A Breath of Fresh Air

New Mexico

Supercomputing Challenge

Final Report

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Team 63

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Executive Summary

The issue of global warming has become a major concern as well as a political hot potato and this project aims to provide education and insight by using high-quality data and scientific visualization.

Our goal was to find and understand a single, reliable source of data for the world-wide change in the most important man-made greenhouse gas CO_2. We then wrote an interactive program to analyze and visualize this change so as to provide new insights.

We found the highest-quality data set for CO_2 density to be that measured by the NASA AIRS instrument. We downloaded and analyzed monthly measurements, and successfully visualized it using the Processing language.

We found that interactive exploration was very important to both debug the program and understand the data.

Even over a period as short as one decade, the user of this program can clearly see significant global increases in CO_2 densities in both the Northern and Southern hemispheres.

Seasonal variations in CO_2 concentrations are also clearly visible, and we are researching whether one can see effects of continent-wide forest fires in CO_2 measurements as viewed from space.

Background

About 97 percent of climate scientists agree that human-made global warming is happening, and that it is largely due to excessive levels of greenhouse gases being released by a fast-growing population. It is unclear whether this will be merely a minor and easily fixed problem, or whether it will turn into the most serious problem of this century.

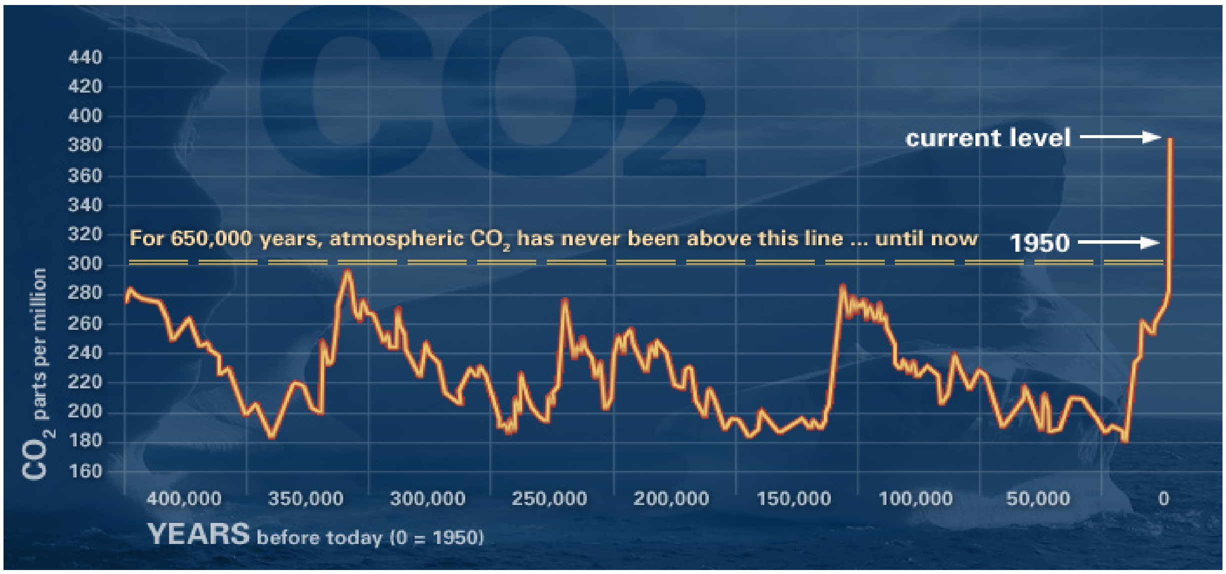
Without an atmosphere, the temperature of our earth would be approximately -18°C (0°F). Our atmosphere increases the average temperature to a much warmer 14.4°C (57.9°F). After millions of years, it has stabilized to a composition of 78.09% Nitrogen, 20.95% Oxygen, around 1.25% water vapor, 0.93% Argon, 0.03% CO_2, followed by traces of other gases. If this composition is disturbed, our ecosystem and climate would be dramatically different (imagine a hot Venus versus a chilly Mars). The (so-called) greenhouse gases act to block the escape of heat from Earth in the form of long-wave infra-red radiation. Both Oxygen and Nitrogen are practically invisible to infra-red radiation, but CO_2 and water vapor are very good at

Forest fires also produce large amounts of CO2 each year, especially in developing countries where they start each spring and can spread through continents.

blocking infra-red radiation, and this fact together with their abundance make them the two most important greenhouse gases. The amount of water vapor is not much changed by humans, but ever since the industrial age we have been pumping enormous amounts of CO_2 into our atmosphere.

In this project we study CO_2 as the most important greenhouse gas that is a by-product of human activities such as: burning fossil fuels and biomass, and manufacturing concrete.

The figure below shows the rise and fall of CO_2 levels over the past 650,000 years, as measured from ancient air pockets in Antarctic ice cores [Lűthi et al.]. Since the 1950s CO_2 has been growing in lockstep with the human population and GDP, has broken the 300 parts per million (ppm) level record of the past 650,000 years, and at this rate of growth could double by 2050. The question is how drastic the consequences will be; will it be merely a storm in a teacup or will it start a global economic and agricultural disaster?



Our initial goal for this project was to collect and understand reliable data on the change in CO_2 across the world, to visualize it, and then to model and simulate pollutant (including smog and CO_2) buildup and spread over large cities and regions. However, a Google search on “CO2” and “data” showed more than 80 million hits. It was clearly impossible to sift through all of this to determine who is right and who is wrong. This is also a major problem for the general public and is responsible for many false truths that confuses the discussion of global warming, such as false assumptions like: "In one volcano eruption more CO_2 is released than the entire human race has emitted in their entire existence.” We therefore changed our question due to this vast amount of confusing data and opinions, and our lack of time to go through all of it. After looking at all our obstacles, we decided we were going to take a different path and focus only on the first part of our original goal.

Problem Statement

Our goal is to find a single, reliable source of data for the world-wide change in CO_2, and write an interactive program to analyze and visualize this change so as to provide new insights. By building a website that runs this visualization, anyone anywhere in the world can rapidly understand the data without being confused by the wide variety of largely political opinions.

Data Sources

After a search for various sources of CO_2 data, we finally decided to use the NASA AIRS CO_2 data in our project.

The Atmospheric Infrared Sounder (AIRS) is an instrument on the NASA Aqua satellite whose mission is to look at the density of important gases in the mid-troposphere (approximately 10km above the surface of earth).

AIRS was launched into Earth-orbit on May 4, 2002 and is one of six instruments on-board the Aqua satellite, part of the NASA Earth Observing System.

The Aquas satellite with the AIRS instrument on board.

AIRS uses cutting-edge infrared technology to daily create large data sets that characterize greenhouse gases. It can measure CO_2 and water vapor plus other trace greenhouse gases such as ozone, carbon monoxide, and methane. With 2378 spectral channels it can collect more data about greenhouse gases than any other satellite, and it can do it globally. Our research shows this to be the best current source for CO_2 data. On the AIRS website it states that *"studies have shown AIRS has improved global weather prediction more than any other single satellite instrument in the past 10 years."*

The AIRS website provides daily, weekly, and monthly-averaged measurements. We use the monthly-averaged data because it is more accurate with fewer missing readings of data. The data can be downloaded in HDF5 format from (http://mirador.gsfc.nasa.gov/cgibin/mirador/collectionlist.pl?keyword=airxc2m).

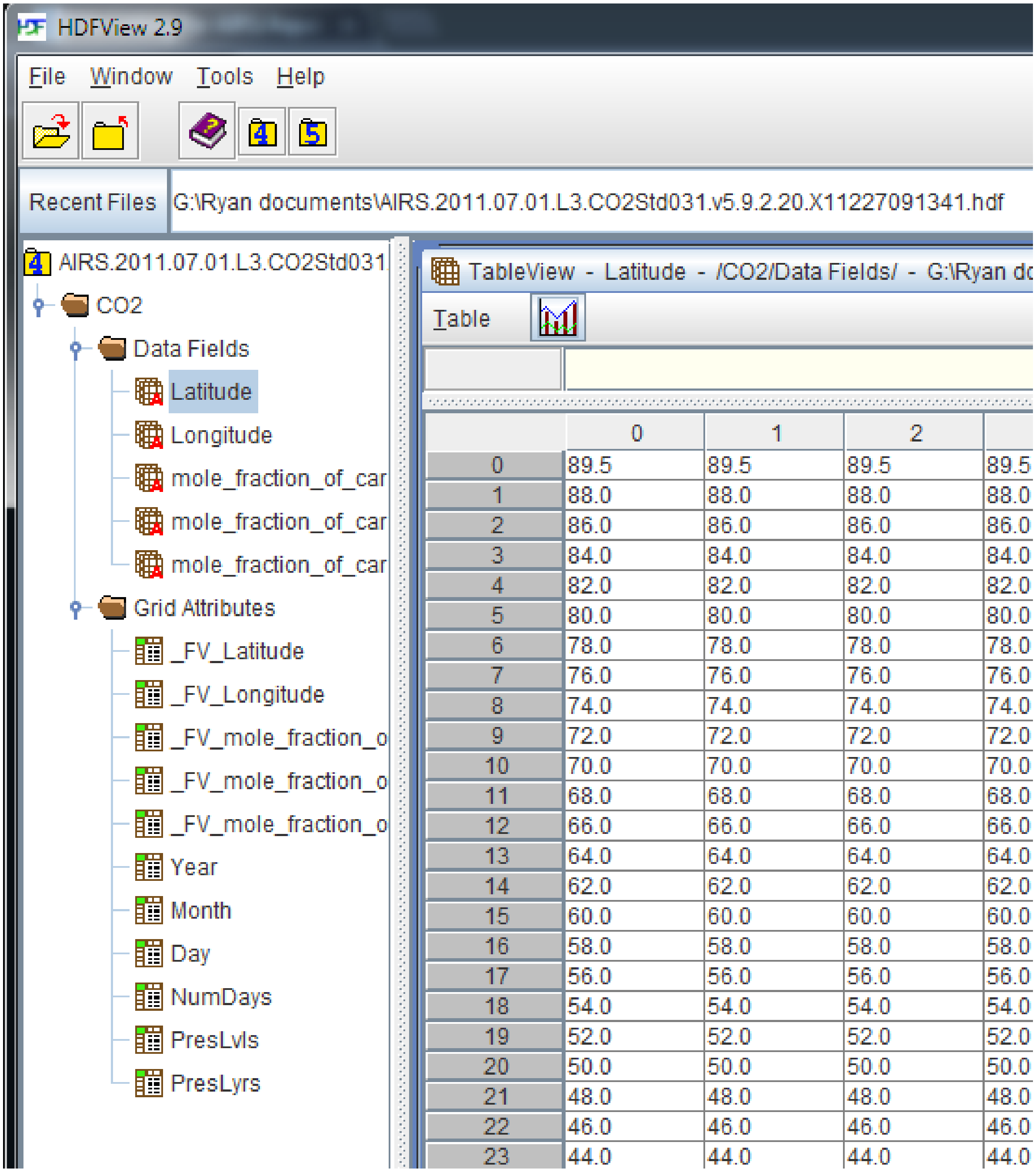
The HDF5 Data Format

HDF5 stands for Hierarchical Data Format (version 5) and is mainly used for storing and reading large data sets. HDF5 is an international standard and is designed to store high volume and complex data sets together with its documentation as a compressed file system. It is used by all NASA satellites, as well as many other satellites and observatories. The *HDFView* program (see http://www.hdfgroup.org for a free download of this software) includes elementary tools and applications for managing, manipulating, viewing, and analyzing data in the HDF5 data format. We used this program to analyze our data in the following way:

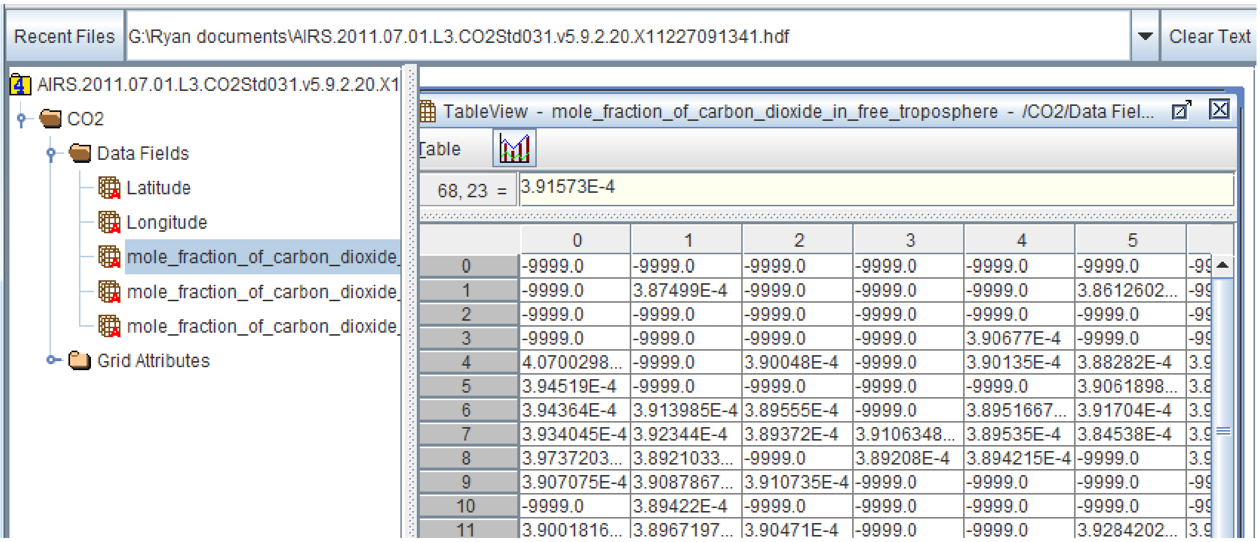
We downloaded the monthly-averaged CO_2 measurements from the NASA AIRS website in HDF5 format. We then used the HDF5View software to convert the data into ASCII. This was imported into Excel and reformatted as CSV (Comma Separated Values format) files, and the latter was read as input by our Processing program. (It would have been much easier if we had a Processing language library that could read HDF5 data files, but we could not find one.)

NASA Datasets

The downloadable data from the AIRS website
(http://airs.jpl.nasa.gov/data/get_airs_co2_data/)
is available in several different formats. We used the monthly level 3 data because of the higher quality and fewer missing data points. This data is binned in 1x1 latitude-longitude degree bins, as shown below with HDFview.



The CO_2 concentration data is measured in parts per million and organized in, the same 1x1 degree bins, as shown in the screenshot below. Note the file system layout and the missing data indicators.

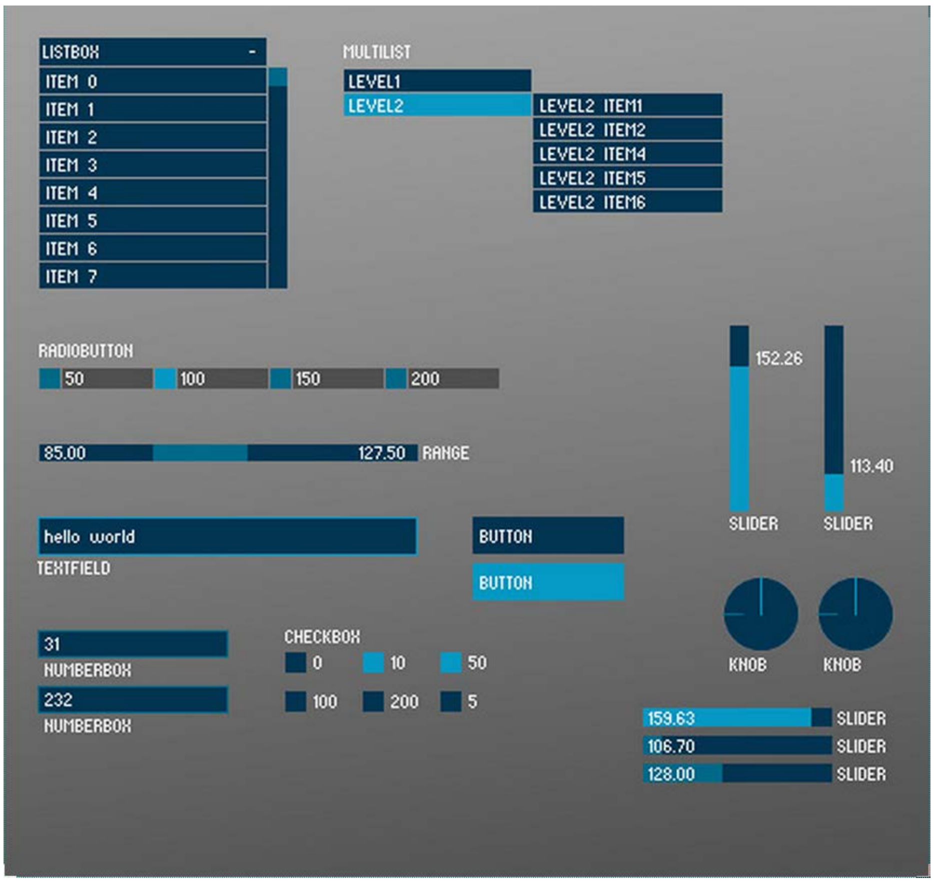


These monthly data sets are available for every month starting October 2002. We downloaded and converted each monthly average data set, and stored the results in CSV files in folders that are sorted by year and by month. In this wway large data sets can be saved on disk and not in memory, thereby this program should be able to cope with much larger data sets.

Software

We used the Processing language, designed by Casey Reas & Ben Fry, in 2001, at MIT. Processing is a visual, interactive language that borrows from Java. The code is open source and available for many architectures at http://processing.org. Processing is becoming very popular with artists and graphic designers for visualizations. There are many libraries and books available, and we learned most of our skills from openprocessing.org. It is outstanding for animation, which is why we are using it. We also used a powerful library called ControlP5. ControlP5 is a Graphical User Interface

(GUI) Processing library (http://www.sojamo.de/libraries/controlP5/) that provides the ability to interactively change variables while running a Processing program. For example, this can be shown as sliding bars. This is very useful for interactively changing the year and month of the data set and choosing the best visualization format in our program.



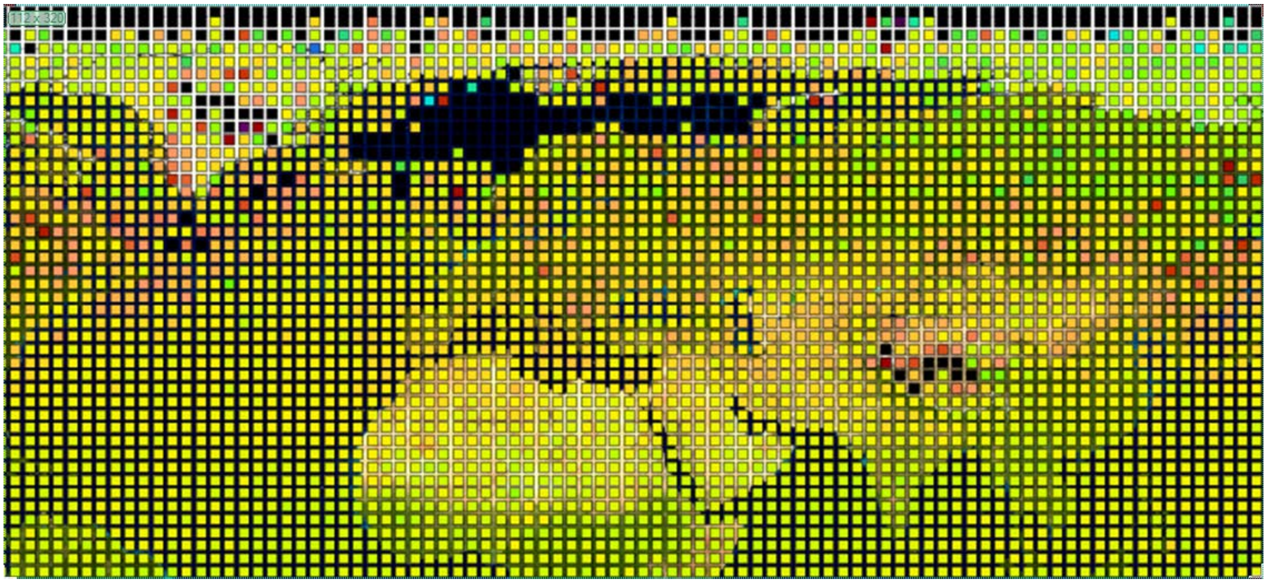
Example of ControlP5 GUI Controllers

Adapting to Missing or Poor Data

The AIRS satellite does not always record highly accurate data. The first reason is due to the fact that it uses infrared channels to determine CO_2 levels, and that these measurements are blocked by excessive cloud cover. Secondly, as shown below, the satellite orbits the Earth from North to South while scanning the troposphere. The cause of bad data at the poles is due to the fact that often there is not enough sunlight at the poles for high accuracy measurements. AIRS indicates inaccurate data measurements with the value of -9999. Henceforth, in our visualization, we indicate incorrect data by black squares (see figure below). In most of the data sets that we analyzed, the incorrect or missing data are located around the North and South poles and the Himalayas.

We use the function isGoodData() (see below) to change many algorithms, for example, the code to calculate the maximum and minimum CO_2 levels in a dataset that must exclude the -9999 values and uses this function to do so.

```
boolean isGoodData(float x) {
   // returns true if not very close to -9999.0
   if ( x > -9998.999 || x < -9999.0001 ) return true;
   else return false;
 }
```



In this example black rectangles indicate where AIRS data is missing or of low precision, in this case over the Arctic, the Norwegian Sea and the Himalayas. An example of how we cope with bad data is shown in the code snippet above.

Our Program

Our program evolved through at least 11 major versions. Like a typical Processing program it has a setup and a draw section, with the draw section repeating at a high frame rate to make interactive visualization possible. See outline below and attached code for more details. Unfortunately there are many processed data files that are too large to be included with this report.

setup:

setup GUI using ControlP5

define heatmap colors

select and load year & month csv files

read latitude, longitude, co2 data & convert to screen location using geoToPixel() function, store in matrix

draw:

set background map

read co2min & co2max from sliders

for each 1x1 grid rect:

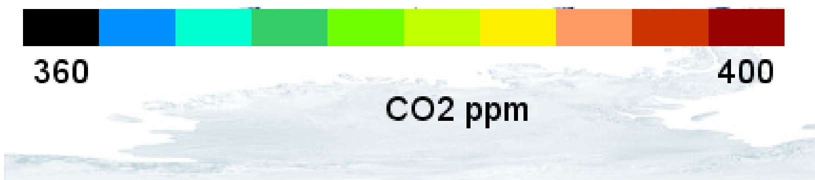
if bad data, then draw black rect at screen location

else: calc color using heat map, draw rect at screen location

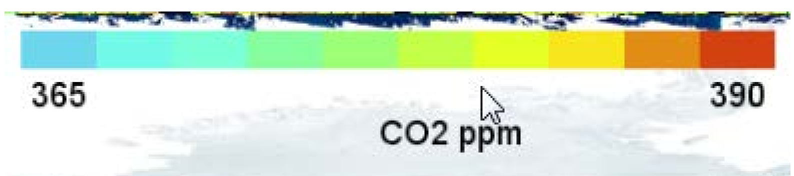
repeat draw section while interactively changing some visualization parameters

Pseudocode outline of our program

An advantage of this approach is that one can interactively tune the visualization as well as explore the data. We found that the choice of effective colors is very important to making it possible to see small changes.

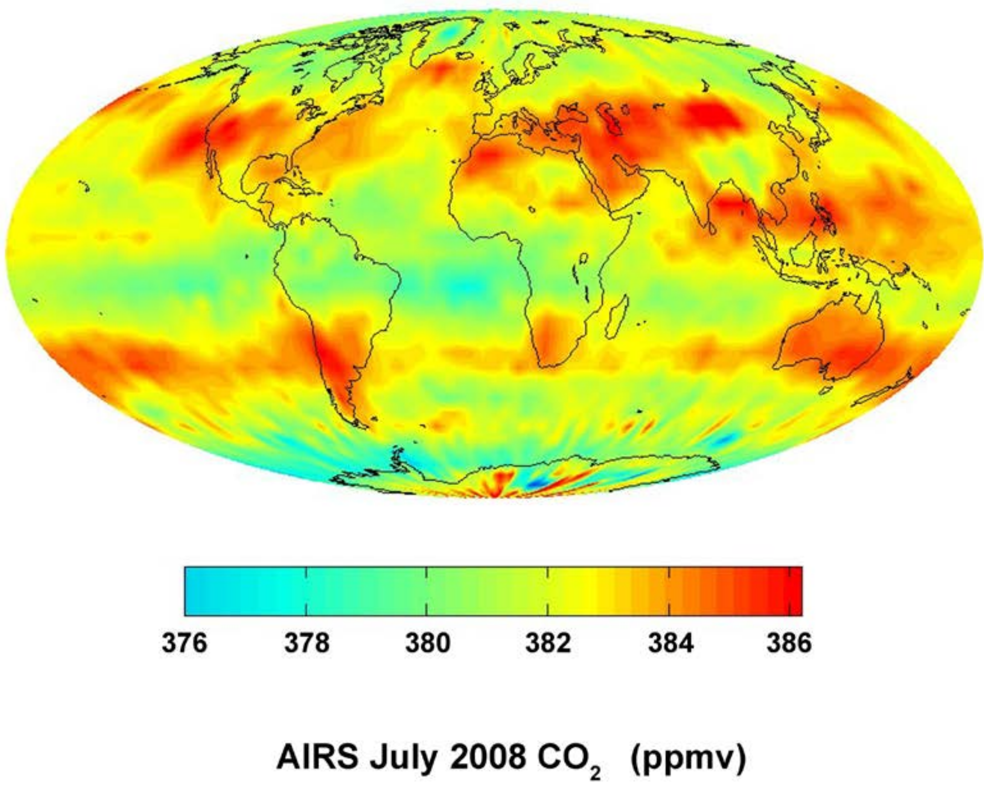


The above figure shows an example heat map indicating CO_2 concentration. In the end we used a color matcher to get as close as possible to the colors used by the AIRS team. The final heat map is shown below.

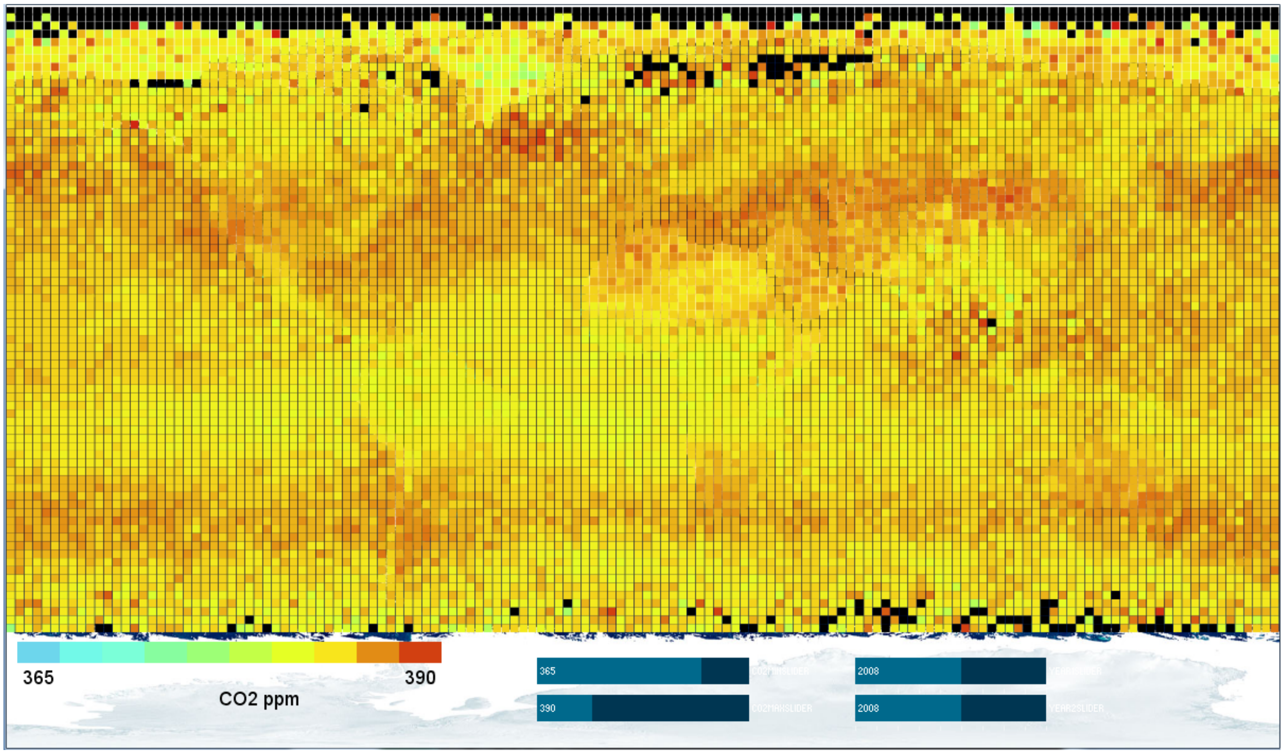


Results

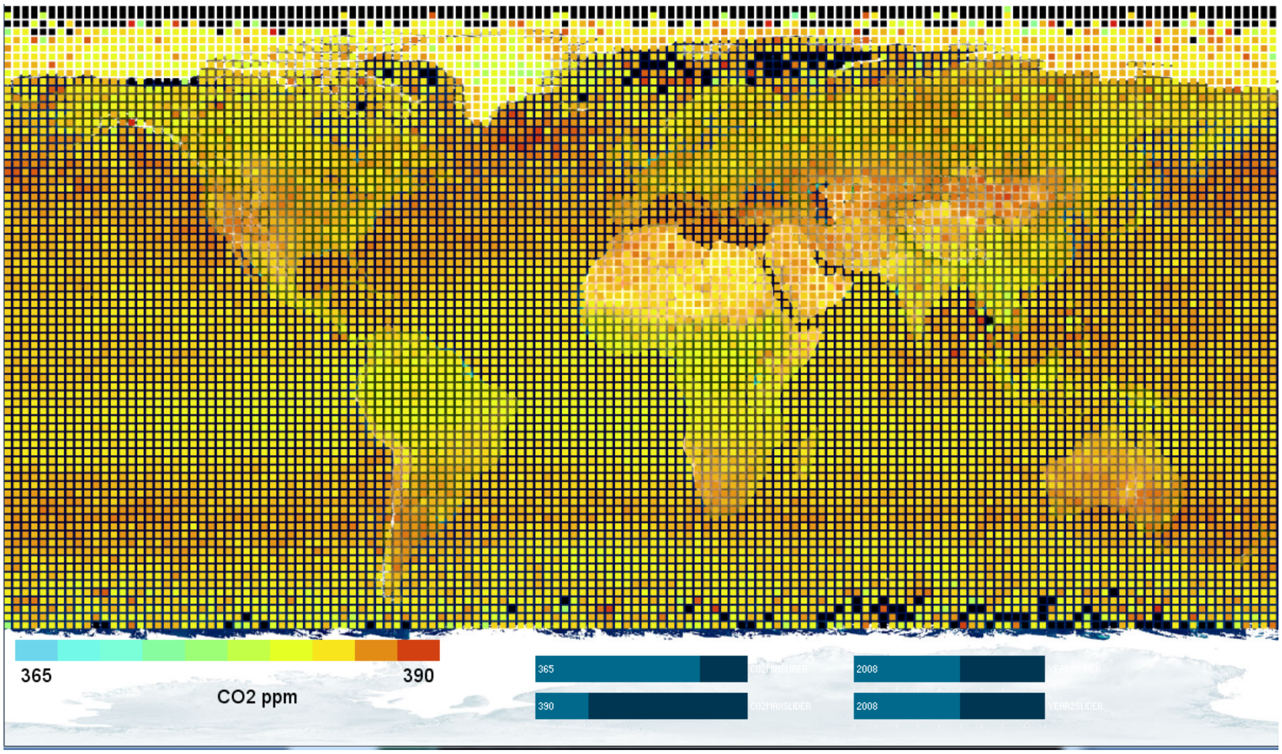
We first show below how our visualization compared with the high-resolution NASA visualization of a July 2008 CO_2 intensity measurement (shown below). We reproduced a rough copy of the NASA heat map. We expect the data used by NASA to be of higher quality than what was available to us. Also, we are not doing any smoothing of the data below. This comparison shows that we are on the right path.



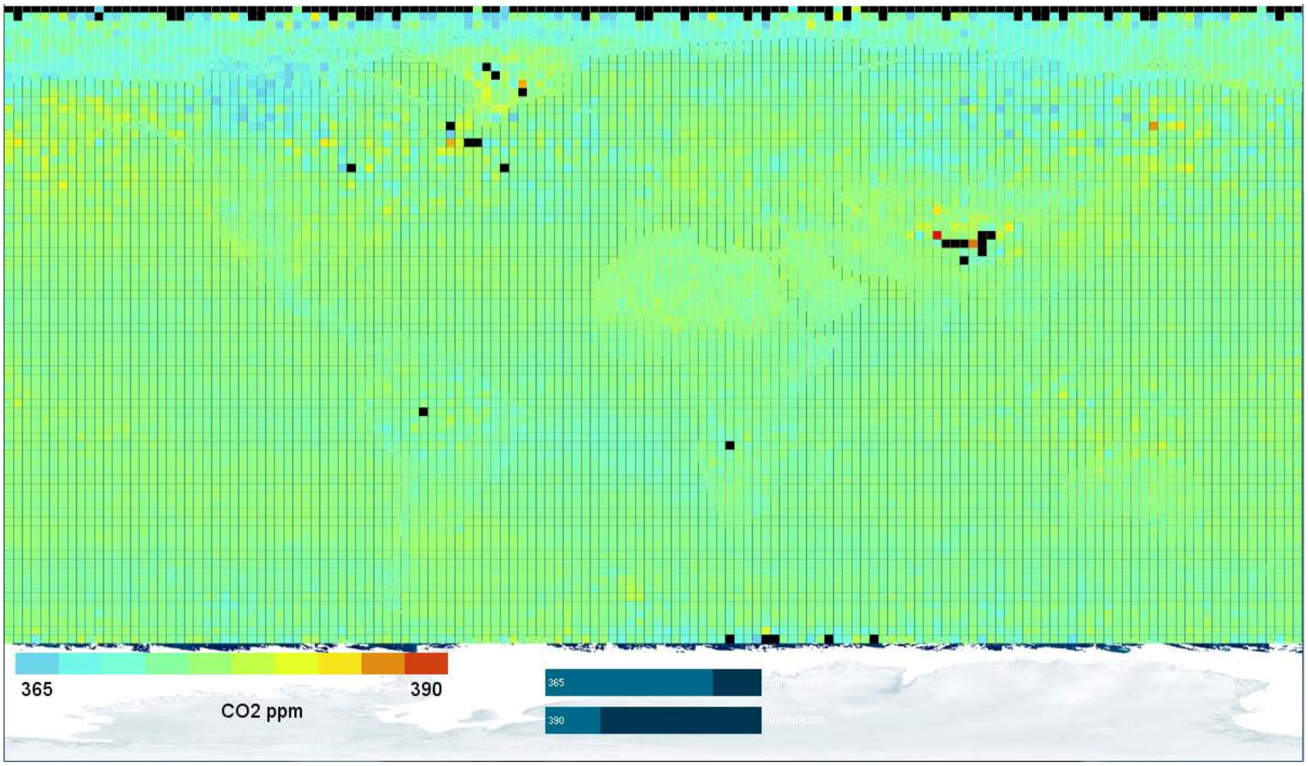
High resolution NASA visualization of a July 2008 CO_2 intensity measurement using AIRS.



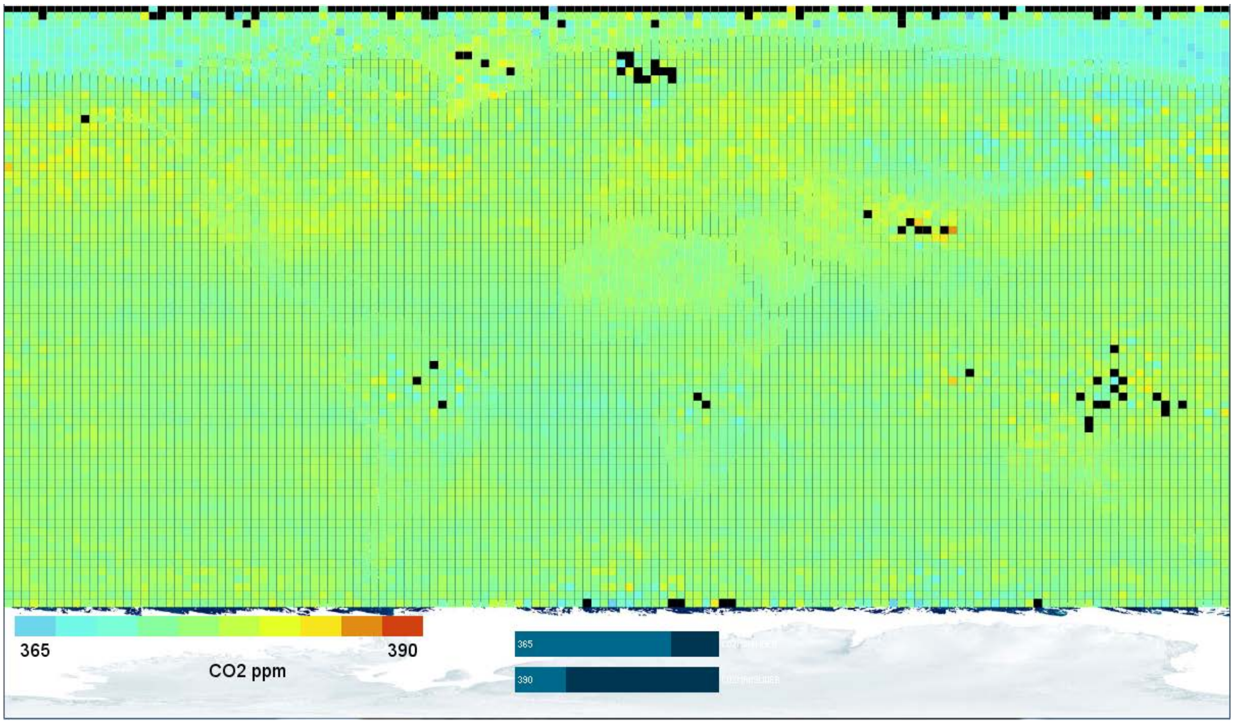
The above Figure shows our visualization of the L3 monthly averaged CO_2 intensities for July 2008, using a Mercator projection. Note the black rectangles showing missing data. Continents are vaguely outlined but some of these outlines are due to the underlying map showing through. When making the rectangles slightly smaller but with everything else unchanged, as shown below, the colors of the map show through and make some data points darker/lighter than in reality. It turns out to be very hard to create a good black outline map that will not bias the interpretation of data while still showing the continents. Overall though, we see a good match with the NASA image.



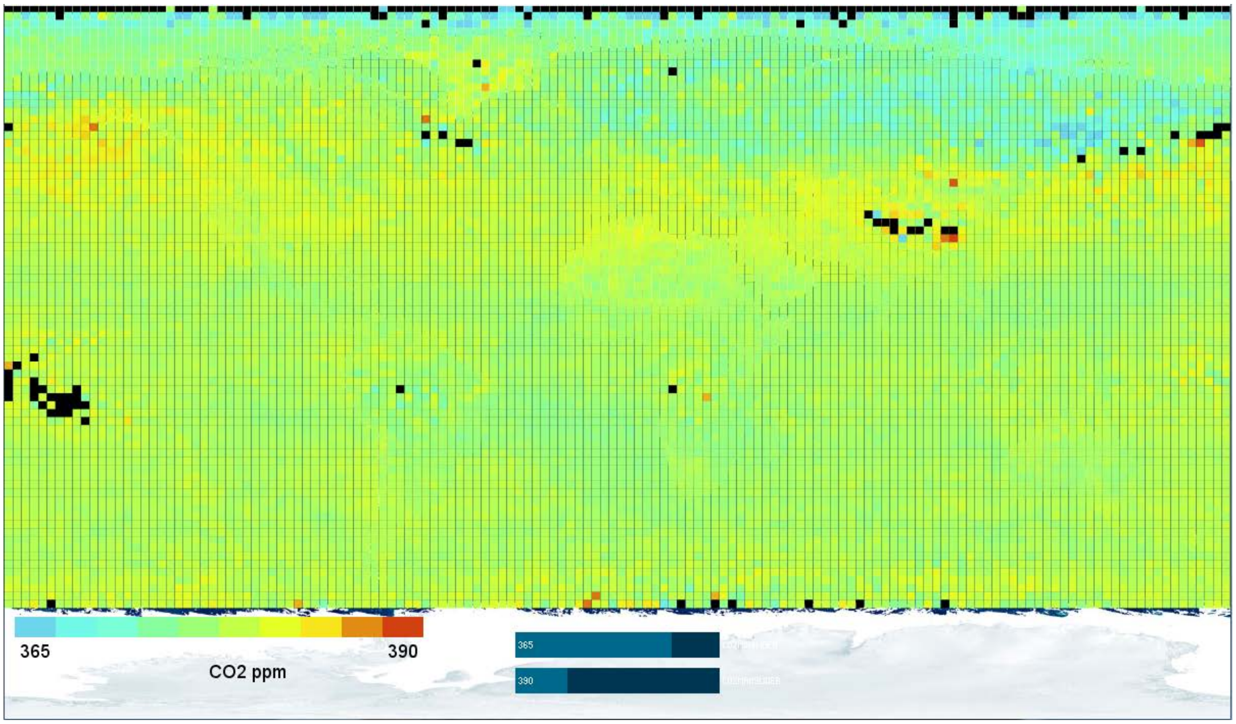
The next figures show monthly-averaged CO_2 concentration as measured by the NASA AIRS instrument during February for the years 2003 to 2012. The heat map is chosen to be the same in each visualization so that data can be compared between the years. An increase in CO_2 levels can be seen in both hemispheres.



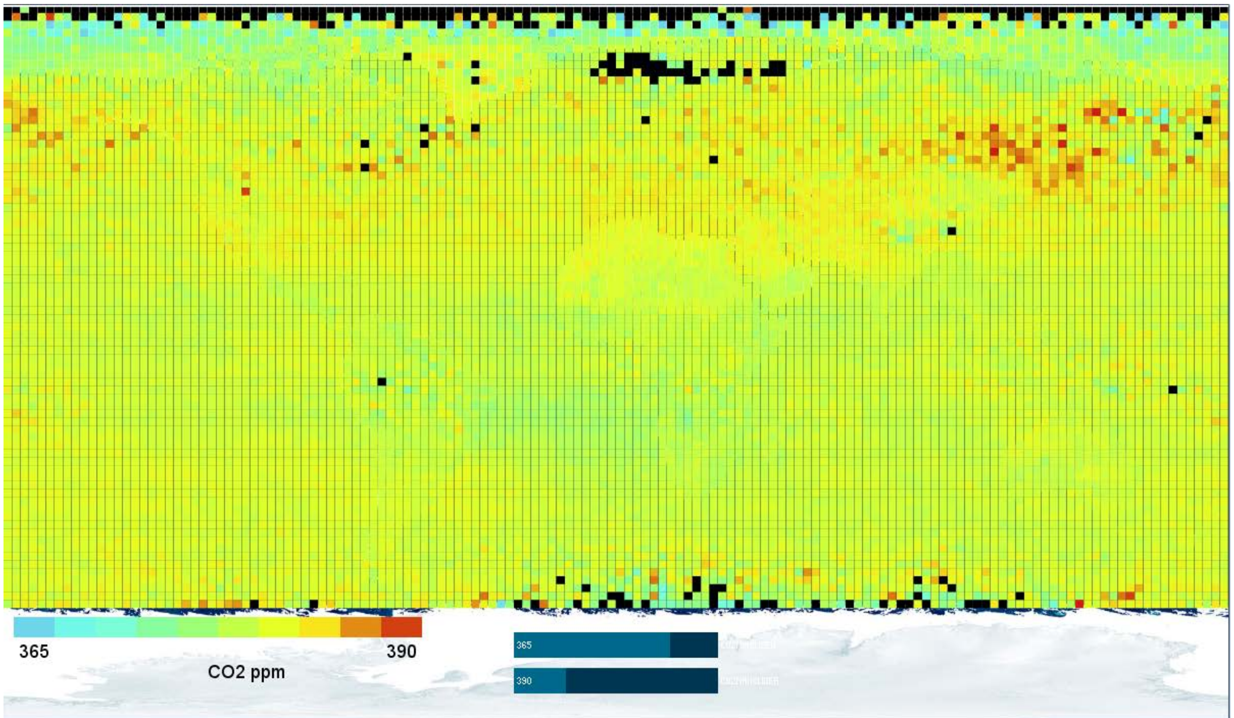
CO_2 concentration in ppm for Feb 2003 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



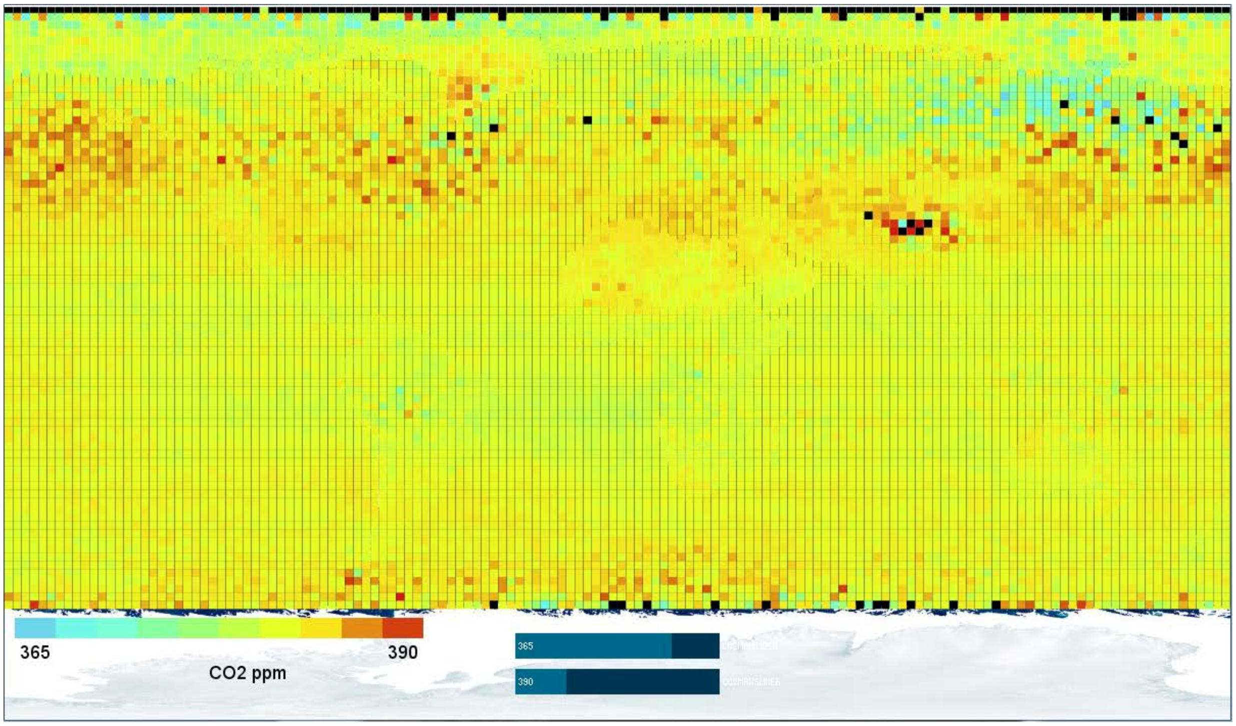
CO_2 concentration in ppm for Feb 2004 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



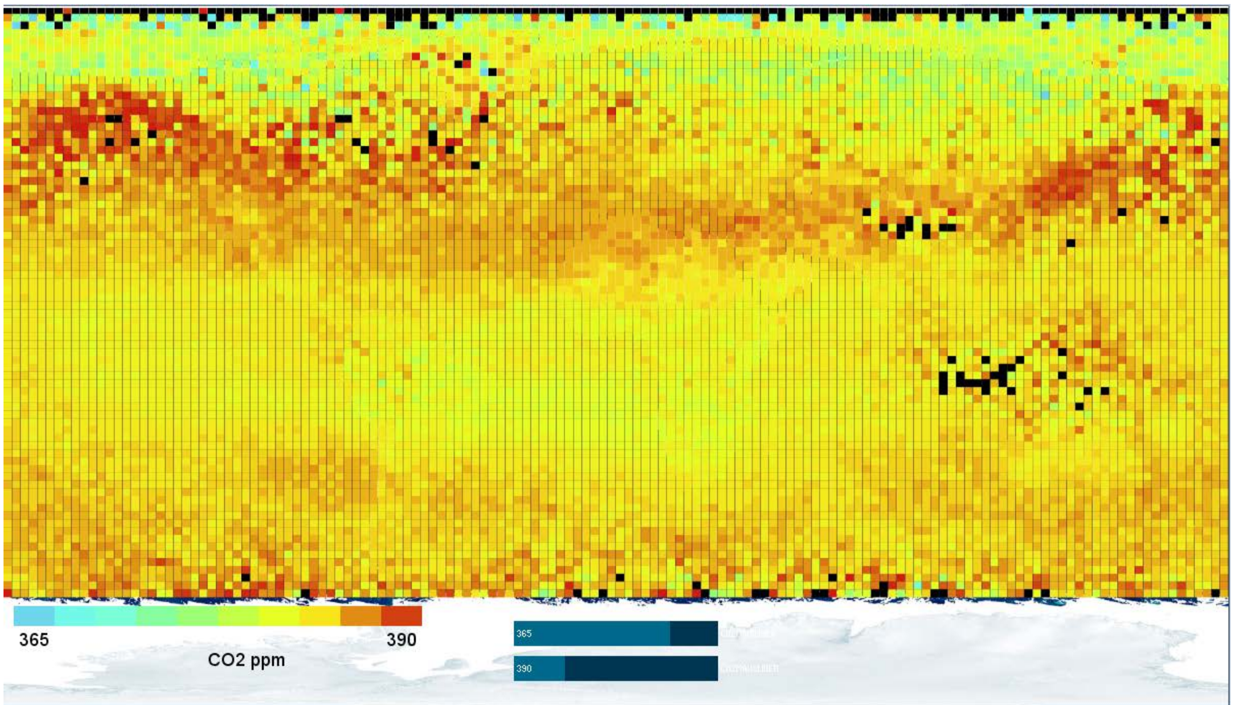
CO_2 concentration in ppm for Feb 2005 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



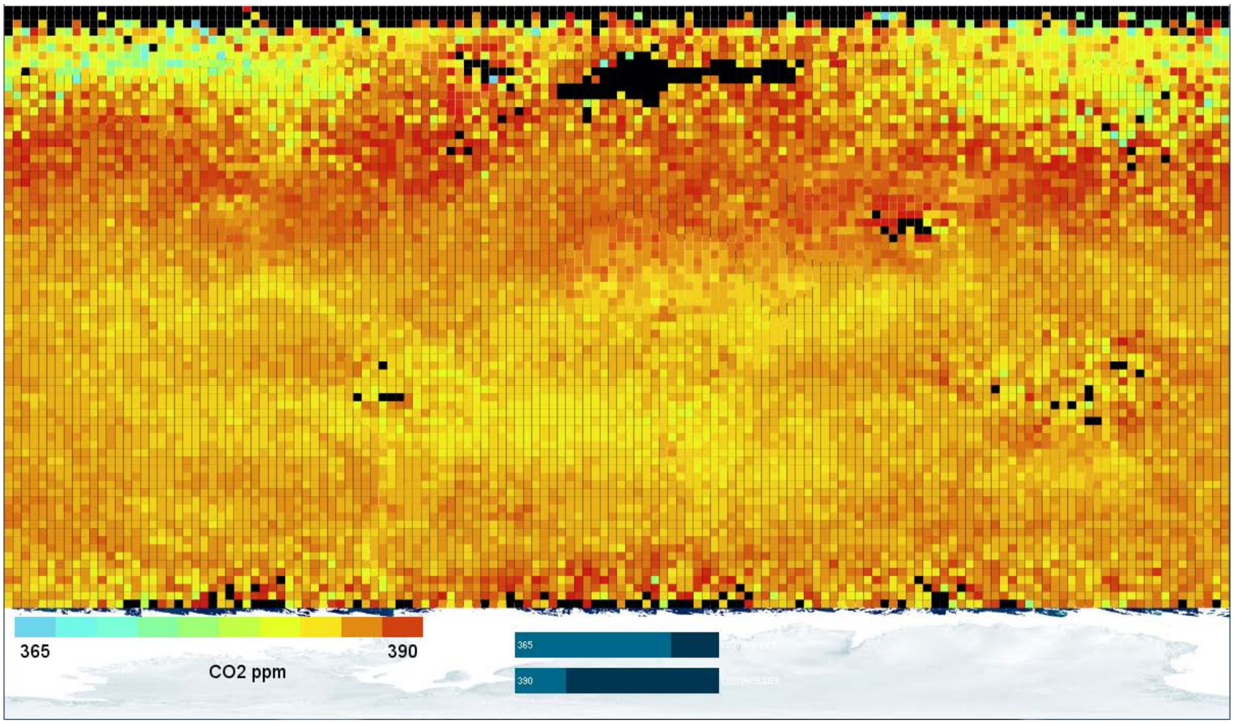
CO_2 concentration in ppm for Feb 2006 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



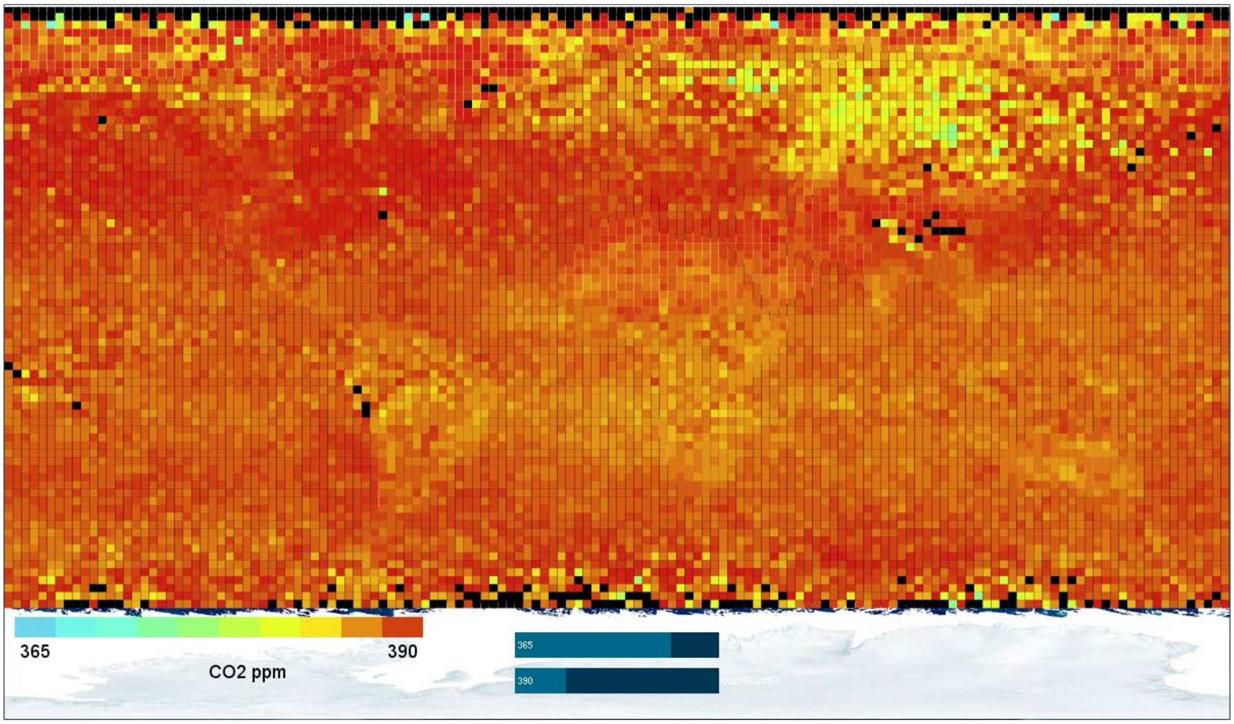
CO_2 concentration in ppm for Feb 2007 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



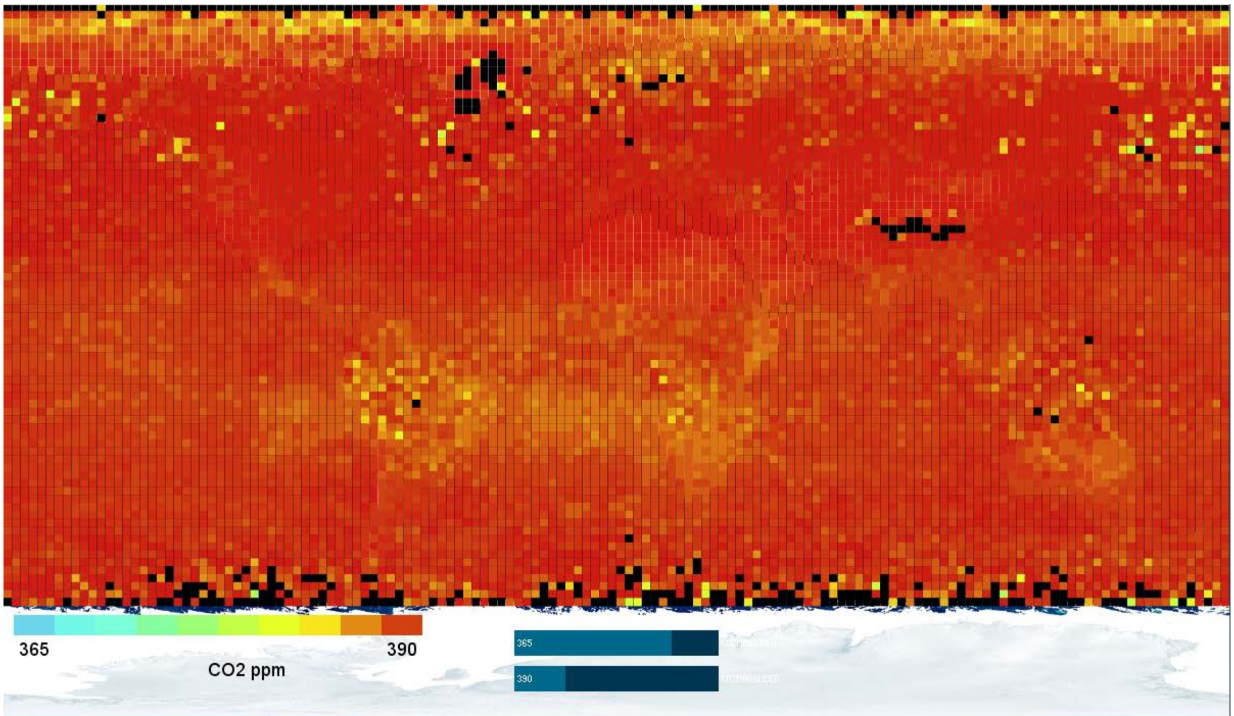
CO_2 concentration in ppm for Feb 2008 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



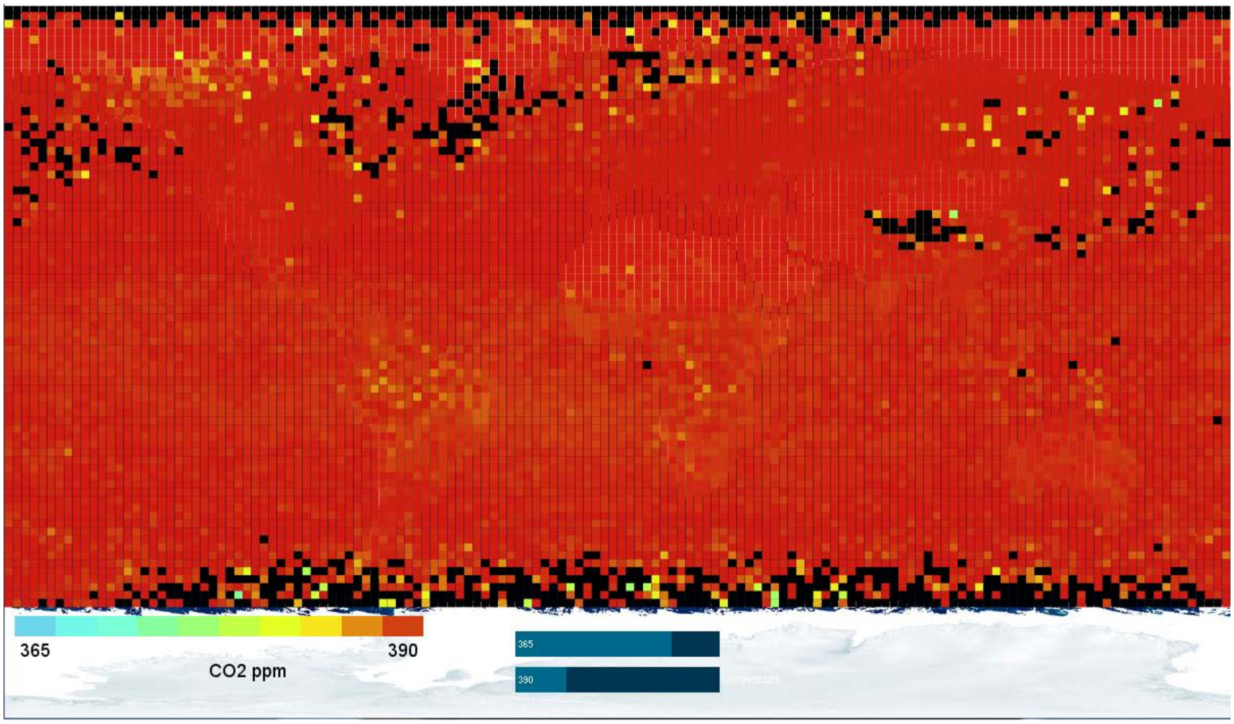
CO_2 concentration in ppm for Feb 2009 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



CO_2 concentration in ppm for Feb 2010 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



CO_2 concentration in ppm for Feb 2011 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)



CO_2 concentration in ppm for Feb 2012 (monthly averaged) as measured by NASA AIRS instrument (black indicates missing data)

Conclusions

We found the highest-quality data set for CO_2 density to be that measured by the NASA AIRS instrument.

We downloaded and analyzed monthly measurements, and successfully visualized it using the Processing language.

Interactive exploration was very important to debug the program and understand the data.

Even over a period as short as one decade, the user of this program will be able see the global changes in CO_2 densities in both the Northern and Southern hemispheres.

Seasonal variations in CO_2 concentrations are clearly visible, and we are researching whether one can see effects of continent-wide forest fires in CO_2 measurements as viewed from space.

Most Original Achievement

We consider our most original achievement the surprisingly large amount of change that can be observed over such a short period of time. We also wrote software that visualizes the difference between two data sets, and allows the user of this program to compare the differences between any two months or years. This ability is very useful because you can see the CO2 difference change in a single area or a very large region. At this time we are still studying these results and plan to publish it on our website.

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