Aircraft Measurements of Air Pollut
Greenhouse Gases

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Air Quality & Greenhouse Gas (GHG) Emissions

Air Quality

Significant economic burden and health effects of poor air quality

Air pollution is controlled by complex chemistry, emissions, and meteorology.

Aircraft measurements of air pollution

- ❑ To measure local chemical/physical conditions during air pollution events;
- ❑ To perform data analysis and model evaluations
- ❑ To test air pollution control strategies for the non-attainment areas

GHG Emissions

~70% of the anthropogenic GHG emissions are from urban areas.

Quantification of GHG emissions is important to provide policy relevant science for mitigating GHGs.

Aircraft Measurements of GHGs

- ❑ To determine emissions and sources of GHGs from urban areas
- ❑ To evaluate existing emission inventories of GHGs
- ❑ To investigate long-term trends of GHG emissions and the impact of meteorology and social/economic drivers

Goals:

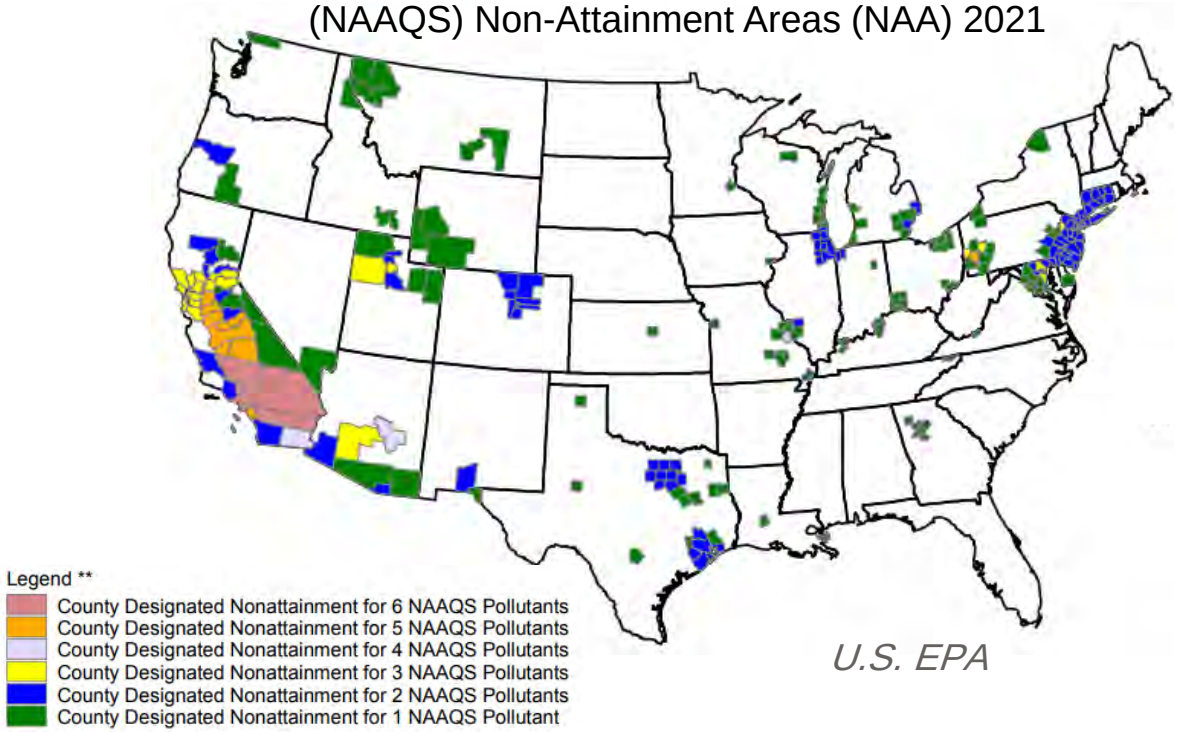
- ➢ To improve the understanding of emissions, air quality, and the interaction of meteorology and chemistry.
- ➢ To provide evidence-based guidance to decision makers through the analysis of in-situ measurements.

Relevance: Policy Relevant Science for Air Quality & GHG Mitigation

NOAA vision area: Reducing societal impacts from hazardous weather and other environmental phenomena

- Detect changes in the ocean and atmosphere
- Make Forecasts better
- Drive innovative science

U.S. National Ambient Air Quality Standards (NAAQS) Non-Attainment Areas (NAA) 2021



U.S. EPA

NOAA Climate Research:

To provide data, tools, and information to help people understand and prepare for climate variability and change.

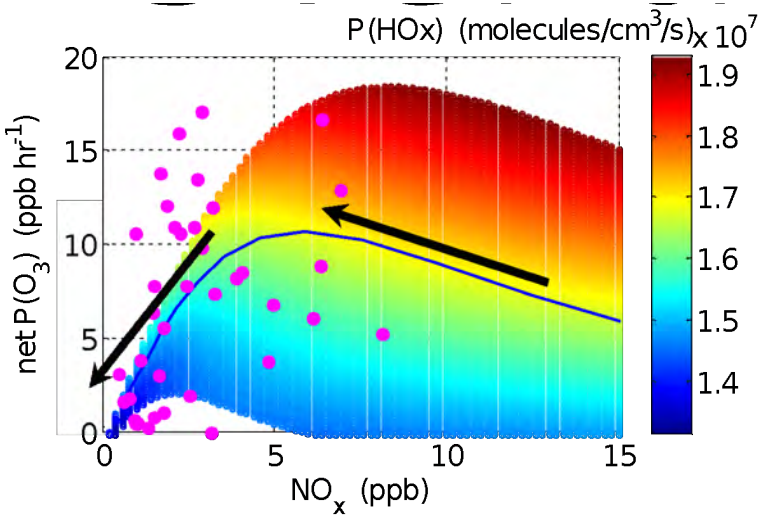
COP26: Glasgow Climate Pact

- Carbon emissions will have to fall by 45 percent by 2030 to reach the 1.5°C goal.
- Global Methane Pledge: To cut 30 percent of methane emissions by 2030
  - Methane dissipates more quickly but 84 times more potent than carbon dioxide over a twenty-year period, i.e., quick temperature benefits with methane emission reduction.
  - Larger cuts in methane emissions are achievable with current technologies.
  - More ambition is needed to help limit warming to 1.5°C.

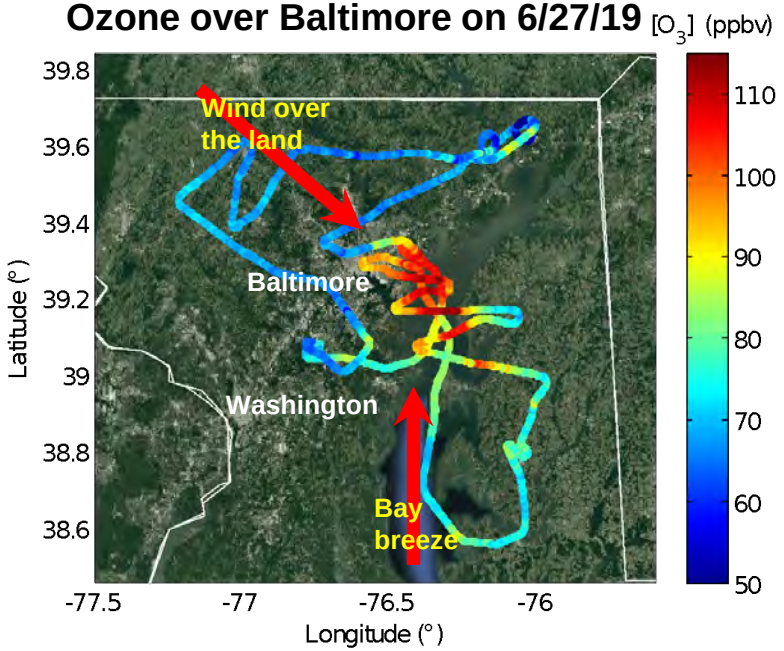
Editorial, Methane Matters, Nature Geosci., 2021

Summer Flights Focusing on Ozone and PM

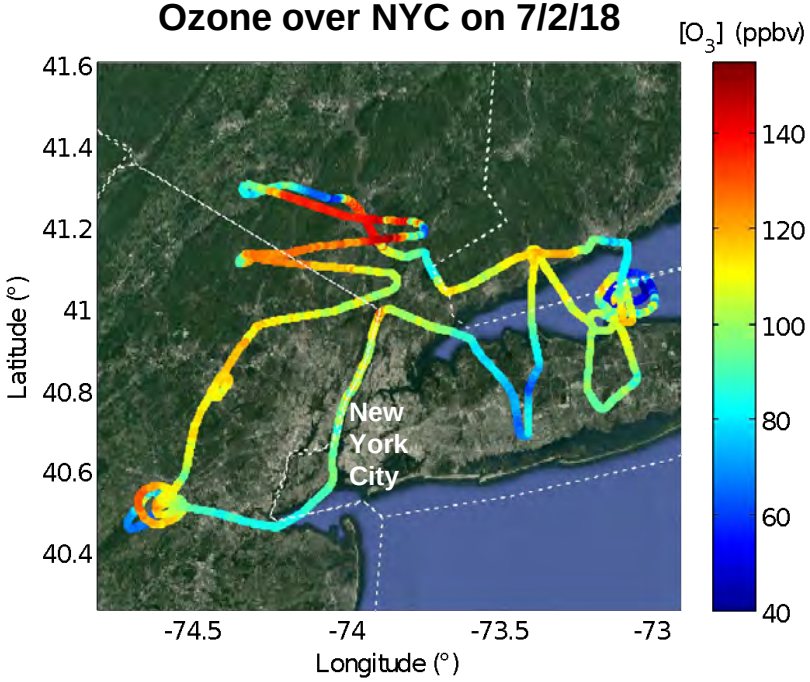
Cessna 402 Research Aircraft



Ozone over Baltimore on 6/27/19



Ozone over NYC on 7/2/18

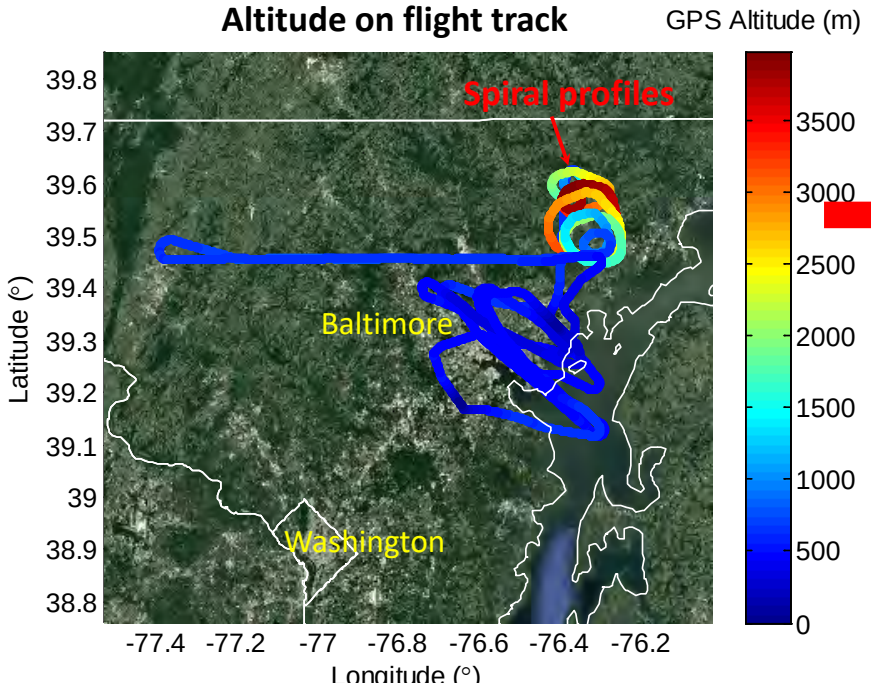


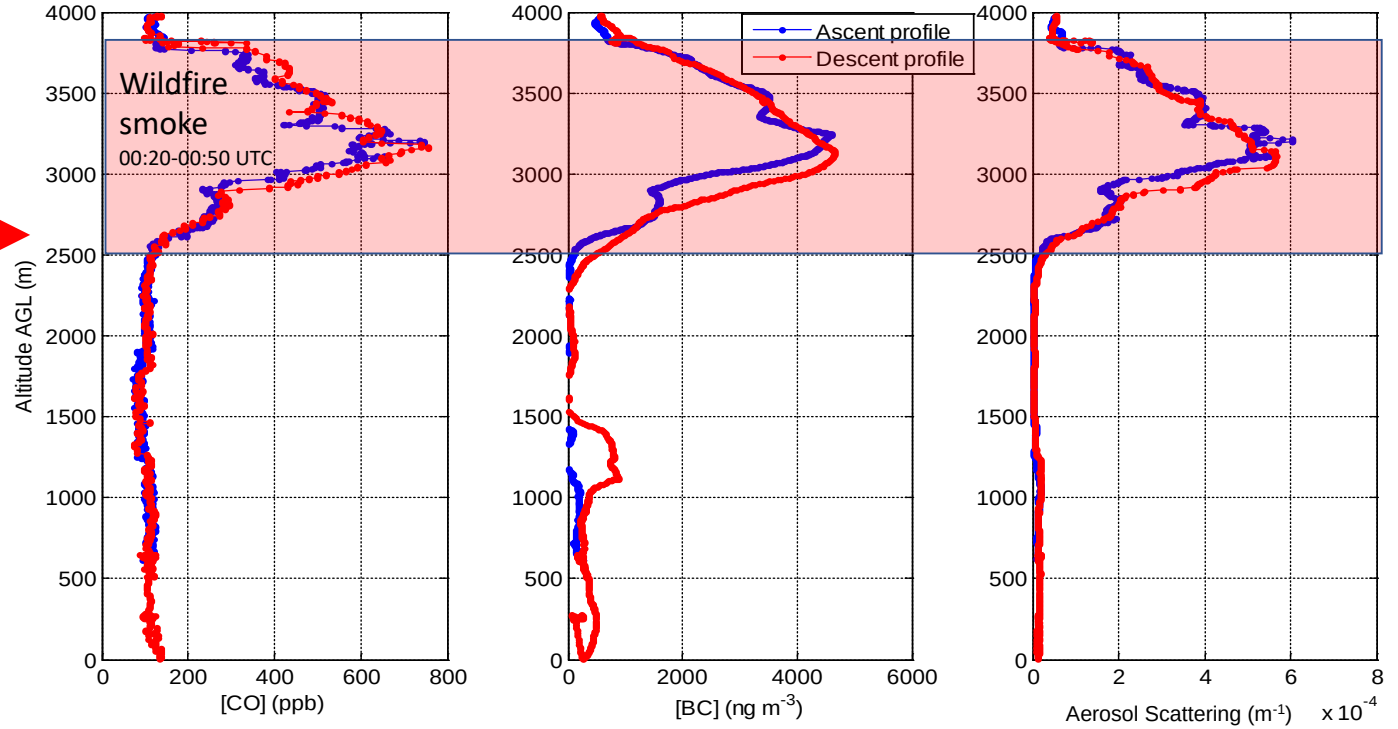
- In general, WNW wind over the land
- SSE bay breeze observed over the Bay
- Convergence over east of Baltimore

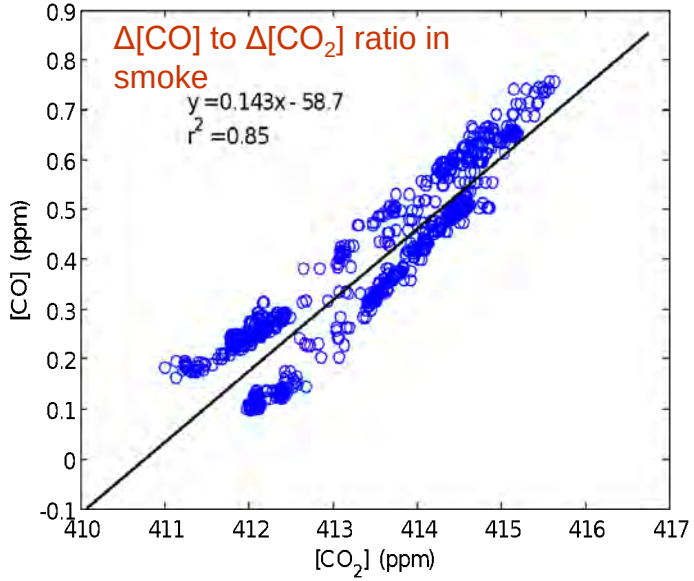
Max. 1 min [O$_3$] ~ 150 ppb to the north of NYC.
Worst air quality in a decade.

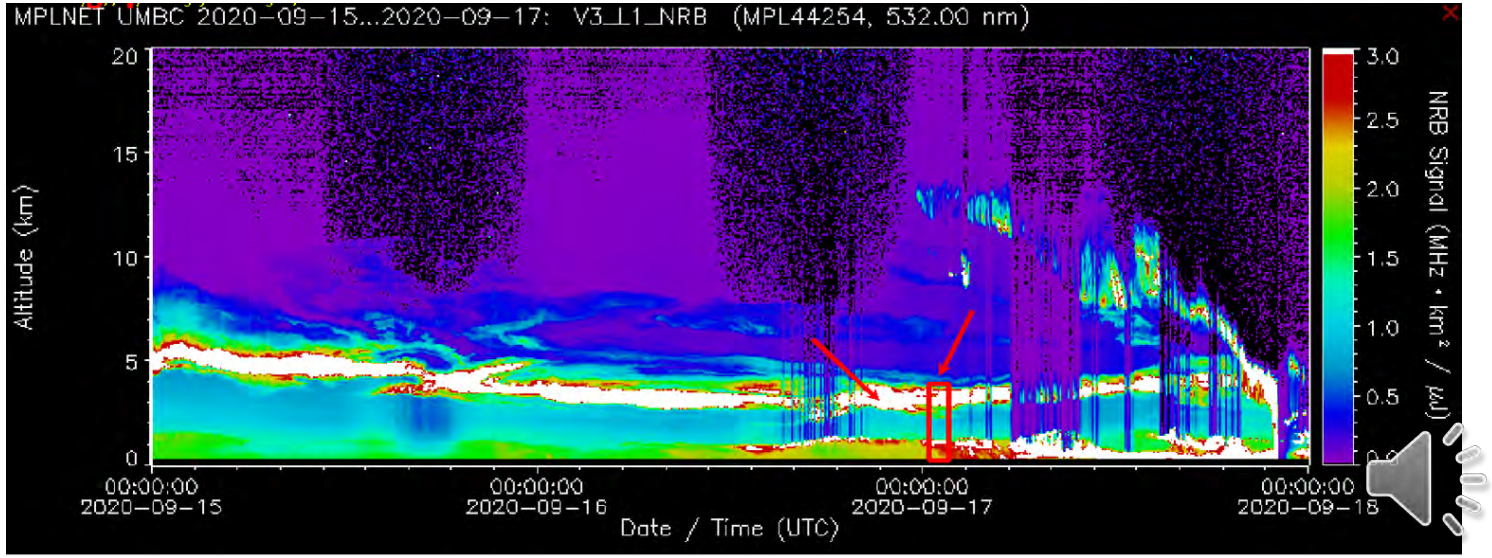
To improve our understanding of three key components: emissions, meteorology, and chemistry for the formation of air pollution

West Coast Wildfire Smoke Observed on 9/16/2020



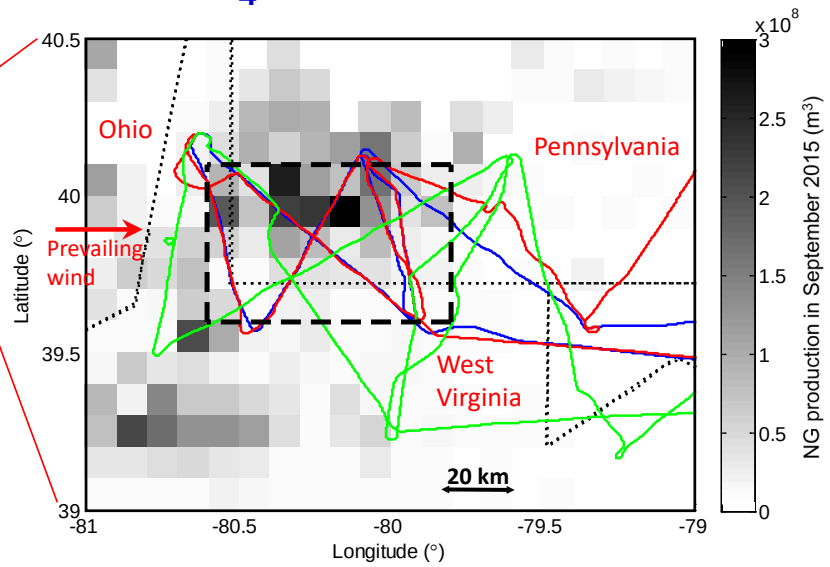






Mass Balance and Inversion to Estimate O&NG CH_4 Emissions

Aircraft observations of CH_4 over the SW Marcellus



Ren et al., JGR, 2019

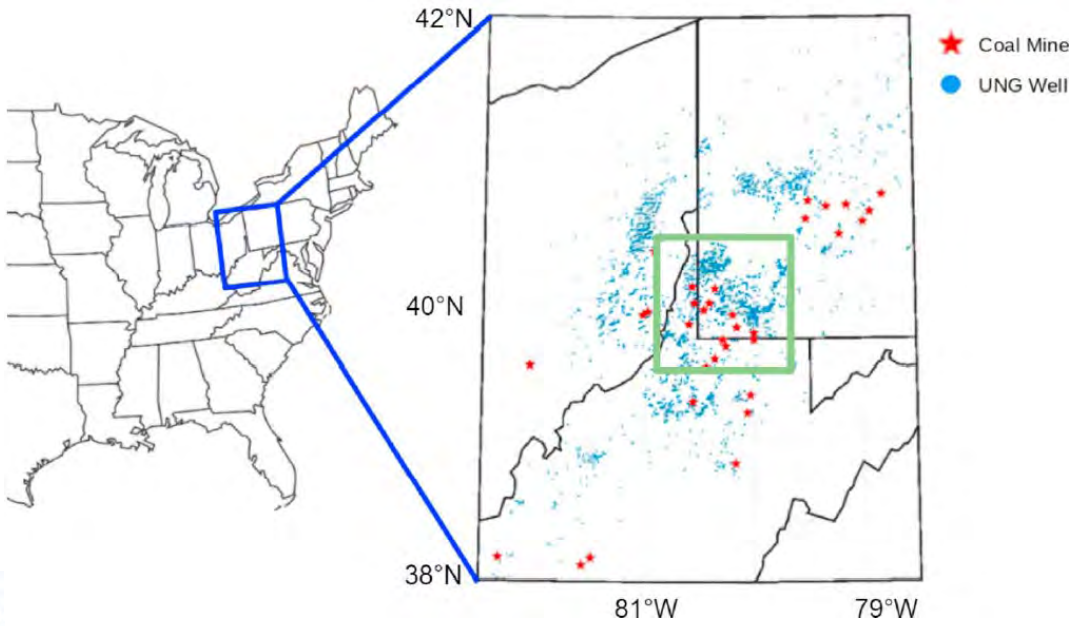
Table 4

Methane Emission Rates From Different Sources and Derived Emission Rate as Fraction of Total Natural Gas Production in the Surveyed Marcellus Shale Area in Southwestern Pennsylvania and Northern West Virginia

Flight date	Obs. CH_4 E. R.[a] (kg/s)	Coal mining CH_4 E.R.[a] (kg/s)	NG distrib. CH_4 E.R.[a] (kg/s)	Enteric ferment. CH_4 E.R.[a] (kg/s)	Landfills CH_4 E.R.[a] (kg/s)	O&NG CH_4 E.R. (kg/s)	NG prod[b] (m^3/s)	CH_4 emission rate (% of NG prod.)
8/25/2015	23.44 ± 7.74	15.04 ± 2.26	0.09 ± 0.03	0.06 ± 0.01	0.03 ± 0.02	$8.21^{+10.76}_{-8.21}$	918.1	$1.50^{+1.97}_{-1.50}$%
8/29/2015	20.52 ± 6.77	15.04 ± 2.26	0.09 ± 0.03	0.06 ± 0.01	0.03 ± 0.02	$5.30^{+9.71}_{-5.30}$	918.1	$0.97^{+1.78}_{-0.97}$%
9/14/2015	19.66 ± 6.48	15.04 ± 2.26	0.09 ± 0.03	0.06 ± 0.01	0.03 ± 0.02	$4.43^{+9.40}_{-4.43}$	956.5	$0.78^{+1.65}_{-0.78}$%

- A mean CH_4 emission rate of 1.1% (0-3.5%) of total production of natural gas.

CH_4 inversion based on aircraft observations

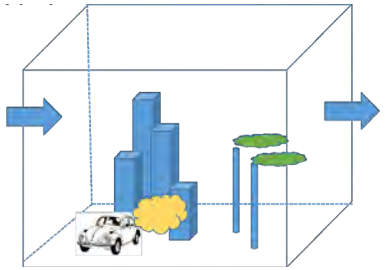


- CH_4 emissions from unconventional natural gas (UNG) were underreported in the region by a factor of 5 (±3).
- CH_4 emissions from UNG sources: 0.5 ± 0.3% of production.

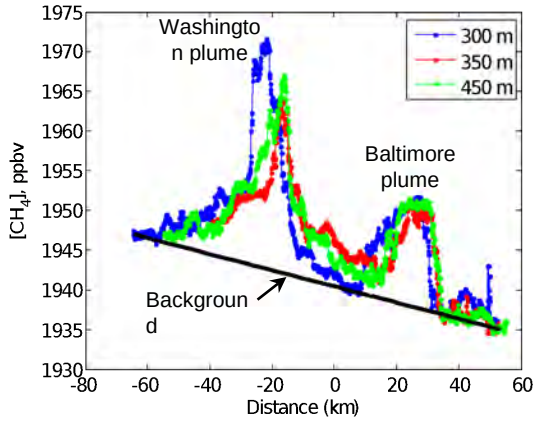
Barkley et al., GRL, 2019

Mass Balance Flights to Estimate Urban GHG Emissions

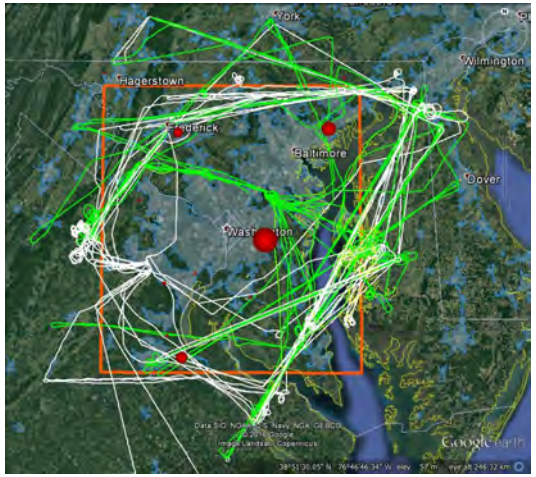
Mass balance approach

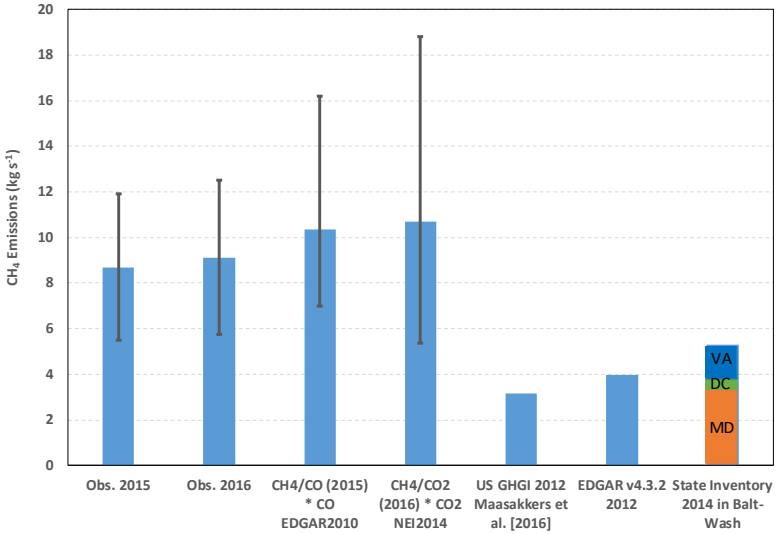


$$E.R_{\cdot CH_4} = \int_0^{z_i} \int_{-x}^{+x} ([C] - [C]_b) \times U_\perp \, dx dz$$



CH_4 emissions from DC- Baltimore

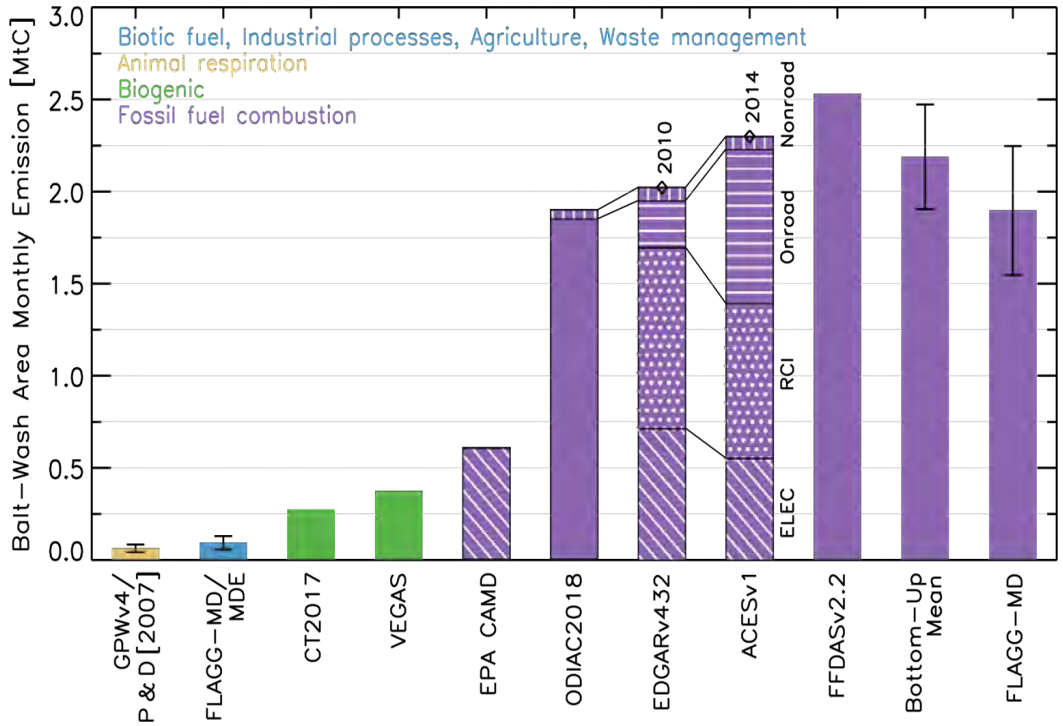




The national inventory underestimates CH_4 emissions for this area by factors of 2.8.

Ren et al., JGR, 2018

CO_2 emissions from DC- Baltimore

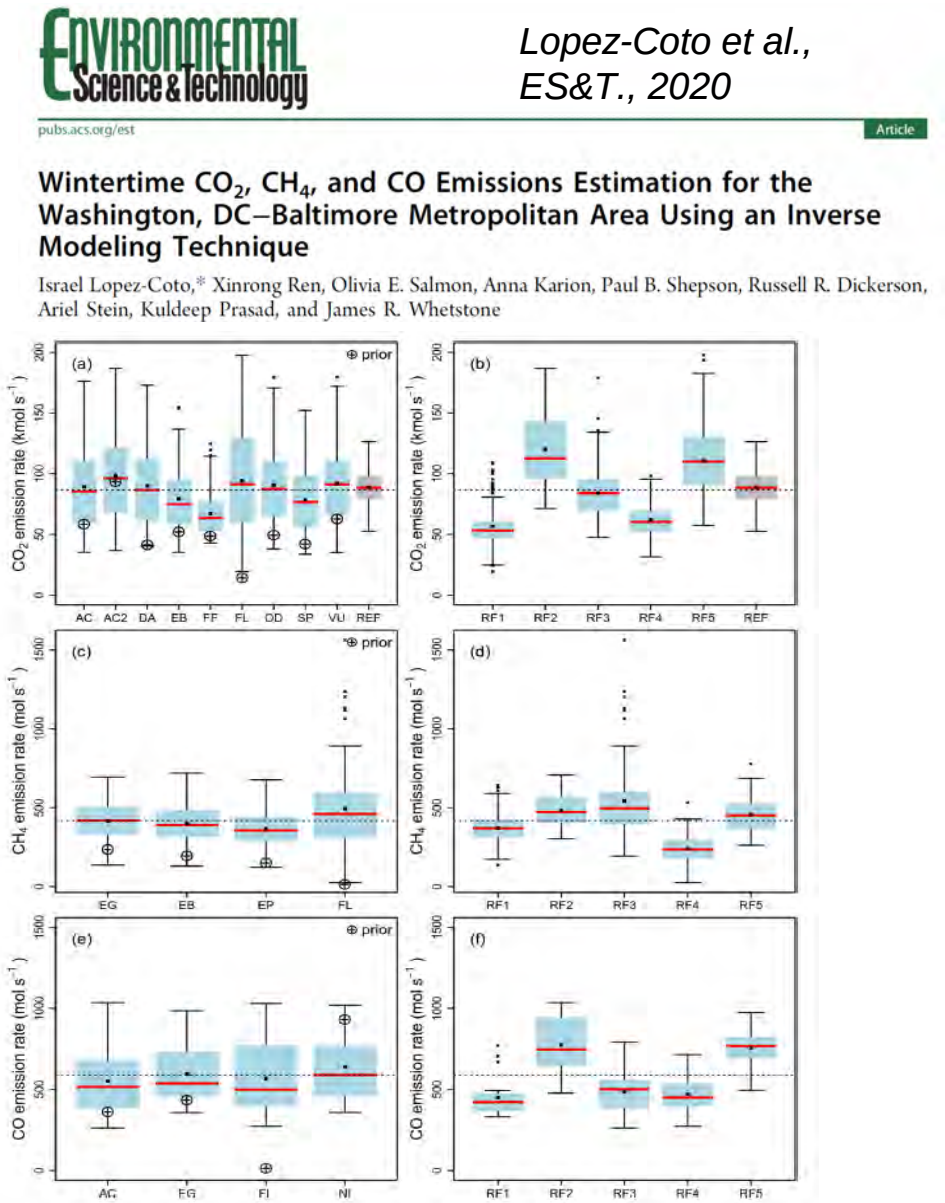


- 1.9 ± 0.3 MtC of fossil fuel CO_2 ($FFCO_2$) emissions from the Balt-Wash area during the month of February 2015 are in a good agreement with the mean estimate of $FFCO_2$ from the four bottom-up models.

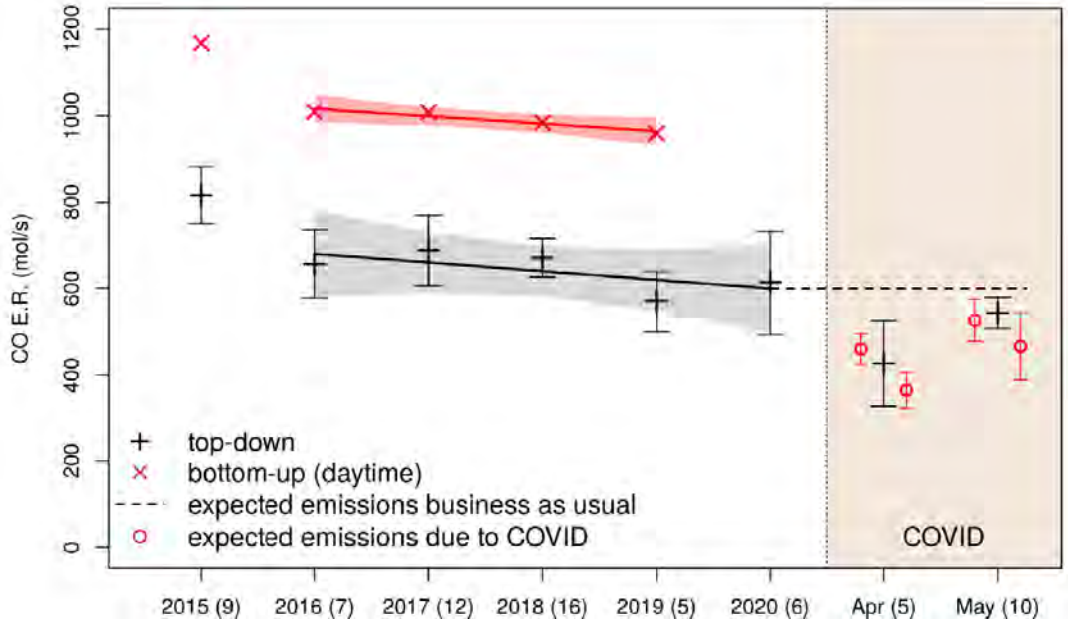
Ahn et al., JGR, 2020

Inversion Modeling to Estimate Urban GHG Emissions and Trends

Lopez-Coto et al., ES&T., 2020



Trend of CO emissions from DC- Baltimore



- CO emissions have been declining in the area at a rate of $-4.5\ \%\ yr^{-1}$ since 2015.
- The trend derived from the NEI agrees well with the observed trend.
- A significant drop in CO emissions driven mainly by a reduction in traffic.

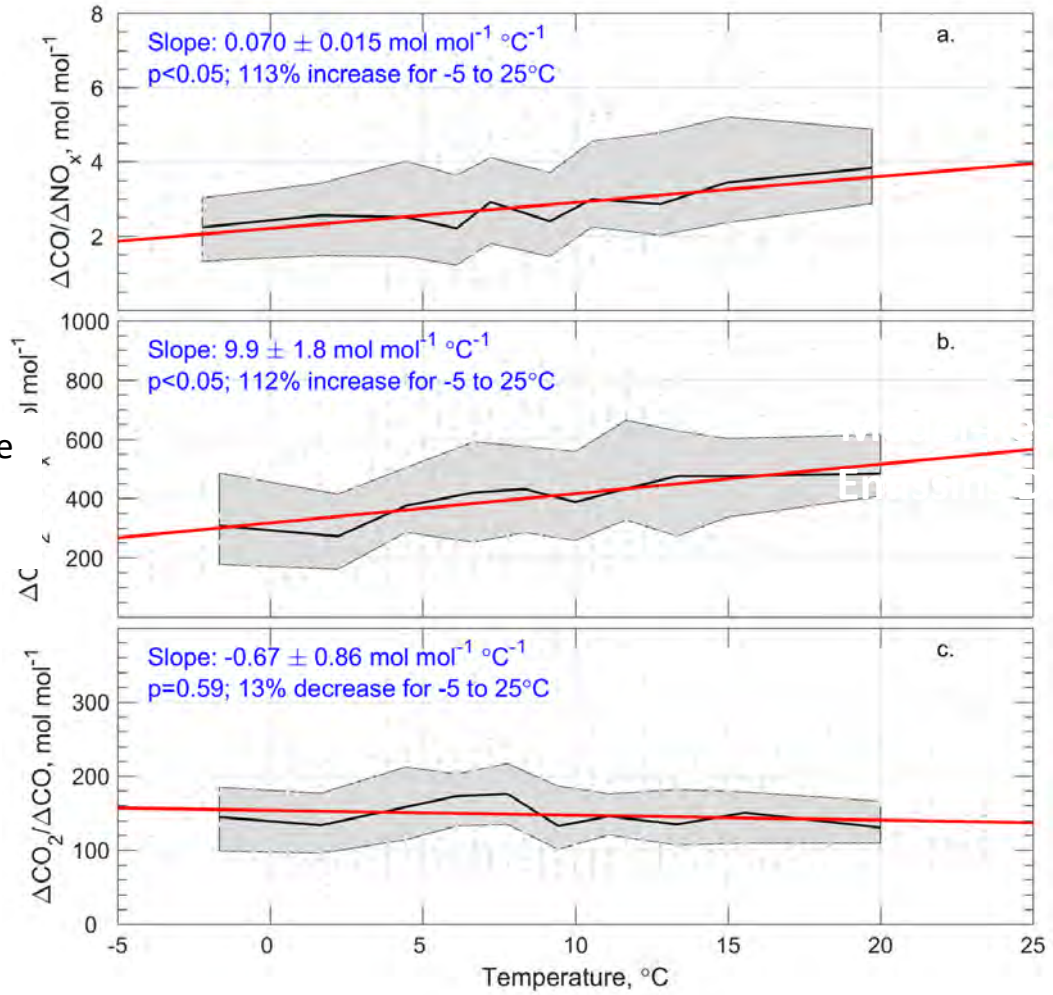
Lopez-Coto et al., ES&T., under review, 2021

Surface Observations to Evaluate Emissions

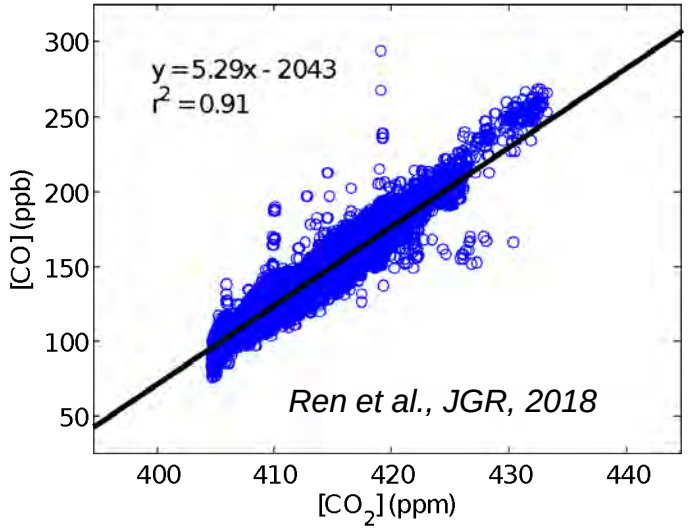
I-95 near-road site btw DC & Baltimore

EPA MOVES model over-estimate NOx emissions from the mobile sector at high temperature.

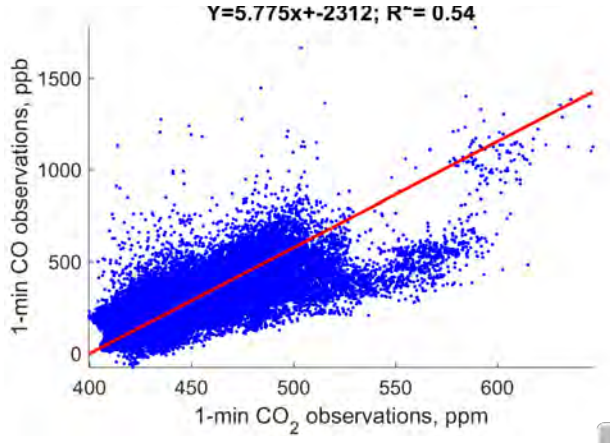
Hall et al., Atmos. Environ., 2019



Aircraft observations, February 2016



I-95 near roadside observations, February 2016



Aircraft & near-road site observed a similar ΔCO/ΔCO$_2$.

Quality and Performance

Publications

1. Brune et al., Extreme oxidant amounts produced by lightning in storm clouds, *Science*, 372, 711-715, 2021.
2. Caicedo et al., Observations of bay-breeze and ozone events over a marine site during the OWLETS-2 campaign, *Atmos. Environ.*, 263, 118669, 2021
3. Coggon et al., Volatile chemical product emissions enhance ozone and modulate urban chemistry, *PNAS*, 118, e2026653118, 2021.
4. Wu et al., Synergistic aircraft and ground observations of transported wildfire smoke and its impacts on air quality in New York City during the summer 2018 LISTOS campaign, *Sci. Total Environ.*, 773, 145030, 2021.
5. Hall et al., Using ambient observations of CO and NOy to infer emissions from vehicles: Evidence for a strong temperature dependence, *Atmos. Environ.*, 232, 117558, 2020.
6. Ahn et al., Fluxes of Atmospheric Greenhouse-Gases in Maryland (FLAGG-MD): Emissions of Carbon Dioxide in the Baltimore-Washington area, *Geophys. Res.– Atmos.*, 125, e2019JD032004, 2020.
7. Lopez-Coto et al., Wintertime CO_2, CH_4 and CO emissions estimation for the Washington DC/Baltimore metro area using an inverse modeling technique, *Environ. Sci. Technol.*, 54 (5), 2606-2614, 2020.
8. Ren, et al., Methane emissions from the Marcellus Shale in southwestern Pennsylvania and northern West Virginia Based on Airborne Measurements, *J. Geophys. Res. – Atmos.*, 124, 1862–1878, 2019.
9. Barkley et al., Estimating methane emissions from underground coal and natural gas production in southwestern Pennsylvania, *Geophys. Res. Lett.*, 46, 4531–4540, 2019.
10. Ren et al., Methane emissions from the Baltimore-Washington area based on airborne observations: Comparison to emissions inventories, *J. Geophys. Res. – Atmos.*, 123, 8869–8882, 2018.
11. Salmon et al., Top-down estimates of NOx and CO emissions from Washington, D.C.-Baltimore during WINTER, *J. Geophys. Res. – Atmos.*, 123, 7705–7724, 2018

Presentations (25)

Quality and Performance

Awards

NASA Group Achievement Award to OWLETS: For designing and executing and unprecedented scientific investigation in the upper and lower Chesapeake Bay to understand the ozone pollution at the land-water interface: Barry Baker, Mark Cohen, Paul Kelly, Christopher Loughner, Winston Luke, and Xinrong Ren

Providing Policy-relevant Science to Policy Makers

Collaboration with state and federal environmental agencies to understand air pollution and GHG emissions

After the publication of Ren et al., JGR, 2018, we communicated with the Maryland Department of Environment to inform them **the state methane emission inventory for landfills may be lower by a factor of 2-3**.

The Washington Post

Md. landfills emit much more greenhouse gases than state estimated, environmentalists find

Simple arithmetic error led state to miscalculate total, Environmental Integrity Project says

Maryland has significantly underestimated the amount of potent greenhouse gases leaking from its landfills and should take immediate steps to remedy the problem, an environmental group said.

About 51,500 tons of methane escaped from the state's landfills in 2017, or more than four times the amount reported by the Maryland Department of the Environment ...

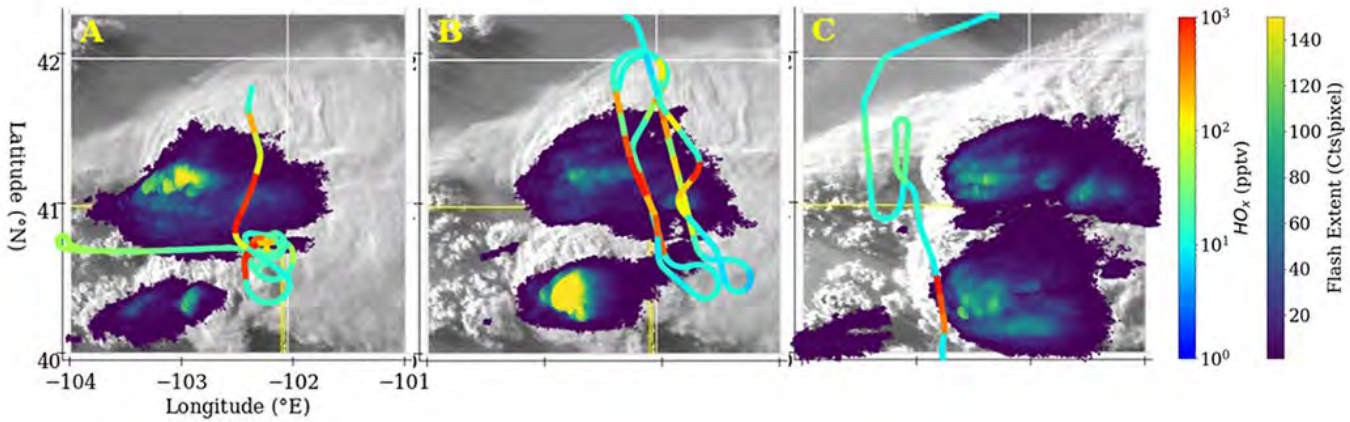
Quality and Performance

Collaborations

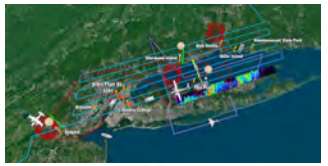
NOAA/CSL, NOAA/GML, NOAA/NESDIS, NIST, US EPA, University of Maryland, Maryland Department of Environment, Purdue University, Stony Brook University, City College of New York, Penn State University, University of Colorado Boulder, and University of Michigan

DC3
Deep Convective Clouds & Chemistry Experiment

Brune et al., Science, 2021

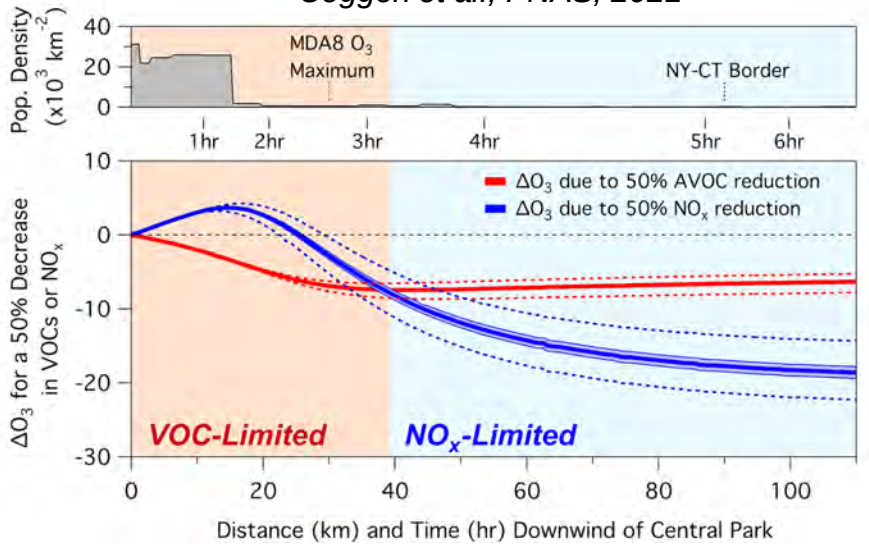


Lightning-generated OH can be responsible for substantial 2-16% of global atmospheric OH oxidation.



LISTOS
(Long Island Sound Tropospheric Ozone Study)

Coggon et al., PNAS, 2021



Volatile Chemical Products (VCP):

- are important to ozone production
- have impacts on key atmospheric processes.

Future Plans

Continued aircraft measurements of air pollutants and GHGs

- To help understand air pollution formation and improve air quality over the northeast US
- Mass balance estimate of urban GHG emissions with reduced uncertainties
- Inverse modeling based on aircraft and tower measurements to estimate urban GHG emissions

Surface measurements of air pollutants and GHGs

- GHG measurements in addition to existing air monitoring stations
- Mobile and remote sensing measurements of GHGs to characterize emissions of point sources (landfills, natural gas compression stations, etc.)

Continued efforts to provide policy-relevant science to decision makers

- Collaboration with Maryland Department of Environment to improve air quality and reduce GHG emissions in MD
- To work with regional (e.g., NESCAUM) and state environmental agencies in the Northeast U.S. to improve air quality and quantify GHG emissions

Different Air Quality in New York City on Two different days

Our aircraft measurements contribute to understand air pollution formation and GHG emissions in order to improve air quality and reduce GHG emissions in urban areas