Annual Report

Contract #NNX06AB37G

"High-Resolution Fossil Fuel Emissions Estimates in Support of NACP and OCO-Based CO_2 measurements and assimilation system"

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with contributions from
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1.0 Introduction

The goals of the project, "High-resolution fossil fuel emissions estimates in support of NACP and OCO-based CO_2 measurements and assimilation system" are to generate a highly resolved spatiotemporal inventory of fossil fuel CO_2 for North America in order to support the larger carbon budget goals of the NACP. Key to those goals are the support of inverse/assimilation estimates of net carbon exchange using OCO-based measurements of atmospheric CO_2. The spatiotemporal goals were to quantify fossil fuel CO_2 at the spatial scale of 10s kilometers and an hourly temporal scale. We planned to quantify emissions for data available years, currently 1999 and 2002. For the remainder of this report we refer to this project by it's public name of "Vulcan".

The research goals for the 2007 funding year were focused on producing CO_2 emissions at both "native" resolution and a gridded resolution. The grid resolution exceeds the original goals set forth in the proposed research and is now resolved at 10 km x 10 km every hour for 2002. Additional goals were to maintain the full process fidelity (combustion type, fuel, sector, sub-sector) in the emissions inventory. Finally, evaluation of the inventory was established as a key goal of the 2007 research effort.

We have achieved these goals. Furthermore, the Vulcan inventory release, version 1.0 was met with overwhelming interest from both the scientific community, policymakers and the public. Evaluation has shown the inventory to be consistent with aggregate products and initial atmospheric transport indicates that the Vulcan inventory will lead to improved carbon cycle budget estimation and understanding. The results in 2007 have shown that this research is the "tip of the iceberg" and the final year of research on this project will undoubtedly be the most productive yet.

2.0 Reprise of 2006 funding year results

The following provides a succinct recap of the progress made during the funding year 2006. Because this 3 year funded project was divided into two grants, a one-year and a contiguous two-year, this recap covers year one of the contiguous two-year grant. New progress, reported in section 3 is therefore the second year of this second two-year grant.

2.1. Methods

All methodological details encompassing all of the CO_2 sources were finalized in funding year 2006. On-road mobile sources and emissions from monitored power production facilities utilized direct fuel use and/or direct CO_2 measurements. In other cases, NOx emissions were used to compute fuel used. This, combined with fuel type and combustion technology/controls, allowed for a calculation of CO_2 emissions. Data sources were primarily the National Emissions Inventory, the ETS/CEMS data, Federal Highway Administration data, and US Census data.

2.2. Area sources

These encompassed primarily the residential and commercial sector and were available at the county level. Roughly 74,000 area source emission records were processed and processing involved applying NOx emission factors to NOx emissions to compute fuel amounts used. CO_2 emission factors were then applied to produce CO_2 emissions. Some emission factors supplied in the National Emissions Inventory were utilized but much was found unreliable and independent emission factor databases were utilized.

2.3. Point sources

The overlap between the power production point sources and the large number of point sources in the NEI was accomplished (avoids double-counting). The remaining point sources in the NEI are predominantly industrial (and cement) sources but there are commercial and residential sources as well. NOx emissions were processed including control technology/factors and supplied emission factor decisions. These emission sources are geolocated in their “native” format and hence, are the highest resolution data in the Vulcan Project.

2.4 Mobile sources

The on-road portion of mobile sources was completed utilizing the Mobile6 combustion model and the National Mobile Inventory Model database. This produced CO_2 emissions at the county scale every month for 12 vehicle types and 12 road types. Further temporal structure was accomplished through the use of weight in motion data from various US locations. This achieved an hourly resolution by county/road/vehicle. This was further spatially disaggregated utilizing a GIS road atlas in which the total county emissions were distributed to the amount of road type within a county.

2.5 Total gridded emissions

All 2002 data types were placed onto a common 36 km grid (this has now moved to a 10 km grid) across the United States. This was produced for each hour of 2002 but only power production and mobile sources were truly hourly-based (roughly 65% of US emissions).

Independent evaluation at the national scale was performed with the Vulcan totals very close to sectoral EIA and EPA estimates.

3.0 New results

3.1 Introduction/history

Fossil fuel CO_2 inventories began as a simple accounting exercise based on the production/consumption of fossil fuels at the national scale [*Marland and Rotty*, 1984]. In most cases, little sub-national allocation of the emissions was performed because the initial purpose – meeting regulatory commitments (e.g. Kyoto targets) or reconstructing 20th century climate change – required little sub-national information. Thus, the most common spatiotemporal structuring of fossil fuel CO_2 emissions occurred at an annual timescale and at the national spatial scale. Starting in the 1980s, research was begun to further subdivide these emissions into finer spatial and temporal scales [*Rotty* 1983; *Marland et al.,* 1985]. By the beginning of the 21st century, fossil fuel CO_2 emissions had been produced which were resolved at the 1° x 1° spatial scale and most commonly at an annual time scale [*Andres et al.,* 1996]. This downscaling in space and time is quite deceiving, however, as the sub-national spatial allocation was performed using population density statistics. Further, temporal downscaling had only been attempted in a comprehensive fashion for the U.S. and Europe and had only achieved monthly resolution [*Andres et al.,* 1999; *Blasing et al.,* 2005; *Gregg and Andres,* 2008].

In the last decade, there has been a growing need, from both the science and policymaking communities, for quantification of fossil fuel CO_2 emissions at space and time scales finer than the available 1°/annual product [*Gurney et al.,* 2007]. Carbon cycle science required more accurate and more finely resolved quantification due to downscaling of carbon budget and inverse approaches, which use space/time patterns of atmospheric CO_2 to infer exchange of carbon with the oceans and the terrestrial biosphere. [*Gurney et al.,* 2002; *Gurney et al.,* 2005; *Denning et al.,* 2005]. These scientific needs have contributed to the planned launch of the Orbital Carbon Observatory (OCO), which will measure the column concentration of atmospheric CO_2 at less than 10 km and at a daily time scale [*Crisp et al.,* 2004].

The policymaking community in the U.S. has also recognized the need for accurate, highly resolved CO_2 emissions due to the emerging requirements of proposed carbon trading systems or sectoral emissions caps. For example, all of the pending congressional bills aimed at emissions mitigation identify the need to quantify greenhouse gas emissions with improved accuracy (e.g., [*Lieberman and Warner,* 2007]). Many of these bills also recognize the need to move beyond broad sectoral quantification and call for much finer detail in space and time in order to facilitate a more robust trading system.

To answer this growing need for better resolution and accuracy, research was begun on the Vulcan project (www.purdue.edu/eas/carbon/vulcan). Vulcan has achieved a U.S. fossil fuel CO_2 emissions inventory at <10 km spatial scales and an hourly time scale. It has been produced for the year 2002, and a 2005 product will be available in late 2008. Furthermore, Vulcan includes significant process-level detail, dividing the U.S. fossil fuel CO_2 emissions into economic sectors and sub-sectors in addition to 23 fuel types.

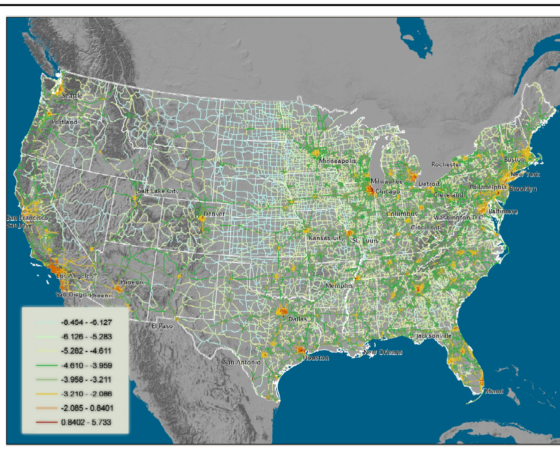


Figure 1. Vulcan carbon dioxide emissions from the mobile sector for the year 2002. Units: log base 10 of million metric tonnes of carbon per km per year

The Vulcan model/data system leverages the information provided by four decades of air quality research and regulation in the U.S. To meet air quality mandates established by the Clean Air Act, extensive reporting of criteria air pollutants (CAPs) and hazardous air pollutants (HAPs) from nearly every emitting source is made and warehoused by the U.S. Environmental Protection Agency (EPA) [*USEPA* 2005a; *CFR* 2002]. The six CAPs are: carbon monoxide (CO), lead, Nitrogen oxides (NOx), sulfur oxides (SOx), Ozone (O_3), and particulates. In addition to emission reporting, a number of other key attributes are submitted, including emission controls, locations, fuel, source classification, and combustion technology.

The EPA data are combined with a number of other data and model sources including information on mobile sources, power plants and U.S. census data. The goal is to transform these data, constructed to meet air quality regulations, into a fine-scale fossil fuel CO_2 emissions inventory. Three broad source classifications act as the starting point for the data processing: “point”, “area” and “mobile” sources.

3.2 Mobile source progress

The mobile emissions are based on a combination of county-level data and on standard internal combustion engine stochiometry. The county-level data comes from the National Mobile Inventory Model (NMIM) County Database (NCD) and quantifies the vehicle miles traveled in a county in a particular period of time, specific to vehicle class and road type [*OTAQ*, 2005]. The VMT portion of the NCD has been compiled from available historical data obtained from the Federal Highway Administration’s (FHWA) Highway Performance Monitoring System (HPMS) [*FHA* 2005]. The HPMS is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the Nation's highways and roadways. The diurnal pattern of mobile emissions is included from *in situ* “weight in motion” (WIM) studies [*Marr et al.,* 2002]. The Mobile6.2 combustion emissions model is used to generate CO_2 emission factors on a per mile basis given inputs such as temperature, fuel type, and vehicle speed [*USEPA,* 2001; *Harrington*, 1998]. After generating CO_2 emissions at the county level, these emissions are placed onto roadways using a road network GIS layer which includes all but small city streets. The resultant product provides hourly CO_2 emissions on U.S. roadways specific to county, vehicle class, road type, and vehicle age class. Figure 1 shows the total annual CO_2 emissions from the mobile sector in 2002.

3.3 Point source progress

Point sources in Vulcan rely on two different data streams. Because of the reliability of direct CO_2 monitoring, continuous stack monitoring data provided through the DOE’s Energy Information Agency (EIA) and the EPA’s Clean Air Market Division (CAMD) Emission Tracking System/Continuous Emissions Monitoring (ETS/CEM) for electrical generating units (EGUs) are utilized [*ERG and EHP*, 2004; *USEPA* 2005b]. The ETS/CEM data are collected under the Acid Rain Program (ARP), which was instituted in 1990 under Title IV of the Clean Air Act [*CFR,* 2000; *USEPA* 2008]. The ARP regulates EGUs that burn fossil fuel and are greater than 25 MW capacity or are less than 25 MW but which burn coal with a sulfur content of greater than 0.05% by weight. In addition to heat input, these facilities are required to engage in continuous monitoring and reporting of sulfur dioxide (SO_2), CO_2, and nitrogen oxides (NOx) emissions. These data are reported directly as hourly CO_2 emissions monitored from an

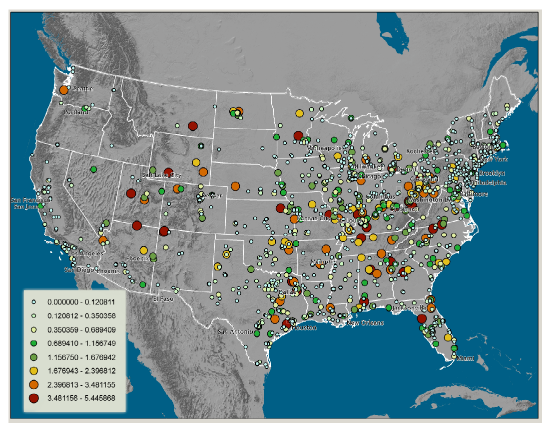


Figure 2. Vulcan carbon dioxide emissions from the ETS/CEMS data. Units: million metric tonnes of carbon/facility/year

emitting stack or based on records of fuel use. All emitting locations are geocoded to latitude, longitude and postal address. Figure 2 shows the annual emissions of these CO_2 sources.

The point source CO_2 emissions not covered under the ARP reporting system are derived from the EPAs National Emissions Inventory (NEI) of all the CAPs emissions across the U.S. [*ERG* 2001; *USEPA* 2006a]. As with the ETS/CEM data source, the emitting locations are geocoded to latitude, longitude and postal address.

The Vulcan model utilizes the reported emissions of carbon monoxide (CO) for all the point fossil fuel combustion sources. Emission factors derived from laboratory studies are used to calculate the amount of fuel consumed, taking into account the reported emission controls, if any [*USEPA* 1997; *USEPA* 2006b; *WebFIRE* 2005; *Gurney et al.,* in prep]. With knowledge of the fuel type and the combustion technology, appropriate CO emission factors can be identified. The fuel consumed in combustion is used to calculate CO_2 emissions based on the carbon content of the fuel and oxidation factors [*Gurney et al.,* in prep.].

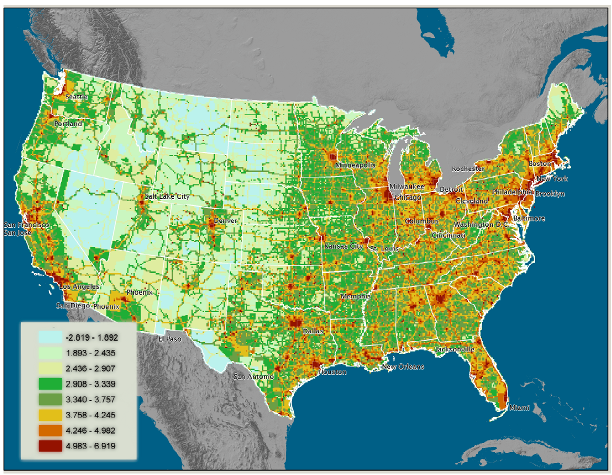


Figure 3. Vulcan total carbon dioxide emissions for 2002. Units: log base 10 of metric tonnes of carbon/100km^2/year

The point source module also includes the emission of CO_2 from the production of cement and cement-related products. These are emissions derived not from the fuel burned to heat kilns (captured in the fossil fuel throughput component), but direct CO_2 emissions derived from the calcining process. These CO_2 emissions are generated through reported NOx emissions combined with throughput estimates where available.

3.4 Area source progress

The area or nonpoint source emissions (dominated by residential and commercial activity) are stationary sources that are not inventoried at the facility-level and represent diffuse sources within a geographic area. They are calculated from NOx emissions present in the NEI [*USEPA* 2006c]. In a process similar to the point source treatment, NOx emission factors are combined with emission levels, fuel type and reported combustion technology to calculate CO_2 emissions.

This data is reported spatially at the county level and at the annual level with regards to time. This county-level data is further downscaled to the census tract level by availing of US Census estimates of residential, industrial and commercial square footage in each census tract. Census tract size varies according to population density across the United States.

3.5 Total fossil fuel CO_2 emissions

The combination of these data sources comprises the near-complete fossil fuel CO_2 emissions in the U.S. Currently, two sources are not included in the emissions inventory: non-road emissions (snowmobiles, trains, tractors) and aircraft. These sources will be included the next release of the Vulcan inventory (version 2.0 planned for early 2009).

In addition to the space and time detail, process-level information is retained on all emitting sources such as the SCC and fuel type. To facilitate atmospheric transport modeling and intercomparison with other independent sources, the CO_2 emissions are placed onto a 10 km x 10 km grid. All point and mobile sources resident within a 10 km x 10 km grid cell were summed while area sources were apportioned via area weighting.

Figure 3 shows the total fossil fuel CO_2 emissions for the year 2002 on a common 10 km x 10 km grid.

4.0 Evaluation

Evaluation of the Vulcan inventory as begun and will continue into 2009. Current evaluation includes comparison at the national level to aggregate annual inventories and at the state/annual level. Atmospheric transport modeling has begun utilizing two transport models, PCTM and the RAMS model. Results are being analyzed and further transport integrations will occur into 2009.

4.1 Comparison to EIA estimates

The Department of Energy's Energy Information Agency (EIA) compiles statistics of energy production and consumption across the United States in a systematic fashion. The EIA has compiled CO_2 emissions resulting from the consumption of fossil fuels by state on an annual basis [*EIA* 2008a; *EIA* 2007a]. This data is derived from state level consumption data and national-level CO_2 emission factors [*EIA* 2008b; *EIA* 2007b].

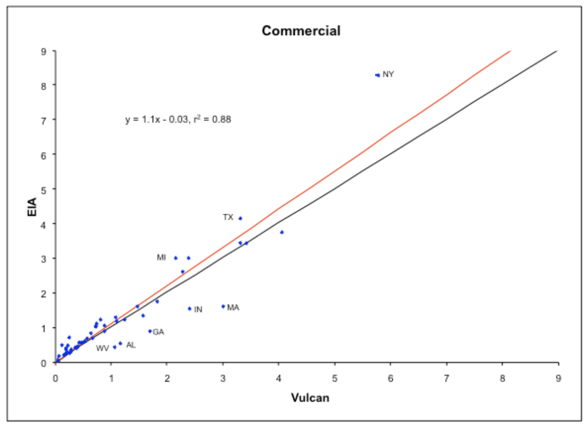


Figure 4. State-by-state EIA versus Vulcan commercial fossil fuel CO_2 emissions for the year 2002. Black line denotes 1:1 relationship, red line denotes linear regression across all states.

Figure 4 presents a comparison of the state-by-state EIA versus Vulcan fossil fuel CO_2 emissions for the commercial sector, 2002. Denoted on the figure are states for which there is a discrepancy between the EIA and Vulcan estimates. In general, the Vulcan inventory appears to have a lower Commercial CO_2 emission for the state of New York and greater emissions for the states of West Virginia, Alabama, Georgia, Indiana, and Massachusetts. A linear fit to the state distribution results in a slope slightly greater than unity (EIA = 1.1*Vulcan - 0.3; r^2=088).

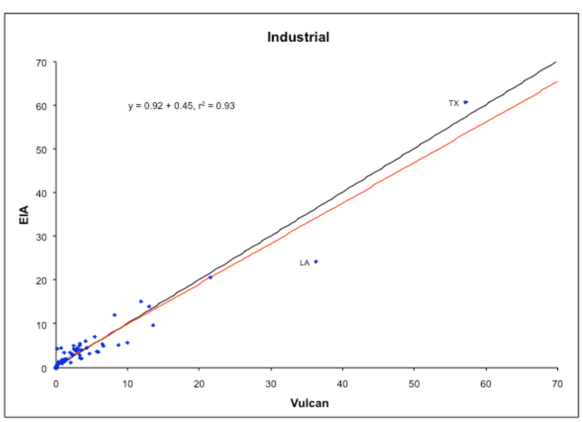


Figure 5. Same as in figure 4 for the industrial sector.

Figure 5, 6, and 7 present the same information but for the industrial, mobile, and residential sectors, respectively. Two noticeable discrepancies occur for the states of Texas and Louisiana in the industrial sector with Vulcan estimating less industrial CO_2 than the EIA for Texas and the opposite for the state of Louisiana. A linear fit to the state industrial distribution results in a slope slightly less than unity (EIA = 0.93*Vulcan + 0.46; r^2=0.93). The mobile sector discrepancy is considerable and likely due to the fact that the EIA includes nonroad emissions in the mobile sector while Vulcan currently has not included those emissions in the inventory. Residential fossil fuel CO_2 shows considerable agreement with Texas and Alabama as outliers. A linear fit results in a slope slightly less than unity (EIA = 0.97*Vulcan + 0.08; r^2=0.92).

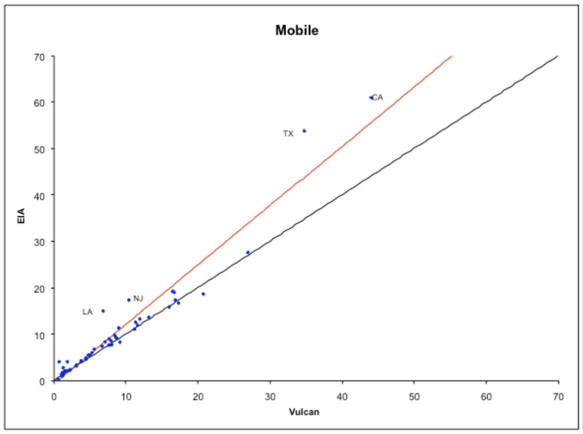


Figure 6. Same as figure 4 for the mobile sector

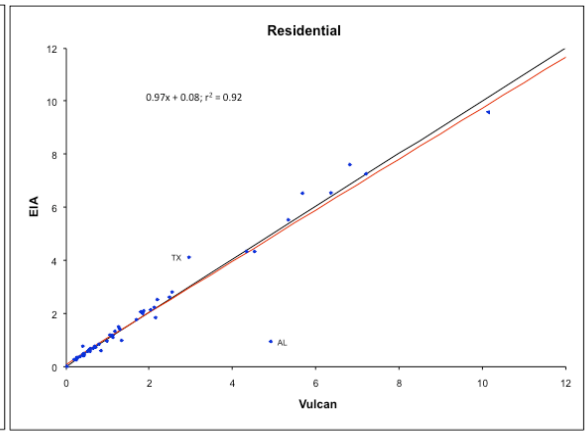


Figure 7. Same as figure 4 for the residential sector

The utility sector is not shown here as the estimates are nearly identical owing to the fact that they are derived from the same data (there are a few slight differences but they are not noticeable graphically). The total CO_2 emissions without including the mobile sector is shown in figure 8. Overall agreement is quite good with outliers for the states of Texas, Louisiana, Alabama and Oklahoma. It is noteworthy that these states are the group of states for whom petroleum refining remains a sizeable industry. Given the size of the industrial sector emissions overall, the discrepancies in the industrial sector are reflected in the total. Furthermore, the dominance of the utility sector in the total emissions (58%) accounts for some of the excellent agreement. The better agreement in the total emissions versus the sectoral emissions may also be due to definitions of the sector boundaries (commercial versus industrial versus residential). A linear fit to the total CO_2 fossil fuel comparison results in a slope that is slightly less than unity (EIA = 0.99*Vulcan + 0.11; r^2=0.98).

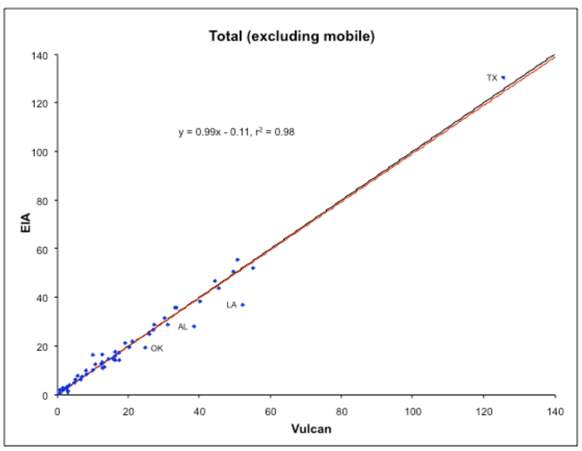


Figure 8. Same as figure 4 for total CO_2 emission without the mobile sector included

4.2 Atmospheric transport simulations

Atmospheric transport of the Vulcan gridded CO_2 emissions has been performed by collaborators at Colorado State University. This simulation utilized the Simple Biosphere Model Version 3 (SiB3) coupled to the Brazilian version of the Colorado State Regional Atmospheric Modeling System (RAMS). In these simulations, adjustments are made to the gross biospheric fluxes to best match observed CO_2. Hence, the fossil fuel CO_2 emissions are used as a fixed background flux.

To investigate the impact of Vulcan's spatial and temporal fossil fuel emission patterns on atmospheric CO_2 concentrations, the model was run with both the Vulcan 10 km x 10 km CO_2 inventory and the *Andres et al.* (1996) 1x1 degree CO_2 inventory. In order to match the model transport winds (2004), the total United Stated annual emissions were scaled in both inventories to match the total 2004 estimated emissions from the Energy Information Administration (*EIA* 2007c).

4.2.1 Tower observations

Modeled concentrations were compared to CO_2 observations at a series of observational towers listed in Table 1. To evaluate any seasonal impacts of the fossil fuel emissions, the year-long simulations were separated into three time periods: January through April (JFMA), May through August (MJJA), and September through December (SOND). For each of these three time periods the root mean square errors (RMSE) between the model and the measurements was calculated.

Table 1. List of CO_2 observational towers used in comparison

Ref.	Site	Lat (N)	Lon (W)	Ref.	Site	Lat (N)	Lon (W)
A	WKT	31.32	97.33	G	WBG	44.82	89.06
B	SGP	36.62	97.5	H	SYL	46.25	89.35
C	LEF	45.92	90.2	I	HRV	42.54	72.17
D	BRU	46.47	91.57	J	AMT	45.03	68.68
E	RED	46.83	90.84	K	HOW	45.2	68.74
F	FEN	45.74	88.43				

Simulation with the Vulcan inventory has very little impact at all the towers and over all three time periods. Changes between the Vulcan versus *Andres et al.* (1996) inventory are usually less than 1 ppm, and the mean change across all the towers was < 0.2 ppm for all three time-periods. The errors are reduced at the towers in the northeastern U. S. during the beginning of the year; however, the errors are increased for the remainder of the year due to the concentrations being shifted slightly higher in the Vulcan inventory simulation. Although the concentrations did improve at WKT throughout the year and in the northeast during the winter and early spring, in general using the Vulcan database minimally increased the RMSE.

The small magnitude of changes at the towers can likely be primarily attributed to their locations, as all of these towers are located in relatively remote regions heavily impacted by biology but not by fossil fuel emissions. The Vulcan inventory will likely have a significant impact in regions more directly influenced by anthropogenic emissions, and will be evaluated more thoroughly at towers located closer to metropolitan areas.

4.2.2 Annual mean surface concentration

The annual mean CO_2 contribution difference between the Vulcan and *Andres et al.* (1996) inventories at 30 m height above the surface is displayed in Figure 10. The differences are threefold: 1) petroleum extraction/refining regions of Texas, Louisiana and Oklahoma show greater 30 CO_2 concentration in the Vulcan inventory, 2) large power production facilities in low population regions show elevated CO_2 in the Vulcan inventory, and 3) some large population centers show lower CO_2 concentrations in the Vulcan inventory. The largest CO_2 concentration differences are as much as +/- 6 ppm in the annual mean.

The most significant changes occur in California, where the region surrounding San Francisco has higher concentrations while the regions downwind of Los Angeles have considerably lower concentrations, with differences over 6 ppm.

This example and the other regional differences noted above are primarily driven by the differences underlying the two approaches to quantifying CO_2 emissions. Many of the large emitting sources in the Vulcan inventory are not coincident with high population density and hence, cause a redistribution of emissions compared to the *Andres et al.* (1996) inventory. This is most noticeable for many large industrial sources and power production facilities.

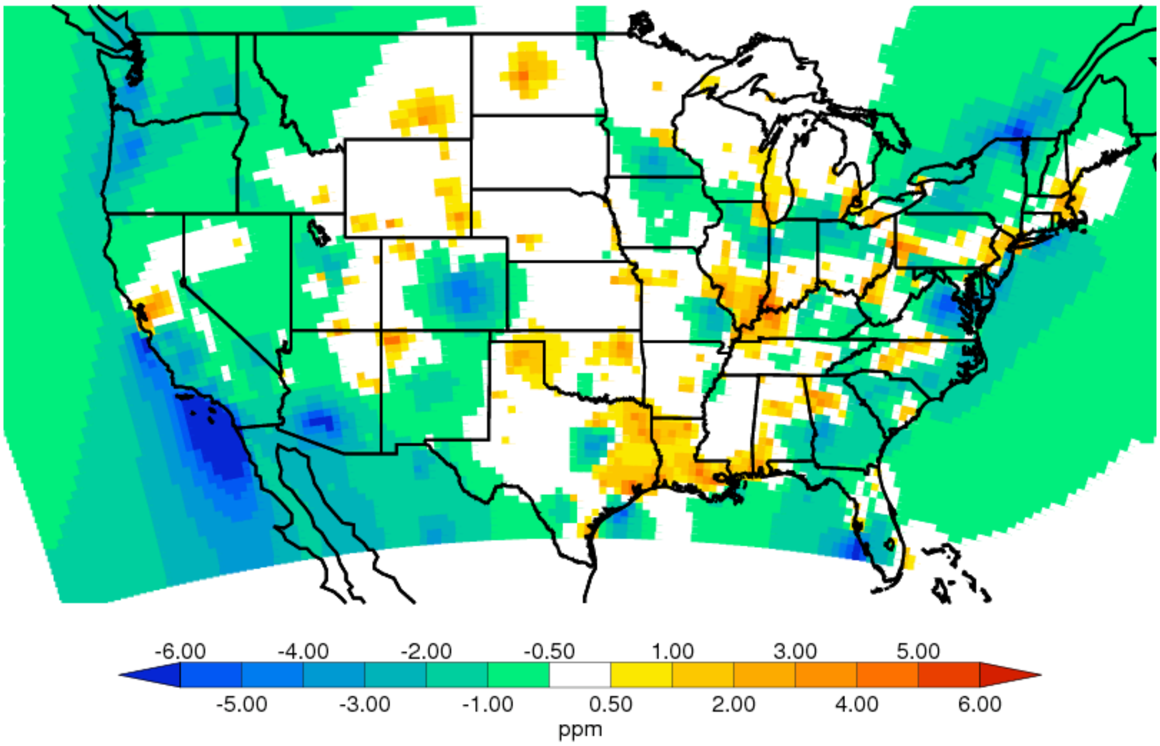


Figure 10. Annual mean 30 m difference between simulated Vulcan and Andres et al., (1996) fossil fuel CO_2 emissions inventories (Vulcan – Andres).

4.2.3 Temporal redistribution

Monthly total fossil fuel emissions over the U. S. in the Vulcan inventory are displayed in Figure 11. The total emissions have a seasonal cycle, with maximum emissions in July and August and lower emissions during the spring and fall. A small secondary maximum occurs in January. This seasonal cycle differs from the mean seasonal cycles for 1981-1985 and for 1998-2002 reported in *Blasing et al.* (2005). In *Blasing et al.* (2005), maximum emissions occurred in January and the secondary maximum in the summer was smaller than the January emissions; however, the magnitude of the summer maximum substantially increased between the 1980s and the 1990s. It should also be noted that the seasonality in the residential and commercial sectors have not yet been included in the Vulcan inventory (*Gurney et al.,* 2008). These emissions makeup ~11% of the total emissions, and thus

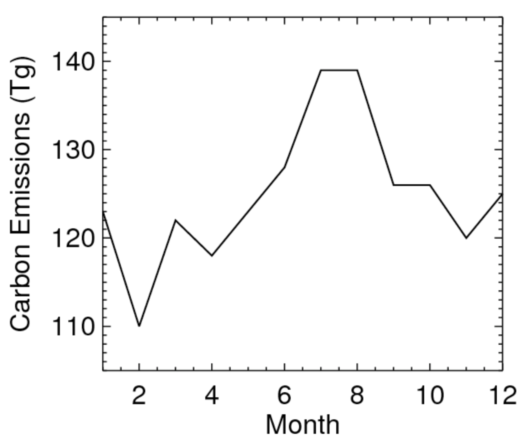


Figure 11. Monthly total fossil fuel emissions over the United States from the Vulcan inventory.

including their seasonality may alter the seasonal cycle. Furthermore, the seasonality in *Blasing et al.* (2005) relies on sales of fuel which may not be temporally coincident with combustion.

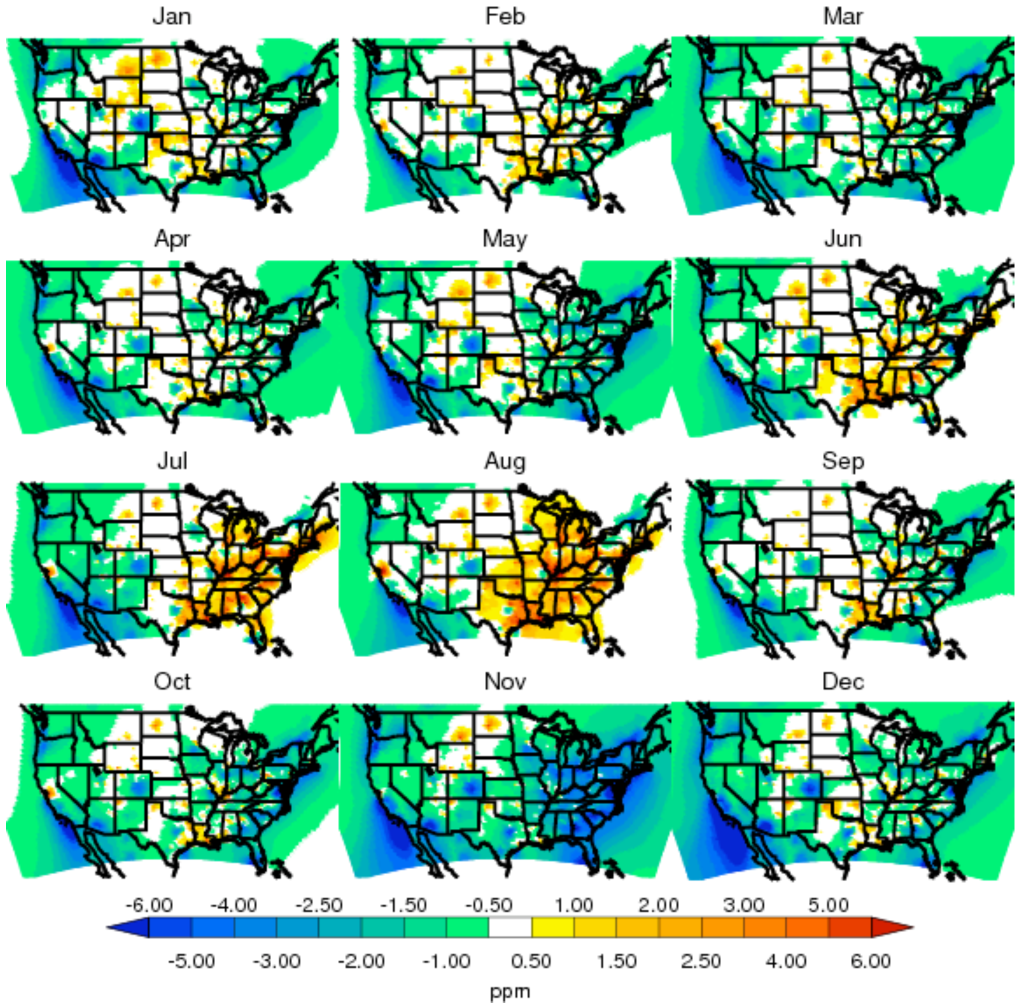


Figure 12. Monthly differences in the 30 m CO_2 concentrations between the Vulcan and Andres et al., (1996) inventory simulations (Vulcan - Andres).

Including seasonality in fossil fuel emissions impacts regional CO_2 concentrations on monthly timescales. Monthly differences in CO_2 concentrations at 30m are shown in Figure 12. Differences due to including a seasonal cycle in the fossil fuel emissions can clearly be seen in the eastern half of the country. During the spring, concentrations over the east coast in the Vulcan inventory simulation are lower compared to the concentrations in the *Andres et al.* (1996) simulation, with changes of a few ppm. Moving to summer, concentrations over the eastern U. S. are higher in the Vulcan simulation, and the magnitude of the differences increases. The largest differences between the two cases occur in August, where near-surface CO_2 is more than 15 ppm lower in the Vulcan simulation at individual grid cells. On average, differences between 3-6 ppm are seen over the entire region. In the Fall when the emissions decrease, the concentrations in the Vulcan simulation also decrease, and broad-scale differences of 4-6 ppm on average occur in the southeast, with maximum differences in November. Between lower concentrations in the Fall and higher concentrations in the Summer, the amplitude of the seasonal differences is more than 20 ppm at some locations. The seasonality in the concentrations is less dramatic over the central and western U.S., where the contribution of fossil fuel emissions to the total CO_2 concentrations is smaller.

In certain locations, the sign of the differences remain the same throughout the year, but the magnitude of the differences changes from month to month. Over Texas, the region of lower CO_2 between Dallas and Austin persists year-round, but the magnitude of the difference varies from ~1 ppm in the fall to over 3 ppm in the spring. Similar features can be seen over Montana and North Dakota, with differences between Vulcan and *Andres et al.* (1996) inventories varying from less than 1 ppm in September to more than 4 ppm in January. Over California, the changes due to spatial redistribution dominate over the seasonality in emissions, as the plume of low CO_2 concentration from the southern coastline persists throughout the year; however, differences of more than 15 ppm occur in November and December. Lower concentrations are also seen over Oregon and Washington year-round in the Vulcan simulation, with a seasonal amplitude of ~2-3 ppm.

5.0 Vulcan version 1.0 public release

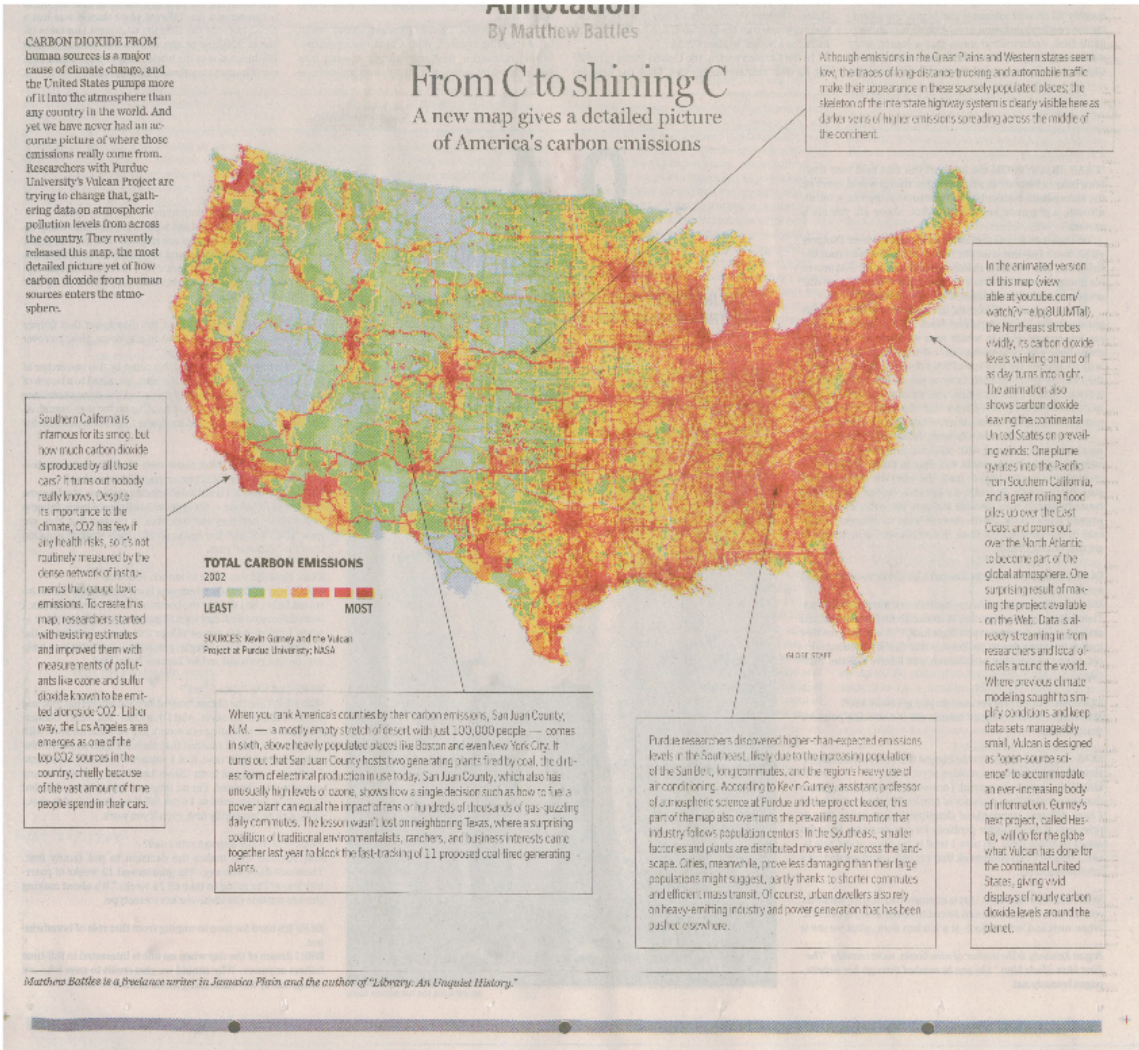
The Vulcan inventory (version 1.0) was released to the public in early April 2008. The release preceded the publication of a peer-reviewed paper due to the overwhelming demand from the carbon cycle science community for the emissions inventory. In addition to the establishment of the Vulcan website (www.purdue.edu/eas/carbon/vulcan), a video of various aspects of atmospheric transport was released on Purdue University's YouTube website. Following the issuance of a press release, the following media coverage as been tabulated:

1) Top-level stories have been carried in the:
   - NY Times (Dot Earth series: dotearth.blogs.nytimes.com)
   - the Boston Globe (full page Sunday edition)
   - Reuters
   - Scientific American (a video story)
   - Wired Magazine
   - National Public Radio
   - the Discovery Channel

2) The press release appeared in over 150 online news sources and countless regional print news outlets, local TV and radio shows. The story in Wired Magazine drove so much traffic and blogging, the editors requested additional analysis.

3) The YouTube video, representing the atmospheric evolution of the Vulcan emissions, has received over 180,000 (and still climbing) YouTube views making it one of the most successful video rollouts in Purdue history.

Here is a snapshot of the Boston Globe story:



Annotation

By Matthew Battles

From C to shining C

A new map gives a detailed picture of America's carbon emissions

CARBON DIOXIDE FROM human sources is a major cause of climate change, and the United States pumps more of it into the atmosphere than any country in the world. And yet we have never had an accurate picture of where those emissions really come from. Researchers with Purdue University's Vulcan Project are trying to change that, gathering data on atmospheric pollution levels from across the country. They recently released this map, the most detailed picture yet of how carbon dioxide from human sources enters the atmosphere.

Although emissions in the Great Plains and Western states seem low, the traces of long-distance trucking and automobile traffic make their appearance in these sparsely populated places; the skeleton of the interstate highway system is clearly visible here as darker veins of higher emissions spreading across the middle of the continent.

Southern California is infamous for its smog, but how much carbon dioxide is produced by all those cars? It turns out nobody really knows. Despite its importance to the climate, CO2 has few if any health risks, so it's not routinely measured by the dense network of instruments that gauge toxic emissions. To create this map, researchers started with existing estimates and improved them with measurements of pollutants like ozone and sulfur dioxide known to be emitted alongside CO2. Either way, the Los Angeles area emerges as one of the top CO2 sources in the country, chiefly because of the vast amount of time people spend in their cars.

In the animated version of this map (viewable at youtube.com/watch?v=elp8UUMTal), the Northeast strobes vividly, its carbon dioxide levels winking on and off as day turns into night. The animation also shows carbon dioxide leaving the continental United States on prevailing winds: One plume gyrates into the Pacific from Southern California, and a great rolling flood piles up over the East Coast and pours out over the North Atlantic to become part of the global atmosphere. One surprising result of making the project available on the Web: Data is already streaming in from researchers and local officials around the world. Where previous climate modeling sought to simplify conditions and keep data sets manageably small, Vulcan is designed as "open-source science" to accommodate an ever-increasing body of information. Gurney's next project, called Hestia, will do for the globe what Vulcan has done for the continental United States, giving vivid displays of hourly carbon dioxide levels around the planet.

TOTAL CARBON EMISSIONS
2002
LEAST MOST

SOURCES: Kevin Gurney and the Vulcan Project at Purdue University; NASA

GLOBE STAFF

When you rank America's counties by their carbon emissions, San Juan County, N.M. — a mostly empty stretch of desert with just 100,000 people — comes in sixth, above heavily populated places like Boston and even New York City. It turns out that San Juan County hosts two generating plants fired by coal, the dirtiest form of electrical production in use today. San Juan County, which also has unusually high levels of ozone, shows how a single decision such as how to fuel a power plant can equal the impact of tens or hundreds of thousands of gas-guzzling daily commutes. The lesson wasn't lost on neighboring Texas, where a surprising coalition of traditional environmentalists, ranchers, and business interests came together last year to block the fast-tracking of 11 proposed coal fired generating plants.

Purdue researchers discovered higher-than-expected emissions levels in the Southeast, likely due to the increasing population of the Sun Belt, long commutes, and the region's heavy use of air conditioning. According to Kevin Gurney, assistant professor of atmospheric science at Purdue and the project leader, this part of the map also overturns the prevailing assumption that industry follows population centers. In the Southeast, smaller factories and plants are distributed more evenly across the landscape. Cities, meanwhile, prove less damaging than their large populations might suggest, partly thanks to shorter commutes and efficient mass transit. Of course, urban dwellers also rely on heavy-emitting industry and power generation that has been pushed elsewhere.

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The public interest was so intense in the first 48 hours of release that the Vulcan website host server was brought down by the overwhelming traffic to the site. The release has generated a flood of email from nearly every corner of the globe (in the first week we were #3 in US, #6 in Ireland, #17 in New Zealand, #5 in Canada and many other countries in "Science and Technology" on YouTube). Google has contacted Kevin Gurney regarding embedding the Vulcan results into Google Earth and this process has now begun with the aid of a Google engineer.

Senator Richard Lugar opened recent Senate Foreign Relations Committee testimony with praise of the Vulcan Project and has written a "dear colleagues" letter in the Senate highlighting the importance of Vulcan to the legislative work on climate change policy.

The Vulcan website currently has the complete gridded/hourly product available in both ascii and binary formats along with a number of reduced datasets such as county-level emissions, annual emissions, and sectoral totals.

A Vulcan listserve has been created and updates of data availability will be ongoing through the listserve announcement system.

The Vulcan release has also opened up a number of additional funding opportunities including venture capital inquiries, Foundation inquiries and further agency funding opportunities. These opportunities are being pursued and will focus on further development of Vulcan from the scientific as well as the policy perspective in addition to spreading the Vulcan approach across the globe.

A new initiative has begun, the Hestia Project, which will attempt to build off of the Vulcan inventory but significantly downscale the emissions to the building level with a complete process-level simulation system driving the CO_2 emissions. This multi-year, multi-agency effort has begun with seed funding but large agency collaborations are anticipated and discussions have begun.

6.0 Summary key accomplishments

1) A near-complete fossil fuel CO_2 emissions inventory at 10 km/hourly for the United States.

2) Full retention of native resolution (geolocated points, roads, etc) and process-level/fuel attributes. This makes the Vulcan inventory not only useful to atmospheric modelers and carbon cycle scientists but holds tremendous value to

3) The Vulcan Project has supported the successful completion of Kathy Corbin's Ph.D. at Colorado State University, a collaborator on the Vulcan effort.

4) The Vulcan inventory, version 1.0, has been released to the public. The release garnered significant media attention for both the inventory and the YouTube video of the atmospheric transport. The inventory is already being incorporated into simulations at a number of research institutions including NOAA ERSL and University of Michigan.

5) Evaluation and comparison of the Vulcan inventory has been accomplished and the Vulcan inventory appears reasonably robust to independent aggregated inventory products.

6) Vulcan has received praise from Senator Richard Lugar (Appendix A) and is the focus of a Dear Colleague letter to the complete U.S. Senate.

7.0 Future Plans

1) Both Canada and Mexico will be included in the Vulcan inventory in the coming year. This process will be simpler than the initial Vulcan development as significant resources were devoted to developing the software infrastructure to ingest and manipulate the large volume of data underneath the Vulcan emissions.

2) The two remaining emission categories not included in Vulcan version 1.0 will be incorporated into the inventory. These are nonroad (snowmobiles, trains, watercraft) and aircraft emissions. This work is underway and will be complete by end of calendar year 2008.

3) Evaluation of the inventory via the emission and atmospheric concentration of carbon monoxide will be accomplished. This will be compared against other inventories and against both MOPPITT and in situ CO observations.

4) Vulcan will be improved and used within both the NACP mid-Continent intensive and the NACP Synthesis studies.

5) A series of applications and extensions of the Vulcan inventory are underway including per capita analysis, allocation of emission to electricity demand, socioeconomic analysis, and improved visualization via Google Earth and Google maps. An example of this is shown in figure 13 where the Vulcan inventory as been produced as a per capita emissions product for the state of Indiana. This, and many additional forms of analysis hold great value to a number of scientific and policy communities.

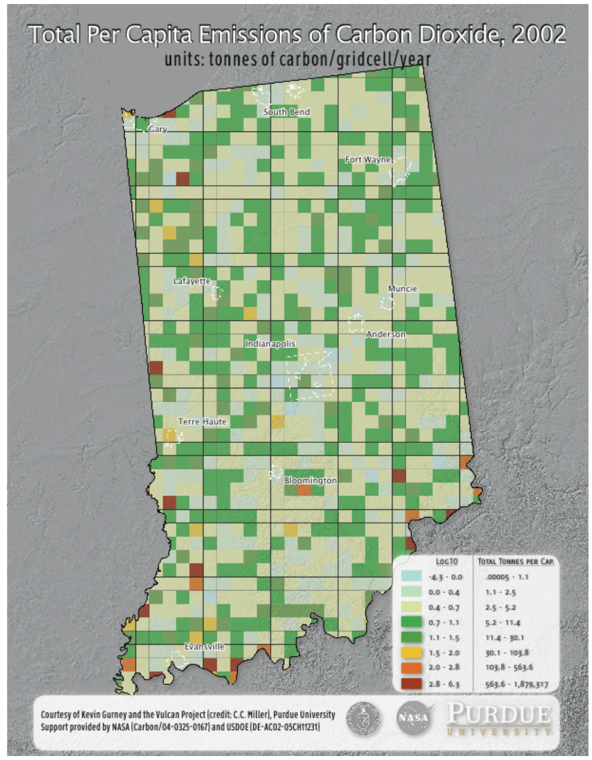

Figure 03. Total per capita fossil fuel CO_2 emissions on a 10 km grid for the state of Indiana.

6) A significant new effort, *the Hestia Project*, (www.purdue.edu/climate/hestia) has been initiated and is in the fundraising and outreach stage. This effort will significantly downscale the Vulcan emissions to the building level and expand to encompass the planet. Furthermore, a complete process-driver model will be incorporated into the inventory allowing for scenario building, process analysis and "what-if" Q&A.

Figure 14 shows a progression of scale that embodies the vision of what Hestia would ultimately look like. This effort would require multi-year, multi-agency support and collaboration and discussion has begun with the Department of Energy, Universities, Foundations, NGOs, and industry.

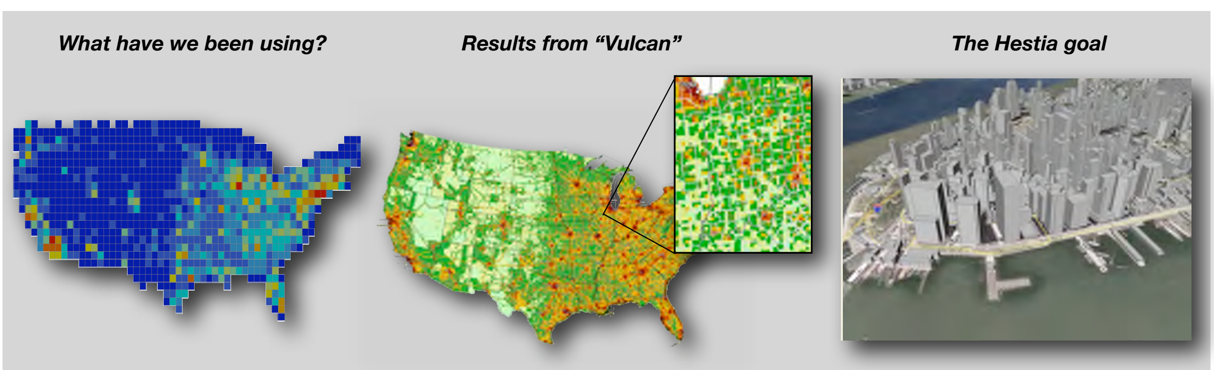

Figure 14. The progression from CO_2 emissions inventories used prior the Vulcan Project (leftmost image), the Vulcan inventory (center image), and the Hestia vision (rightmost image).

7) Publication of results. Peer-reviewed treatment of the basic methodological details of the Vulcan effort are underway. We are also planning a publication on evaluation/comparison, and implications for atmospheric CO_2.

7.1 Work plan in relation to original proposed research

The current work plan for the year extension awarded by NASA will be consistent the original year 3 proposed research as outlined in the original proposal to NASA.

7.2 Budget in relation to original proposed research

As stated in the no-cost extension, the remaining balance on this grant will be costed out in this last year and will be used for graduate student support and scientific programmer salaries. Spending is in accord with the budget approved by NASA.

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9.0 Appendix A

Dick Lugar

U.S. Senator for Indiana

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Opening Statement for Hearing on Climate Change, Deforestation

U.S. Senate Foreign Relations Committee Republican leader Dick Lugar made the following statement at today's hearing on climate change and deforestation:

I thank the Chairman for holding this important hearing. A year ago today, I was on my farm in Marion County, Indiana, for a ceremony recognizing the role of agriculture and forestry in mitigating the social, economic, and political threats posed by climate change. I was joined by Richard Sandor, Chairman and CEO of the Chicago Climate Exchange, and Tom Buis, President of the National Farmers Union, to promote how certain no tillage agricultural practices and forestry can sequester carbon dioxide and help offset the environmental threats from excessive carbon emissions.

For a number of years now, we have dedicated about a third of the 604-acre Lugar family farm to growing black walnut and other hardwood trees. As these majestic trees grow, they absorb and store carbon from the air around Indianapolis. To highlight the opportunities of participating in the markets for carbon sequestration, the Lugar Stock Farm has entered into a binding contract with the Chicago Climate Exchange to provide offset credits to entities that may want to use them to mitigate the greenhouse gasses they produce. These markets can be an important tool in our broader climate change policy.

I believe carbon sequestration and many other innovative ideas can change the dynamic of the political debate on climate change, both in the United States and internationally. The debate should be about more than constraints. It should be about how we can use economic incentives and opportunities to change behavior and to influence the personal and societal choices that we make.

Clearly, there are economic opportunities in clean energy sources, solar, wind and biofuels, and carbon sequestration and storage technologies. But improvements in farming and forestry practices may be among the lowest hanging fruit in the quest to deal with climate change.

During the global climate change discussions in the late 1990s in Kyoto, the concept of carbon sinks provided by forestry and agriculture was taken off the table. Last year during the Bali discussions, the topic of carbon sequestration through forestry and agricultural practices was revived. This is an important development, and it should be embraced by the United States.

I have mentioned the celebration at my Indiana farm last year with the Chicago Climate Exchange. More than twenty years ago, we had a similar celebration at my farm when Secretary of Agriculture John Block announced the Conservation Reserve Program.

This program has encouraged thousands of American farmers to grow trees on marginal lands, especially along watersheds. Many American farmers participate in this program, but many more should do so because almost every American farm has a "back 40" of unused land. Native trees should be planted on this land. This practice provides income for farmers and climate change mitigation for the world.

I also want to note that ten years ago, Senator Joe Biden and I passed the Tropical Forest Conservation Act. Since then, more than 47 million acres of tropical forests around the world have been conserved through "debt for nature swaps" in 12 countries. Recently, the Foreign Relations Committee passed a reauthorization of this bill, which I am hopeful will be approved soon by the full Senate. This program has given the United States a cost-effective tool with which to promote the preservation of tropical forests, but much more needs to be done on a global scale.

All these activities could serve as part of the foundation for any cap and trade system that arises out of legislation in this country or international agreements under the United Nations Framework Convention on Climate Change. A critical element of any cap and trade system is the accountability and transparency of the carbon that is being mitigated, sequestered and stored.

The Chicago Climate Exchange requires me to conduct an annual accounting of my trees. That's not difficult for only two hundred acres of hardwood trees. But how do we analyze tens of thousands of acres of trees in remote areas of the world?

This is one of the questions at the heart of Project Vulcan at Purdue University. I am particularly pleased that Professor Kevin Gurney, who leads Project Vulcan, is here to testify today. Last week I sent a Dear Colleague letter to Senators depicting one of a series of maps produced by Purdue -- along with NASA and the Department of Energy -- showing carbon emissions in the United States. This type of mapping technology will be critical to a vibrant carbon trading market in the future, and to efforts to quantify the benefits of preserving forest lands.

I welcome all of our witnesses and look forward to their testimony.

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