2006－MPS－60 (8)
2006／6／26

Gateau: A 3D Visualization System for Intuitive Analysis of Atmospheric Science

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By recent progress in hardware, 3D visualization including VolumeRendering is adopted in various fields. Though CG is used in the atmospheric field, the scientists mainly use 2D visualization. So, we develop a 3D visualization system Gateau for atmospheric science. Gateau is a quick-look tool that enables the atmospheric scientists to observe 3D grid data with only a few instructions without 3D visualization programming knowledge. Without any manual, the users can understand how to use it interactively on the basis of simple interfaces, and accept multiple input formats including HDF-EOS, which is expected to be the standard file format to distribute earth observation satellite data.

Gateau:大気科学研究のための直感的な分析を実現する3次元可視化システム

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近年ハードウェアの進展に伴って，VolumeRendering のような3 D 可視化技術が様々な分野で取り入れられている．大気科学分野でもCG が使われているが，主流は 2 次元可視化である．そこで我々は，大気科学研究のための 3 次元可視化システム Gateau の開発を行っている．Gateau は可視化プログラミングに精通していない大気科学研究者を対象とし，3 次元格子データを少ない手間で 3 次元可視化を実現するクイックルックツールである．マニュアルを必要とせず，シンプルなインターフェースを基盤にインタラクティブに使い方をマスターすることができ，衛星観測データの標準配布フォーマットとなりつつある HDF−EOS を読み込み可能とする．

1. Introduction

In general, atmospheric scientists tend to have a limited use of 3D visualization for their analysis. Typically, they use 2D visualization for their analysis while the 3D visualization is used just for the presentation. This is because 3D visualization software is very expensive. Without such software, the use of 3D visualization requires more implementation costs and technical knowledge compared with 2D visualization.

For the atmospheric scientists without 3D visualization programming knowledge, we develop a 3D visualization system Gateau [1], which is a quick-look tool that enables them to observe 3D grid data with only a few instructions. The atmospheric scientists mainly use 2D cross sections while they do not usually use 3D visualization. Gateau interactively reproduces the processes where they get a 2D cross section from 3D grid data. Gateau accepts multiple input formats including HDF-EOS [2], which is expected to be the standard file format to distribute earth observation satellite data. HDF-EOS has a self-describing data set with a Hierarchical Data Format (HDF) and extensions of Earth Observing System (EOS). "Self-describing" means that no outside information is needed to fully comprehend the contained data. To manipulate metadata or to understand dimension information, several APIs are provided. Gateau is expected to be used as an HDF-EOS viewer [3].

2. Concept of Gateau

Gateau is developed with the concepts as follows.

<Intuitive Understanding>

While conventional analysis needs deep knowledge and experience, Gateau enables users to discover peculiar phenomenon just with their eyes.

<Three Steps>

The process where atmospheric scientists change 4D data into 2D forms to generate 2D cross sections is performed with three steps. Taking account of huge data, Gateau is designed so that the amount of resultant data decreases as performing the steps.

1. *Overview*
   Users roughly take aim at a position and a time where and when they would discover peculiar phenomenon from given huge data.
2. *Detail*
   The position and the time where and when they discover peculiar phenomenon in *Overview* are reduced down to smaller ranges. Users choose a 2D cross section to analyze the change of the phenomena at an appropriate time.
3. *Time Section*
   A simple animation is generated from the new grids, which are piled from the 2D cross section in *Detail* along the time-axis.

<Simple Interface>

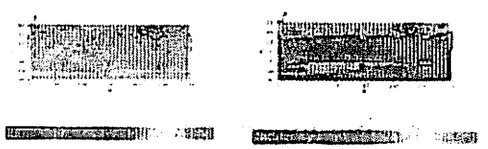
Gateau has a simple GUI with a button and a slider without any manuals. When Gateau reads data, a figure is created. Users interactively learn how to use Gateau by changing the figure with the operations of the button and the slider.

<3D to 2D>

Users do not usually use 3D visualization. So it is easy for them to understand the 3D space that is displayed with 2D cross sections, which they mainly use.

3. Visualization methods

In *Overview*, since we need to visualize earth observation satellite data more intuitively for better understanding, a method of generating animation along the time-axis with visualization results of 3D grids by VolumeRendering is adopted. Because visualization results by VolumeRendering depend on its opacity degrees, we investigate the way of adopting opacity degrees. Fig.1 shows the temperature data of the 1st of September 2002 by ECMWF. In Fig.1 (a), each opacity



(a) Uniform Opacity Degree (b)Non Uniform Opacity Degree
Figure 1: VolumeRendering

degree is uniformly set to 0.03 among all data, while in Fig.1 (b) it is set to 0.9 for the voxcels with 180K to 211K, and to 0.03 for the others. We use the HSV (Hue, Sturation, Value) color space, and the gradation is expressed from (0.667,1,1)(=blue) to (0,1,1)(=red) for the voxcels with 180K to 300K. Fig.1 (a), which is drawn with a uniform opacity degree, shows it is difficult to understand the concrete relations among positions with the same temperature. It also shows it is very difficult to observe the inner structure of 3D grid data by visualizing the outside. Though Fig.1 (b) enables us to understand the relation among positions and the shape with the same temperature, it is lacking in the information about the distribution of the other temperatures. Though we can adopt the color and the opacity degree to visualize both the whole data and the focused data simultaneously, such the combinatorial choice is very difficult in general. Though Fig.1 (a) is difficult to understand the concrete relation among positions with the same temperature and to observe the inner structure, users can grasp rough changes by making an animation along the time-axis. Since the purpose of *Overview* is not to choose concrete positions, VolumeRendering is an effective visualization method.

In *Detail*, it is necessary to reduce down a range for the concrete position and time. For the sake of that, we adopt visualization of Contour and 2D cross sections.

Contour is a polyhedron, which is generated by connecting points with the same value. It is effective to understand the distribution of a given value exactly. The problem of using Contour is to be lacking in the other data without the value. So it is difficult to understand the distribution in the case of multiple values. Atmospheric scientists seem to be reluctant to visualize the atmosphere as a polyhedron.

In *Detail*, users get a 2D cross section from 3D grid data without any reluctant feeling. We call the process Cutting; a 2D cross section is cut off from 3D grid data. Users can interactively choose the position of some cut-off plane with a slider tool. By Cutting, just the cut-off plane is visible. Cutting has an advantage of exactly understanding the distribution of data in the plane. We adopt Color Mapping as a method to visualize the plate data. When atmospheric scientists visualize 2D cross sections, 2D Contour and Color Mapping are used for generating figures. In the case of Color Mapping, the plate data is displayed with a given color representing the same value. In the case of 2D Contour, lines with a given color are used for displaying the plate data by connecting the points with the same value. Thought we took account of using both the visualization methods together, it takes longer time to display them by choosing the position of cut-off planes with a slider tool because of the huge computational cost. We adopt Color Mapping rather than 2D Contour since it is simple and suitable for the Concept of Gateau: Intuitive Understanding.

In the case of Cutting, it requires huge computational costs to visualize using Color Mapping and 2D Contour simultaneously with the slider tool. Meanwhile, in *Detail*, it is possible to display 3D Contour and Cutting simultaneously. By using both the visualization methods, when users discover a peculiar distribution of the same value, it makes users observe a 3D distribution from the plate data to display 3D Contour of the value.

Users can regulate the suitable position for Cutting by the shape of 3D Contour. It is possible to display the distribution of data in the 3D space by making the best use of 3D Contour and Color Mapping. We investigate the combinatorial use of VolumeRendering and Cutting, too. Thought it is effective for atmospheric scientists to visualize atmosphere by VolumeRendering, displaying both of them is not effective. It is difficult to understand the relevance of VolumeRendering results to the distribution of plate data by Cutting.

The aim of *TimeSection* is to observe atmospheric motions along the time-axis. Users get the time cross sections of a latitude/longitude-time cross section by applying Cutting to latitude-longitude-time grids. By changing the time-axis value of latitude-longitude cross sections generated by Cutting, the atmospheric motion is presented as a pseudo animation. By the pseudo animation of the latitude-longitude cross section, the atmospheric motion presented by the time cross sections is displayed by changing the time-axis value of latitude-longitude cross sections at any viewpoints where both time cross sections and latitude-longitude cross sections are visible. When users discover a peculiar value in the time flow, they can fully understand the change of the value along the time flow by using 3D Contour. In *TimeSection*, visualization results by VolumeRendering give too much information for the concept of Gateau: Intuitive Understanding. As a result, we adopt Cutting and 3D Contour for generating *TimeSection*.

4. Function of Gateau

<Step1 *Overview*>

In *Overview*, users need to roughly grasp the given data and try to obtain some sings and clues. Users observe the equatorial, polar, and whole region by Cube, Cylinder, and Sphere, respectively.

Fig.2 shows GUI of *Overview*. Each function is as follows.

(1) Read necessary data files
(2) List of inputted data files
(3) Select a data file to be displayed
(4) Perform an animation of inputted data files
(5) Choose a visualization type
(6) Save pictures displayed in a canvas with a PNG format
(7) Choose the range of values for visualization
(8) Apply (7)

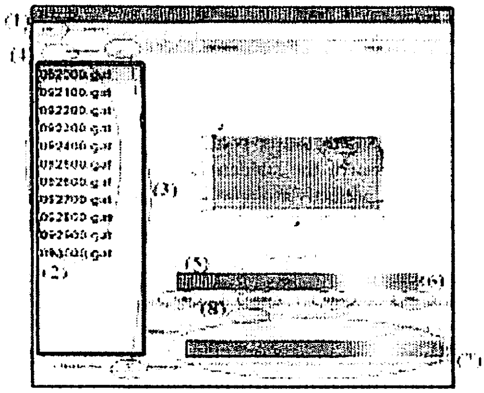


Figure 2: ***Overview*** **Window**

<Step2 *Detail*>

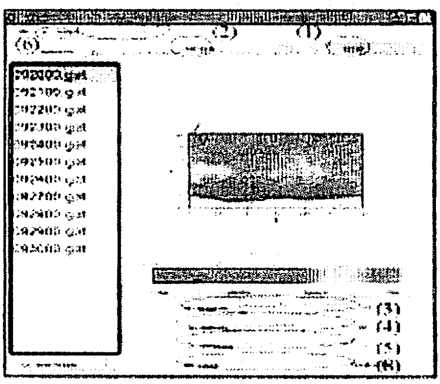


Figure 3: ***Detail*** **Window**

In *Detail*, Gateau cuts off a 2D cross section from 3D grid data and visualizes the cut-off plane by Color Mapping. Then, 3D Contour is applied on the visualized plane. Fig.3 shows the GUI of *Detail*. The GUI provides eight functions as denoted bellow.

(1) Switch the canvas to *Detail*
(2) Switch the canvas to *Overview*
(3) Display longitude-height cross sections
(4) Display latitude-height cross sections
(5) Display latitude-longitude cross sections
(6) Change the camera positions
(7) Toggle of the northern hemisphere and the southern hemisphere
(8) Display 3D Contour

In *Detail*, users choose a visualized type among cube, cylinder and sphere, and perform Cutting by three sliders. Users choose a cut-off plane by one of the three sliders, and the position of the cut-off plane is specified by the slider (3)~(5). In the case of Cube, cut-off planes are equivalent to 2D cross sections. In the other cases of Cylinder and Sphere, cut-off planes are not equivalent to the traditional 2D cross sections. We expect that the use of those makes users find something new knowledge or phenomena by observing target objects from new viewpoints in the 3D space. Gateau helps users, who are mainly accustomed to use traditional 2D cross sections, to understand the three kinds of cut-off planes intuitively by switching them in a moment. Gateau displays all the three kinds of cut-off planes in the same canvas by default. Gateau displays cut-off planes controlled by the checkboxes located next to the sliders. Using a mouse, users control the camera position; rotating, zooming, panning, and spinning. The button of (7) is used only for Cylinder.

<Step3 TimeSection>

Fig.4 (1) shows a 2D cross section adopted in *Detail*. Users choose data files to observe the change of the phenomena by time from the list of Fig.4 (2) and go ahead to *TimeSection* with the button of Fig.4 (3). In *TimeSection*, new grids, which are piled from the 2D cross section in *Detail* along the time-axis, is generated from the chosen data files. By changing the time-axis value of latitude-longitude cross sections generated by Cutting, the change of the phenomena by time is presented as a pseudo animation. Users can choose a 2D cross section again by go back to *Detail*.

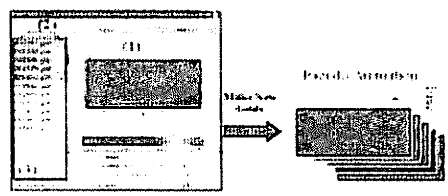


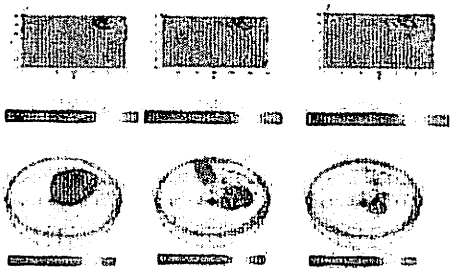
Figure 4: ***TimeSection*** **Image**

5 . Verification of Usefulness

The southern hemisphere ozone hole declined rapidly in late September 2002. This phenomenon may be attributed to the unprecedented occurrence of the major sudden stratospheric warming [4] over Antarctica. A sudden stratospheric warming is a phenomenon that stratospheric temperature in the circumpolar region goes up suddenly. Increases of the stratospheric temperatures go with a large scale change of the distribution of atmospheric pressure in the stratosphere. The stratospheric polar vortex with low temperature usually develops over the Antarctic region in the winter-spring seasons. In late September 2002, this polar vortex splits in two vortexes, and one vortex perfectly collapses while the other remains [5]. As the polar vortex weakens, ozone rich air is mixed with the air in the "ozone hole" region. Furthermore, a chemical ingredient preventing ozone depletion flows into the polar vortex. By these reasons, the concentration of ozone becomes high in the polar region and it seems that ozone hole declined. We verify whether users discover the following by Gateau's visualization of the temperature data of September 2002 by ECMWF.

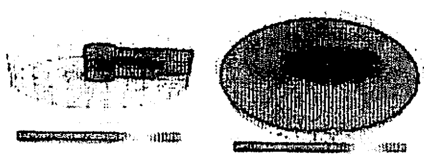
(1) The state of the sudden stratospheric warming
(2) The motion of the polar vortex
(3) The collapse of the polar vortex because of the sudden stratospheric warming

In *Overview*, we roughly observed data of September by Cube. The area with low temperatures in the southern hemisphere is reduced toward late September, and cannot be observed almost on the 29th of September ((a)~(c) of Cube shown in Fig.5). So, we switch the visualization method to Cylinder for the observation of the polar region. Setting the values of visualization range less than 215K, we find that the polar vortex with low temperature splits in two vortexes as shown in Fig.5 (a) ~ (c) of Cylinder.



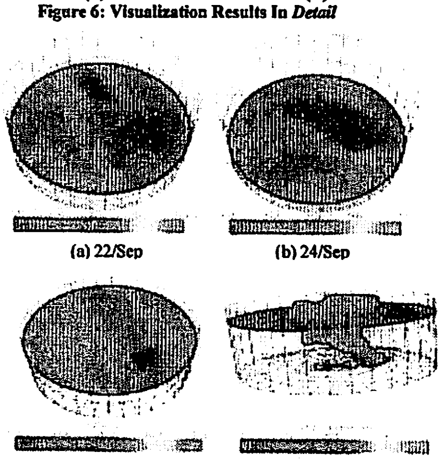
(a)16/Sep (b)24/Sep (c)29/Sep

Figure 5: Visualization Results In *Overview*



(a) (b)

Figure 6: Visualization Results In *Detail*



(a) 22/Sep (b) 24/Sep

(c) 28/Sep (d) 3D Contour at 238K

Figure 7: Visualization Results In *TimeSection*

Switching the canvas to *Detail*, we detect the place where the area with low temperatures exists. It is in the stratosphere by analyzing the data of the 20th of September (Fig.6 (a)). The large area with low temperatures is found at 30hpa (about 24km). Because a sudden stratospheric warming is detected around the area, we select this cut-off plane as shown in Fig.6 (b) to observe the change of the phenomena by time.

In *TimeSection*, new grids are generated with latitude-longitude cross sections at 30hpa, which are cut off from the data of the 20th ~ 30th of September. We get Fig.7 (a) ~ (c) to observe that this polar vortex splits in two vortexes because of the sudden stratospheric warming, and one vortex perfectly collapse while the other remains. Fig.7 (d), which is a visualization result by 3D Contour at 238K, shows the sudden stratospheric warming covers a wide region toward late September. We find the following phenomena in each step of Gateau.

Step1 Overview

Peculiar change of the area with low temperatures (2)
Split of the polar vortex with low temperatures (2)

Step2 Detail

Observation of the area with low temperatures and a sudden warming in the stratosphere (1) (2)

Step3 TimeSection

Development of the sudden stratospheric warming, split of the polar vortex, and perfect collapse of a vortex (3)
Change of the sudden stratospheric warming in late September (1)

Thus we verify that atmospheric scientists get necessary information by Gateau.

6. Conclusion

This paper presents the development of a 3D visualization system Gateau for atmospheric scientists according to the processes where they analyze data as well as a case study usage as the validation.

Our future work is the optimization of Gateau. Also, we will distribute Gateau to atmospheric scientists to get their opinions. Based on the opinions, we will improve the usability of Gateau.

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