

Viewpoint Selection for Shape Comparison of Mode Water Regions in a VR Space

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Abstract—Immersive spaces using VR technologies are available for 3D visualization because of the user-centered operation and the accurate understanding of the target. They recently have been employed for visualization of more various scientific data. Though the VR (virtual reality) space is effective for realistic experiences of users, there are problematic situations for users to operate appropriately and observe complex geometries comprehensively. Here, we propose a viewpoint selection method to solve these situations and a user interface for observing a pair of isosurfaces of the mode water region in a VR space. By setting the selected viewpoint as a starting point, users can observe the geometric of the mode water pairs comparatively with simple intuitive operations. This system enables users to promote efficient observation and a quick understanding of the features and the differences in the mode water pair. This paper introduces the visualization results of two example pairs that have the minimum and maximum dissimilarities.

Index Terms—VR visualization, viewpoint selection, shape comparison, mode water, ocean data

I. INTRODUCTION

Virtual Reality (VR) systems have been applied in various academic and industrial fields such as entertainment, business, medical and education. VR techniques have been employed for 3D visualization for a long time. 3D visualization in immersive spaces using VR technologies enables the following: [1]

- User-centered operation to explore target spaces interactively instead of moving the target because a user is immersed into the space of the target.
- Accurate understanding of shapes by observing the targets in the space that provides depth perception and visual cues.

Immersive VR spaces as described above are therefore effective to understand scientific data [2], and have been applied for visualization of more various scientific data recently. Here, we assume problematic situations of VR spaces as follows:

- If a user explores a target vaguely, it may take a much longer time to understand the whole space and features of the target.

- If a target has a complex shape, a user may overlook features of the target.
- If a user is not accustomed to the VR operation, he/she may cause VR sickness and exhaustion.

We propose a viewpoint selection method to observe targets in a VR space effectively. We applied shapes of mode water as target data. Mode water is a 3D region defined as particular properties of seawater mass and distributed in the ocean. Its formation is caused by the condition change of air on the seawater surface, and its variability is important for analyzing the mechanism of climate change and natural phenomena. Researchers in the field of physical oceanography analyzes a structure of mode water by mainly 2D visualization techniques using two axes out of latitude, longitude, and depth; however, they need to combine several cutting planes to understand the whole shape of mode water. Also, it is often difficult to accurately observe the 3D regions. Since mode water is defined with various conditions, different shapes of mode water may be extracted from the same data. It is therefore important to analyze how different definitions relate to the geometric differences of mode water region [3].

This paper introduces our technique to observe the comparison of **mode water pairs** with various conditions. We color the isosurface of mode water region based on the distance between its pairs and suppose a viewpoint selection for the observation of similar/dissimilar parts of **the mode water pairs** based on **the pair** comparison result by implementing a view-based method. Consequently, users can observe targets in a VR space with simple intuitive operations and understand its features efficiently.

II. RELATED WORK

This section introduces scientific visualization in a VR space and viewpoint selection. Definitions and observations of mode water are described in our previous paper [3].

A. Scientific Visualization in a VR space

Scientific visualization using VR technologies have been applied to observe the target models and datasets. Mirhosseini et al. [1] applied to virtual colonoscopy. Shapes of the colon are observed with keeping the context of the visualization. This would lead to improvement of the accurate and the speed of its detection and result in good screening. Actually, Randall et al. [5] developed a more practical method of virtual colonoscopy and reported the largely positive feedback of their method trialed by some clinicians. Also, Zhang et al. [4] applied to brain tumor surgery. This would provide a better spatial understanding of the important structures including the target tumor before the surgery. A VR environment is suitable for recognition of the complex target shape and the positional relationship with surroundings.

While evaluations of each VR system have become important as the system applied to various data. There are several studies on the effects of VR fidelity [2], [6]. Laha et al. [2] evaluated the effects of three components of the VR system fidelity (field of regard; FOR, stereoscopy; ST, head tracking; HT) on isosurface visualization. They reported ST is better performances for search and spatial judgment tasks and useful for analyzing isosurfaces. High level of FOR and HT improve performance in spatial judgment tasks. In our study, the shapes of the mode water region are extracted and displayed as isosurfaces in a VR space.

B. Viewpoint Selection

The optimal viewpoint selection is very important for displaying 3D models and observing 3D datasets. There have been many related studies applied to volume visualization. Many techniques selected the optimal viewpoints based on the surface geometry based on viewpoint entropy [11]. Takahashi et al. [8] decomposed the volume into feature components and supposed globally optimal viewpoint based on compromises of locally optimal viewpoints for each component. Our implementation does not take into account the interval volumes because past studies in the field of physical oceanography have not focused on inside the mode water regions. Bordoloi et al. [7] calculated the noteworthiness values of each voxel with its opacity and color using properties of the entropy function and specified good viewpoints based on the visibility of each voxel. Ji et al. [10] analyzed the opacity, color and curvature distributions of images from different viewpoints for static view selection. Our implementation of viewpoint selection for observing comparison of isosurface pairs is similar to [10]: it calculates the HSB value from generated images of comparative isosurface pairs which have colored based on the distance between the pair. Also, Ahrens et al. [9] applied an image-based viewpoint selection approach to extreme scale scientific visualization and specified important/particular viewpoints.

III. IMPLEMENTATION OF PROPOSED VR SYSTEM

This section describes a user interface with a viewpoint selection method to observe the comparison of shapes of mode water pairs. Fig. 1 shows the processing flow of the user

interface. We extract the mode water region as an isosurface [3]. The user interface colors the isosurface pair based on the distances between the pair and generates images from various viewpoints. After that, it selects the best viewpoint by evaluating the set of the generated images.

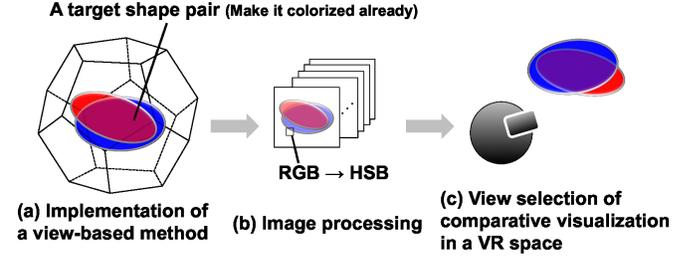


Fig. 1. Processing flow.

A. Comparison of Isosurface Pairs in a VR Space

We describe shape X and Y as an example isosurface pair in this section. We calculate the colors of each shape using minimum distances between each vertex of an isosurface (shape X) and each vertex of the other isosurface (shape Y) and place the colored isosurface pair into a dodecahedron. Then, we generate images of the isosurface pairs setting viewpoints as the vertices of the dodecahedron. We evaluate the viewpoints based on the distribution of hues of the images and finally select the best viewpoint for the isosurface pair. A user thus can observe shapes of isosurface pairs from the optimal viewpoint as a starting point in a VR space.

Our implementation is on the top of Unity¹ to build a VR space. Unity is a powerful game engine and its real-time creation platform offer extensive supports for game developers and creations across industries and applications. It can be easily connected with various VR devices, and therefore easily configured with multiple systems.

1) *Color of Isosurface*: Let $X = \{p_1, p_2, \dots, p_i\}$ be a set of vertices which consist of shape X and $Y = \{q_1, q_2, \dots, q_j\}$ be a set of vertices which consist of shape Y . We first calculate the distances between p_i and q_j described as $dist(p_i, q_j)$. We implement two colormap patterns (Fig. 2) to observe the isosurface pair effectively.

a) *Colormap (A)*: Let $L(p_i) = \min dist(p_i, q_j)$ be a minimum distance with respect to the vertex of shape X . We describe $\min L(p_i)$ and $\max L(p_i)$ as $L_{min}(p_i)$ and $L_{max}(p_i)$ individually. We define normalized $L(p_i)$ as

$$Color_A(p_i) = \frac{L(p_i) - L_{min}(p_i)}{L_{max}(p_i) - L_{min}(p_i)} \quad (1)$$

If $Color_A(p_i)$ is closer to 0, a corresponding part of shape X is drawn in blue, while $Color_A(p_i)$ is closer to 1, a corresponding part of shape X is drawn in red.

¹<https://unity3d.com>

b) *Colormap (B)*: We calculate the center of shape X and treat it as g_x . We describe vertices of $L(p_i)$ as (p_i, q_a) and define the deference from g_x to p_i or q_a as

$$Color_B(p_i) = dist(g_x, p_i) - dist(g_x, q_a) \quad (2)$$

If $0 < Color_B(p_i)$ and the absolute value of $Color_B(p_i)$ is larger, a corresponding part of shape X is drawn in vivid blue, while $Color_B(p_i) < 0$ and the absolute value of $Color_B(p_i)$ is larger, a corresponding part of shape X is drawn in vivid red. If $Color_B(p_i)$ is close to 0, a corresponding part of shape X is drawn in gray.



Fig. 2. Colormap.

Same calculation is also applied to shape Y , and then Y is drawn based on $Color_A(q_j)$ or $Color_B(q_j)$.

We first draw each shape with colormap (A). Here, if shape Y corresponds to the shape that X is enlarged, reduced or translated, most of the parts are likely to be drawn in green. It is difficult to understand the differences among enlarged, shrunk or translated shapes because they are all drawn in green. In that case, we can switch to colormap (B) and observe the isosurface pair more accuracy.

2) *Obtainment of Image of the Isosurface Pair*: We place the colored isosurface pair into a dodecahedron and treat its vertices as viewpoints. We eliminate the effect of light reflection and set the background to white. We then implement a view-based method and obtain 20 images of the isosurface pair.

3) *Viewpoint Selection Based on Image Processing*: We calculate the HSB value of each pixel from images of the isosurface pairs. We then select a viewpoint based on hue value for observation of the isosurface pair. Pixels excluding white, the background color, are used for the image processing. The hue of each pixel is normalized into the range $[0, 1]$. We propose two viewpoint selection methods based on average hue and specific hue section in this study.

a) *Average Hue*: We calculate the average hue of each image from each viewpoint. If the shapes of the isosurface pair are similar, they may be displayed in blue. Otherwise, they may be displayed in red since each of the pair is colored based on the distances between the pair. In other words, if the pair have many similar parts, many pixels are painted in blue. If the pair have many dissimilar parts, many pixels are painted in red. Therefore, if a user wants to observe similar parts of the isosurface pair, he/she is recommended to select the viewpoint which brings a small average hue. Otherwise, he/she should select the viewpoint which brings a large average hue.

b) *Specific Hue Section*: We count the number of pixels of the hue of each image from each viewpoint. The normalized hue is divided into nh ($nh = 10$ in our implementation), and we count the number of pixels for each hue section. The viewpoint is suggested to a user based on the number of pixels

in the hue section selected by the user. This viewpoint selection can satisfy the various interests of users. For example, a user can select the viewpoint to observe the specified part where the distance between the isosurface pair is constant.

B. Visualization in a VR Space

We implemented a VR space using Unity and Oculus Rift². Oculus Rift is one of the popular high-performance head mount displays (HMD). We can build a VR environment easily by combining Unity and Oculus Rift. We can use an Xbox controller as well as a mouse or a keyboard to operate the VR space while he/she observes a target isosurface pair in the VR space.

An isosurface is displayed as a triangular polygon mesh in our VR space. We regard the region of grids where the scalar value is missing as a continent in the North Pacific Ocean targeted by our study. The continent is displayed as a height map.

1) *Viewpoint Selection*: Users can insensibly observe similar/dissimilar parts of the isosurface pair since our technique suggests viewpoints in the ascending/descending order of average hues. Users can also observe the specified parts along to the user's interest and the features of the isosurface pair from other viewpoints. The inspector window of Unity provides the detail of hue distributions of each image from each viewpoint as shown in Fig. 3. Users can select the viewpoint looking at the hue distributions.

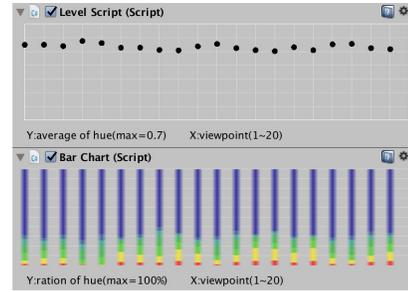


Fig. 3. Hue distribution of each image for each viewpoint. Average hue (upper) and hue section (lower).

2) *Comparative Visualization*: A user can observe the isosurface pair from the selected viewpoint. Similarly shaped pairs are drawn in cool colors such as cyan and blue, while the dissimilarly shaped pairs are drawn in warm colors such as orange and red. If the isosurface pair is mainly displayed in green, it may happen that users cannot understand whether one of the isosurfaces is enlarged, shrunk or translated from the other. In that case, we can switch to colormap (B) as shown in Fig. 2. If one of the isosurfaces is enlarged or shrunk from the other, the pair will be drawn in red or blue. If one of the isosurfaces is translated from the other, the overlapping parts are drawn in gray, and the other parts are in red and blue.

²<https://www.oculus.com>

3) *User Interface*: Fig. 4 (upper) shows the snapshot of our implementation on Unity. Fig. 4 (lower) shows the view on Oculus Rift. An isosurface of the mode water is displayed at the center as shown in Fig. 4 (upper). Users can observe the positional relationship of the mode water and continent in a VR space. Users can also select the isosurface to be compared, calculate colors of isosurfaces pair, and process its images displayed at a view panel on the right side as shown in Fig. 4 (upper). When applying the multiple viewpoint rendering, continent and the view panel are hidden, and isosurface pair is rendered by a shader which does not take light reflection into account. Users can move freely from a selected viewpoint as a starting point and observe the isosurface pair efficiently and effectively in a VR space. Movements of viewpoints can be recorded as a series of frames, and the sequences of scenes can be saved as a set of images. The viewpoint can be suggested to a user using a series of images.

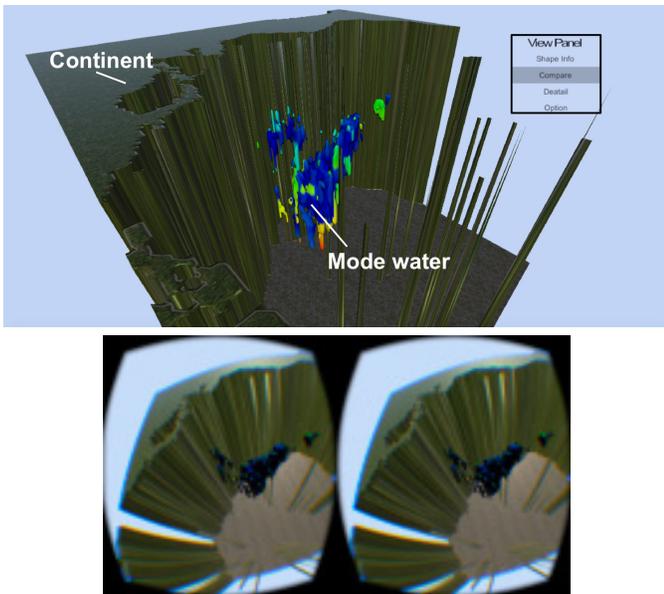


Fig. 4. Implementation screen on Unity display (upper) and Oculus Rift display (lower).

IV. EXAMPLES

We extracted mode water regions applying various conditions from observation and simulation datasets and calculated their geometric similarity [3]. This section introduces two example pairs which have the minimum and maximum dissimilarities.

A. Shape Data

We employed an observation dataset from WOA13³ (World Ocean Atlas 2013) and a simulation dataset from OFES⁴ (Ocean general circulation model simulation For Earth Simulator). WOA13 is a regular volume consisting of rectangular elements sized as 0.25-degree latitude/longitude. Meanwhile,

³<https://www.nodc.noaa.gov/OC5/woa13/>

⁴<http://www.jamstec.go.jp/esc/research/AtmOcn/product/ofes.html>

OFES is also a regular volume consisting of rectangular elements sized as 0.1-degree latitude/longitude. We apply the observation data of WOA13 in July, August, September, and October of period 1(2005 to 2012) and the simulation data of OFES in July, August, and September of 10 years. Two variables, PV and density, are adjusted as the conditions of mode water region in the examples. The detailed conditions and isosurface generation of mode water regions are described in our previous paper [3]. We set the thresholds of PV and density and generated 20 isosurfaces of mode water regions from the monthly data. We generated 80 isosurfaces from WOA13 and 600 isosurfaces from OFES.

B. Analysis of Average Hue Based on Dissimilarity

We compared 48,000 pairs of mode water region extracted from the observation and simulation datasets. This section describes the isosurface pair with the minimum and maximum dissimilarities as the “minimum dissimilarity pair” and the “maximum similarity pair” respectively. Table I shows the conditions of the minimum and maximum dissimilarity pairs. Fig. 5 shows a result of average hues of the minimum and maximum dissimilarity pairs. The horizontal axis represents viewpoint IDs, and the vertical axis represents average hue values. Blue circles indicate the average hues of the minimum dissimilarity pair. Red squares indicate the average hues of the maximum dissimilarity pair. The average hue value in this study corresponds to 0 or 1 for red, 1/3 for green and 2/3 for blue. The average hue of the minimum dissimilarity pair is larger than that of the maximum dissimilarity pair at every viewpoint. In the case of the minimum dissimilarity pair, many pixels of each image are painted in cool colors. Convulsively, many pixels are painted in warm colors in the case of the maximum dissimilarity pair.

TABLE I
CONDITIONS OF THE SHAPE PAIR WITH THE MINIMUM AND MAXIMUM DISSIMILARITY

Data	Minimum Dissimilarity Pair	Maximum Dissimilarity Pair
WOA13	August $PV < 2.0 \times 10^{-10}$ $25.2 \leq \text{density} \leq 25.4$	July $PV < 1.5 \times 10^{-10}$ $25.3 \leq \text{density} \leq 25.5$
	September of the tenth year $PV < 1.5 \times 10^{-10}$ $25.3 \leq \text{density} \leq 25.4$	July of the fifth year $PV < 3.0 \times 10^{-10}$ $25.2 \leq \text{density} \leq 25.5$

C. Case1: the Minimum Dissimilarity Pair

The average hue of the minimum dissimilarity pair is the smallest while looking from the 14th viewpoint, while the average hue is the largest while looking from the fourth viewpoint, as shown in Fig. 6. Fig. 6 (left) shows the minimum dissimilarity pair from the 14th viewpoint. Fig. 6(right) shows it from the fourth viewpoint. We can observe the part painted in orange looks very small and the part painted in blue is large looking from the 14th viewpoint. We can observe the part painted in blue is also large but the convex part (the

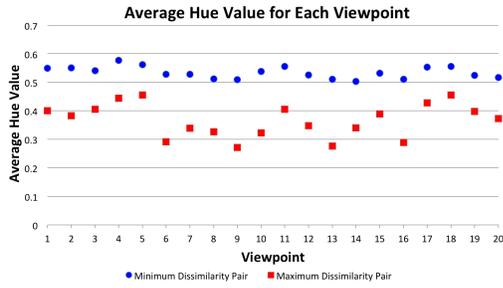


Fig. 5. Average hue values of the minimum and maximum dissimilarity pair.

protruding part) is drawn in warm colors such as red and orange looking from the fourth viewpoint. We found that shapes of this minimum dissimilarity pair are totally similar; however, we found the difference of the appearance of this pair looking from the 14th and the fourth viewpoints.

The observation of the dissimilar part of the minimum dissimilarity pair is very important because it may be a hint to improve the simulation and consider the occurrence of anomalous value caused by climate change. Fig. 7 shows the process of moving toward the part colored warm colors from the fourth viewpoint as a starting point. As a result, we could approach the target part in the order of (a) to (d) in Fig. 7 with simple operations. In addition, we could easily observe the complicated geometric dissimilarity around the target part as shown in Fig. 7 (e). We found the boundary between similar and dissimilar part there since the target part is adjacent to the part painted in cool colors.

We only needed to approach the target part straightly for a few seconds while a series of operations for observing the target part from the fourth viewpoint as a starting point. On the other hand, users will need to move around the isosurface pair in a VR space if appropriate viewpoints are not provided as start points. It is estimated that the larger and more complicated the target shape to observe, the longer the operation takes time. Therefore, the appropriate viewpoint selection enables users to promote efficient explorations to find and observe the target part easily.

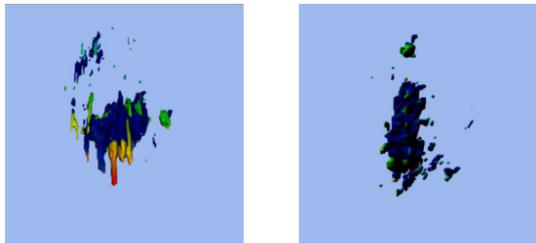


Fig. 6. Minimum dissimilarity pair. Average hue is smallest (left) and largest (right).

D. Case 2: the Maximum Dissimilarity Pair

The average hue of the maximum dissimilarity pair is the smallest while looking from the ninth viewpoint, while

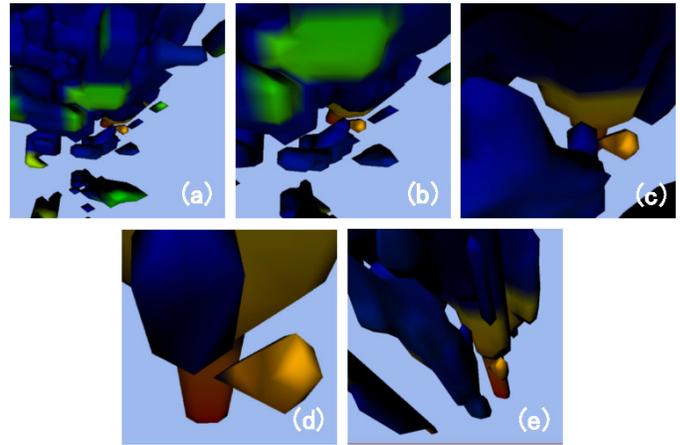


Fig. 7. (a) to (d): Process of moving toward the target part colored warm colors. (e): State around the target part.

the average hue is the largest while looking from the fifth viewpoint, as shown in Fig. 8. Fig. 8 (left) shows the minimum dissimilarity pair from the ninth viewpoint. Fig. 8 (center) shows it from the fifth viewpoint. We can observe the part painted in warm colors is very small and the part painted in light blue and green is large while looking from the fifth viewpoint. Meanwhile, we can observe the part painted in blue is small and the part painted in red, yellow and green is large while looking from the ninth viewpoint. We found the difference of appearance of this pair looking from the fifth and the ninth viewpoint. From these results, we concluded that it is necessary to observe the maximum dissimilarity pair from multiple viewpoints to understand its features. For example, the state from the 20th viewpoint, where the average hue is middle, is as shown in Fig. 8 (right). We can observe the part painted in green is large as well as the part painted in warm and cool colors. We can also observe the part painted in blue is adjacent to the part painted in warm colors from the ninth viewpoint, while the part painted in blue is adjacent to the part painted in cool colors from the 20th viewpoint. Observations from multiple viewpoints are necessary to understand the similar/dissimilar part of the maximum dissimilarity pair. In case, it will be more effective to observe it from the selected several viewpoints rather than moving aimlessly.

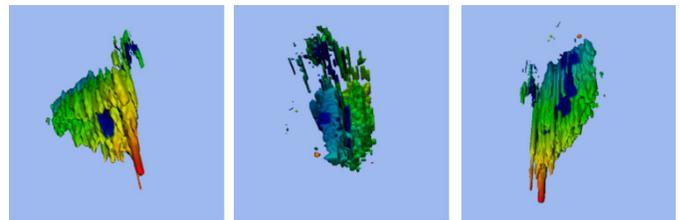


Fig. 8. Maximum dissimilarity pair. Average hue is smallest (left), largest (center) and middle (right) .

V. CONCLUSION AND FUTURE WORK

This paper presented a user interface for observing the geometric comparison of mode water pairs with various conditions in a VR space. The paper also presented a viewpoint selection method which assists the quick understanding of the features and the differences. Users can move toward the target parts straightly from the selected viewpoint as a starting point and observe the shapes of mode water easily. The appropriate viewpoint selection enables a user to compare the geometry of mode water pairs efficiently.

This system would bring benefits to some scenarios. The differences between mode water pairs of the simulation and the observation may be caused by the reproducibility of the simulation data based on the styles of the simulations. In that case, we suppose to review the calculation of the simulations and adjustment of parameters for better simulations. Otherwise, the differences between mode water pairs of the simulation and the observation may be caused by measurement defectives and extreme weather. These kinds of knowledge will lead to a review of observation methods and analyses of climate change. It is therefore effective while improving the simulation and analyzing the occurrence of missing/anomalous values.

We have many future issues. We would like to conduct experiments for evaluating the viewpoint selection method. The improvement of efficiency for observing the target in VR spaces is essential in this system and therefore should be proved. Also, we would like to discuss the physical meanings of dissimilar parts of the minimum dissimilarity pair and the similar parts of the maximum dissimilarity pair with experts in physical oceanography. Finally, we would like to compare various pairs of mode waters applying a further variety of conditions and other ocean datasets.

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