VULCAN AND HESTIA: QUANTIFICATION OF HIGH-RESOLUTION, BOTTOM-UP FOSSIL FUEL CO2 EMISSIONS FOR THE NATION AND US CITIES

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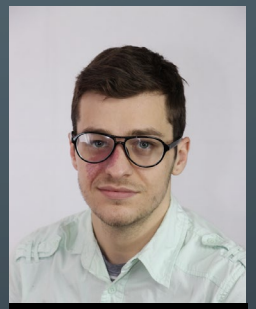
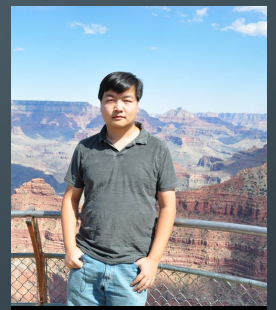
OUTLINE

- Overview and motivation
- Vulcan methodology
- Hestia methodology
- Applications

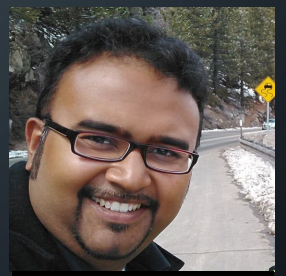
- NASA grant NNX14AJ20G (Vulcan)
- NIST grants 70NANB14H321 & 70NANB16H264 (Hestia)
- NSF CAREER award (All)


K. Gurney


G. Roest


Y. Song


T. Moiz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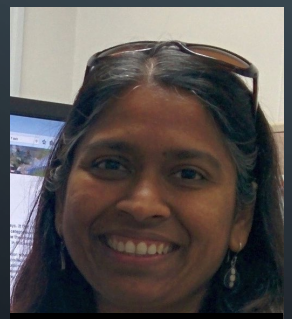
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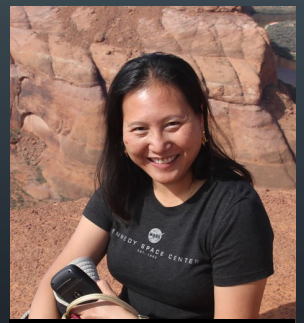
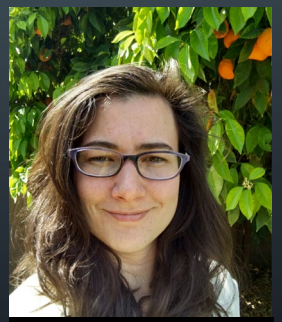

R. Patarasuk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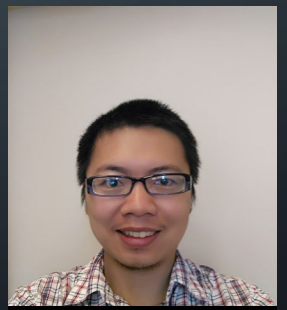
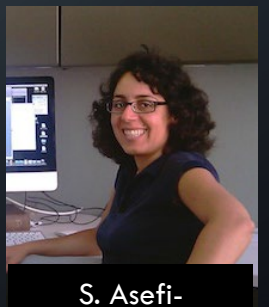
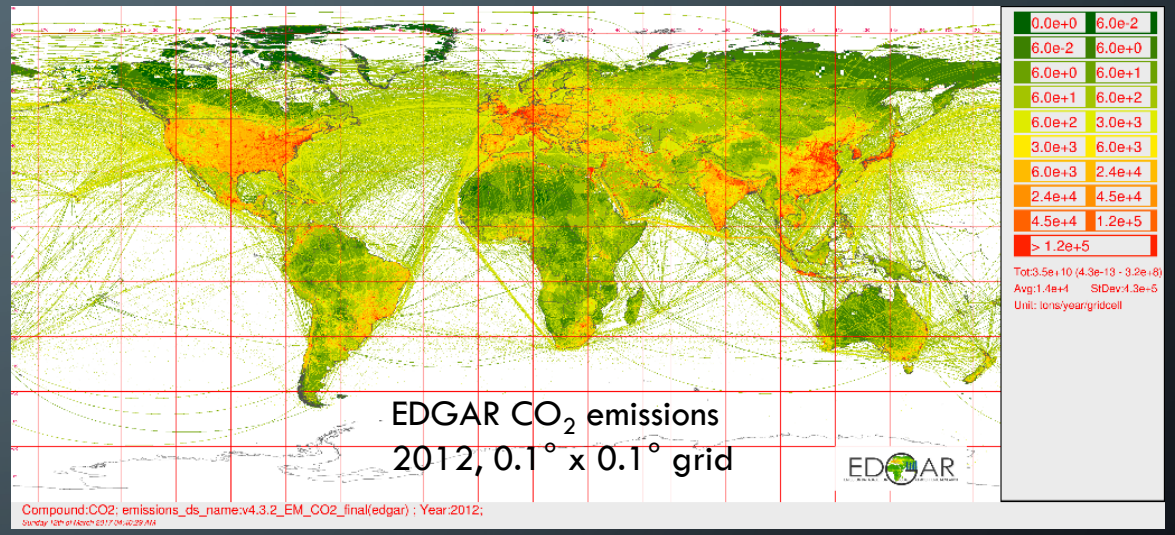

J. Liang


S. Asefi-Najafabady


D. O'Keeffe

MOTIVATION

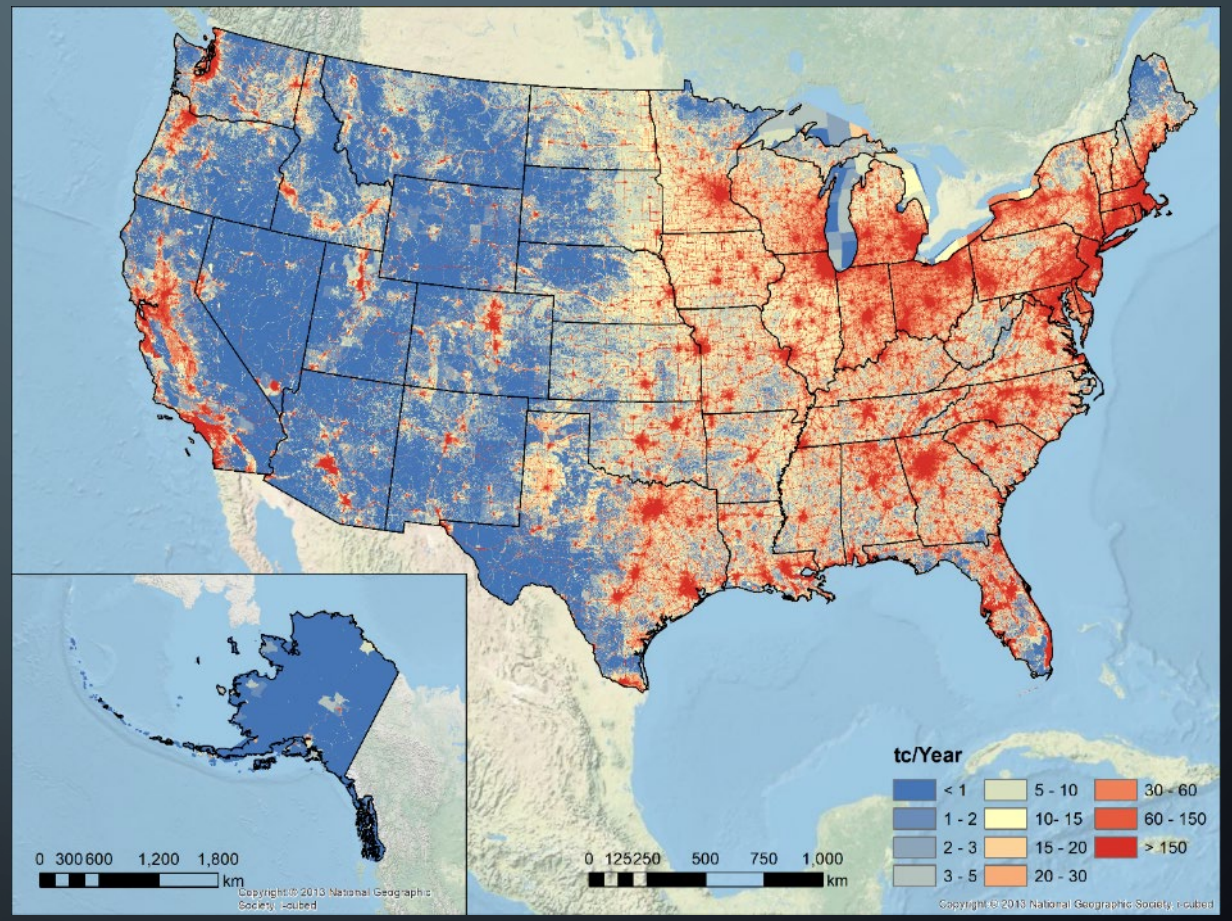
- CO_2 continues to increase
  - ~7 billion tons C $year^{-1}$ from fossil fuels
- Pressure to reduce CO_2 emissions
  - Paris Agreement
  - > 350 mayors in the U.S. have adopted the Paris Agreement goals
  - > 400 U.S. cities are participating in the EV Purchasing Collaborative
  - > 125 cities have pledged to transition their communities to 100% clean energy.
    – Center for Climate and Energy Solutions



- Urban areas:
  - 54% of global population, 70% of global energy use (IPCC 2014, UN 2015)
  - >80% of US population (2010 US Census)

GURNEY LAB AT NAU

- Quantify fossil fuel CO_2 ($FFCO_2$) emissions across spatial scales (scope 1):
  - Global (FFDAS)
  - US (Vulcan v3.0)
  - Cities (Hestia)
- Produce data products
  - Sector-specific
  - Gridded output for modeling
  - State/county/regional output
  - Visualization



Sector/type	Emissions Data Source	Original spatial resolution/information	Spatial distribution	Temporal distribution
Onroad	EMFAC [a] CO2, EPA NEI[b] onroad CO_2	County, road class, vehicle class	FHWA AADT[c]	CCS[e]
Electricity production	CAMD[f] CO2, DOE/EIA[g] 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[d], DOE RECS NE-EUI[h]	eQUEST[i] model
Nonroad	NEI nonpoint CO	County, vehicle class	EPA spatial surrogates (vehicle class specific)	EPA temporal surrogates (by SCC[j])
Airport	EPA NEI point CO	Lat/lon, aircraft class	Lat/Lon	LAWA & OPSNET[k]
Commercial nonpoint buildings	EPA NEI nonpoint CO	County, fuel	FEMA HAZUS, DOE CBECS NE-EUI[l]	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[m]	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	EPA temporal surrogates (by SCC)

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

POINT AND NONPOINT

$$E_{n,f}^{CO_2} = \frac{E_{n,f}^{CO}}{EF_{n,f}^{CO}} EF_{n,f}^{CO_2}$$

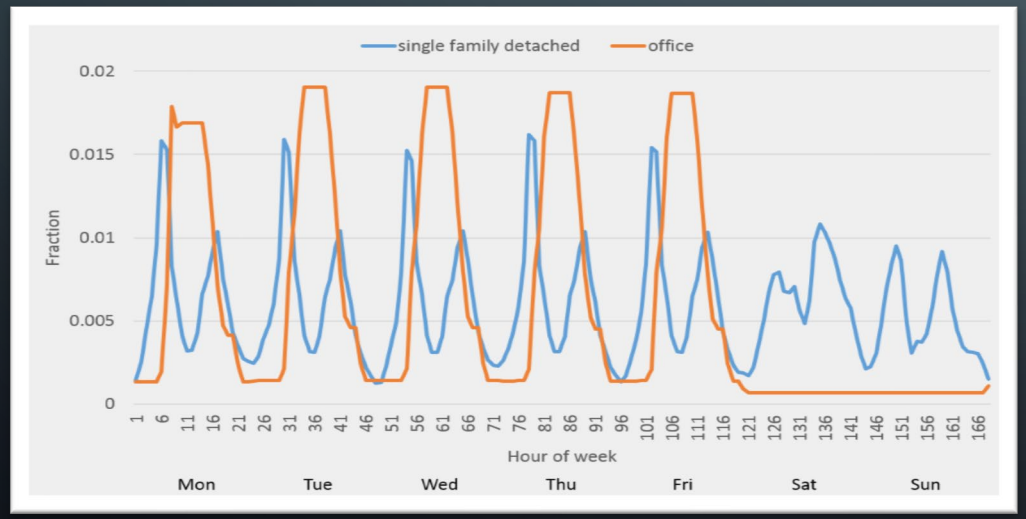
- Process *n* (e.g. commercial 10 MMBTU boiler, industrial reciprocating engine)
- Fuel *f* (e.g. natural gas, bituminous coal)
- E – emissions
- EF – emission factor

- CO emission factors come from either:
  - Self-reported – submitted by SLTs (found through FIPS/SCC
  - Default – created internally but mostly retrieved from WebFIRE/AP-42 and a few literature
- CO2 emission factors:
  - Carbon coefficients/content, from coal sampling literature, EPA (liquids, gas), DOE and based on fuel sample statistics

POINT AND NONPOINT

Point:

- Temporal allocation (hourly): Industrial surveys of occupancy, production cycles, gives SCC categorized temporal structure



Nonpoint:

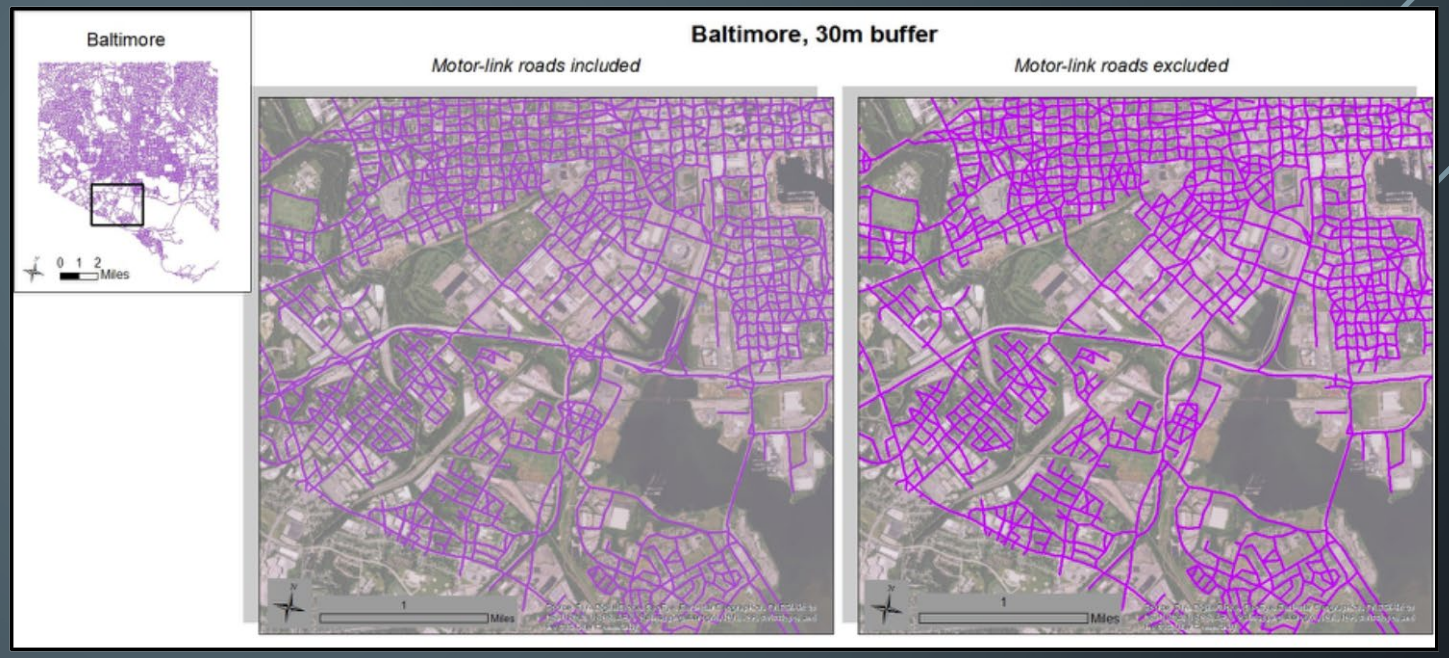
- Spatial allocation:
  - FEMA HAZUS general building stock data
  - Block group totals on residential, commercial, and industrial buildings
  - Energy use intensity – DOE survey by Census Division
- Temporal allocation (hourly):
  - eQUEST building energy model
  - Local meteorology, DOE survey data

ELECTRICITY PRODUCTION

- CAMD – stack monitoring CO_2 (hourly)
- DOE/EIA – fuel throughput (monthly)
- NEI – CO reporting (point process, annual)

ONROAD

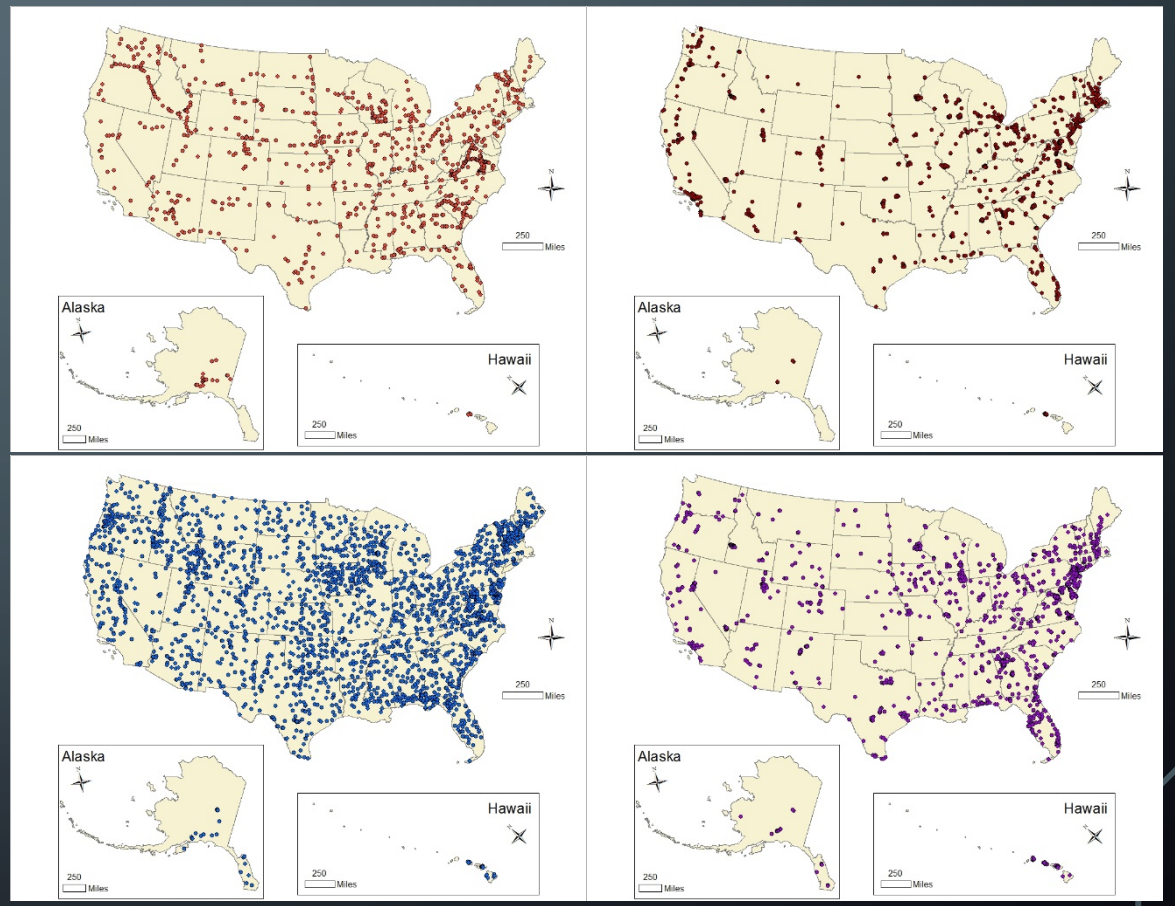
- Merged HPMS road base and Open Street map
- $FFCO_2$ at county scale – EPA MOVES
  - County/vehicle class/road class
- California – EMFAC
  - County/vehicle class
  - Use statistics (FHWA) to distribute to road class



NEI 2011 Road Class	HPMS Road Class	OSM Road Class
Rural Interstate	Rural Interstate; Rural Principal Arterial–Other Freeways and Expressways	Motorway
Rural Other Principal Arterial; Rural Minor Arterial	Rural Principal Arterial–Other; Rural Minor Arterial	Trunk; Trunk-link; Primary; Primary -link
Rural Major Collector; Rural Minor Collector	Rural Major Collector; Rural Minor Collector	Secondary; Secondary-link; Tertiary; Tertiary-link
Rural Local	Rural Local	Residential; Unclassified
Urban Interstate; Urban Other Freeways and Expressways	Urban Interstate; Urban Principal Arterial–Other Freeways and Expressways	Motorway
Urban Other Principal Arterial; Urban Minor Arterial	Urban Principal Arterial–Other; Urban Minor Arterial	Trunk; Trunk-link; Primary; Primary -link
Urban Collector	Urban Major Collector; Urban Minor Collector	Secondary; Secondary-link; Tertiary; Tertiary-link
Urban Local; Parking Area	Urban Local	Residential; Unclassified

ONROAD

- Spatial allocation:
  - FHWA AADT – VMT on all but local roads
  - Non-local roads – gap-filling using nearest neighbor
  - Local-roads – “flat” spatial distribution within counties
- Temporal allocation:
  - CCS classified by road types
  - Allocated to road segments using inverse distance weighting



NONROAD

- CO_2 from EPA nonroad model in all states except CA
- CA: use CO reporting with CO/CO_2 ratio from other western states
- Temporal distribution: SCC time cycle profiles (if available)
- Spatial distribution: EPA shapefiles (if available)

AIRPORT

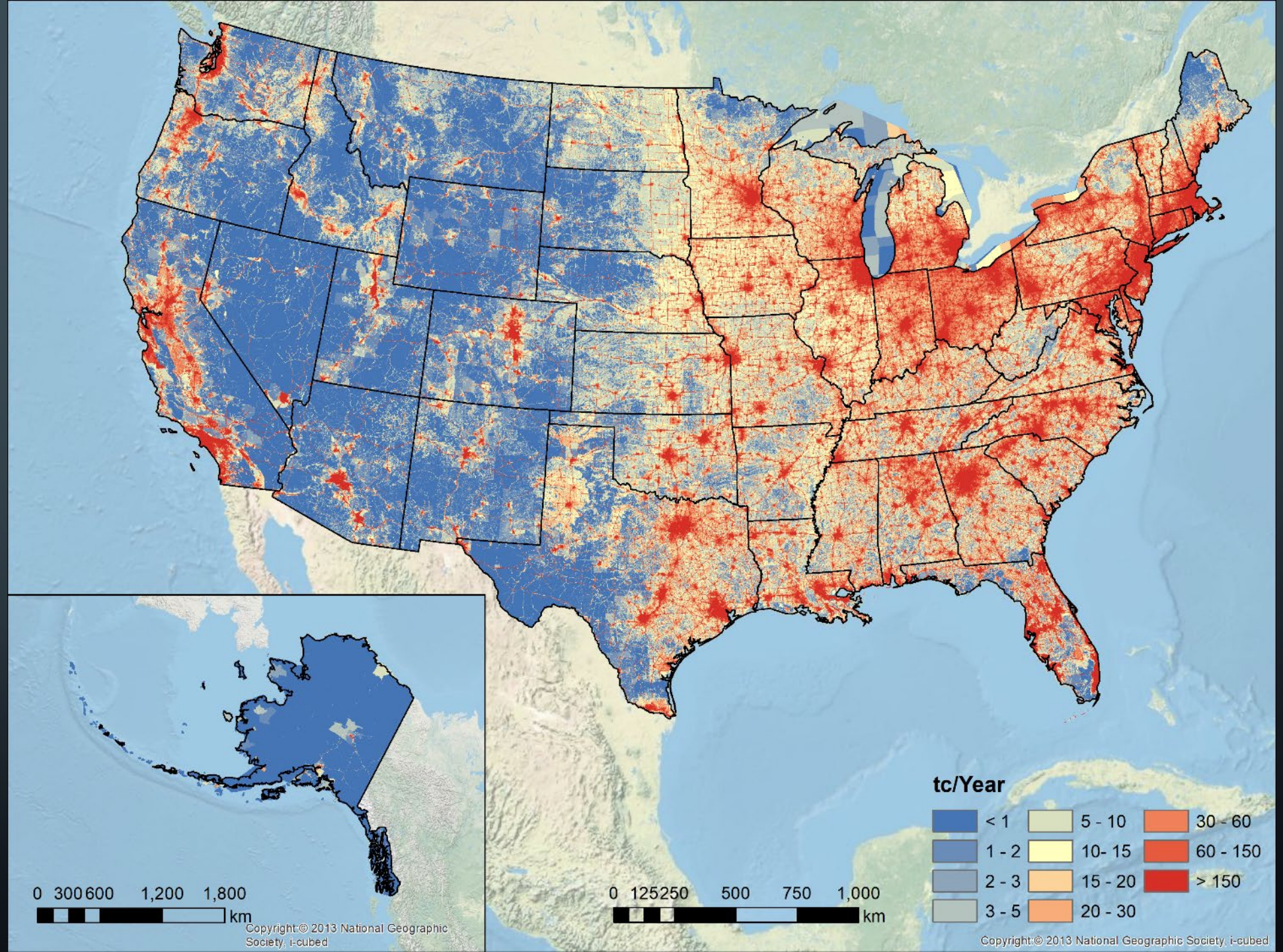
- NEI point source w/ spatial correction to center of runway
- Reflects taxi/takeoff/landing (below 3000 ft)
- CO/CO_2 ratio from literature review, categorized by aircraft type/size/class
- Temporal distribution: airport “type” based on OPSNET (daily flight volumes) and AIRNAV datasets (airport class shares)

RAIL

- CO reporting from point (railyard) and nonpoint (rail travel)
- Map to EPA rail basemap, distributing via freight statistics (RITA data)
- Constant emissions in time

CMV

- CO nonpoint reporting
- Spatial distribution: port and shipping distributed with shapefiles
- Constant emissions in time


tc/Year
< 1
1 - 2
2 - 3
3 - 5
5 - 10
10- 15
15 - 20
20 - 30
30 - 60
60 - 150
> 150
0 125250 500 750 1,000
km
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km
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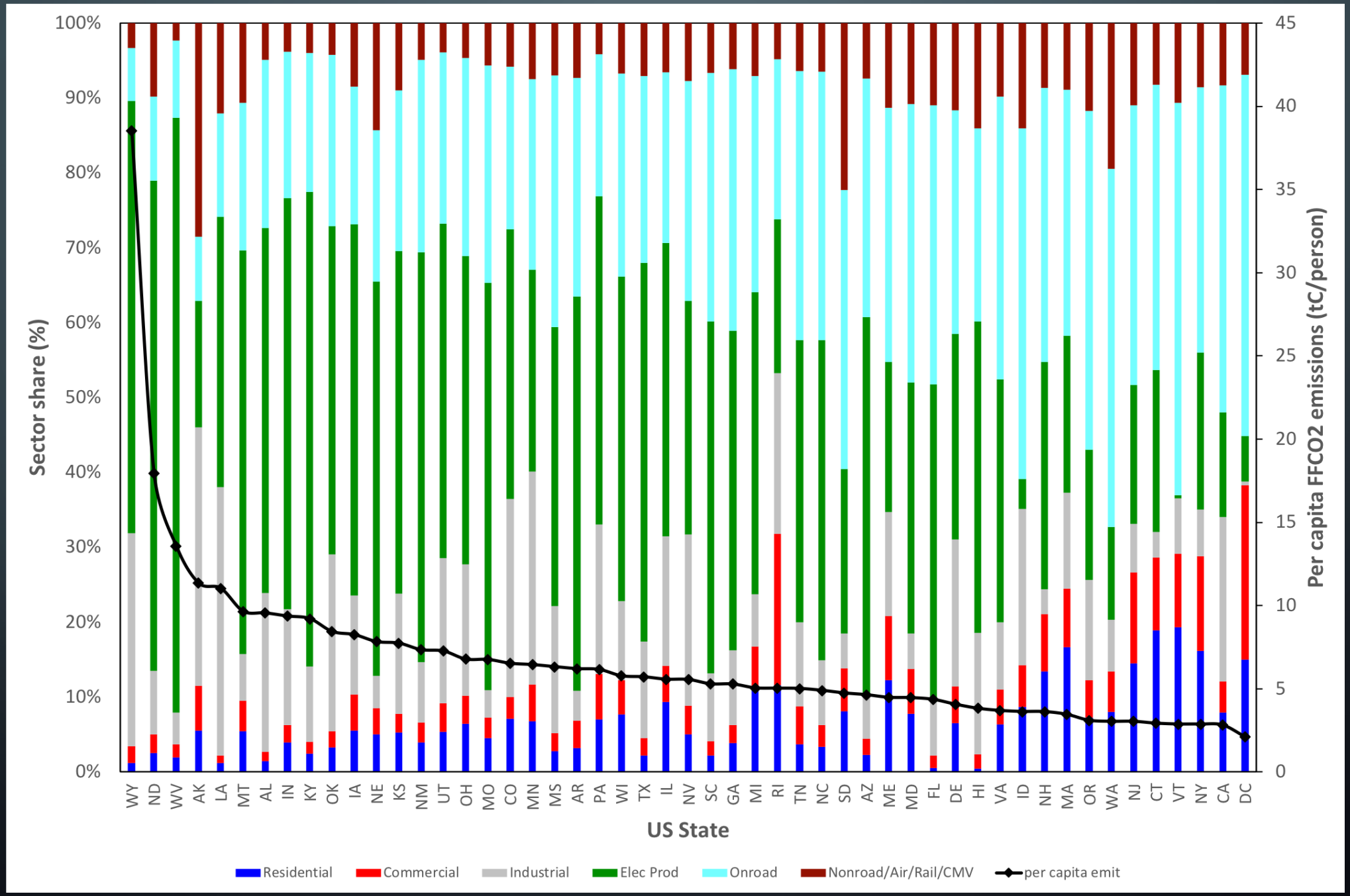
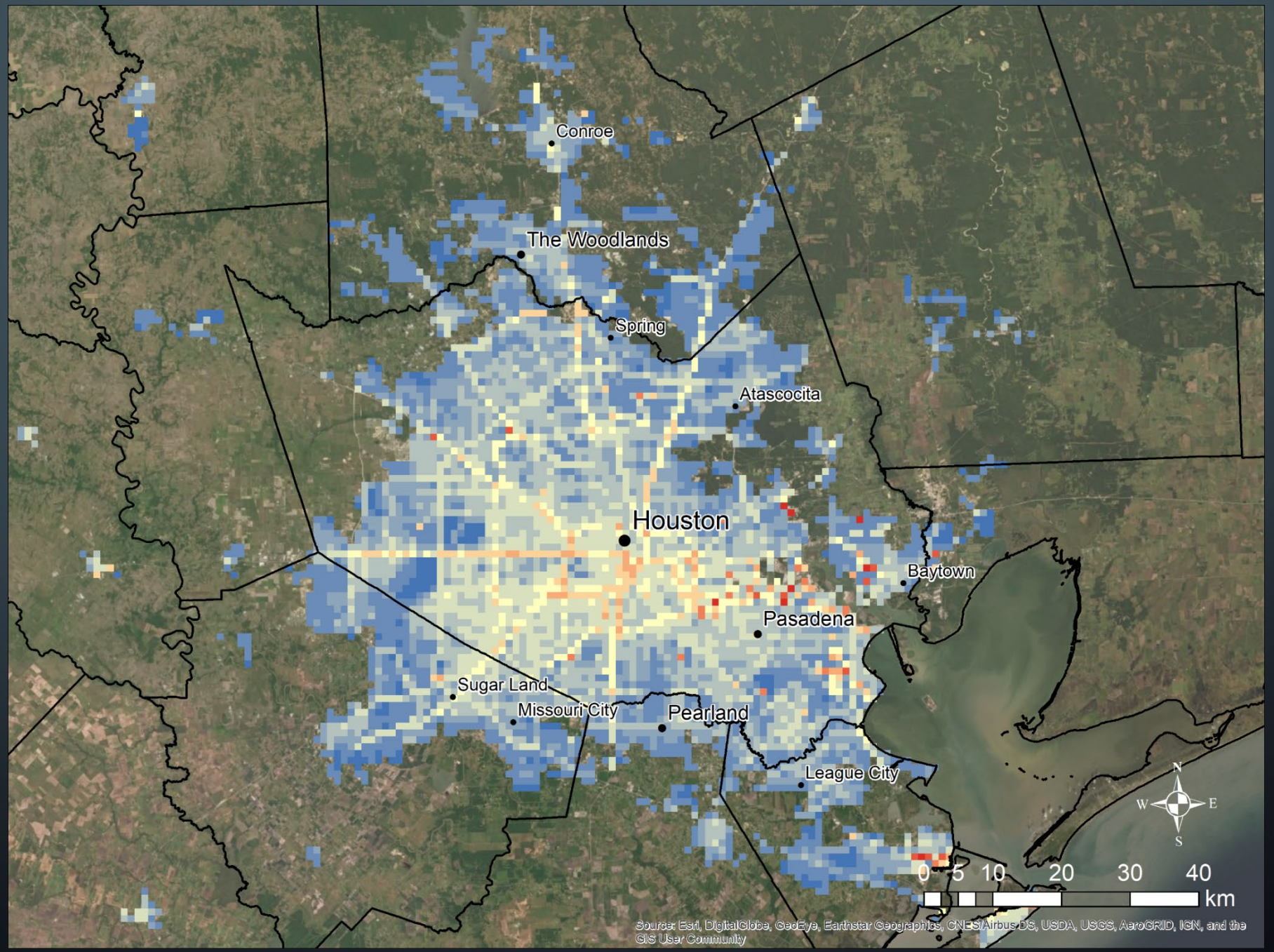
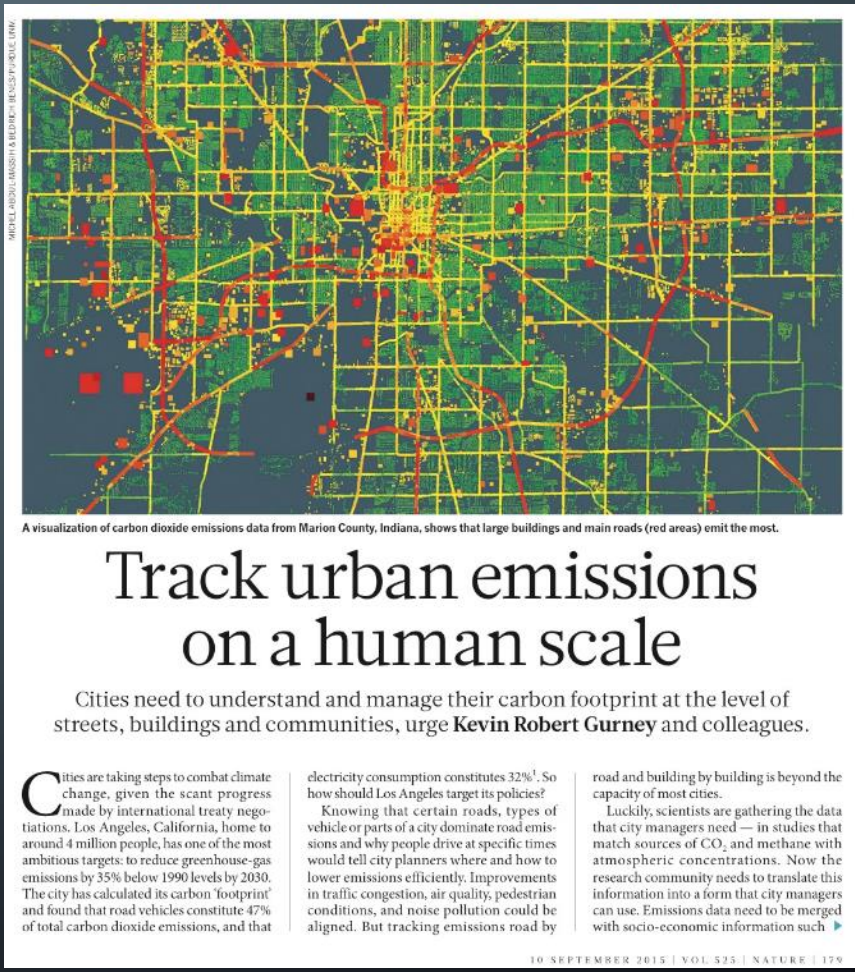

Sector share (%)
Per capita FFCO2 emissions (tC/person)
US State
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
45
40
35
30
25
20
15
10
5
0
WY ND WV AK LA MT AL IN KY OK IA NE KS NM UT OH MO CO MN MS AR PA WI TX IL NV SC GA MI RI TN NC SD AZ ME MD FL DE HI VA ID NH MA OR WA NJ CT VT NY CA DC
Residential
Commercial
Industrial
Elec Prod
Onroad
Nonroad/Air/Rail/CMV
per capita emit


Conroe
The Woodlands
Spring
Atascocita
Houston
Baytown
Pasadena
Sugar Land
Missouri City
Pearland
League City
N
W
E
S
0 5 10 20 30 40
km
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

HESTIA

- Urban $FFCO_2$ estimation embedded within national Vulcan product
- Additional data from local sources
- Codebase depends on city, data sources, unique challenges
- Indianapolis, Salt Lake City, Baltimore, Los Angeles
- Melbourne Australia, Virginia-PA corridor



A visualization of carbon dioxide emissions data from Marion County, Indiana, shows that large buildings and main roads (red areas) emit the most.

Track urban emissions on a human scale

Cities need to understand and manage their carbon footprint at the level of streets, buildings and communities, urge **Kevin Robert Gurney** and colleagues.

Cities are taking steps to combat climate change, given the scant progress made by international treaty negotiations. Los Angeles, California, home to around 4 million people, has one of the most ambitious targets: to reduce greenhouse-gas emissions by 35% below 1990 levels by 2030. The city has calculated its carbon 'footprint' and found that road vehicles constitute 47% of total carbon dioxide emissions, and that electricity consumption constitutes 32%[1]. So how should Los Angeles target its policies?

Knowing that certain roads, types of vehicle or parts of a city dominate road emissions and why people drive at specific times would tell city planners where and how to lower emissions efficiently. Improvements in traffic congestion, air quality, pedestrian conditions, and noise pollution could be aligned. But tracking emissions road by road and building by building is beyond the capacity of most cities.

Luckily, scientists are gathering the data that city managers need — in studies that match sources of CO_2 and methane with atmospheric concentrations. Now the research community needs to translate this information into a form that city managers can use. Emissions data need to be merged with socio-economic information such ▶

Sector/type	Emissions Data Source	Original spatial resolution/information	Spatial distribution	Temporal distribution
Onroad	EMFAC[a], EPA NEI[b] onroad	County, road class, vehicle class	SCAG AADT[c]	PeMS[d], CCS[e]
Electricity production	CAMD[f] CO2, EIA[g] fuel, EPA NEI point CO	Lat/lon, fuel type, technology	EPA NEI Lat/Lon, Google Earth	CAMD, EIA and EPA
Residential nonpoint buildings	EPA NEI nonpoint CO/DOE fuel consumption statistics	County, fuel type/state, fuel	SCAG Parcel, floor area, DOE RECS NE-EUI[h], LA County building footprint	eQUEST[i]
Nonroad	NEI nonpoint CO	County, vehicle class	EPA spatial surrogates (vehicle class specific)	EPA temporal surrogates (by SCC[j])
Airport	EPA NEI point CO	Lat/lon, aircraft class	Lat/Lon	LAWA[k]
Commercial nonpoint buildings	EPA NEI nonpoint CO/DOE fuel consumption statistics	County, fuel/state, fuel	SCAG Parcel, floor area, DOE CBECS NE-EUI[l]	eQUEST
Commercial point sources	EPA NEI point CO	Lat/lon, fuel type, combustion technology	EPA NEI Lat/Lon, Google Earth	eQUEST
Industrial point sources	EPA NEI point CO/EPA GHGRP	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	SCAG-Parcel, floor area, DOE MECS NE-EUI[m]	eQUEST
Commercial Marine Vessels	EPA NEI nonpoint CO	County, fuel type, port/underway	MEM[n]	MEM
Railroad	EPA NEI nonpoint CO, EPA NEI point CO	County, fuel type, segment	EPA NEI rail shapefile and density distribution	EPA temporal surrogates (by SCC)

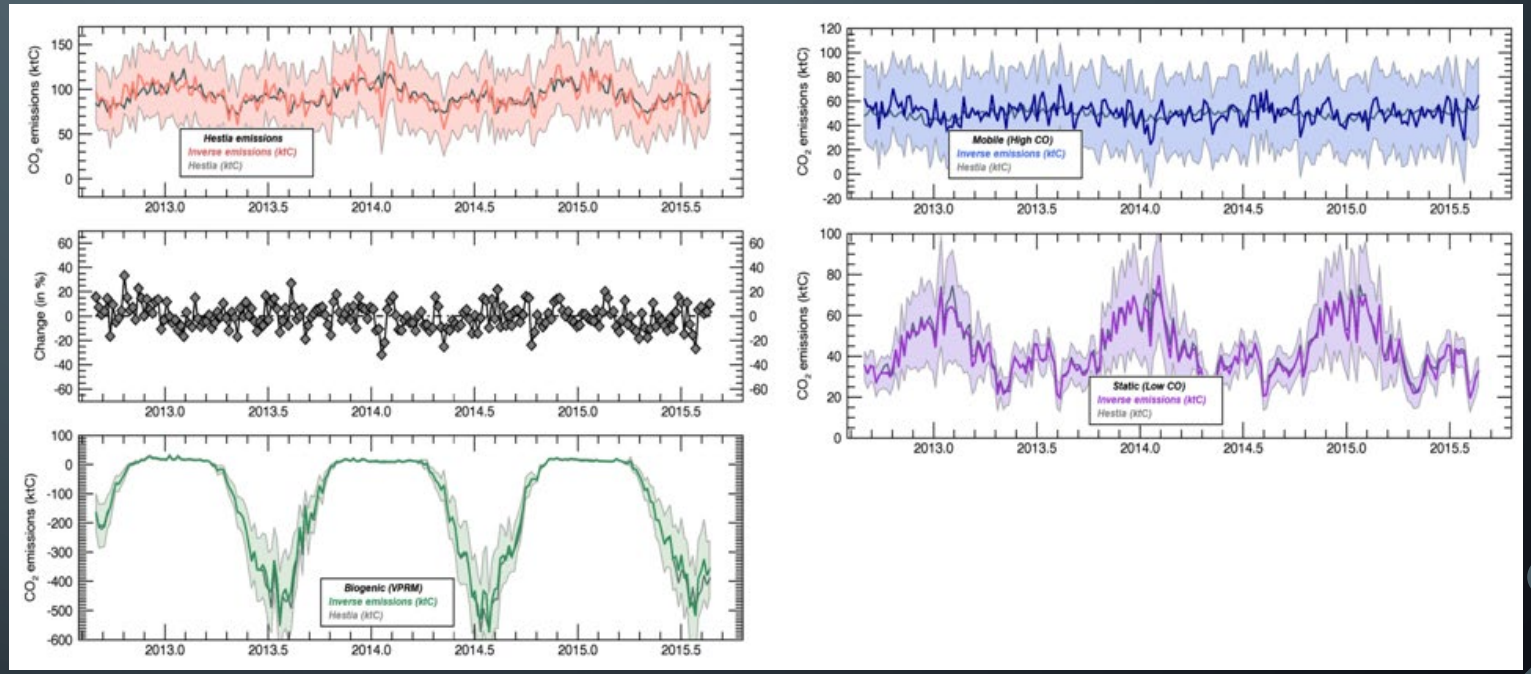
a. Emissions Factors Model
b. Environmental Protection Agency, National Emissions Inventory
c. Southern CA Assoc. of Governments, Average Annual Daily Traffic
d. Caltrans PeMS
e. Continuous Count Stations
f. Clean Air Markets Division
g. Department of Energy/Energy Information Administration
h. Department 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
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
n. Marine Emissions Model

EXAMPLE: RESIDENTIAL BUILDINGS

RECS building type	Pre-1980 NG NE-EUI (kbtu/ft^2)	Post-1979 NG NE-EUI (kbtu/ft^2)	Pre-1980 Fuel oil NE-EUI (kbtu/ft^2)	Post-1979 Fuel oil NE-EUI (kbtu/ft^2)
Mobile home	52.56	22.90	NA*	NA
Single-family detached house	24.53	18.00	18.87	7.23
Single-family attached house	42.56	32.38	NA	NA
Apartment building with 2-4 units	27.84	42.27	NA	NA
Apartment building with 5 or more units	17.21	30.85	NA	NA

APPLICATION: INVERSE MODELING

- Indianapolis Hestia compared to atmospheric CO_2 inversion (Lauvaux et al., 2016)
- Biotic respiration prior to persistent ground freeze explains majority of difference



FINAL REMARKS

- Vulcan v3.0 (national) data product to be published soon
  - Gridded down to 1km
  - Hourly available on request

Please contact Gurney group for data requests and re-gridding!

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- Hestia available for select cities
  - Indianapolis
  - Salt Lake City
  - Baltimore
  - LA (accepted)
  - Melbourne, Australia (ongoing)
  - Virginia-PA corridor (ongoing)