to always face the HMD, so that users are able to easily read them regardless of the viewing angle.

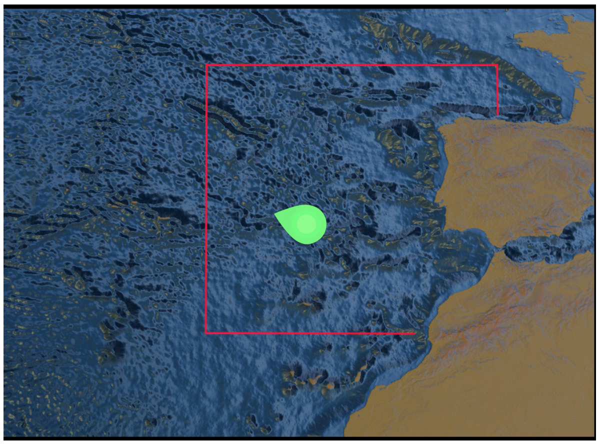
Figure 3. The sliding map displays the limits of the active perimeter and the current user location

2.4 Visual Cues

Besides showing the real-time position of the user on the sliding map, we implemented a number of visual cues in order to enhance the user orientation regarding their location both within and outside the active perimeter. The colour of the active perimeter bars shifts from white to red the closer the user is located to them (Figure 4). The user located outside the active perimeter will result in halting a playing simulation, while the HUD circular progress bar and the colour legend will no longer be displayed. Also, the shading of the salinity isosurface will switch from Fresnel transparent to simple opaque shading (Figure 5). Upon re-entering the active perimeter, the reverse events will take place.

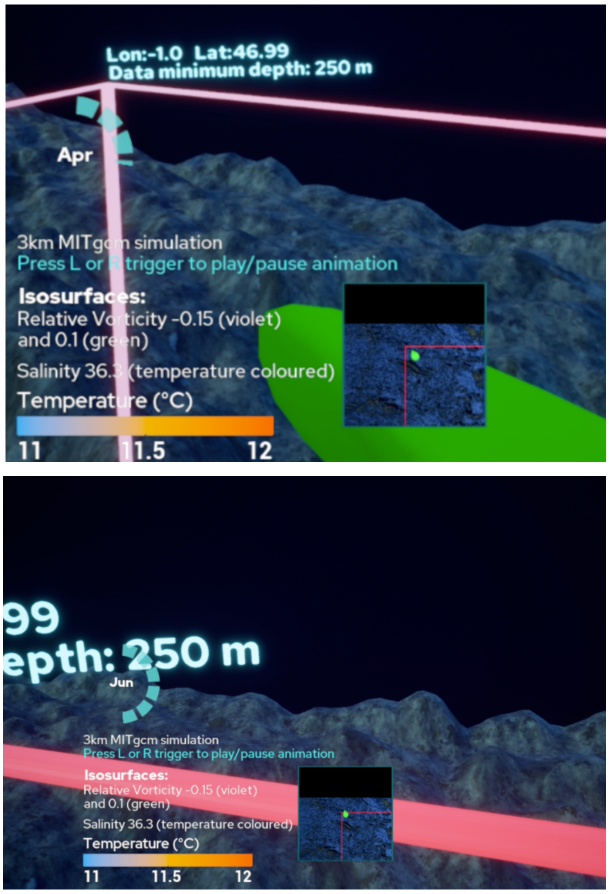

Figure 4. The colour of the active perimeter bars shifts from white to red the closer the user is located to them

3. Usability Test Results

Due to the current COVID-19 related restrictions, we were able to recruit only five volunteer participants. Of these five participants, two were professors or senior scientists and three were students. One participant had a research or study background in oceanography, the rest of the participants in other Climate Sciences fields. The participants were given a short instruction followed by them performing the navigation and data observation tasks. All users were able to adapt to the the motion controls and easily interact with the scene and simulation within one minute. Furthermore, the participants found it useful to have the ability to dive inside the eddies and observe the inner structure evolution as well as the ability to follow closely, with easy navigation gestures, the eddies on their wandering paths. The usability questionnaire contained the following questions:

- It was easy to perform the navigation tasks
- The motion speed was comfortable
- The sliding location map was helpful for spatial orientation
- The colour legend and months display were easy to interpret
- The active/non-active state visual cues were helpful
- Overall the application was easy to use

The choice of answers spanned the "strongly disagree/disagree/neutral/agree/strongly agree" range. Overall, participants had a positive view of our environment and found it easy to interpret the colour legend and time progress information as well as orient themselves in the environment with the help of the sliding map. With one exception, participants considered the visual cues helpful. While all participants considered that the visibility of the simulation data is not impeded by the heads-up display, one user suggested implementing its optional deactivation to allow a full view of the data. Another participant suggested the addition of a temporal jump option enabling users to forward or backtrack to user-selected time steps and focus on certain time intervals. None of the participants reported significant motion sickness or asked to stop during the experiment.

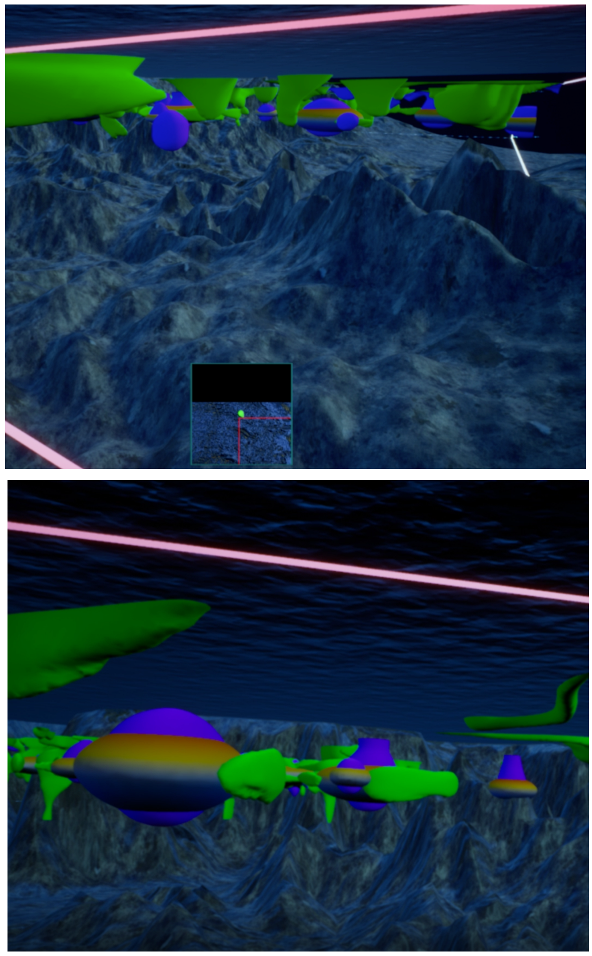

Figure 5. The user is located outside the active perimeter: the salinity isosurface switches from Fresnel transparency to simple opaques shading, the circular progress bar and the colour legend are no longer displayed.

4. Performance Results

We aimed to ensure that our application will run on commodity hardware. Therefore, we developed and tested the application on a mid-range system with an NVidia Geforce GTX 1080Ti graphic card, Intel i7-8700 3.20GHz main processor and 32GB RAM, where we achieved a rate of 56-58 frames/second, slightly below the recommended 60 frames/second, but ensuring a smooth visualization with no latencies or artefacts.

5. Conclusion

We presented a real-time visualization of a high resolution ocean data set in an immersive VR environment. The users are able to move around freely and arbitrarily play the simulation in order to observe changes and evolution of ocean eddies in real time. This application can be used as a tool for scientific exploration, teaching and outreach. Our future work will involve evaluating our application with general users outside the climate sciences scope in order to establish if further functionality has to be developed or adapted to serve their needs. Furthermore, we intend to investigate improving the workflow to achieve real-time performance for climate data sets of higher resolution.

References

[1] Helbig, C., Bauer, H. S., Rink, K., Wulfmeyer, V., Frank, M., & Kolditz, O. (2014). Concept and workflow for 3D visualization of atmospheric data in a virtual reality environment for analytical approaches. In: Environmental earth sciences, 72(10), 3767-3780.
[2] Visualization of climate simulation data in virtual reality using commercial game engines, D. Kolb, W. Kurtz, A. von Ramm, J. Weismueller. EnviroInfo 2018
[3] The MITgcm (MIT General Circulation Model) numerical model designed for study of the atmosphere, ocean, and climate. http://mitgcm.org/
[4] Serra, N., I. Ambar & D. Boutov (2010). "Surface expression of Mediterranean Water dipoles and their contribution to the shelf/slope - open ocean exchange". Ocean Science, 6, 191-209
[5] GEBCO Compilation Group (2020) GEBCO 2020 Grid. http://www.gebco.net
[6] The "UE4 Community Free Ocean Project" libraries, https://github.com/UE4-OceanProject/Environment-Project
[7] Serra, N., Ambar, I., 2002. Eddy generation in the Mediterranean undercurrent. Deep-Sea Research II 49 (19), 4225–4243
[8] D'Asaro, E.A., 1988. Generation of submesoscale vortices: a new mechanism. Journal of Geophysical Research 93 (C6), 6685–6693
[9] Kase, R.H., Beckmann, A., Hinrichsen, H.-H., 1989. Observational evidence of salt lens formation in the Iberian Basin. Journal of Geophysical Research 94 (C4), 4905–4912
[10] Cherubin, L., Carton, X., Paillet, J., Morel, Y., Serpette, A., 2000. Instability of the Mediterranean Water undercurrents Southwest of Portugal: effects of baroclinicity and of topography. Oceanologlia Acta 23 (5), 551–573