Visualization of Output from Community Multiscale Air Quality Model

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ABSTRACT

A visualization tool for EPA's Community Multiscale Air Quality modeling system, VisCMAQ, which is developed in this study as an OpenGL based visualization tool that has the capability to render data on both regular and irregular grids. The goal of this project is to enhance the VisCTM model, which was created last summer with additional flexibilities such as reading from NetCDF files. Also, the ability to process multiple time steps for multiple species at the same time. VisCMAQ would be able to read, and visualize different types of data that is written in C Language. These enhancements will allow the new VisCMAQ to accept an incorporation of data sets for various spatial domains and sets of chemical species. At this process the Visualization of the output from Multi scale Air Quality (VisCMAQ) model will be created. This VisMAQ project will link VisCTM tools with the Environmental Protection Agency's Community Multi-scale Air Quality (CMAQ) Model system; which will utilize VisCTM import files written by the IOAPI library that is built upon the NetCDF file format.

Key terms: Visualization, Irregular grid, volume rendering, OPEN-GL, Vis5D, VisCTM, CMAQ.

Presenter/Authors Biography

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INTRODUCTION

The objective of this project is to enhance the VisCTM [1-4] in additional flexibilities permitting it to read files in the NETCDF format. This allows ready rendering of a wide range of dataset types, including not only chemical concentrations, but also properties of atmospheric particulate matter (such as aerosols), meteorological variables, and gas and particulate emission rates. The present extensions also permit easy rendering of varied spatial domains.

VisCMAQ (Visualization for the Community Multiscale Air Quality Modeling System), developed in this study, is an OpenGL-based visualization tool that has the capability to render data on both regular and irregular grids. VisCMAQ was implemented to link VisCTM tools with the Environmental Protection Agency's (EPA) Community Multiscale Air Quality (CMAQ) modeling system and creates VisCTM input files from the NETCDF (Network Common Data Form)-formatted files written by the Input/Output Applications Programming Interface (IOAPI) library upon which the CMAQ file system is based.

VisCMAQ's main functionality is accessible through a menu-driven interface that includes volume rendering, plane slicing, and interactive operations such as rotations, translations, and zooming.

ALGORITHMS AND DEVELOPMENT

There exists several software packages both commercial and non-Commercial for analysis and visualization of scientific data; these include Matlab interface, Java interface, python interface, perl interface and VisAD. These software packages usually render scientific data on regular grids, thereby not providing a completely accurate representation of the chemical concentrations, aerosol properties, meteorological data and emissions data.

VisAD for instance does give the illusion of irregular grids by interpolating the z-axis data, thereby transforming it into a regular grid. But it is not true rendering of irregular grids. The VisCMAQ software processes five-dimensional environmental data (longitude, latitude, altitude, physical species variables, & time) contained in custom formatted file created from any netCDF-formatted file, and displays the visual output that is generated through a volume-rendering algorithm into a three-dimensional grid that can be manipulated and examined from all angles using built-in menu-driven GUI (graphical user interface) controls.

VisCMAQ incorporates a modified version of the volume-rendering algorithm from Vis5D+; however instead of using quad strips, VisCMAQ uses triangle strips for volume rendering. The reason for using a different polygon shape is due to the fact that the atmospheric data must be rendered using an irregular grid. OpenGL allows non-coplanar quadrilaterals, but it does not guarantee proper rendering of the resulting twisted ("bowtie") shape. Therefore, triangles are used since the three vertices of the triangle primitive will always lie in the same plane (coplanar). By combining strips of triangles, an irregular grid can therefore be generated [5].

ViSCMAQ uses an OpenGL primitive called a triangle strip for rendering the data [6]. This strip produces a faster rendering than does a triangle primitive by reducing the number of vertices transmitted for processing. This improvement is demonstrated as follows: if *n* represents the number of triangles, then the number of vertices transmitted is reduced from *3n* to *n + 2* [5-7.]. For instance, if ten individual triangles are rendered, thirty vertices would need to be transmitted for processing. However, due to the implementation of a triangle strip, only twelve vertices are needed. By using this primitive, a 50% efficiency is achieved for two rendered triangles, but this efficiency gradually decreases a bit and tapers off as the number of triangles increases due to the fact that the formulas are of first order magnitude. However, no matter the number of triangles transmitted, efficiency is still maintained.

In addition to the triangle strip, rendering incorporates a cardinal direction algorithm, which determines the direction that 2D slices will be rendered. This algorithm guarantees that the image is rendered properly from all possible viewing angles.

DISCUSSION AND FEATURES

VisCMAQ has a number of features and capabilities that make it a valuable visualization tool. One such capability is the use of a triangle strip algorithm for an irregular sized 3D grid. This algorithm has been adopted from Vis5D+ in order to process irregularly sized species volume rendering. VisCMAQ also uses an adding algorithm for selecting multiple species and determining the total concentration of the combined species, which in effect would render the concentration of a new hypothetical species.

Another feature is the use of plane slicing, which is the generation of cross-sectional planes to view rendered volumes at specific coordinates of equal longitude (yz-plane), equal latitude (xy-plane), or equal height (xz-plane). The generated planes can be incremented along their respective axes so that a cross-sectional volume of a specific thickness (number of degrees for latitude or longitudinal planes or a vertical distance for altitudinal planes) can be seen and analyzed. Alternately, these slicing planes can be displayed so that the entire volume of the atmosphere behind a particular plane can be viewed.

The base of the grid on which the volume rendering is displayed consists of an outline map of the northern hemisphere in order to show the viewer the geographical areas over which specific species are concentrated. This map can also be adjusted by longitude during program execution. By default, the applications starts with zero degrees longitude (the Prime Meridian) displayed on the left, but the map can be shifted to the east or west by entering a specific longitudinal value.

VisCMAQ also has the ability to import netCDF formatted data files and to convert them into the VisCTM file format that is necessary for rendering. In addition, once a data file has been loaded, it can be changed during program execution.

The data files contain information on species during different time steps. Thus, one set of data might contain concentrations of a particular species throughout the northern hemisphere, and another set of data might show the concentrations of the same species at a different time. VisCMAQ has the capability to change among these time steps once they are loaded and therefore provides the user with different “snapshots” to compare and to follow not only pattern of species movement but also properties of atmospheric particulate matter, meteorological and emissions data as well (Figures 1-4).

Additional features of VisCMAQ enhance its overall functionality. One such feature is the use of a Graphical User Interface (GUI) (Figures 5–7) which allows the user to view and use buttons, menus, and other controls in a familiar Windows-like environment. Controls exist for selecting species, hiding or displaying of various grid components, controlling the rotation and translation of the rendered volume, and the generation of planes (as noted before) among others. The displayed volume is also accompanied by a color legend in a logarithmic scale that is composed of 256 colors from blue (lowest concentrations) to red (highest concentrations).

In addition to the GUI, VisCMAQ provides a command line interface for many of its features to provide even greater control and flexibility of input methods. However, the commands are carried out in the Linux operating system environment on which VisCMAQ runs at this time, and some familiarity with Linux commands is assumed for command line input. Documentation is also provided to help the users with commands and with other aspects of the VisCMAQ application.

The VisCMAQ visualization software is not only intended to render principal input or output files in EPA’s CMAQ modeling system over the northern hemisphere of the Earth. This tool has the ability to display a map of both hemispheres of the Earth, or even those of a planet such as Mars. Maps of just a portion of the atmosphere between certain longitudes could also be configured for display. In addition, other atmospheric species, either natural or man-made, could be rendered and displayed for visual analysis.

Figure captions and Variable Descriptions

Figure 1. Shows the model variable GR_INORG, which is the diameter growth rate of new-formed nanometer-sized particles in the atmosphere (in nanometer per hour) due to the condensation of inorganic vapors, and is often in range of 1-10 nanometers per hour. GR_INORG tends to be largest near the surface, or wherever gas-phase sulfuric acid concentrations are present.

Figure 2. Shows the model variable CS_PRIME, the condensational sink (in meter^{-2}), as it represent the capacity of the existing larger aerosol particles to absorb the sulfuric acid vapor that gives rise to new particle formation and growth. When CS_PRIME is large, new particle formation and growth will be suppressed. CS_PRIME also tends to be larger near the surface, as aerosol particle concentrations are typically greater in the planetary boundary layer than at higher altitudes.

Figure 3. Shows the model variable DMEAN_NM, the average ambient diameter (in nanometers) of the existing larger aerosol particles and in part determines the condensational sink. As the aerosol particles in the CMAQ model have chemical compositions what enable them to absorb considerable water vapor, depending on

relative humidity, DMEAN_NM will tend to be larger in regions of high relative humidity.

Figure 4. Shows the model variable RH, the ambient relative humidity (in percent).

FUTURE ENHANCEMENTS

There are a number of possible enhancements that will increase the functionality and capabilities of VisCMAQ in future development. Since VisCMAQ allows for multiple time steps, animation is a desirable and possible functionality that can be implemented. At present, VisCMAQ uses as little allocated memory as possible, and without the use of double buffering and/or threads, an ideal effect cannot be achieved with animation. The current implementation is only capable of taking a snapshot with one data file; the future development can extend this capability to automatically take many snapshots with the same data file. In addition, VisCMAQ will be able to visualize as many snapshots as data file permits. Those visualization images will be either saved in disks or created on demand. Species are currently mapped to a fixed color table, with the lowest concentration mapped to blue and the highest mapped to red. A possible enhancement would allow the user to determine how species concentrations are mapped to the color table.

CONCLUSIONS

The research that was conducted to explore functionality in existing 3D visualization software packages found them inadequate for handling irregular grids. This led to the development of VisCTM and VisCMAQ, tools able to render and interact with such data. However, that EPA data has been collected into input files, which has the NETCDF (Network Common Data Form)-format and is written by the Input/Output Applications Programming Interface (IOAPI) Library. In order to visualize the output of CMAQ, an interface code has been developed to support this project.

The capability of accommodation to a wider range of input data became the driving force for the development of VisCMAQ. After the enhancement of data format interface in VisCMAQ program, this tool not only can be utilized by atmospherically data modeling but also extended to CMAQ with EPA’s data file, which is widely used in environmental studies.

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FIGURES

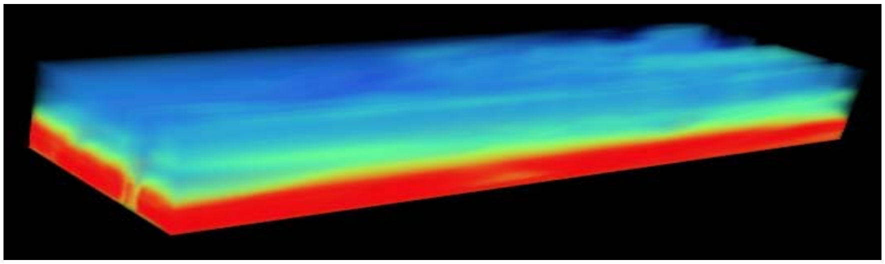

Figure 1

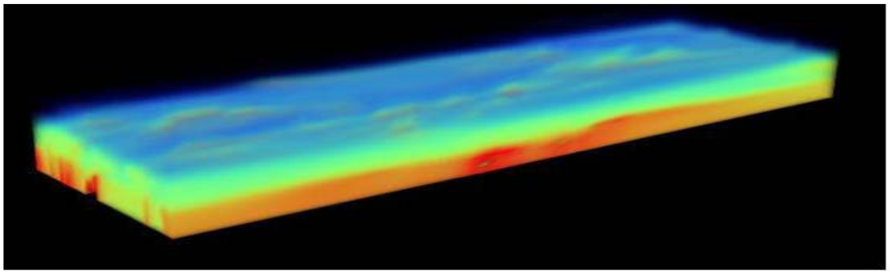

Figure 2

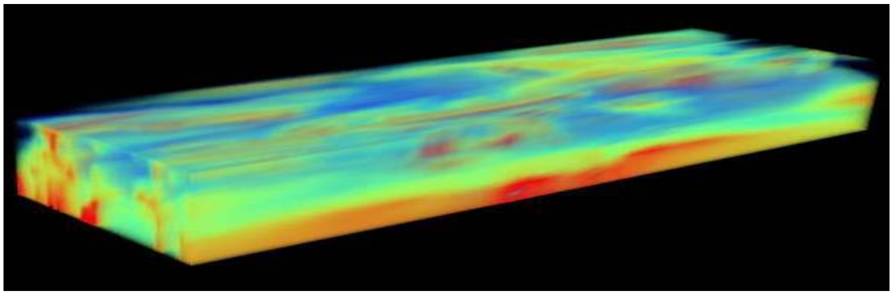

Figure 3

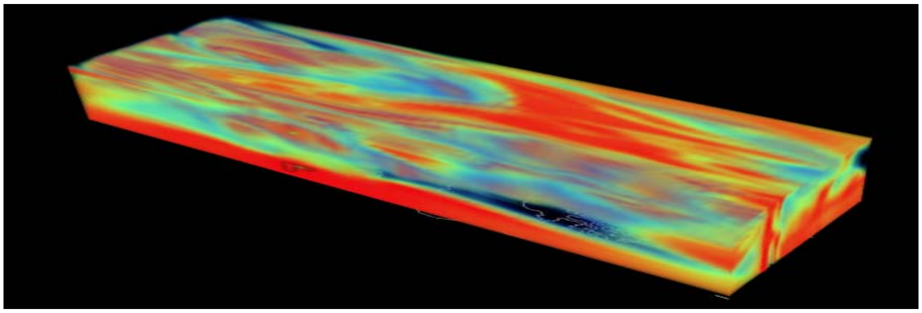

Figure 4

Graphical User Interface Control Layout for VisCMAQ

Figure 5.
Expanded main menu.

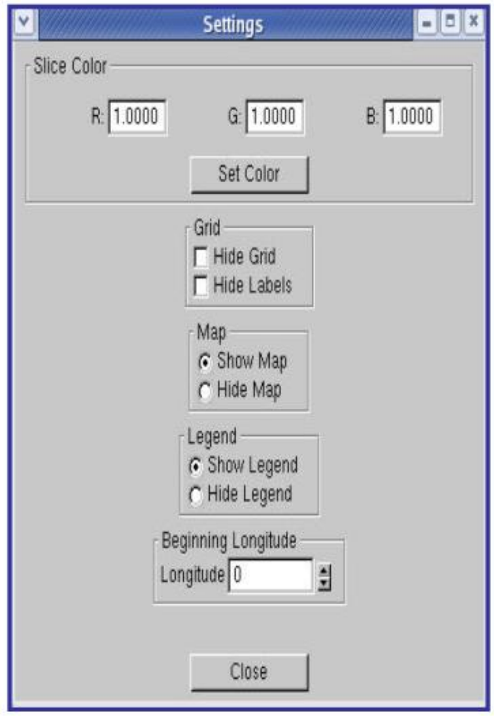

Figure 6.
Settings Window.

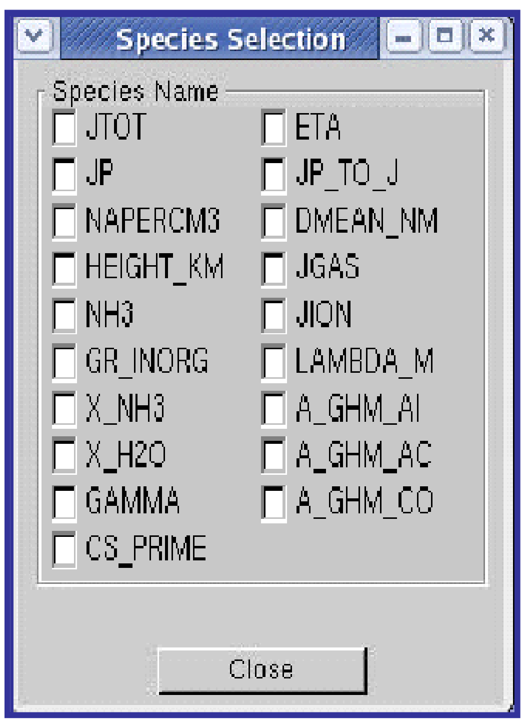

Figure 7. Species Selection Menu