3D Visualization System Gateau for Atmospheric Science: Design Concept and Practical Evaluation

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Atmospheric scientists tend to use a 2D visualization method rather than 3D visualization for data analysis because 3D visualization requires some expert knowledge. We have developed a 3D visualization system Gateau for atmospheric scientists who are not familiar with visualization programming. Gateau accepts various data formats used in atmospheric science, reconstruct the analysis procedure which atmospheric scientists perform with 3D visualization, and leads to the discovery of target phenomenon. The resultant visualization can be used for presentation. In this paper, we explain a conventional visualization method in atmospheric science field, give the 3D visualization system overview, and describe practical evaluation.

大気科学のための 3 次元可視化システム Gateau: デザインコンセプトと実用評価

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3 次元可視化を独自で作成するためには専門的知識を必要とするため，大気科学者はデータ分析において 2 次元可視化を利用している．そこで，我々は可視化プログラミングに精通していない大気科学者を対象とした 3 次元可視化システム Gateau の開発を行っている．Gateau は大気科学分野で扱われている様々なデータフォーマットを読み込み可能とし，3 次元可視化を用いて従来のデータ分析の過程を再現し，目的の現象の発見へと導く．さらに，その可視化結果はプレゼンテーションなどに直接利用可能である．本稿では，大気科学分野における従来の可視化手法と提案する 3 次元可視化システムの概要を説明し，実用評価を行う．

1. Introduction

We have investigated why atmospheric scientists, especially in Japan, insist on the use of 2D cross section rather than 3D visualization. The reasons we have so far are: 1) acclimatization of 2D cross section, 2) programming difficulty of 3D visualization and 3) lack of specialized visualization packages for atmospheric science. For these reasons, we come to think that some specialized visualization packages should be developed for atmospheric scientists.

Without programming expertise, atmospheric scientists may use visualization software packages for 3D visualization rather than their programming. Since most visualization software packages such as [1~4] are general purpose, they provide for too many functions and too much volume of manuals to understand the packages. Such general-purpose packages do not include special functions for some research area, and they are sometimes insufficient for the analysis use. Furthermore, as the recent improvement of hardware resources such as computational power, storage, and various sensor-devices, atmospheric scientists have larger data for their analysis. The prompt increase of the data sets may make the application of 2D cross section to the data sets be difficult.

In this paper, we propose a 3D visualization system Gateau [5] for the atmospheric scientists who have the above described problems. The interface of Gateau is based on the seven important operating functions for information visualization proposed by Ben Schneiderman [6]. It is a GUI-oriented simple interface that does not need any manuals for atmospheric scientists without deep knowledge of 3D visualization. Also, Gateau does not require special data formats.

The rest of the paper is organized as follows. In the next section, we describe visualization for atmospheric science. In section 3, we illustrate the design and implementation of a 3D visualization system Gateau. Some validation of Gateau is given in section 4, and we investigate if Gateau satisfies the Schneiderman's rule in section 5.

2. Visualization for atmospheric science

Since the number of data formats which existing visualization systems accept is limited, atmospheric scientists have to convert their data into those acceptable formats to use existing visualization systems. When converting data with a text format, it is not a laborious task because the text body is human-readable. However, text formats are not suitable for a large amount of data because of long read-write time. So the use of text format data is very limited. On the other hand, binary format data are quickly readable-writable, but it requires appropriate APIs to access them. So the atmospheric scientists need to have enough knowledge about the APIs as well as minimum programming skills. Consequently, visualization systems accepting as many formats as possible are required.

Atmospheric scientists analyze data by using 2D cross sections. Since atmospheric (mainly satellites) data are measured two to four times every day, the amount of 2D cross sections for a long period becomes extremely large. Atmospheric scientists must discover peculiar phenomenon from the large amount of 2D cross sections. A well-known visualization method in atmospheric science to analyze a lot of data sets is quick-look [7]. Quick-look literally requires quick operability rather than good shows. Since a huge number of 2D cross sections have to been displayed, simpler operation without any stress is important.

In quick-look, a lot of 2D cross sections are projected directly to atmospheric scientists for better understanding of the 3D grids. They explore their target peculiar phenomena by imaging the time flow in their mind, and select the best 2D cross section. Such process requires knowledge and experience in atmospheric science with many trial-and-errors, which is almost a heuristic method. Once a 2D cross section for a peculiar phenomenon is selected, the figure of the 2D cross section must be finalized to obtain the best show; editing color contrast, grid scaling, color bar, axis format, graph notation, etc. by hand.

3. 3D visualization system Gateau

We propose a 3D visualization system Gateau for atmospheric science without 3D visualization programming knowledge.

3.1 Concepts

Through 3D visualization, users can understand data intuitively and grasp the overview of all data to discover peculiar phenomena. It is effective to use 3D visualization at analysis phase since rotation and zoom of 3D grid are interactively operatable to explore the phenomena. Gateau can also generate 2D cross sections used in conventional analysis. By combinatorial use of 3D visualization and 2D cross sections, Gateau helps users analyze data intuitively. Experts who mainly use 2D cross sections can make use of Gateau for their research purposes, and students can make use of Gateau as an educational tool to learn 2D cross sections. Since simple and interactive interface without any manual is the conceptual purpose of Gateau, just sliders and buttons based GUI is adopted. When Gateau reads data, figures are automatically created. Users interactively learn how to use Gateau by changing the figure with the operation of buttons and sliders.

3.2 Design

In Gateau design, we adopt seven operating functions for information visualization, which Ben Shneiderman has proposed [6]: overview, zoom, filter, details-on-demand, relate, history, and extract. We explain how Gateau is designed to meet Shneiderman's concept.

- Overview: Gain an overview of the entire collection.
  The whole 4D data is displayed through animation with visualization results of 3D grids. First, VolumeRendering is applied for intuitive understanding of 3D grids. With VolumeRendering, all data in 3D grids are translucently displayed in 3D space. Secondly, animation is generated from the 3D visualization along the time axis. As the result, users can grasp the entire collection of the 4D data.
- Zoom: Zoom in on items of interest.
  3D grids are scalable in Gateau. Gateau also has interactive functions for rotation and movement.
- Filter: Filter out uninteresting items.
  By filtering, effective data analysis is performed. In particular, when peculiar phenomena are discovered, Gateau displays a 3D visualization of their values by VolumeRendering with animation.
- Details-on-demand: Select an item or group and get details when needed.
  It is difficult to know the concrete position and extent of a given value with some distribution just by VolumeRendering. Therefore, VolumeRendering is less adapted to the investigation of detail information. For detailed figures, Gateau displays them by 2D cross sections and 3D Contour. By adding 3D Contour to the 2D cross sections, the distribution with the same value can be exactly grasped. Thereby users can get detail information.
- Relate: View relationships among items.
  Gateau displays the relation between selected elements which have the same property for classification. For example, date information of atmospheric data is related to a property, and it is used for the comparison of data by date.
- History: Keep a history of actions to support undo, replay, and progressive refinement.
  Gateau can keep the history of user's operations including setting.
- Extract: Allow extraction of sub-collections and of the query parameters.
  Gateau can extract and save the selected parts of atmospheric data where users want to apply other analysis and/or visualization tools.

3.3 Data analysis

Gateau visualizes data in three kinds of shapes: Cube, Cylinder and Sphere to present the equatorial, polar, and globe, respectively. The visualization results are easily rotated, zoomed in and out, and moved by mouse. Gateau provides three steps to analyze and visualize atmospheric data. The three steps are based on the mantra that Ben Shneiderman advocates as an operating procedure of the visual information seeking: "Overview first, zoom and filter, then details-on-demand" [6]. In step-1, "Overview first, zoom and filter" is implemented. In Step-2, "details-on-demand" is constructed, and users observe the change of the phenomena by time in Step-3. By using these steps, a peculiar phenomenon is found out and the 2D cross section which clearly shows the peculiar phenomenon is explored. The explanations of these three steps are given below.

Step-1 *Overview*: Users grasp the overview of given huge data and roughly take aim at a position, a time and a value where, when and what they would discover peculiar phenomena from the data.

Step-2 *Detail*: The area obtained by Step-1 is reduced down to smaller ranges. Users choose a 2D cross section to analyze the change of the phenomena by time.

Step-3 *Time Section*: New grids, which are piled from 2D cross sections in Step-2, are generated. By changing the time-axis value, the change of the phenomena by time is presented as a pseudo animation.

3.4 Generation of Detailed Figures

Generating detailed figures, users adjust the tone for Color Mapping and the size of 3D grids. The GUI for the generations is displayed by pushing the "property" button. In the default tone for Color Mapping, a gradation between blue and read is used. Blue and red are set to the minimum and maximum values, respectively. Both this minimum and maximum values can be changed by spinners. The Canvas reflects the change of these values immediately. Therefore, users can operate GUI with checking the reflection. In some detailed figures, zooming in a part of the 3D grids may be better. In Gateau, once the Canvas is checked and the range of data for cutting off is decided by slider, new data related to the range is regenerated automatically. Hence, the size of 3D grids can be easily adjusted. In addition, the extracted data can be used by other applications.

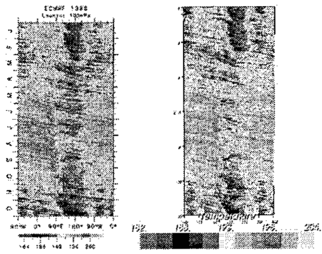
3.5 Special functions for atmospheric

Not only 4D grids data but also swath data is sometimes used in atmospheric science. Swath data is used for satellite remote sensing. An instrument takes a series of scans perpendicular to the ground track of the satellite as it moves along that ground track. Swath data basically has the coordinates of quadrilateral apexes and the value in a quadrangle. Gateau reads arbitrary data and visualizes quadrangles on the map by using colors allocated to data values. Here, quadrangles can be drawn without decision of the order in quadrilateral apexes.

As described in the previous section, there are various data formats used in atmospheric science. Gateau provides two kinds of original text formats and will provide two kinds of binary formats of HDF-EOS [8] and NetCDF [9]. As for HDF-EOS, Gateau is expected to accept it as a 3D viewer, while several commands are prepared to transform NetCDF into Gateau original format.

4. Practical evaluation

Using Gateau, atmospheric data can be analyzed easily



(a) (b)

Figure 1: Comparison between conventional and Gateau generating 2D cross section.

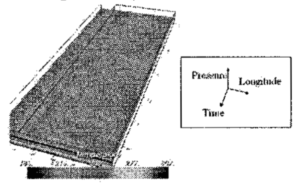


Figure 2: Another presentation of Fig.1(b).

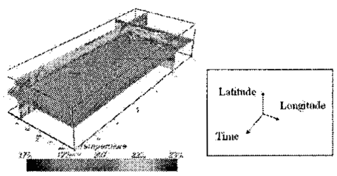


Figure 3: Yet another presentation of Fig.1(b).

with 3D visualization, and a peculiar phenomenon can be discovered through only a few operations. Furthermore, Gateau can also generate conventional 2D cross sections. In this section, we validate whether a 2D cross section generated by Gateau looks like the 2D cross section generated by atmospheric scientists by several tools.

We select a Figure 1(a) from [10], which is published as a journal paper of atmospheric science, to compare with one by Gateau. The figure shows a 2D cross section of temperature on the averaged deviations of geo-potential heights of 100*hPa* at the equator in 1996 provided by ECMWF (European Center for Medium-Range Weather Forecasts). The time and spatial resolutions of the ECMWF data are twice daily for one year and 2.5°×2.5°, respectively.

In Figure 1(a), the horizontal and vertical axes are longitude and time, respectively. Time in the vertical axis goes on from top to bottom. The region 90°W-0°is duplicated. Since Figure 1(a) shows a striped pattern from top left to bottom right, the temperature data includes eastward moving signals. Eastward moving signals mean that atmosphere goes on eastward as time goes by.

Figure 1(b) shows a visualization result of the temperature data in 1996 by Gateau as in Figure 1(a). We generated this figure using the tone similar to the one used in Figure 1(a). Figure 1(b) can show eastward moving signals as well as Figure 1(a).

Gateau displays various 2D cross sections in the 3D grids. Figure 2 shows the (longitude, pressure, time) grid at the equator. In Figure 1, only a 2D cross section of 100*hPa* is presented. On the other hand, longitude-latitude cross sections of various pressures can be presented easily by a slider as shown in Figure 2. Figure 3 shows the (longitude, latitude, time) grids of 100*hPa*. In the grids, longitude-time cross sections on various latitudes can be observed. By collate longitude-latitude cross sections with longitude-time ones, it is possible to understand the 3D grids intuitively. Hence, we confirm that Gateau can generate a similar 2D cross section to one generated by conventional methods. Furthermore, new discoveries are expected since 4D data are intuitively understandable by using 3D visualization for quick-look.

5. Discussions

We have developed Gateau as a 3D visualization system for atmospheric science. Although the target of Gateau is special, the design concept is very conservative as shown in subsection 3.1. In this section, we discuss if Gateau's GUI satisfies famous "Eight Golden Rules of Interface Design" by Shneiderman [11]. The eight golden rules are: 1) Strive for consistency, 2) Enable frequent users to use shortcuts, 3) Offer informative feedback, 4) Design dialog to yield closure, 5) Offer simple error handling, 6) Permit easy reversal of actions, 7) Support internal locus of control, and 8) Reduce short-term memory load.

With Gateau, input values are given by sliders, and visualization type, step and data file are changed by buttons. In this way, we acquire coherent operations throughout the system. To avoid input error, Gateau adopts buttons and sliders as a GUI, except the case of inputting missing values from command line. Gateau Canvas reflects each operation immediately. For frequent users, Gateau has a start-up option of tone contrast. Consequently, when suitable tone of color is given, any adjustment with GUI is not needed.

The GUI displays just the necessary items related to data analysis in each step. As operational procedures, we have four stages: three steps described in subsection 3.3 and the generation phase of detailed figures with the "property". So, Gateau is designed to understand which step users are in. Each step can be progressed both forward and backward. In any case, data analysis can be restarted without any trouble, because the history is recorded. The viewpoint of Gateau can be freely rotated, zoomed in and out and moved by mouse. In this way, the user can take the initiative in controlling the system.

As described above, the implementation of Gateau almost satisfies "Eight Golden Rules of Interface Design" by Shneiderman.

6. Conclusions

In this paper, we propose Gateau, which supports data analysis of atmospheric scientists. Using Gateau, 3D visualization can be used lightheartedly from data analysis stage. We designed and implemented an interactive and simple interface based on seven kinds of main operating functions for information visualization, which Ben Shneiderman proposed. We have showed that Gateau can generate 2D cross sections as well as conventional methods in atmospheric science.

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