Vulcan Fossil Fuel Carbon Dioxide (FFCO$_2$) Emissions Data Product version 3.0, 1km grid

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CONTENTS

1. DATA SOURCE AND CONTACTS

This directory contains gridded output from the Vulcan version 3.0 fossil fuel CO$_2$ (FFCO$_2$) product, which estimates CO$_2$ emissions from fossil fuel combustion and cement production across the United States. Data are gridded annually on a 1 km grid for the years 2010 to 2015, and are available across ten sectors. These data are designed to be used as emission in atmospheric transport modeling, mapping, and other data analyses. These data were last modified on August 19, 2019.

Correspondence concerning these data should be directed to:

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2. USE OF DATA

The Vulcan data product represents many years of development by many people with support from the National Aeronautics and Space Administration. If you use the Vulcan data product in your research we recommend that you contact Dr. Kevin Gurney to assure that the data product is being used in a way consistent with its strengths and weaknesses. In some instances we consider it appropriate to include the Vulcan team in publications resulting from use of the Vulcan data product. At a minimum, we kindly

3. WARNINGS

The Vulcan data product is an attempt to estimate fossil fuel CO_2 ($FFCO_2$) emissions at fine time and space scales. It should be considered a "climatology" of emissions rather than the "weather" of emissions. By that, we mean that the estimates represent "typical" emissions at a specific time and place (average conditions). Hence, we do not consider it appropriate to use in comparison to short-term "campaign" style atmospheric measurements (e.g. 5 days of continuous monitoring at a specific location) without consideration of the mismatch between the measurement and the Vulcan estimation approach.

4. DATA COMMENTS

LINEAGE:
Vulcan data were first published in 2009 as version 1.0 (Gurney et al., 2009). Several iterations have been developed since then as the methods have been refined and additional data sources have been incorporated into the emissions data product.

UNCERTAINTY:
Uncertainty in the $FFCO_2$ emissions were accounted for within each sector and quantified as the 95% confidence interval bounds. High and low bounds for each sector were gridded in addition to the mean emissions estimates. More information on uncertainty bounds are available in the peer-reviewed paper (see section 2).

SECTORAL COMPOSITION:
The Vulcan version 3.0 $FFCO_2$ emissions represent emissions due to the combustion of fossil fuel and cement production in the United States. The emissions are generated using a bottom-up/engineering approach. The data sources lend themselves to categorization by economic sector (Table 1). The native spatial resolution of the Vulcan $FFCO_2$ emissions data product is a combination of points, lines, and polygons dictated primarily by the underlying data sources. The $FFCO_2$ emissions are placed into a regularized continuous gridded landscape for ease of analysis and incorporation into atmospheric transport modeling efforts. The Vulcan version 3.0 $FFCO_2$ emissions are generated using two time-resolutions: annual and hourly for the 6 year timespan of 2010 to 2015.

Table 1. Sector categories in the Vulcan V3.0 $FFCO_2$ emissions data product and the abbreviation used in the filename scheme.

Economic sector	Abbreviation
electricity production	elec_prod
onroad	onroad
commercial	commercial
residential	residential
industrial	industrial
nonroad	nonroad
railroad	railroad
cement	cement
airport	airport
total	total

OUTPUT FILE NAMES AND FILE STRUCTURE:
Individual files are named according to a series of key attributes listed in sequence with a period (".") between the attribute categories. Files begin with the "Vulcan.v3". The next attribute denotes the domain geography: either Alaska ("AK") or the contiguous US ("US"). Next is the temporal resolution ("annual") followed by the grid resolution (there is only "1km"), followed by the sector (e.g. "total", "residential", "onroad"), followed by the run attribute ("mn" for central estimate, "lo" for the lower 95% confidence interval boundary value, "hi" for the upper 95% confidence interval boundary), followed by the year (e.g. "2010", "2011"). The file format, "nc", indicates the netCDF file format. For example, "Vulcan.v3.AK.annual.1km.onroad.lo.2014.nc" refers to the Alaska domain, annual temporal resolution, 1km x 1km grid resolution, the onroad sector, the lower 95% CI boundary estimate, for the year 2014, in netCDF file format.

These netCDF files contain spatial metadata within the file header and use standard netCDF protocols.

PARAMETERS:
1 variable:
- Name: Carbon emissions
- Units: Metric Tons of Carbon (tC)
- No data value: NaN
- Description: This variable represents the annual emissions of $FFCO_2$, represented as the mass of carbon
- in metric tons (Mg), per grid cell (1 km^2).

3 dimensions:
- 'X' - 4648 columns, units=meter
- 'Y' – 2900 rows, units=meter
- 'T' – 1 year per file

GRID DOMAIN AND UNITS:
The United States (U.S.) is divided into two spatial domains, the Contiguous U.S. and Alaska with separate file sets for each domain. The $FFCO_2$ emissions are represented in a Lambert conformal conic projection (Table 2) and the emissions units are metric tons of carbon per year (tC/yr).

Table 2. Spatial reference definitions for the gridded Vulcan V3.0 FFCO$_2$ emissions.

Parameter	Value
Projection	Lambert_Conformal_Conic
false_easting	0.00000000
false_northing	0.00000000
central_meridian	-97.00000000
standard_parallel_1	33.00000000
standard_parallel_2	45.00000000
Latitude of origin	40.00000000
Linear Unit	Meter
Geographic Coordinate System	GCS_WGS_1984
Datum	D_WGS_1984
Prime Meridian	Greenwich
Angular Unit	Degree

Text representation:
PROJCS["Vulcan",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION["Lambert_Conformal_Conic"],PARAMETER["false_easting",0.0],PARAMETER["false_northing",0.0],PARAMETER["central_meridian",-97.0],PARAMETER["standard_parallel_1",33.0],PARAMETER["standard_parallel_2",45.0],PARAMETER["latitude_of_origin",40.0],UNIT["Meter",1.0]]

Table 3 shows the spatial extent, resolution and dimensions of the Contiguous U.S. and Alaska grid domains. The grid cell center coordinates (longitude/latitude) are listed within each netCDF file under the attributes 'X' and 'Y'. The units associated with the spatial dimensions and emissions are also provided within the netCDF files.

Table 3. Spatial domain definitions for the gridded Vulcan V3.0 FFCO$_2$ emissions.

Parameter	Contiguous U.S.	Alaska
Grid resolution	1000 meter	1000 meter
Minimum X (west)	-2305363.04969	-5283064.20637
Minimum Y (south)	-1624104.18664	2054999.51448
Maximum X (east)	2342636.95031	-1949064.20637
Maximum Y (north)	1275895.81336	4615999.51448
Number of columns	4648	3334
Number of rows	2900	2561

CHECKSUMS:
To ensure correct interpretation and processing of the Vulcan version 3.0 results, Tables 4-6 provide totals for the two domains and across the sectors for the base year of 2011 for mean, high, and low emission bounds.

Table 4. Checksum FFCO2 emission values ("mean" emissions) for the two Vulcan V3.0 domains and sectors for 2011.

File	Contiguous U.S. (MtC)	Alaska (MtC)	Total (MtC)
Airport	18.63	0.76	19.39
Cement	9.7	0	9.7
CMV	21.37	1.5	22.87
Commercial	62.25	0.53	62.78
Electricity production	636.84	1.49	638.33
Industrial	224.42	3.02	227.44
Nonroad	62.85	0.23	63.07
Onroad	438.52	0.76	439.28
Rail	11.92	0.02	11.95
Residential	88.7	0.49	89.2
Total	1575.2	8.81	1584.01

Table 5. Checksum FFCO2 emission values ("high" emissions bound) for the two Vulcan V3.0 domains and economic sectors for 2011.

File	Contiguous U.S. (MtC)	Alaska (MtC)	Total (MtC)
Airport	25.01	1.03	26.04
Cement	10.67	0	10.67
CMV	31.86	2.24	34.1
Commercial	64.21	0.54	64.75
Electricity production	797.03	1.89	798.93
Industrial	309	4.2	313.2
Nonroad	66.29	0.25	66.55
Onroad	500.79	0.87	501.66
Rail	15.46	0.03	15.49
Residential	88.77	0.51	89.28
Total	1909.08	11.58	1920.66

Table 6. Checksum FFCO2 emission values ("low" emissions bound) for the two Vulcan V3.0 domains and economic sectors for 2011.

File	Contiguous U.S. (MtC)	Alaska (MtC)	Total (MtC)
Airport	14.38	0.59	14.96
Cement	8.73	0	8.73
CMV	14.68	1.03	15.71
Commercial	60.96	0.52	61.48
Electricity production	477.77	1.12	478.9
Industrial	170.33	2.24	172.57
Nonroad	59.81	0.2	60.01
Onroad	376.25	0.65	376.9
Rail	9.56	0.02	9.58
Residential	88.66	0.48	89.15
Total	1281.12	6.87	1287.99

5. REFERENCES

Gurney, Kevin R., Daniel L. Mendoza, Yuyu Zhou, Marc L. Fischer, Chris C. Miller, Sarath Geethakumar, Stephane de la Rue du Can (2009): High Resolution Fossil Fuel Combustion CO_2 Emission Fluxes for the United States, 43(14), 5535-5541, *Environmental Science & Technology*, https://doi.org/10.1021/es900806c.

Gurney, K.R., J. Liang, R. Patarasuk, Y. Song, J. Huang, G. Roest (2019) The Vulcan Version 3.0 High-Resolution Fossil Fuel CO_2 Emissions for the United States, *submitted to Earth System Science Data*.