Interactive Poster: Visual Analytic Techniques for CO_2 Emissions and Concentrations in the United States

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Abstract

Climate Change has emerged as one of the grand global challenges facing humanity. The dominant anthropogenic greenhouse gas that seems to be contributing to the climate change problem, carbon dioxide (CO_2), has a complex cycle through the atmosphere, oceans and biosphere. The combustion of fossil fuels (power production, transportation, etc.) remains the largest source of anthropogenic CO_2 to the Earth's atmosphere. Up until very recently, the quantification of fossil fuel CO_2 was understood only at coarse space and time scales. A recent research effort has greatly improved this space/time quantification resulting in source data at a resolution of less than 10 km^2/hr at the surface of North America. By providing visual tools to examine this new, high resolution CO_2 data, we can better understand the way that CO_2 is transmitted within the atmosphere and how it is exchanged with other components of the Earth System. We have developed interactive visual analytic tools, which allows for easy data manipulation, analysis, and extraction. The visualization system is aimed for a wide range of users which include researchers and political leaders. The goal is to help assist these people in analyzing data and enabling new policy options in mitigation of fossil fuel CO_2 emissions in the U.S.

Keywords: Visual Analytics, CO_2, Multivariate and Spatio-Temporal Data, Volume Visualization, GIS, Interactive Visualization

Index Terms: I.3.8 [Computer Graphics]: Applications—

1 Introduction

Environmental change is a topic that is of the utmost importance since it impacts how we live our everyday life and how our future will be affected by our present day environmental choices. Anthropogenic climate change is driven by the emission of greenhouse gases into the Earth's atmosphere, with the foremost being carbon dioxide. CO_2 naturally exists in the earth's atmosphere and is essential to life. However, it is the combustion of fossil fuels since the onset of the industrial revolution that has perturbed the natural background biogeochemical cycle and has driven a rise in the atmospheric CO_2. The combustion of fossil fuel forms the basis of industrial economies and can be found in everything from electricity production, transportation, and heating.

Visualization of CO_2 is a problem that has not been extensively addressed by the scientific visualization community, most likely due to the difficulty of obtaining accurate data and the complexity and scale that is inherent in environmental data [3]. CO_2 is measured in the earth's atmosphere at roughly 100 isolated points leaving little opportunity to visualize atmospheric CO_2 in anything but rudimentary ways. Almost all of these measurements are at the surface, leaving the majority of the atmosphere devoid of any CO_2 observation. Recently, a new data product has been constructed that quantifies this most important source of CO_2 emissions for the United States. This research effort, called the Vulcan Project [2], is a NASA/DOE funded effort to quantify North American fossil fuel carbon dioxide emissions at space and time scales much finer than has been achieved in the past.

Our visualization system has been created in conjunction with the researchers responsible for constructing the Vulcan fossil fuel CO_2 emissions inventory. CO_2 researchers have used atmospheric visualization programs for their previous research, but these programs are severely lacking in user interactivity and options for visualization. By using our visualization system we can easily show interesting aspects of the data that were previously very difficult to isolate.

The visualizations produced in this study were sent to various media outlets. The work has been featured in the New York Times [1], Wired, Scientific American, Popular Science, as well as numerous blogs and local newspapers. The YouTube video generated over 100,000 hits in the first week after the initial press release.

2 CO_2 Data

The Vulcan project has achieved the quantification of the United States fossil fuel CO_2 emissions at the scale of individual factories, powerplants, roadways and neighborhoods. These CO_2 emissions are then run through the Regional Atmospheric Modelling System (RAMS). RAMS advects the emissions throughout the atmosphere and outputs CO_2 concentrations at various heights over the U.S. These concentrations are output as a 3D scalar field and are for the months of May through August 2002 at three hour time intervals. The data has a resolution of about 40 km^2 along the surface and has 45 atmospheric layers with uniform differences in sigma coordinates.

3 CO_2 Visualization

3.1 Background Map

The use of a background map is very important in our study. First, it gives the user spatial landmarks, which helps convey the information to the viewing public, and in particular, policy makers. The background map also provides us with anchor points with which we can map all other data sets to, which is needed in this study since three different map projection systems are used with the various data.

3.2 Histogram

Visualizing CO_2 concentrations purely at different atmospheric layers, without any regard to latitude/longitude position, brings important insight about the CO_2 transportation. To eliminate latitude and longitude from consideration we project each geographic point to a single line using its CO_2 concentration. Which particular horizontal line we project to is determined by which atmospheric level the CO_2 value was taken. The position on the x-axis is determined

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by the CO_2 concentration, with low concentrations mapped to the left. We connect the projected latitude/longitude points with colored lines, which are colored based on the density of points with similar CO_2 concentration. Red indicates there are many CO_2 concentrations at the given height level in the atmosphere, with blue indicating few CO_2 concentrations.

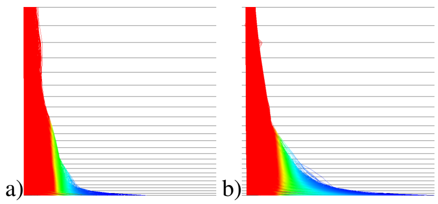

Figure 1: a) A histogram for the entire U.S. in early May. b) A histogram for late August. Notice how the CO_2 values have shifted to the right.

3.3 Two Dimensional Visualization

CO_2 researchers are most comfortable with using 2D slices of data corresponding to various atmospheric heights above sea level since the extreme complexity of atmospheric flow makes 3D visualizations difficult. We provide the ability to display 2D slices using two visualization techniques with interactive controls. Our first 2D visualization technique is done by using a color map and blending/shading capabilities to create a composed image of CO_2 values. The second technique is Marching Squares and allows for multiple iso-contour values. The later is important for showing areas with higher than critical values of CO_2 and its evolution up into the atmosphere. Examples of both can be seen in Figure 2.

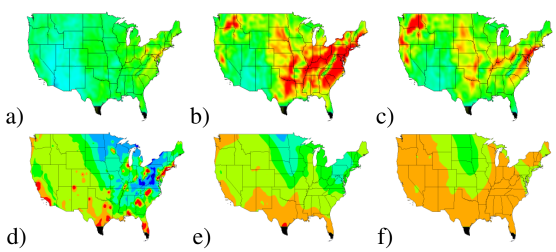

Figure 2: 2D slices of CO_2 concentrations at different periods of the day, a) Morning, b) Noon, c) Evening. Note, high CO_2 concentrations are located at areas with high population or heavy industrial activity. Iso-contours depicting CO_2 concentrations at different atmospheric heights, a) layer nearest surface (35 m), b) 750 m, c) 2500 m

3.4 Three Dimensional Visualization

We provide CO_2 researchers with the ability to render the data in 3D. Marching cubes is provided with interactive controls for colors, illumination of the isosurface, and isovalue selection. The use of marching cubes allows CO_2 researchers to easily see phenomena such as CO_2 transportation and weather fronts, which had previously been difficult to extract using their prior visualization methods. Further description of these phenomena and images can be found in the next section.

4 Results and Discussion

A number of features are evident in the surface 2D visualizations. Most notable is the diurnal cycle of the emissions field itself. The surface concentrations are a close reflection of the surface emissions but modified by the diurnal cycle of the boundary layer. In simple terms, this boundary layer is generally dominated by heightened stability at night and early morning and increased vertical mixing during the afternoon and early evening. Hence, the height of the boundary layer is generally smaller at night and morning than the daytime and evening.

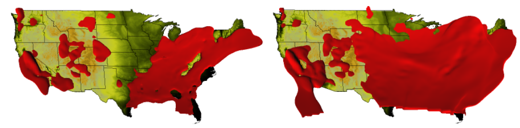

Figure 3: Isosurfaces extracted using marching cubes. Note how CO_2 is traveling from the United States in the first image and into Mexico and across the Atlantic Ocean in the second image.

The Vulcan emissions have a less-straightforward temporal structure due to the mix of activities driving the emissions over a 24 hour period. The mobile sector has a rush hour structure. Power production exhibits a complicated temporal structure due to the tradeoff power companies make with baseload and peak power demand. Broadly speaking there are greater emissions during the day and less emissions at night.

The other broad feature immediately noticeable in the visualization is the broad maxima over populated or industrially-intensive locations. This is driven by the surface sources.

The 3D simulation allows one to get a glimpse of the transport of these source region CO_2 through larger scale dynamics. A number of features are notable. First, the summertime transport of air in Southern California southward over the tropical Pacific and Mexico. The transport over much of the upper tier of the continental portion of the U.S. is also noticeable. The geostrophic flow from west to east is evident with CO_2 moving off of the East coast out over the North Atlantic. The summertime influence of Gulf air is evident as well with some of the CO_2 washing out over the gulf probably due to lower-level mixing in summer thunderstorm activity.

This same thunderstorm activity is likely responsible for the middle- and late-summer elevated parcels of CO_2 rich air evident in the marching cubes visualization in Figure 3. These detached parcels are likely the result of surface air transported rapidly to thunderstorm outflow regions, where they remain in coherent form.

Frontal systems are evident in the upper tier of the continental U.S. as large wedge-shaped features likely denoting fronts of warm air climb up low-level wedges of polar air outbreaks. Some of the cyclonic motion can be discerned as well.

The histogram visualizations in Figure 1 show a number of interesting features. Near the surface, the spread of concentration is evidence of both the spectrum of source function strength and perhaps spatial variability in the boundary layer height. This spread shows the diurnal cycle as well. The convergence of value just above the surface likely denotes the boundary layer lid. Above this lid, there appears to be irregular spreading and compression of the vertical profile traces. This is likely due to the penetration of synoptic events that smear CO_2 rich air above the source locations downwind which weakens the horizontal gradients by eliminating the influence of the surface source function.

References

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