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[NASA Projects](#) >
[North American Carbon Program \(NACP\)](#) >
User guide

# Vulcan: High-Resolution Hourly Fossil Fuel CO2 Emissions in USA, 2010-2015, Version 3

## Get Data

Documentation Revision Date: 2020-10-01

Dataset Version: 1

## Summary

The Vulcan version 3.0 hourly dataset quantifies hourly emissions at a 1-km resolution for the 2010-2015 time period. Estimates are provided of hourly carbon dioxide (CO2) emissions from the combustion of fossil fuels (FF) and CO2 emissions from cement production for the conterminous United States and the state of Alaska. Referred to as FFCO2, the emissions from Vulcan are categorized into 10 source sectors including; residential, commercial, industrial, electricity production, onroad, nonroad, commercial marine vessel, airport, rail, and cement. Files for hourly total emissions are also available. Data are represented in space on a 1 km x 1 km grid as hourly totals for 2010-2015. This dataset provides the first bottom-up U.S.-wide FFCO2 emissions data product at 1 km2/hourly for multiple years and is designed to be used as emission estimates in atmospheric transport modeling, policy, mapping, and other data analyses and applications.

Vulcan v3.0 is the first bottom-up inventory to report FFCO2 and cement production CO2 fluxes at a 1 km x 1 km gridded resolution for all major carbon-emitting sectors across the entire United States landscape at an annual and hourly timestep. Vulcan v3.0 is constructed from numerous public datasets that generate the magnitude, spatial representation, and temporal representation of FFCO2 emissions.

There are 48,202 data files associated with this dataset. There are 10 individual sectors and a total, each of which is comprised of one file for each day (24 hours, based on UTC) of all six years (2010-2015) of hourly FFCO2 emissions output. For each of these 11 sectors there is output representing the mean estimate, while output representing the upper 95% confidence interval boundary, and output representing the lower 95% confidence interval boundary, are available only at the annual timescale (see related dataset: <https://doi.org/10.3334/ORNLDAAC/1741>). There is a fileset for the contiguous United States and a separate fileset for Alaska. All files are in netCDF version 4 (.nc4) format.

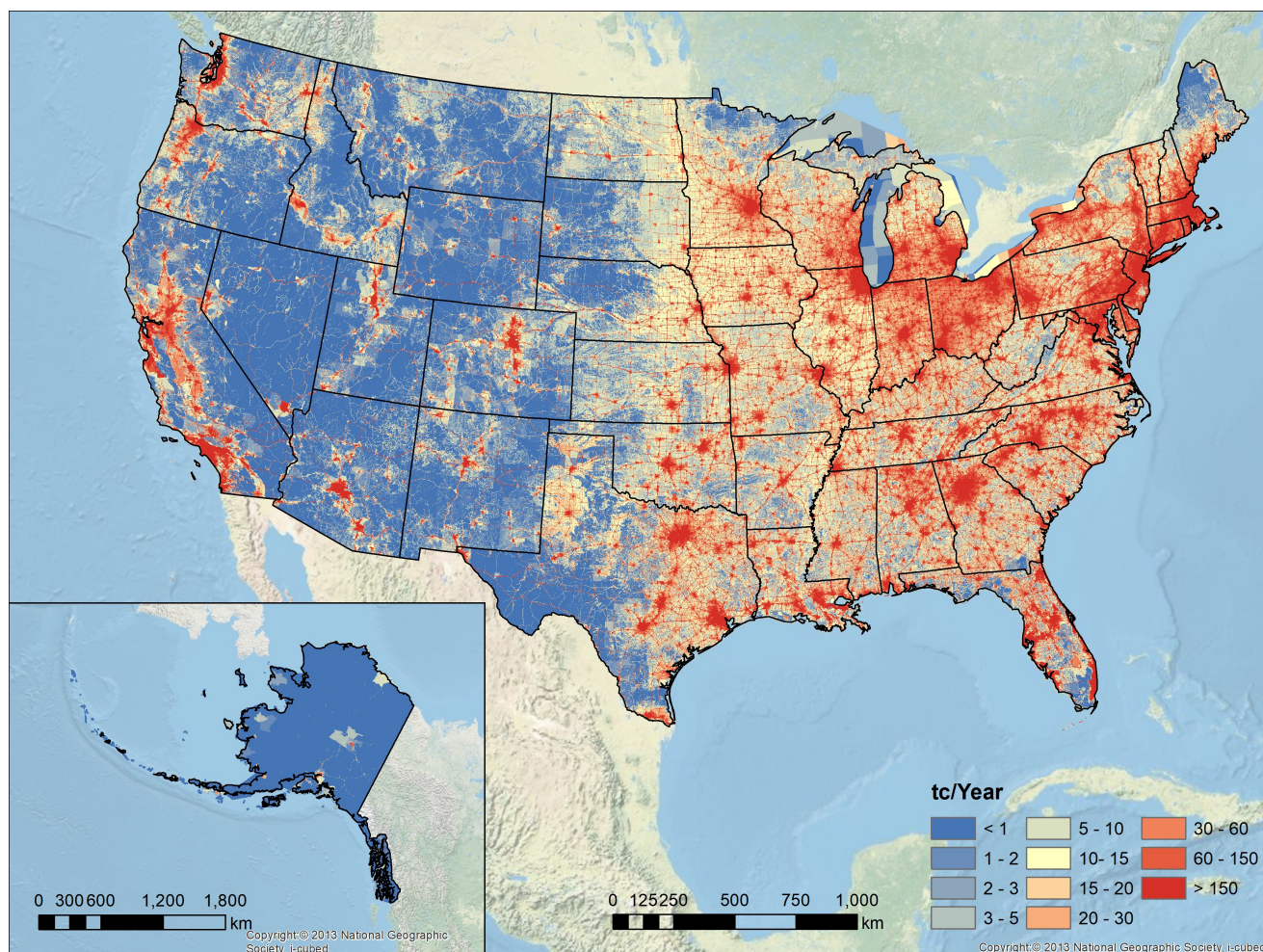


Figure 1. Vulcan v3.0 FFCO<sub>2</sub> annual total emissions (tc/km<sup>2</sup>/year) for the United States in 2011 at 1-km resolution. Source: Figure 3(a) in Gurney et al., 2020.

## Citation

Gurney, K.R., J. Liang, R. Patarasuk, Y. Song, J. Huang, and G. Roest. 2020. Vulcan: High-Resolution Hourly Fossil Fuel CO<sub>2</sub> Emissions in USA, 2010-2015, Version 3. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAAC/1810>

## Table of Contents

1. Dataset Overview
2. Data Characteristics
3. Application and Derivation
4. Quality Assessment
5. Data Acquisition, Materials, and Methods
6. Data Access
7. References

## 1. Dataset Overview

The Vulcan version 3.0 hourly dataset quantifies hourly emissions at a 1-km resolution for the 2010-2015 time period. Estimates are provided of hourly carbon dioxide (CO<sub>2</sub>) emissions from the combustion of fossil fuels (FF) and CO<sub>2</sub> emissions from cement production for the conterminous United States and the state of Alaska. Referred to as FFCO<sub>2</sub>, the emissions from Vulcan are categorized into 10 source sectors including; residential, commercial, industrial, electricity production, onroad, nonroad, commercial marine vessel, airport, rail, and cement. Files for hourly total emissions are also available. Data are represented in space on a 1 km x 1 km grid as hourly totals for 2010-2015. This dataset provides the first bottom-up U.S.-wide FFCO<sub>2</sub> emissions data product at 1 km<sup>2</sup>/hourly for multiple years and is designed to be used as emission estimates in atmospheric transport modeling, policy, mapping, and other data analyses and applications.

Vulcan v3.0 is the first bottom-up inventory to report FFCO<sub>2</sub> and cement production CO<sub>2</sub> fluxes at a 1 km x 1 km gridded resolution for all major carbon-emitting sectors across the entire United States landscape at an annual and hourly timestep. Vulcan v3.0 is constructed from numerous public datasets that generate the magnitude, spatial representation, and temporal representation of FFCO<sub>2</sub> emissions.

**Project:** North American Carbon Program

The North American Carbon Program (NACP) is a multidisciplinary research program designed to improve understanding of North America's carbon sources, sinks, and stocks. The central objective is to measure and understand the sources and sinks of Carbon Dioxide (CO<sub>2</sub>), Methane (CH<sub>4</sub>), and Carbon Monoxide (CO) in North America and adjacent oceans. The NACP is supported by a number of different federal agencies.

**Related Publication:**

Gurney, K. R., Liang, J., Patarasuk, R., Song, Y., Huang, J., & Roest, G. (2020). The Vulcan Version 3.0 High Resolution Fossil Fuel CO<sub>2</sub> Emissions for the United States. *Journal of Geophysical Research: Atmospheres*, 125, e2020JD032974. <https://doi.org/10.1029/2020JD032974>

### Related Dataset:

Gurney, K.R., J. Liang, R. Patarasuk, Y. Song, J. Huang, and G. Roest. 2019. Vulcan: High-Resolution Annual Fossil Fuel CO<sub>2</sub> Emissions in USA, 2010-2015, Version 3. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAC/1741>

### Acknowledgements:

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## 2. Data Characteristics

**Spatial Coverage:** Two geographic regions: contiguous United States and the State of Alaska

**Spatial Resolution:** 1-km grid

**Temporal Coverage:** 2010-2015

**Temporal Resolution:** Hourly (UTC)

**Study Areas** (All latitude and longitude given in decimal degrees)

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Contiguous USA	-128.22655	-65.30824167	47.89015278	22.85824167
Alaska	-165.2138056	-127.1191611	73.75332778	39.75995278

### Data File Information

There are 48,202 netCDF version 4 (\*.nc4) data files provided with this dataset. This includes files for each of the two geographic areas -- the Conterminous United States and Alaska.

These netCDF files contain parameter and spatial metadata within the file header following Climate and Forecast metadata convention version 1.6 (CF-1.6, <https://cfconventions.org/>).

There are 10 individual sectors (i.e., residential, commercial, industrial, electricity production, onroad, nonroad, commercial marine vessel, airport, rail and cement sectors) and a sector total, each of which is comprised of one file for each day (00-23 UTC) of all six years (2010-2015) of hourly FFCO<sub>2</sub> emissions output. For each of these 11 sectors there is output representing the mean estimate. The annual emission dataset (<https://doi.org/10.3334/ORNLDAAC/1741>) also has output representing the upper 95% confidence interval boundary, and output representing the lower 95% confidence interval boundary. There is a filesset for the contiguous United States and a separate filesset for Alaska. All of these files are in netCDF Version 4 (.nc4) format. Units are metric tonnes of carbon per grid cell (1 km<sup>2</sup>) per hour (tC/km<sup>2</sup>/hour).

### Filename descriptions

All netCDF Vulcan v3.0 filenames follow a naming convention: Vulcan.v3.<domain>.hourly.1km.<sector>.mn.<year>.<day>.nc4

**Table 2.** Vulcan v3.0 filename conventions

<domain>	
"AK"	Alaska
"US"	Contiguous United States
<sector>	
"elec_prod"	electricity production sector
"commercial"	Commercial sector
"residential"	Residential sector
"onroad"	Onroad sector
"industrial"	Industrial sector
"nonroad"	Nonroad sector (e.g. snowmobiles, ATVs)
"railroad"	Railroad sector
"cement"	Cement production sector
"airport"	Airport sector (taxi/takeoff to 3000')
"cmv"	Commercial Marine Vessel sector
"total"	Total emissions
<day>	
d001	File for the first day of the year
...	Days 2 through 364
d365	File for the last day of the year (non-leap years)
d366	File for the last day of the year (leap years)

**Table 3.** Variables in NetCDF files.

Name	Features
Carbon emissions	3-dimensional (x, y, and time) variable. Units are metric tons (Gg) of carbon emissions per unit time per grid cell (1 km <sup>2</sup> )

**Table 4:** Dimensions in NetCDF files.

Name	Features
x	east/west dimension. size: 4846 for US and 3334 for AK. units: meters
y	north/south dimension. size: 2900 for US and 2561 for AK. units: meters
time	time. size: 24. units: hours. The time coordinate represents the midpoint of the hour, measured as hours since 2010-01-01 00:00:00 UTC

#### Coordinate reference system

Datum: WGS84  
Projection: Lambert Conformal Conic (LCC)  
Units: meter  
False easting: 0.0 m  
False northing: 0.0 m  
Longitude of origin: -97.0°  
Latitude of origin: 40.0°  
Standard parallel 1: 33.0°  
Standard parallel 2: 45.0°

Proj.4 string: +proj=lcc +lat\_1=33 +lat\_2=45 +lat\_0=40 +lon\_0=-97 +x\_0=0 +y\_0=0 +ellps=WGS84 +units=m +no\_defs

## 3. Application and Derivation

The Vulcan v3.0 FFCO<sub>2</sub> emissions data product can be applied to both scientific and policy related objectives. It can supply a high-resolution boundary condition (“prior”) to atmospheric CO<sub>2</sub> inverse efforts to better isolate biospheric net exchange or as a direct constraint to assessing anthropogenic fluxes. Better understanding of both the FFCO<sub>2</sub> emissions and the net biosphere carbon exchange improves projections of climate change through more reliable estimation of climate-carbon feedback. It can also be used in direct policy-making by offering more granular detail on FFCO<sub>2</sub> emission processes and magnitudes. This can provide sub-national stakeholders with more optimal policy choices, isolating where and when the largest-emit entities are to more specifically target them for mitigation.

## 4. Quality Assessment

The uncertainty of the Vulcan results are estimated by attempting to capture key input parameter variation. This is accomplished by completing a simulation with key input parameters (e.g. CO emission factor, CO<sub>2</sub> emission factor, CO emissions) set at their upper and lower range (an approximate 95% confidence interval). These two additional simulations estimated total annual domain FFCO<sub>2</sub> emissions as -14.0%/+16.6% of the central estimate for the example year of 2011.

Two separate techniques are used to test the general quality of the Vulcan v3.0 FFCO<sub>2</sub> emissions estimate. The first is a comparison to other similar space/time-resolved FFCO<sub>2</sub> emission data products. Comparison to the ACES granular FFCO<sub>2</sub> estimate which only covers 13 Northeastern states was performed. In this comparison, total relative difference of 1.7% (ACES>Vulcan) was found, but much larger differences at the grid cell scale with a grid cell absolute median relative difference of 53.4%. Vulcan v3.0 results was also compared to the ODIAC global gridded FFCO<sub>2</sub> emissions data product which found a total relative difference of 6.9% (100.3 MtC/yr; Vulcan>ODIAC) in 2011. At the grid cell-scale a grid cell absolute median relative difference of 104.4% was observed. See Gurney et al. (2020) for more details.

A second approach that compared the results presented here to atmospheric CO<sub>2</sub> inverse estimates was performed. At the whole contiguous US spatial scale and annual temporal scale, the 2010 Vulcan results were within 1.4% of an atmospheric 14CO<sub>2</sub> inversion effort (Basu et al., 2020).

## 5. Data Acquisition, Materials, and Methods

Vulcan v3.0 is a bottom-up high-resolution model for FFCO<sub>2</sub> and cement production CO<sub>2</sub>. Vulcan generates these FFCO<sub>2</sub> emissions for the years 2010 to 2015, annually and hourly on a 1 km x 1 km grid with sector-specific output.

Following are brief descriptions of the data sources and processing methods employed to create the Vulcan v3.0 emission products. A bibliography for the data sources is provided at the end of this section. For details and descriptions of uncertainty calculations please refer to Gurney et al. (2020).

#### **Data Sources**

Emissions of FFCO<sub>2</sub> from the residential, commercial, industrial, nonroad, commercial marine vessels, airport, and rail sectors were derived from the CO emissions reporting within the U.S. Environmental Protection Agency’s (EPA) National Emissions Inventory (NEI) for 2011 (EPA, 2015a). Emissions from electricity production were derived from three datasets: the Environmental Protection Agency’s Clean Air Markets Division (CAMD) data (USEPA, 2015b); the Department of Energy’s Energy Information Administration (EIA) reporting data (DOE/EIA, 2003); reporting within the NEI point source reporting.

For onroad FFCO<sub>2</sub> emissions, county scale results are retrieved from the 2011 EPA NEIv1 onroad output (USEPA, 2011), based on simulations using the Motor Vehicle Emissions Simulator (MOVES) model with inputs supplied to a county database (CDB) by SLT agencies (USEPA, 2012; USEPA, 2015a). The state of California did not report FFCO<sub>2</sub> to the 2011 NEI. Hence, the Vulcan onroad FFCO<sub>2</sub> emissions for California used the 2011 results from the Emissions FACTors 2014 model (EMFAC2014), produced by the California Air Resources Board (CARB, 2014).

CO<sub>2</sub> emissions from cement production utilizes two datasets: the data provided by the Portland Cement Association which provides the annual clinker capacity at individual facilities (PCA, 2006); and the Minerals Yearbook produced by the United States Geological Survey (USGS 2013). Distribution of the sources to space and time utilize numerous federal datasets outlined in Table 5. Further details of this

processing are provided in the following methods subsections.

Distribution of the sources to space and time utilize numerous federal datasets outlined in Table 1. Further details are provided in the following methods sub-sections.

Table 5. Data sources used to derive the Vulcan v3.0 FFCO<sub>2</sub> emissions data product. A bibliography for the sources is provided at the end of this section.

Sector/type	Emissions Data Source	Original spatial resolution/information	Spatial distribution	Temporal distribution
Onroad	EMFAC <sup>a</sup> CO <sub>2</sub> , EPA NEI <sup>b</sup> onroad CO <sub>2</sub>	County, road class, vehicle class	FHWA AADT <sup>c</sup>	CCS <sup>e</sup>
Electricity production	CAMD <sup>f</sup> CO <sub>2</sub> , DOE/EIA <sup>g</sup> fuel, EPA NEI point CO	Lat/lon, fuel type, technology	EPA/EIA NEI Lat/Lon, Google Earth	CAMD, EIA and EPA
Residential nonpoint buildings	EPA NEI nonpoint CO	County, fuel type	FEMA HAZUS <sup>d</sup> , DOE RECS NE-EUI <sup>h</sup>	eQUEST <sup>i</sup> model
Nonroad	NEI nonpoint CO	County, vehicle class	EPA spatial surrogates (vehicle class specific)	EPA temporal surrogates (by SCC <sup>j</sup> )
Airport	EPA NEI point CO	Lat/lon, aircraft class	Lat/Lon	LAWA & OPSNET <sup>k</sup>
Commercial nonpoint buildings	EPA NEI nonpoint CO	County, fuel	FEMA HAZUS, DOE CBECS NE-EUI <sup>l</sup>	eQUEST model
Commercial point sources	EPA NEI point CO	Lat/lon, fuel type, combustion technology	EPA NEI Lat/Lon, Google Earth	eQUEST model
Industrial point sources	EPA NEI point CO	Lat/Lon, fuel type, combustion technology	EPA NEI Lat/Lon, Google Earth	EPA temporal surrogates (by SCC)
Industrial nonpoint buildings	EPA NEI nonpoint CO	County, fuel type	FEMA HAZUS, DOE MECS NE-EUI <sup>m</sup>	eQUEST model
Commercial Marine Vessels	EPA NEI nonpoint CO	County, fuel type, port/underway	EPA port and shipping lane shapefiles	Flat time structure
Railroad	EPA NEI nonpoint CO, EPA NEI point CO	County, fuel type, segment	EPA NEI rail shapefile and density distribution	Pointwise records: EPA temporal surrogates (by SCC), nonpoint: flat time structure
Cement	Portland Cement Association, USGS	Lat/lon	PCA lat/lon checked in Google Earth	Flat time structure

#### Footnotes:

- a. Emissions Factors Model
- b. Environmental Protection Agency, National Emissions Inventory
- c. Federal Highway Administration, Annual Average Daily Traffic
- d. Federal Emergency Management Agency
- e. Continuous Count Stations
- f. Clean Air Markets Division
- g. Department of Energy/Energy Information Administration
- h. Department of Energy Residential Energy Consumption Survey, non-electric energy use intensity
- i. Quick Energy Simulation Tool
- j. Source Classification Code
- k. Los Angeles World Airport, The Operations Network
- l. Department of Energy Commercial Energy Consumption Survey, non-electric energy use intensity
- m. Department of Energy Manufacturing Energy Consumption Survey, non-electric energy use intensity

#### Methods

[Note that equations given in Gurney et al. (2020) have been omitted to simplify presentation of the following text.]

#### Nonpoint source (residential, commercial, industrial)

Fossil fuel CO<sub>2</sub> emissions are created from NEI-reported county-scale CO reporting through the application of CO and CO<sub>2</sub> emission factors. Where the CO<sub>2</sub> emissions for a process  $n$  (e.g. industrial 10 MMBTU boiler, industrial gasoline reciprocating turbine) and fuel  $f$  (e.g. natural gas, bituminous coal); are the equivalent amount of CO emissions for a process  $n$  and fuel  $f$ ; is the CO emission factor for a process  $n$  and fuel  $f$ ; and is the CO<sub>2</sub> EF for a process  $n$  and fuel  $f$ . The CO EF is retrieved from two categories of source information: 1) “self-reported” values (supplied by state or federal air quality specialists submitting the CO emissions reporting: [http://newftp.epa.gov/air/nei/2011/doc/2011v2\\_supportingdata/nonpoint/](http://newftp.epa.gov/air/nei/2011/doc/2011v2_supportingdata/nonpoint/)) or 2) “default” values generated from a combination of values retrieved from the EPA WebFIRE EF database (<https://cfpub.epa.gov/webfire/>) and values accumulated through literature review. The self-reported CO EF values are assessed for reliability and replaced by a default value if the self-reported value is less than 0.1 or greater than 5 times the identified default value.



The state total FFCO<sub>2</sub> emissions calculated as described above are compared to sector and fuel-specific fuel consumption totals reported by the Department of Energy/Energy Information Administration (DOE/EIA) State Energy Data System (DOE/EIA, 2018). Adjustment of the Vulcan state/sector/fuel totals are made to the nonpoint residential and commercial sectors only and for natural gas and petroleum fuel (aggregate) only.

Sub-county distribution of the county/sector/fuel-specific FFCO<sub>2</sub> emissions to US Census block-groups uses the total floor area (m<sup>2</sup>) of buildings (specific to a building class) within each US Census block-group combined with estimates of energy use intensity (EUI). The general approach follows: where the total emissions, *TE*, associated with a building of type, *n*, using fuel, *f*, in a block-group, *bg*, is equal to the product of the total floor area, *TFA*, and the energy use intensity, *EUI*, of buildings in a census division, *cd*.

Building floor area is retrieved from HAZUS General Building Stock data collected and compiled by the Federal Emergency Management Agency (FEMA, 2017). The non-electric energy use intensity (NE-EUI; joules/m<sup>2</sup>) values are compiled by the DOE from building consumption energy surveys in different regions of the US (CBECS, 2016; MECS, 2010; RECS, 2013).

The product of the total building area for a given Census block-group/sector/building type combination and the sector/building type/fuel NE-EUI values act as a distributional fraction of the county total county/sector/fuel FFCO<sub>2</sub> to each Census block-group. Hence this acts to provide a relative distribution of building FFCO<sub>2</sub> emission within a US county only.

The time distribution of the annual FFCO<sub>2</sub> emissions for the nonpoint data source uses a building energy model, eQuest, to generate simulated building energy consumption which, in turn, is used to represent hourly time patterns (Hirsch & Associates, 2004).

### Point sources (commercial, industrial)

Each point emission record is also associated with an SCC which is used to retrieve the needed CO and CO<sub>2</sub> EFs to enact the same procedure outlined in the description of the nonpoint source processing. All point source emission records designated as industrial, railroad, and nonroad are distributed to hourly temporal resolution from the 2011 annual total using SCC-specific temporal surrogate profiles provided by the EPAs Clearinghouse for Inventories and Emissions Factors (CHIEF) (USEPA, 2015c). The temporal surrogate profiles are constructed from monthly, weekly and diurnal cycles (data available at: [ftp://newftp.epa.gov/air/emismod/2011/v3platform/ancillary\\_data/ge\\_dat\\_for\\_2011v3\\_temporal.zip](ftp://newftp.epa.gov/air/emismod/2011/v3platform/ancillary_data/ge_dat_for_2011v3_temporal.zip)). These temporal surrogates are comprised of three cyclic time profiles (diurnal, weekly, monthly) specific to SCC that are combined to generate hourly SCC-specific time fractions for an entire calendar year. Records which do not have an SCC match are distributed as a constant hourly emission.

### Electricity production

Overlap exists between these three data sources (described above) which is corrected according to the prioritization in the order listed above. A detailed comparison made between the CAMD and EIA FFCO<sub>2</sub> emissions along with greater detail regarding data sources, data processing and procedures can be found in Gurney et al. (2016).

Some manual corrections are performed to the geocoordinates of both the CAMD and EIA electricity production data, as a result of searching in Google Earth or via alternative online information resources (e.g. utility websites).

A hierarchy was employed given that there was overlap between the two datasets. This was performed at the unit level given that a single facility might have individual power units reporting to CAMD and another only reporting to the EIA. Where overlap did exist at this scale, preference was made to retain the CAMD data. Further details and rationale can be found in Gurney et al. (2016).

### Onroad

County-scale FFCO<sub>2</sub> emissions for all US states are spatially assigned to road segments via a road basemap that best represents the entirety of the road surface occupied by onroad vehicles. Vulcan uses a combination of the 2011 Highway Performance Monitoring System (HPMS, 2017) road network and Open Street Map (OSM; <http://download.geofabrik.de/>) road network. The Census Urbanized Areas boundary (<https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm>) was used to assign an urban/rural distinction to each of the 7 original HPMS road classes making them compatible with the onroad NEI road classes (supplementary material, Table S4).

The distribution of the county-scale road/vehicle-specific FFCO<sub>2</sub> emissions along the complete length of road class in a county, is achieved through the use of the 2011 AADT data from the FHWA's HPMS (<http://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm>; state scale data files were used).

With a complete US map of AADT values and road segment length, the vehicle miles traveled (VMT) can be estimated. The fraction of a non-local road class-specific road segment's VMT within a county acts as the distribution means to allocate county-scale onroad FFCO<sub>2</sub>. For local roads, given the paucity of AADT data, the fraction of a road segment's length out of all local roads within a county acts as the allocation method.

Hourly traffic volume data for the years 2011-2013 were obtained from the FHWA Continuous Count Stations (CCS) dataset (previously known as the Automatic Traffic Recorder; ATR) (Jessberger, 2016). The CCS stations measure hourly traffic volume at a fixed location in space and we use the station's latitude and longitude as a unique station identifier.

In order to distribute the temporal distribution measured at the gap-filled CCS measurement stations to all road segments in the US, interpolation/extrapolation of the traffic patterns is required. Given the paucity of traffic measurement stations relative to the total area of the US landscape and the fact that the temporal distribution of traffic is less related to road class than space, it was determined to aggregate the eight road classes to four, "temporal" road classes for purposes of spatial interpolation.

Inverse Distance Weighted (IDW) interpolation was performed for each of the four temporal road classes separately, and only for grid cells that are occupied by roads of that road class. The two inputs are the gap-filled CCS traffic data, and the locations of road segments for each of the four road classes.

### Nonroad

The results used here are based on output from the National Mobile Inventory Model (NMIM) which relies on data inputs from the National County Data base (NCD) (USEPA 2005c; 2005d). Both the NMIM and the NCD were described previously (Gurney et al., 2009). The EPA updated data within the NCD from 12 SLT agencies along with EPA default values to generate the results in the 2011 NEIv2 (for a description of these updates see [ftp://ftp.epa.gov/EmissionInventory/2011/doc/2011nei2\\_supdata\\_nonroad](ftp://ftp.epa.gov/EmissionInventory/2011/doc/2011nei2_supdata_nonroad)).

As with the onroad sector, California presents a special case. The CO emissions are reported comprehensively using California's OFFROAD model ([www.arb.ca.gov/msei/offroad/offroad.htm](http://www.arb.ca.gov/msei/offroad/offroad.htm)) but no CO<sub>2</sub> was reported. Hence, we scaled the California CO emissions by the mean SCC-specific CO<sub>2</sub>/CO ratio from all other US counties.

Spatial distribution uses the spatial surrogates generated by the EPA reflecting a series of spatial representations such as the mines, golf course and agricultural land (The shapefiles can be found here: [ftp://ftp.epa.gov/EmissionInventory/emiss\\_shp2003/us/](ftp://ftp.epa.gov/EmissionInventory/emiss_shp2003/us/) or [ftp://ftp.epa.gov/EmissionInventory/2011v6/v1platform/spatial\\_surrogates/shapefiles/](ftp://ftp.epa.gov/EmissionInventory/2011v6/v1platform/spatial_surrogates/shapefiles/)). There were instances in which nonroad FFCO<sub>2</sub>

emissions could not be associated with a spatial entity due to missing data. These emissions are spatialized by first aggregating all the unassociated sub-county emission elements to the county scale for a given spatial shape (e.g., golf courses, mines) and then distributing these emissions evenly across the county.

The sub-annual temporal distribution of the nonroad FFCO<sub>2</sub> emissions uses SCC-specific temporal surrogate profiles provided by the EPAs Clearinghouse for Inventories and Emissions Factors (CHIEF) (USEPA, 2015c). The temporal surrogate profiles are constructed from monthly, weekly and diurnal cycles (data available at:

[ftp://newftp.epa.gov/air/emismod/2011/v3platform/ancillary\\_data/ge\\_dat\\_for\\_2011v3\\_temporal.zip](ftp://newftp.epa.gov/air/emismod/2011/v3platform/ancillary_data/ge_dat_for_2011v3_temporal.zip)). These temporal surrogates are comprised of three cyclic time profiles (diurnal, weekly, monthly) specific to SCC that are combined to generate hourly SCC-specific time fractions for an entire calendar year.

### **Airport**

The airport FFCO<sub>2</sub> emissions are only associated with the taxi & takeoff/landing sequences. The airports are geocoded to the airport location in the NEI though some manual adjustments have been made to the original coordinates using manual inspection in Google Earth.

Temporal distribution of the FFCO<sub>2</sub> airport emissions use a series of datasets. The Los Angeles World Airports (LAWA) dataset reports hourly flight volume for three airports in the LA Basin domain: Los Angeles International airport (LAX), Ontario airport (ONT), and Van Nuys airport (VNY) (Hastings, 2014). The Operations Network (OPSNET) dataset from the FAA reports total date-specific, daily flight volume (365 values) at specific airports (<https://aspm.faa.gov/opsnet/sys/Default.asp>). An hourly time profile was constructed by combining the LAWA diurnal profile and the OPSNET annual profile. The three LAWA airports constituted the diurnal cycle at all US airports with the LAX assigned to international airports, the ONT to non-international airports and the VNY to local airports.

Airports were matched with a Federal Aviation Administration (FAA) international airport database (FAAINTL) by airport code to determine whether an airport is international ([https://hub.arcgis.com/datasets/4782d6f5aa844591a16d46df635b7af4\\_1](https://hub.arcgis.com/datasets/4782d6f5aa844591a16d46df635b7af4_1)). Airports which could not be matched to the OPSNET data by airport code/airport name were assigned a temporal invariant (“flat”) hourly time structure.

### **Railroad**

The 2011 NEIv2 CO emissions reporting results were originally developed for the 2008 NEI (ERG 2011) and scaled to 2011 values (ERG 2012). Emissions related to the railroad sector were reported as a mixture of nonpoint and point emissions and hence, these were managed separately but combined when represented as spatial entities. The CO emissions were converted to FFCO<sub>2</sub> following the procedures outlined in the nonpoint and the point sections, respectively. The point source railroad emissions are associated with rail yards and related geo-specific locales and are placed in space according to the provided latitude and longitude. The railroad FFCO<sub>2</sub> emissions associated with the nonpoint NEI reporting contain an ID variable that links to a spatial element (rail line segment) in the EPA railroad GIS shapefile ([https://www.epa.gov/sites/production/files/2015-06/railway\\_20140730.zip](https://www.epa.gov/sites/production/files/2015-06/railway_20140730.zip)). A large number of railroad emission records have no railroad segment match and are spatialized using freight statistics described in supplementary material. The annual railroad FFCO<sub>2</sub> emissions are distributed to the hourly timescale with no additional temporal structure (a “flat” time distribution), unless they originated from point source data for which the SCC-specific time profiles, previously described, are used.

### **Commercial Marine Vessels (CMV)**

The CMV emissions encompass maneuvering, hoteling, cruise and reduced speed zone travel and are specific to geographically located ports and shipping lanes that extend 12 nautical miles from the US shoreline. As with the nonroad reporting, the EPA used a mixture of SLT data submissions and default values, in collaboration with the Office of Transportation and Air Quality to generate an estimate of CO emissions for CMV. The spatialization utilized the EPA shapefiles that delineate US ports and US shipping lanes through spatial IDs associated with the emission records ([https://www.epa.gov/sites/production/files/2015-06/ports\\_20140729.zip](https://www.epa.gov/sites/production/files/2015-06/ports_20140729.zip); [https://www.epa.gov/sites/production/files/2015-06/shippinglanes\\_072914.zip](https://www.epa.gov/sites/production/files/2015-06/shippinglanes_072914.zip)). In the instance that no spatial entity is identified for an emission record, a simple spatial alternative is employed whereby all the unlinked port (or “underway”) emissions are summed within a county and evenly distributed to the shapes that are identified within that county (either ports or shipping lanes).

The CMV sector has no data allowing for the designation of hourly time structure. Hence, the emissions are temporally invariant over all hours of the year (“flat” distribution).

### **Cement**

The geolocation for each of the individual facilities was achieved by entering the PCA document’s facility address into Google Earth and visually inspecting the scene for the primary emitting stack of the cement facility. This approach succeeded in locating all 105 facilities present in the PCA document. The cement sector has no data allowing for the designation of hourly time structure. Hence, the emissions are evenly distributed over all hours of the year (a “flat” distribution).

The file “NonPoint\_Activity2011V2.csv” is no longer archived and/or available from the United States Environmental Protection Agency.

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## 6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

[Vulcan: High-Resolution Hourly Fossil Fuel CO<sub>2</sub> Emissions in USA, 2010-2015, Version 3](#)

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## Home

## About Us

Mission  
Data Use and Citation Policy  
User Working Group  
Partners

## Get Data

Science Themes  
NASA Projects  
All Datasets

## Submit Data

Submit Data Form  
Data Scope and Acceptance  
Data Authorship Policy  
Data Publication Timeline  
Detailed Submission  
Guidelines

## Tools

MODIS  
THREDDS  
SDAT  
Daymet  
CARVE Data Viewer  
Soil Moisture Visualizer  
Land - Water Checker

## Resources

Learning  
Data Management  
News

## Contact Us

