外 国 語 要 旨

学位論文題目：Comparative Visualization with 3D and Virtual Reality Techniques for Observing Mode Water Regions

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The ocean environment is closely related to our lives. There are many variations due to global warming and climate change. Recently, plastic pollutions in the ocean have become a major problem. Analyzing those variations in the ocean environment requires ocean data with high reproducibility. Ocean data collected by ship/satellite altimetry observations contained spatial and seasonal bias depending on areas that were easy to obtain; however, the Argo project has started since 2000 and made it possible to obtain accurate observation data. On the other hand, with the evolution of supercomputers, the global ocean general circulation models (OGCMs) have generated high-resolution simulations. Moreover, researchers have developed ocean data using techniques called data assimilation that combines observed values and the numerical models of simulations. As improvements in observation methods and computational techniques, various ocean data have been generated. Therefore, the evaluation of ocean space reproduced in ocean data becomes increasingly important.

The reproducibility of the remarkable ocean phenomena is the criteria for the evaluation of ocean data in physical oceanography. Researchers often observe the variation on seawater surfaces on the sea surface height map and the specific positions in the ocean using vertical cutting planes. These observations are not sufficient to evaluate the ocean space because major observations are on the ocean surface and at specific positions. Here, this thesis focuses on shapes of the mode water regions and visualizes comparison results of those shapes to understand the features of ocean data in 3D space, which would be helpful to improve the accuracy of ocean data.

Mode water is one of the criteria for the evaluation of ocean data in physical oceanography. Mode water is a type of seawater mass that has similar physical characteristics and distributed in the world ocean. Mode water is defined as a 3D region using parameters such as temperature, salinity, and density. The combinations of parameters and their thresholds for extracting the mode water regions are differences between observation methods and computational techniques of ocean data. Therefore, there may be differences in shapes of mode water regions even though mode water regions are extracted from the same region. Following those backgrounds, this thesis proposes two approaches to analyze how different definitions of the thresholds might bring different results. One is to visualize shape comparison results of the mode water regions applied to various conditions. The other is to suggest the viewpoints for observing a pair of mode water regions in a Virtual Reality

(VR) system.

Shape comparison implements a view-based method to obtain silhouette images of the mode water region from different viewpoints and calculate shape similarity based on features extracted images. In the presented tool, shape similarity data is displayed as time-series multi-dimensional data in a time series plot. Users can interactively select a pair based on similarity and observe similar/dissimilar parts of the pair of mode water regions according to their interests. The condition search in the tool enables users to observe each pair of mode water regions efficiently. This thesis introduces the shape comparison results of the mode water regions that applied various mode water conditions and extracted relatively long-term three ocean datasets (observation, simulation, and assimilation). In comparing shapes from the observation dataset with those from the simulation and assimilation datasets, there found to be differences in the reproducibility of ocean datasets.

Furthermore, pairs of mode water regions are observed in a VR (Virtual Reality) space to analyze the detailed shape comparison results of the mode water regions. Immersive spaces using VR technologies provide depth perception and visual cues, which enables users to understand the targets (shapes of the mode water regions in this thesis) accurately. Users can explore the target spaces by their operations instead of moving the targets because they are immersive in the target. The viewpoint selection for observing pairs of mode water regions in a VR space is based on features of images rendering a pair of mode water regions. Each shape of the pair is colored based on distances between the pair of mode water regions. Then, a view-based method is implemented to obtain images of the colored pair from different viewpoints. This thesis introduces case studies of mode water pairs of the observation and simulation datasets. There found to obverse the featured parts of the pair efficiently.

This thesis proposed features of the 3D space of each ocean data through shape comparison of the mode water regions applied various mode water conditions using visualization techniques. These results will be useful to produce ocean data with higher reproducibility and specialized for the formation process of mode water regions.