

Studies of Data Visualization for Large-Scale Geophysical Fluid Dynamics Simulations

Project Representative

Fumiaki Araki

Center for Earth Information Science and Technology, Japan Agency for Marine-Earth Science and Technology

Authors

Fumiaki Araki^{*1}, Shintaro Kawahara^{*1}, Daisuke Matsuoka^{*1} and Yumi Yamashita^{*1}

^{*1} Center for Earth Information Science and Technology, Japan Agency for Marine-Earth Science and Technology

This paper reports progresses of Advanced Visualization and Computation Research Group (AVCRG), Center for Earth Information Science and Technology (CEIST) in fiscal year 2014.

A new multi-dimensional transfer function to understand ocean configuration data is proposed. Users manually extract characteristic features and assign color component to their features in multiple arbitrary 2-variable space. As a result of case studies, ocean currents and eddies are intuitively extracted and clearly represented with their physical properties such as current speed, temperature and salinity.

The ocean flow field is mixture of innumerable multi-scale vortices and streams. They are highly intermingled intricately, and their boundary lines are ambiguous and indefinable. These features make us difficult to recognize structure of the flow field. We proposed a stream segmentation method that extracts boundary line of streams last year. In this report, the method is expanded to consider multiple parameters, and to detect the dominant scale at each field point.

A method to visualize three-dimensional cloud photo-realistically on Google Earth is proposed. This is achieved by multiple applications of VDVGE with both downward shortwave radiation and cloud distribution.

Keywords: Visual analytics, feature extraction, VDVGE, photo-realistic cloud representation

1. Introduction

Data visualization is one of the most powerful measures for enhancing new discovery from almost all kinds of numerical simulations. A lot of general-purpose visualization methods have been designed so far for analytical and presentation uses in the various simulation studies. In the large-scale simulations especially geophysical fluid dynamics simulations performed by the Earth Simulator, however, most of these methods can be impaired. The main reason is that computation cost, time and resources that would be required for visualizing the simulation data are much huger than users' commonly-used visualization environments. Therefore, advanced visualization methods that contributes to drastically reduce the burden in their analytical works and efficiently lead them to new findings are needed.

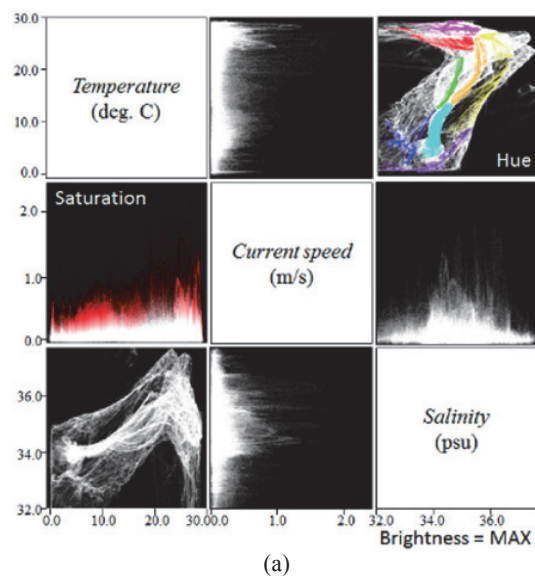
Aiming at establishing such the methods, we have been proceeding researches and developments of the visual data mining and the graphical representation for the large-scale visualization. In this report, we introduce three topics conducted in fiscal year 2014 as following: (a) visual analytics for multivariate ocean simulation data, (b) segmentation of streams with multi-parameter and multi-scale method, and (c) photo realistic representation of clouds in Google Earth. The

progresses are described in the following sections.

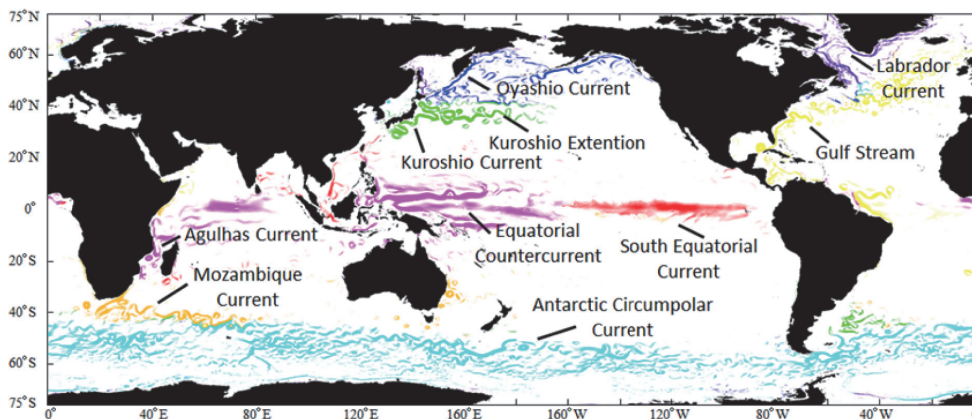
2. Visual analytics for multivariate ocean simulation data

High resolution ocean general circulation models (OGCMs) reproduce various kinds of ocean configurations with multiple physical properties. In order to understand these structures, it is necessary to analyze simulation data from the perspective of multivariable. We had developed automatic multivariate analysis method such as cluster analysis since fiscal year 2013. In fiscal year 2014, we developed a new visual analytics method, a multiple-scatter-plots-based multi-dimensional transfer function, which includes user's empirical knowledge and judgement based on their domain knowledge into analyze process [1].

The proposed method is based on a scatter-plot matrix of multiple variables. Each component of the scatter-plot matrix, which is displayed as a two-dimensional scatter plot, is composed of every two variables among given variables. For each of components, a user can manually extract arbitrary regions of interest, each of which is a set of data points that can represent characteristic field structures. Different color



(a)



(b)

Fig. 1 Feature extraction, classification and representation of ocean currents; (a) Multi-dimensional transfer function and (b) visualization result.

components such as hue, saturation and brightness are assigned to the extracted regions, respectively. By simultaneously using multiple 2-dimensional transfer function, feature extraction, classification and representation from multivariate data are realized.

We applied the proposed method for visualizing ocean currents in global scale. Ocean currents extracted in 2-variable space of current speed and temperature (setting 2D transfer function of hue) are classified in 2-variable space of temperature and salinity (setting 2D transfer function of saturation). By using both 2D transfer function (Fig. 1 (a)), ocean currents and their multivariate properties are clearly visualized as shown in Fig. 1 (b).

3. Segmentation of Streams with Multi-parameter and Multi-scale Method

Ocean flow field contains innumerable multi-scale vortices and streams. They are highly intermingled intricately, and further, their boundary lines are ambiguous and indefinable. These features make us difficult to recognize forms of streams and how they are entangled each other.

To reveal the structure of flow field in the ocean, we proposed a segmentation method that extracts and visualizes boundary lines of streams in the annual report in fiscal year 2013. In this report, we propose the expanded segmentation method for multi-parameter and multi-scale flow field.

3.1 Multi-parameter segmentation method

A region that is recognized as one bold stream usually contains multiple sub-streams as its substructure. Component sub-streams have different parameter values each other although they have similar current speed. The previous our method segments a bold stream as one segment, however it is important to distinguish each sub-stream to understand more details of continuous structure of flow. Therefore we use multiple parameters (for example: salinity, temperature, current speed) to distinguish these sub-streams in the expanded method. A vector consists of arbitrarily selected multi-parameter is defined at all grid points, and distance of the vector between adjacent grid points are calculated. The local minimum points of this distance value are extracted as flow axis. Then, our segmentation method reported last year is applied to this axis to segment individual

sub-streams. An example of the results by this method is shown in Fig. 2.

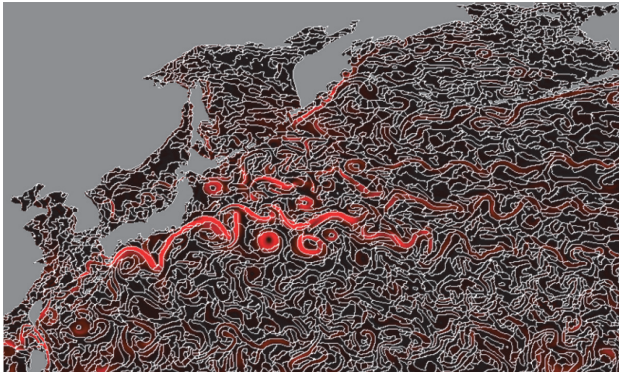


Fig. 2 Stream segmentation by the multi-parameter segmentation method.

3.2 Multi-scale segmentation method

Streams of various scales exist in the ocean flow field. Evaluation and determination of unique scale for a stream or vortex is difficult because they are usually a complex of sub-streams of various scales. We tried to remove sub-scales and detect the most dominant scale at each point. Based on the Gaussian-tree method developed in the field of computer vision, we detected the scale that most drastic change occurs. The continuous region has continuous scales. Streams are segmented supported by this feature. An example of the results by this method is shown in Fig. 3.

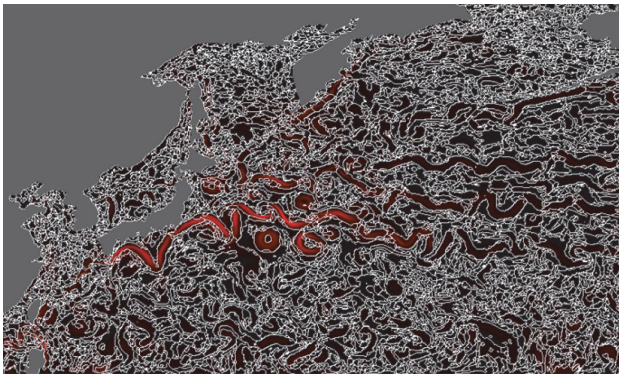


Fig. 3 Stream segmentation by the multi-scale segmentation method.

4. Photo-realistic representation of clouds in Google Earth

A novel representation method of atmospheric clouds is developed. The clouds generated by a computer simulation are represented realistically in Google Earth using this method. In this method, our original volume representation method developed in the EXTRAWING project [2] is used as a basic expression to visualize the clouds. It is achieved by laminating surfaces where color slice images visualized on each slice of a volume data set are mapped. In the proposed method, two physical quantities that are the downward shortwave radiation and the cloud distribution generated by an atmospheric simulation are used to determine drawing color and opacity of

each pixel in the color slice images. Solar radiation is scattered and absorbed by aerosols and clouds when it passes through the atmosphere. In other words, the color of the cloud looks bright at the place which downward shortwave radiation is higher. In a similar way, it looks darkly at the place which downward shortwave radiation is lower. Therefore, we employed the downward shortwave radiation to determine drawing color of the clouds. Moreover, the cloud distribution indicates how many materials forming the clouds exist in a grid. Therefore, we employed the cloud distribution to determine the opacity of the clouds.

Figure 4 shows a schematic figure of the proposed method when using VDVGE. Firstly, two content files for Google Earth are visualized and exported from a downward shortwave radiation and a cloud distribution via VDVGE. These are visualized separately by using the volume representation function of VDVGE and exported as content files for Google Earth. When the downward shortwave radiation is used as input data to VDVGE, a color table is set so that the brightness increases in proportion to the quantity of it. When the cloud distribution is used as input data to VDVGE, a color map is set so that the opacity increases in proportion to the quantity of it. Secondly, the opacity of PNG images included in the content file that is generated from the downward shortwave radiation are replaced to the opacity of the corresponding PNG image

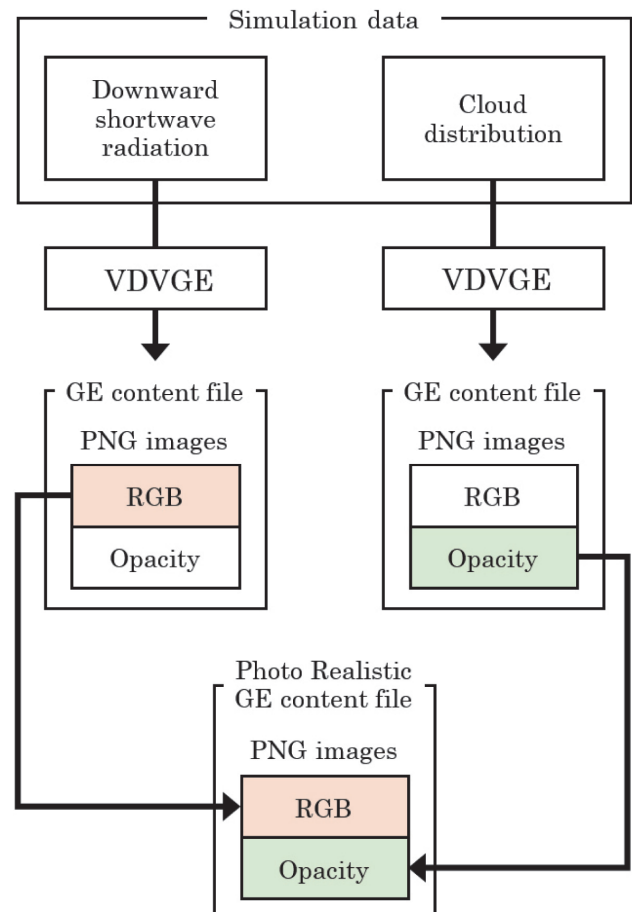
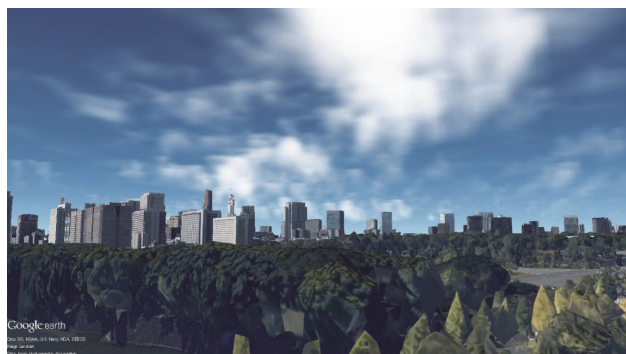


Fig. 4 Schematic figure of the proposed method when using VDVGE.

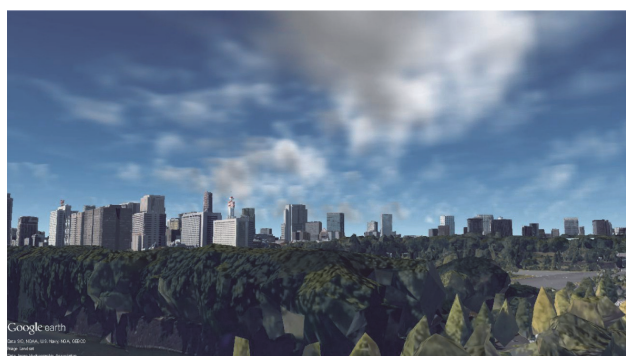
included in the content file that is generated from the cloud distribution.

Figure 5 shows the results of applying this method. Contrast clearly different in upper layers and lower layers of the clouds and it is seen that three-dimensional structures of the clouds are represented realistically. In this figure, the shadows that the clouds dropped on the ground are also represented from the downward shortwave radiation at the ground surface.

We applied for a patent about this algorithm (Application Number (2014) 232222). Use in the information transmission for the disaster prevention can be expected.



(a)



(b)

Fig. 5 Three-dimensional cloud representations in Google Earth.

(a) Ordinary use of VDVGE; (b) Application of our new method.

References

- [1] Daisuke Matsuoka, Fumiaki Araki, and Yumi Yamashita: “Multiple Scatter Plots based Multi-Dimensional Transfer Function for Visualizing Ocean Simulation Data”, *Communications in Computer and Information Science*, Vol. 474, pp. 187–200, 2014.
- [2] Fumiaki Araki, Shintaro Kawahara, Daisuke Matsuoka, Takeshi Sugimura, Yuya Baba, and Keiko Takahashi: “Studies of Large-Scale Data Visualization: EXTRAWING and Visual Data Mining”, *Annual Report of the Earth Simulator Center*, April 2010-March 2011, pp.195–199, 2011.

大規模地球流体力学シミュレーションのためのデータ可視化の研究

課題責任者

荒木 文明 海洋研究開発機構 地球情報基盤センター

著者

荒木 文明^{*1}, 川原慎太郎^{*1}, 松岡 大祐^{*1}, 山下 由美^{*1}

^{*1} 海洋研究開発機構 地球情報基盤センター

地球情報基盤センター 情報・計算デザイン研究開発グループの2014年度における研究開発の進捗を報告する。

多変量という視点から海洋シミュレーションデータを理解するための新しい可視化手法を提案した。提案手法では、解析者が複数の任意の2変数空間上で特徴領域の抽出および色付けを行う。提案手法を海洋データに応用した結果、海流や渦等の海洋構造を流速や水温、塩分等の特徴で分類し、特徴を可視化することに成功した。

海洋流れ場は様々な規模の流れが入り組んだ複雑な構造をしている。ひとつひとつの流れの境界線は曖昧で個々の流れの領域を定義することは難しい、このため流れ場の構造を明瞭に認識することが困難となっている。これを解決する手法として、2013年度、流速分布の情報をもとに流れの境界線を抽出して可視化する手法を提案した。2014年度はこの手法を拡張し、複数パラメータを同時に考慮して領域分割した他、流れ場の各地点における支配的なスケールを特定してスケールに応じた領域分割を行った。

気象シミュレーションにより得られた雲を Google Earth 上で写実的に表現する手法を開発した。本手法では、気象シミュレーションにより得られた下向き短波放射量と雲分布量の二つのデータを用いて、雲の描画色と不透明度をそれぞれ決定する。本手法の適用により、上層と下層とで明暗の異なる雲の三次元構造を Google Earth 上で写実的に表現し、かつインタラクティブな視点の移動を実現することができた。本手法に関して特許出願を行った。

キーワード: ビジュアル・アナリティクス, 特徴抽出, 海洋シミュレーション, VDVGE, 写実的可視化

