A41C-0045

Development of a US Carbon Dioxide Emission Inventory with High Spatial and Temporal Resolution

Gregory Frost*[1,2], Gabrielle Pétron[2,3], Stuart McKeen[1,2], Shannon Capps[1,4], and Michael Trainer[1]

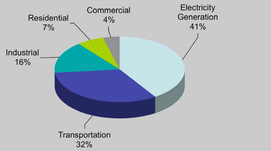
[1]NOAA Earth System Research Laboratory, Chemical Sciences Division, Boulder, Colorado
[3]NOAA Earth System Research Laboratory, Global Monitoring Division, Boulder, Colorado
[2]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado
[4]NOAA Hollings Scholar, Vanderbilt University, Nashville, Tennessee

*E-mail address: **Gregory.J.Frost@noaa.gov**

Abstract

Power generation and transportation are responsible for about 40 percent and 33 percent, respectively, of the CO_2 generated from US fossil fuel combustion. We are developing a US CO_2 emission inventory of the power generation and on-road motor vehicle sectors that incorporates the high spatial and temporal resolution available in a variety of data sets. CO_2 emission data with up to hourly resolution are measured by continuous emission monitors installed at most US power generation facilities. CO_2 emissions from on-road motor vehicles are determined from 1999 Federal Highway Administration statistics on gasoline and diesel sales in every US state. These statewide data are spatially allocated to 4-km resolution using the EPA's National Emission Inventory 1999 estimates of NO_x and CO emissions from on-road gasoline and diesel combustion. The inventory incorporating these highly resolved components is compared with other available bottom-up estimates of CO_2 sources for the US. Comparisons are also made between this inventory and atmospheric measurements made during the past decade.

1999 US Fossil Fuel CO_2 Emissions



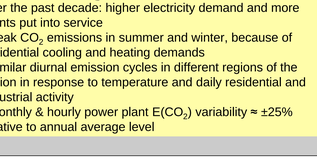
Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2004, US Environmental Protection Agency, Rep. No. 430-R-06-002, 2006

CO_2 Emissions from Power Plants

Continuous **E**mission **M**onitoring **S**ystems
- Direct observations of point source emissions made by utility companies
- Hourly NO_x, SO_2, and CO_2 emissions and heat input
- Reported quarterly to EPA Clean Air Markets Division
- Data for 966 facilities in 1999 and 1427 facilities in 2004
- Most sources: electric power generation, co-generation with other industry

Extracting CEMS Data using the EPA's Clean Air Markets Query Wizard

http://cfpub.epa.gov/gdm/index.cfm?fuseaction=emissions.wizard
- Useful web tool to extract and aggregate CEMS data
- User specifies:
  - Unit or monitoring level
  - Time aggregation period
  - Year
  - Emissions aggregation level
  - Output fields
  - View or download reports



Spatial Distribution of Power Plant E(CO_2)

Annual Power Plant E(CO_2) Variability

Monthly Power Plant E(CO_2) Variability

Hourly Power Plant E(CO_2) Variability

Power Plant CO_2 Emission Characteristics
- CEMS provide direct observations of power plant CO_2 emissions
- CEMS data have hourly frequency and are available from 1980 through previous calendar quarter
- ➢Analysis of temporal variability of power plant emissions
  - Power plants are large CO_2 sources
  - About one-third of all power plant CO_2 is emitted in 6-state region including the Ohio River Valley
  - US power plant CO_2 emissions have increased somewhat over the past decade: higher electricity demand and more plants put into service
  - Peak CO_2 emissions in summer and winter, because of residential cooling and heating demands
  - Similar diurnal emission cycles in different regions of the nation in response to temperature and daily residential and industrial activity
  - Monthly & hourly power plant E(CO_2) variability ≈ ±25% relative to annual average level

CO_2 Emissions from On-road Mobile Sources

Building the NOAA-NEI On-Road CO_2 Inventory

1. On-road Fuel Use by State
- 1999 US Dept of Transportation's Federal Highway Administration statistics
- Gasoline, diesel, and ethanol sales for highway use in every state
- Monthly breakdown
- Ethanol use and emissions by state are not shown because of small contribution to total

2. On-road CO_2 Emissions by State
- Use US Dept of Energy's Energy Information Administration conversion factors for gasoline, diesel, and ethanol
- Convert state on-road fuel use to CO_2 emissions
- From monthly use breakdown, calculate emissions for summer ozone season (May-Sept)
- Report as summer ozone season daily average

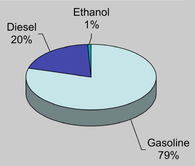
3. On-road NO_x Emissions by State
- US Environmental Protection Agency's 1999 National Emission Inventory (NEI99)
- NO_x emissions from on-road combustion of gasoline and diesel
- Estimate additional NO_x emissions from ethanol combustion from fractional ethanol/gasoline use
- Use ozone season average daily NO_x emissions
- Sum up by state (continental US only)

4. On-road CO_2/NO_x Mass Emission Ratios by State
- Combine data from steps 1-3 above to obtain state-level mass emission ratios of gasoline, diesel, and ethanol for an average ozone season day

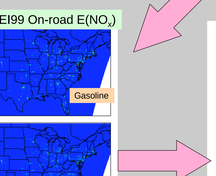
5. On-road CO_2 Emissions on 4x4 km² Grid
- Use state-level mass emission ratios from step 4 above to scale NEI99 on-road NO_x emissions gridded at 4x4 km² resolution
- Result is ozone season daily average on-road CO_2 emissions gridded at 4x4 km² resolution
- Calculate gridded total on-road CO_2 emissions and contributions from gasoline, diesel, and ethanol combustion

1999 US Totals

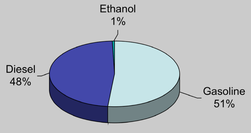
Fuel Use = 1.607x10^{11} gallons/year



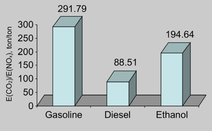
CO_2 Emissions = 4.55x10^6 tons CO_2/day



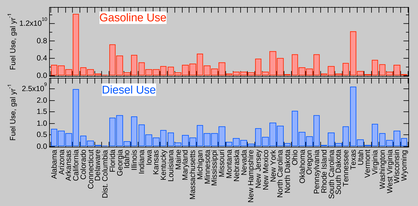
NO_x Emissions = 2.34 x10^4 tons NO_2/day

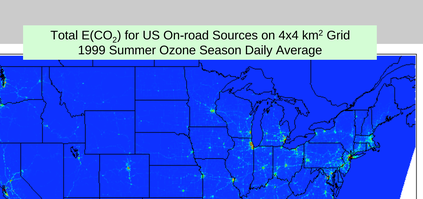


Overall US CO_2/NO_x by mass = 195



1999 State Totals





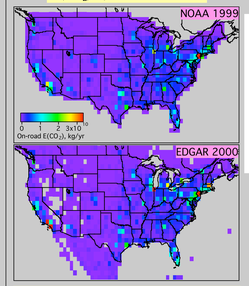
4x4 km² NEI99 On-road E(NO_x)

Total E(CO_2) for US On-road Sources on 4x4 km² Grid
1999 Summer Ozone Season Daily Average

Validation of NOAA-NEI On-Road Inventory

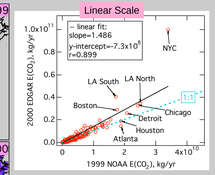
Comparisons between NOAA and EDGAR On-road Inventories

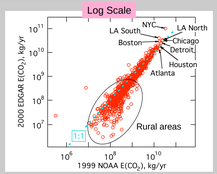
E(CO_2) Spatial Distribution



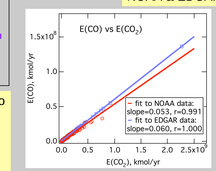
- Reduce resolution of 1999 NOAA EI to 1°x1° and convert to annual totals
- Compare to 1°x1° EDGAR 3.2 FastTrack 2000 Road Transport data
- Exclude grid cells with EDGAR Canadian & Mexican sources

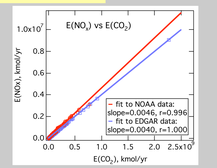
EDGAR vs NOAA E(CO_2)

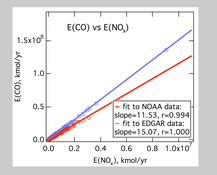




NOAA & EDGAR Emission Ratios

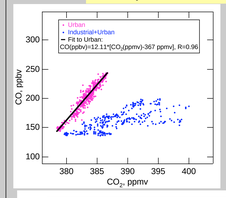


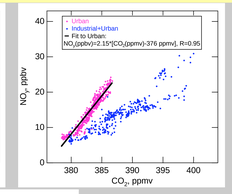


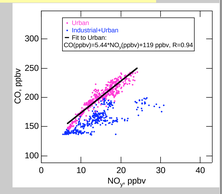


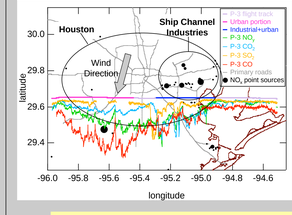
- Total US on-road E(CO_2):
  - NOAA 1999 = 1399 Tg CO_2/yr
  - EDGAR 2000 = 1504 Tg CO_2/yr
  - Δ = 7.5%
- EDGAR generally higher than NOAA EI in urban areas, while EDGAR rural emissions smaller than NOAA
  - ➢EDGAR distributed using population only, misses emission controls
  - ➢NOAA uses NEI99 road surrogates to spatially distribute emissions and incorporates information on vehicle emission controls
- Both inventories give similar emission ratios for on-road sources

Example of Emission Ratio Observations: NOAA P-3 in Houston









- 20 minutes of NOAA P-3 aircraft data from the Texas Air Quality Study (26 Sept 2006, 13:00 CDT, 400-500 m altitude)
- NO_y, CO, CO_2, and SO_2 observations with 1-sec frequency
- NO_y = NO_x + HNO_3 + organic nitrates + other reactive N; changes in NO_y along flight track reflect changes in E(NO_x)

- Can distinguish plumes from predominantly urban (mobile) sources and mixtures of industrial and urban sources
- Houston urban/mobile sources show higher CO/CO_2, NO_y/CO_2, and CO/NO_y emission ratios than industrial sources in the Houston Ship Channel

Comparison of Observed and Inventory Emission Ratios in Urban Areas

	Data	Location	Year	CO/CO_2	NO_y/CO_2	CO/NO_x
Observational	NOAA P-3	Houston	2000			6.1
	NOAA P-3	Los Angeles	2002	0.021	0.0027	7.6
	NOAA P-3	Houston	2006	0.012	0.0022	5.4
	NOAA P-3	Dallas	2006	0.010	0.0020	4.6
	Fuel-based	Nashville	1995			8.4
	Fuel-based	Denver	1996-2001	0.018-0.044		5.8-7.8
Inventory	EDGAR	US average	2000	0.060	0.0040	15.1
	NOAA/NEI	US average	1999	0.053	0.0046	11.5
	NOAA/NEI	Houston	1999	0.049	0.0046	10.6
	NOAA/NEI	Dallas	1999	0.049	0.0046	10.6

Emission ratios in units of mole/mole.
NOAA P-3: NOAA Aeronomy Lab/ESRL Chemical Sciences Division observations made on the NOAA P-3 aircraft during 2000 and 2006 Texas Air Quality Studies and 2002 ITCT Study. NO_y ambient data used to extract NO_x emissions. Data taken near midday on weekdays (May-Sept). Fuel-based: Used roadway observations to derive vehicle emission factors and a fuel-based approach to calculate mobile emissions across an urban area. See Harley et al., *JGR*, 2001 (Nashville), and Pokharel et al., *Atmos. Environ.*, 2002 (Denver).

- Compare emission ratios derived from ambient observations in urban areas with bottom-up inventory estimates from on-road sources.
- Observed CO and NO_y emissions are lower than those in inventory:
  - CO/CO_2: 1-4% vs 5-6%
  - NO_y/CO_2 = 0.2-0.3% vs 0.4-0.5%
  - CO/NO_x = 5-8 vs 10-15
- Differences between observations and inventories appear larger than yearly decreases resulting from addition of cleaner vehicles to fleet.