The Northeast Corridor Urban Testbed

Advancing Urban Greenhouse Gas (GHG) Monitoring and Modeling

Anna Karion, Israel Lopez-Coto, Kimberly Mueller, Tyler Boyle, Julia Marrs, Annmarie Eldering, James Whetstone
+
Collaborators

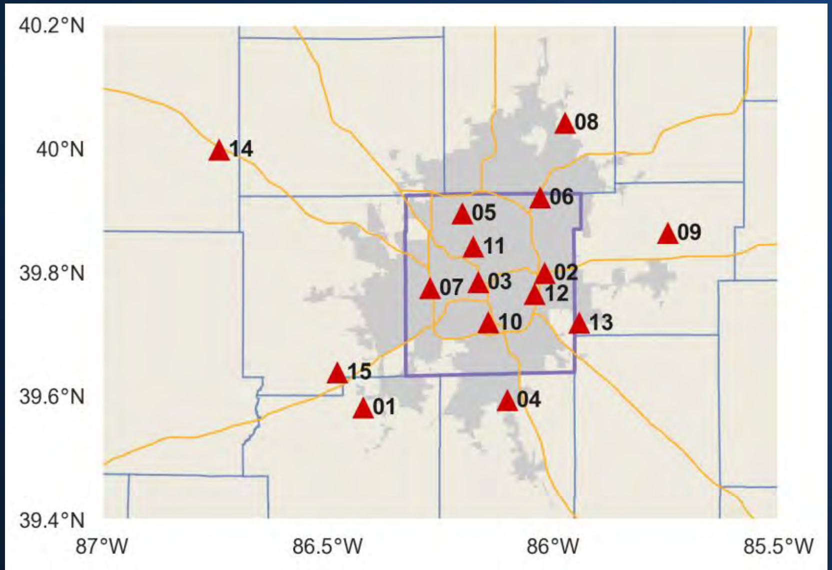
2025 AiRMAPS Coordination Workshop
September 3-4, 2024
College Park, MD

National Institute of Standards and Technology
U.S. Department of Commerce

1. Ongoing activities in Washington and Baltimore
    - Measurements/observations
    - Modeling
2. Lessons learned

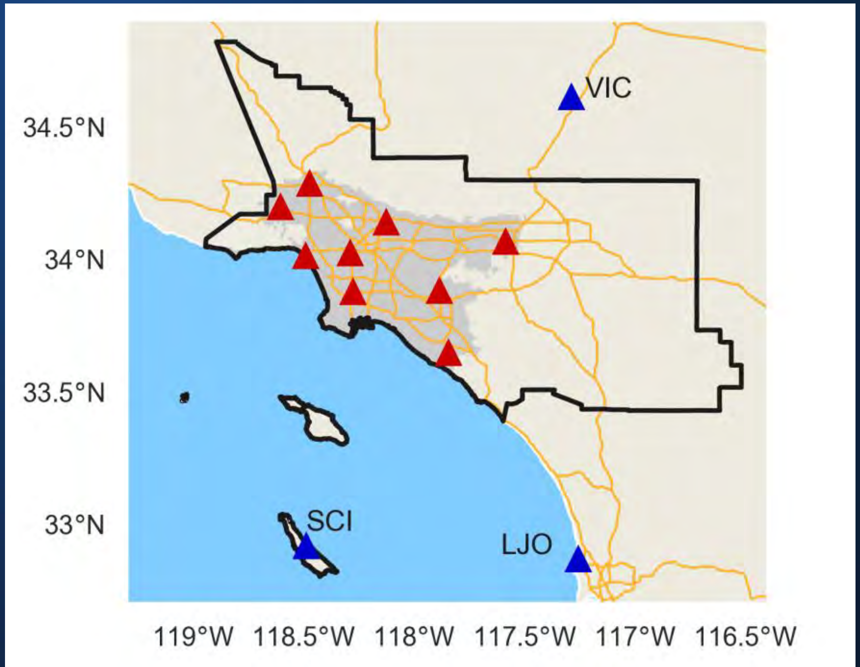
NIST's Three Urban Testbeds

Indianapolis



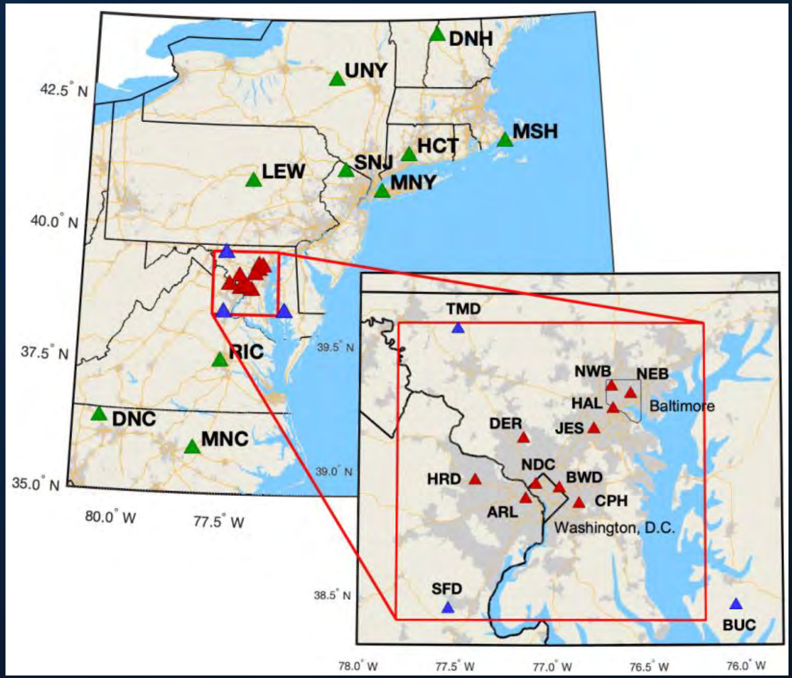
Penn State monitoring network

Los Angeles Megacity



- Scripps Institution of Oceanography
- Earth Networks
- NASA / Jet Propulsion Lab

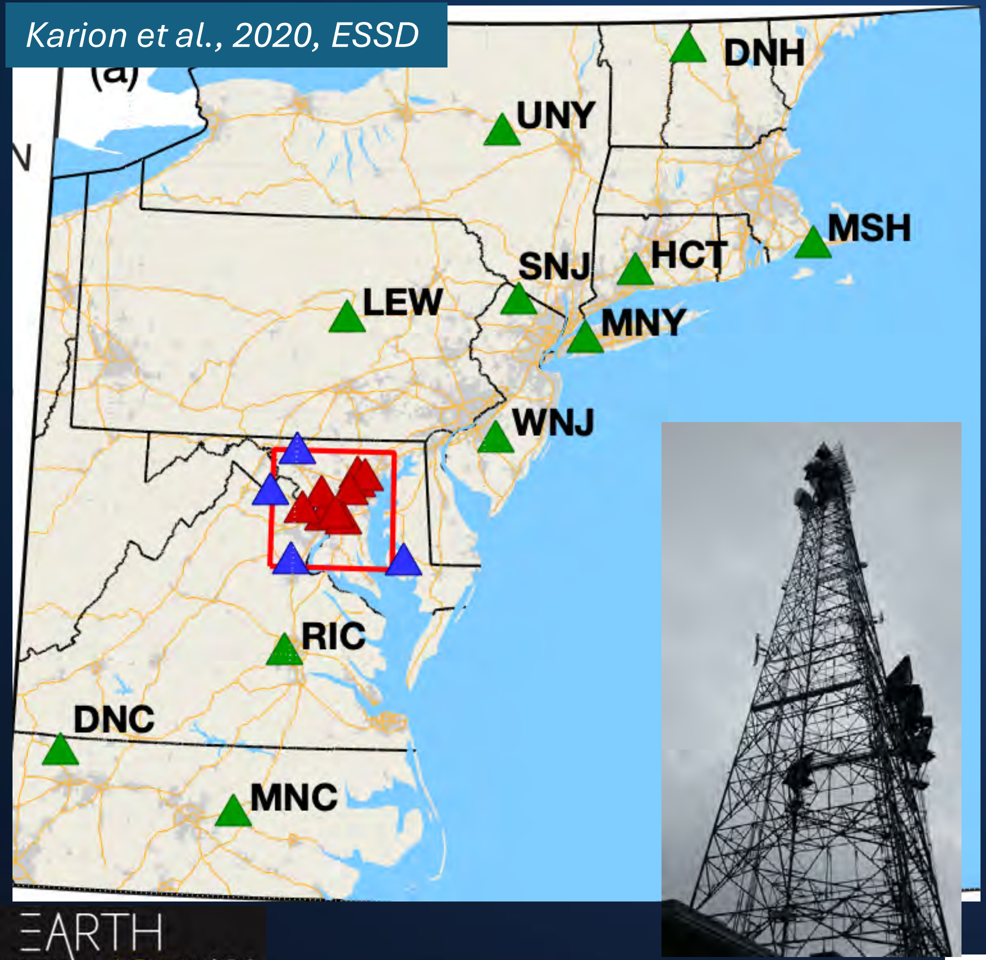
Northeast Corridor



- Earth Networks
- NIST

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

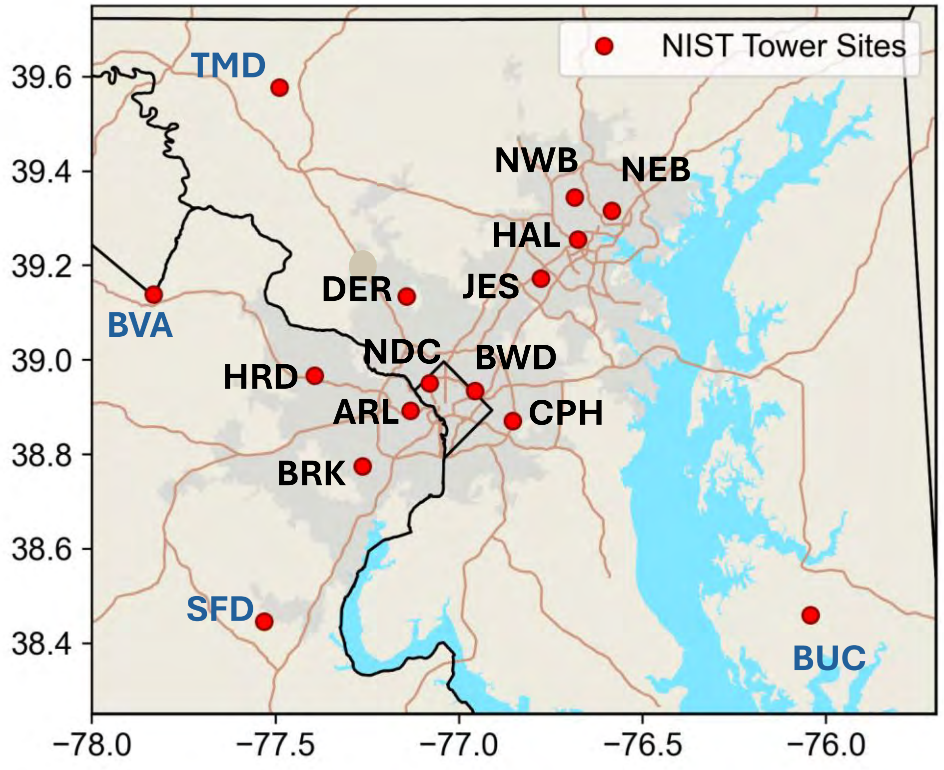
Northeast Corridor (NEC) Tower Network



- Instrumented communications towers with CRDS analyzers
- High-accuracy CO_2 / CH_4 / CO reported on WMO scales
- High density in the DC/Baltimore area
- Plans to extend to Philadelphia, NYC, Boston
- Include regional non-urban sites to characterize background (inflow) conditions
- NOAA/GML flasks for $^{14}CO_2$ & other gases to help characterize biosphere, attribute sources to economic sectors, etc.
- Data available at data.nist.gov and on the GHG Center
- https://doi.org/10.18434/mds2-3012

Karion, A., Callahan, W., Stock, M., Prinzivalli, S., Verhulst, K. R., Kim, J., Salameh, P. K., Lopez-Coto, I., and Whetstone, J.: Greenhouse gas observations from the Northeast Corridor tower network, Earth Syst. Sci. Data, 12, 699–717, https://doi.org/10.5194/essd-12-699-2020, 2020.

Northeast Corridor (NEC) Testbed
Washington/Baltimore focus region



1 (BG)	TMD	Thurmont, MD
2 (BG)	BVA	Bluemont, VA
3 (BG)	SFD	Stafford, VA
4 (BG)	BUC	Bucktown, MD (eastern shore)
5	NEB	Northeast Baltimore, MD
6	NWB	Northwest Baltimore, MD
7	HAL	Halethorpe, MD
8	JES	Jessup, MD
9	CPH	Capitol Heights, MD
10	BWD	Brentwood, MD
11	DER	Derwood, MD
12	NDC	Northwest Washington, DC
13	ARL	Arlington, VA
14	BRK	Burke, VA
15	HRD	Herndon, VA

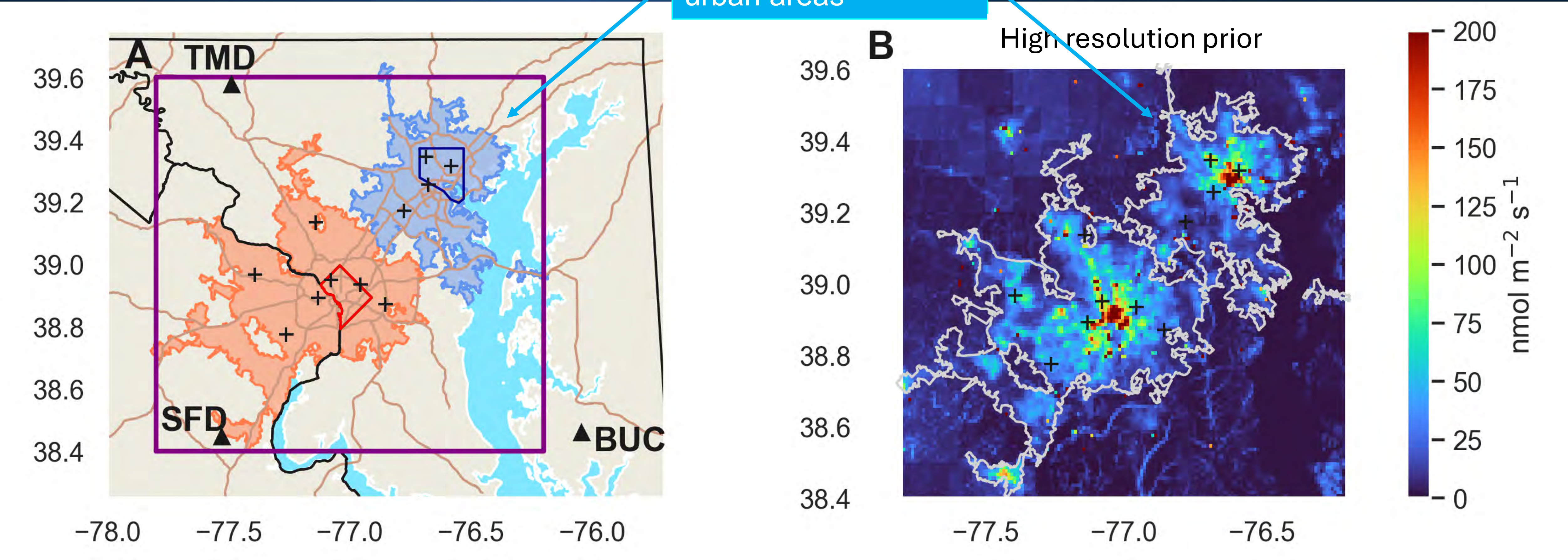
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Whole/sub-city CH_4 Emissions: Multi-year

Northeast Corridor

6 to 11 urban towers
3 background towers

Census-designated urban areas

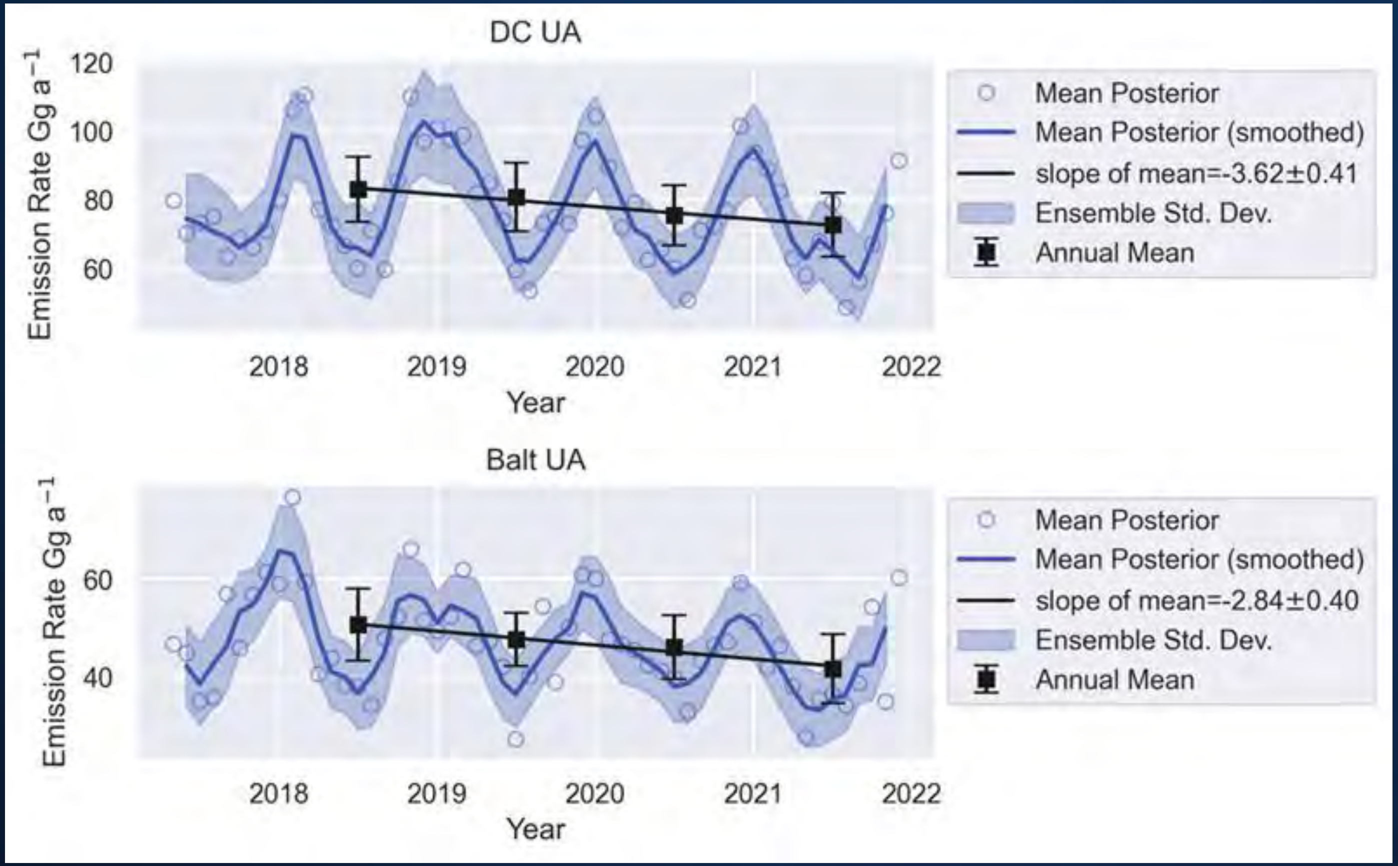


Karion, A., Ghosh, S., Lopez-Coto, I., Mueller, K., Gourdji, S., Pitt, J., and Whetstone, J.: Methane Emissions Show Recent Decline but Strong Seasonality in Two US Northeastern Cities, Environmental Science & Technology, 57, 19565-19574, 10.1021/acs.est.3c05050, 2023.

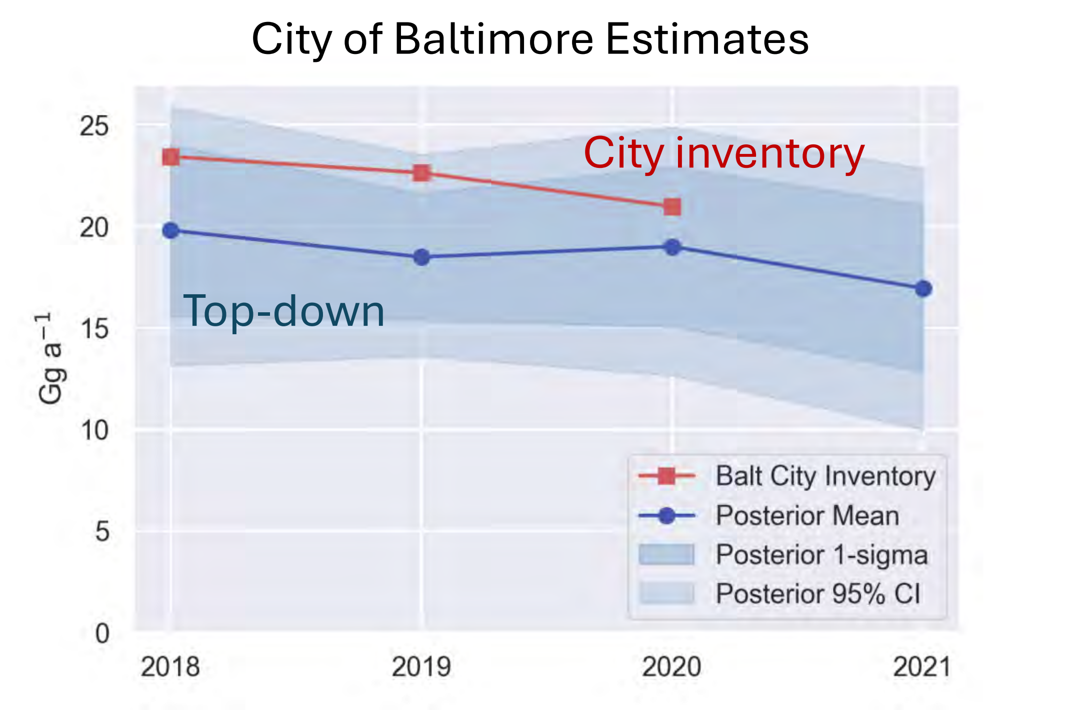
Whole/sub-city CH_4 Emissions: Multi-year

Northeast Corridor

NIST will be continuously extending this inversion in time



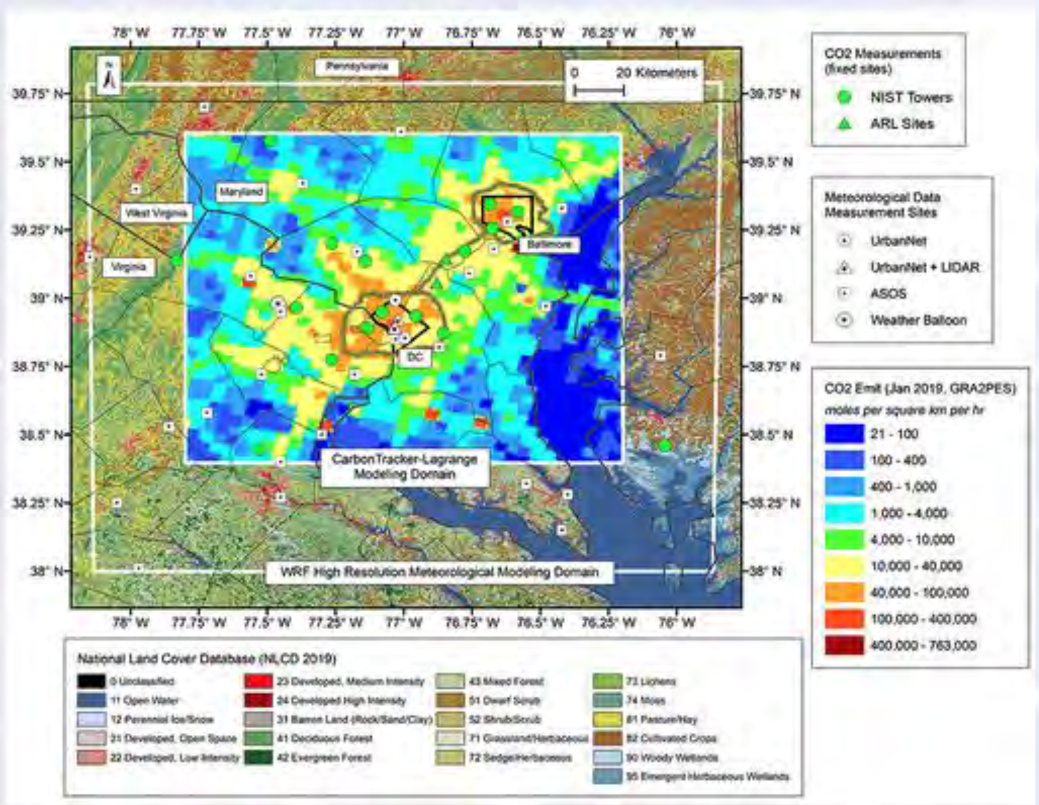
- Estimates reflect seasonality with a decreasing trend over time
- Detect a decreasing trend in CH_4 emissions over 5 years using Bayesian inversion with tower observations.
- Estimated urban emissions correlate with natural gas consumption.
- Thermogenic emissions are higher in winter than in summer suggesting that emission seasonality is driven by natural gas.



Karion, A., Ghosh, S., Lopez-Coto, I., Mueller, K., Gourdji, S., Pitt, J., and Whetstone, J.: Methane Emissions Show Recent Decline but Strong Seasonality in Two US Northeastern Cities, Environmental Science & Technology, 57, 19565-19574, 10.1021/acs.est.3c05050, 2023.

Urban-GEMMS system: Prototype near-real-time inversion

- NOAA/ARL, NIST, and NOAA/GML collaborating on creating a near-real time system for urban inversions.
- Beginning with quantifying CO_2 and CH_4 in the DC/Baltimore area using NIST tower observations.
- Goal is to make analyses like those shown more operational and also extensible to other urban areas.
- Using HYSPLIT and Carbon-Tracker Lagrange code base.



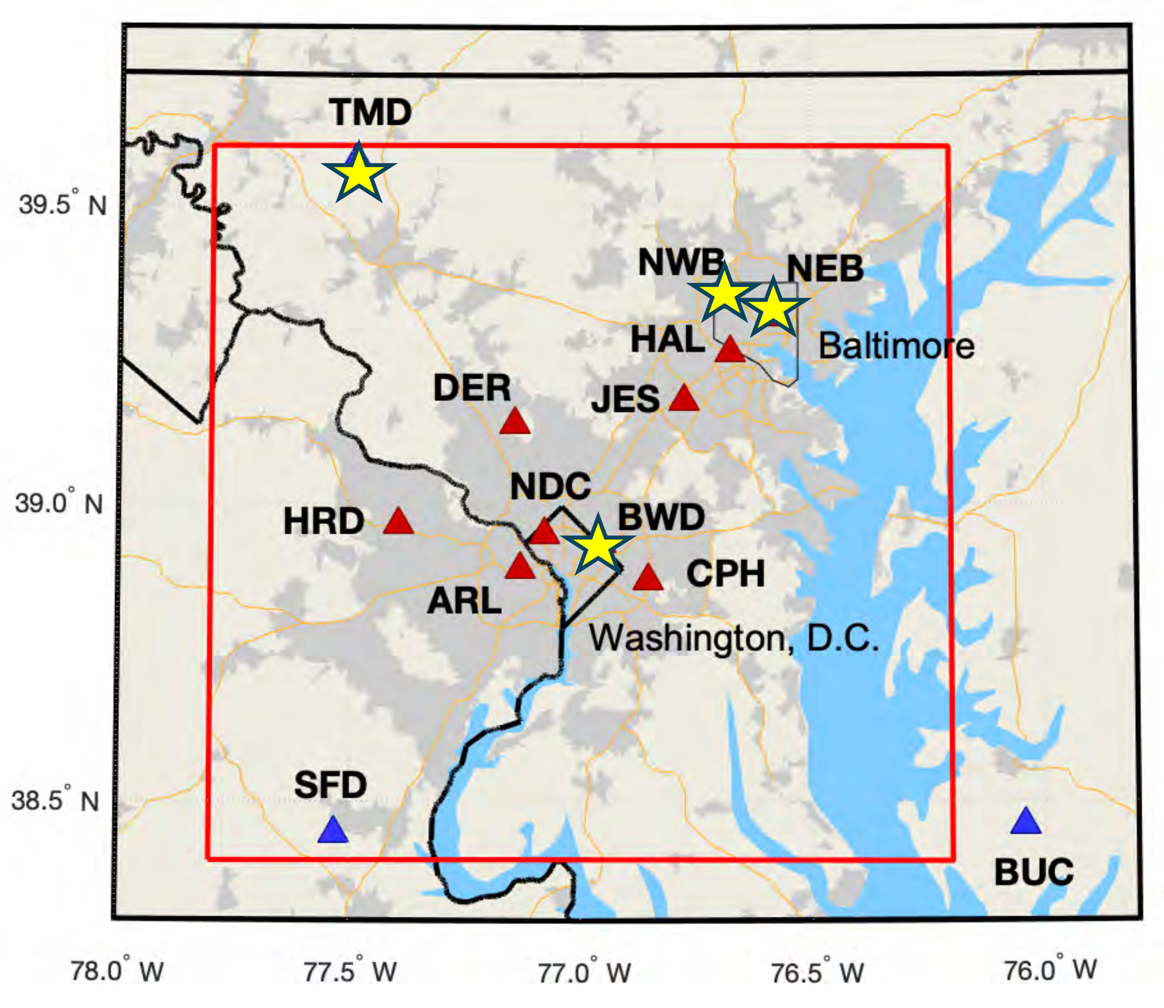
https://www.arl.noaa.gov/research/atmospheric-transport-and-dispersion/urban-gemms/

Emissions attribution: Assigning top-down estimates to specific activities

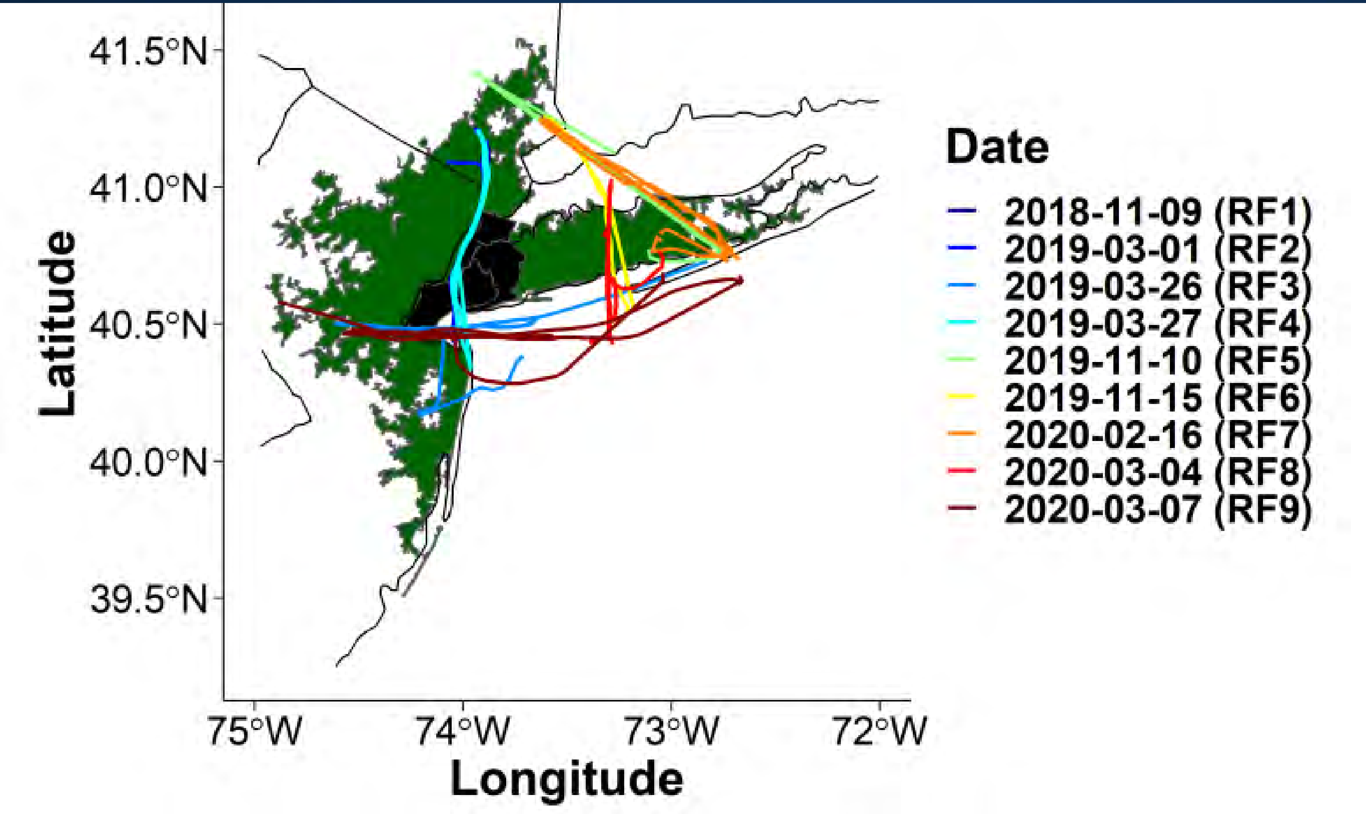
Measuring additional tracers that correlate with a given gas for a given source sector can provide some differentiation.

We have ethane and methane measurements from flask samples collected at several towers, but they are sparse.

Also measuring 14CO2 (radiocarbon) for fossil-fuel CO2 quantification. Using measurements together with biosphere modeling (VPRM) to understand urban biospheric fluxes.



Airborne campaigns & Lessons learned



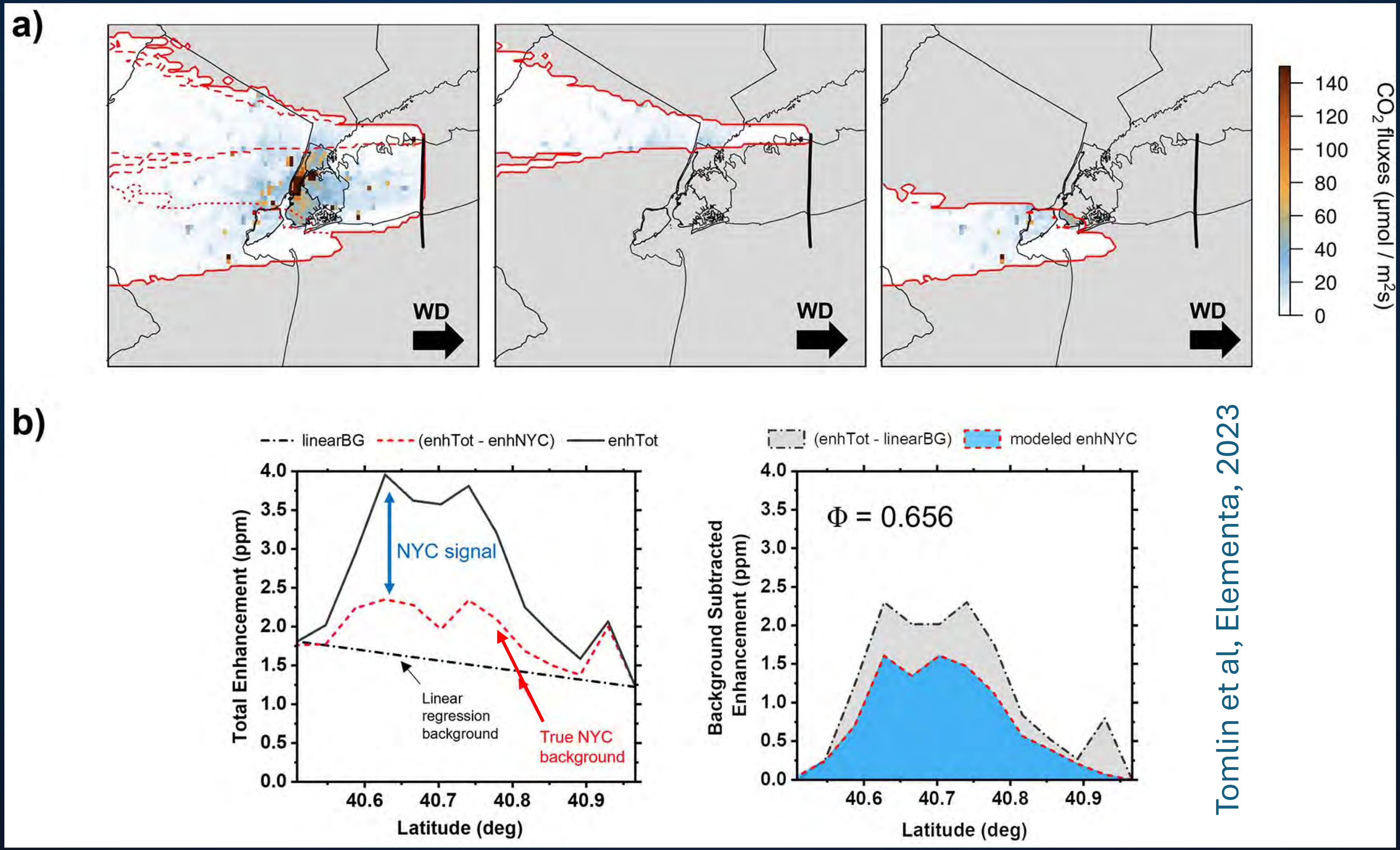
Stonybrook U./Purdue U. flight tracks used for GHG flux estimation. Figure from Hajny et al, 2022.

- University of Maryland, Purdue, & Stonybrook University conducting flight campaigns in Indianapolis, DC and NYC areas.
- Measurements of CO_2, CH_4; sometimes include CO, O_3, NO_2, & turbulence / meteorology
- Mass balance, scaling factor, and full model inversion analyses using flight GHG data.
- *Flight campaigns will continue at regular intervals.*

Refs: Pitt et al., ES&T (2024); Lopez-Coto et al., ES&T (2020, 2022), Pitt et al., Elementa (2021), Ren et al., JGR (2018); Hanjy et al., Elementa (2022) & many more

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Airborne plume sampling & background

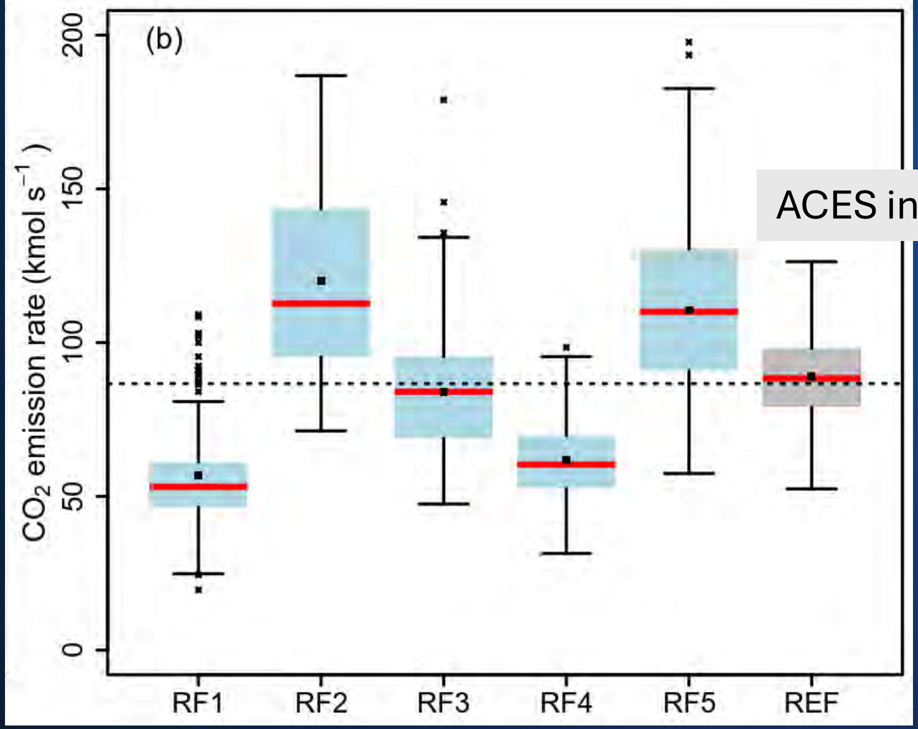


Or: why is it a good idea to use a model to interpret flight data?

Jay M. Tomlin, Israel Lopez-Coto, Kristian D. Hajny, Joseph R. Pitt, Robert Kaeser, Brian H. Stirm, Thilina Jayarathne, Cody R. Floerchinger, Róisín Commane, Paul B. Shepson; Spatial attribution of aircraft mass balance experiment CO2 estimations for policy-relevant boundaries: New York City. Elementa: Science of the Anthropocene 5 January 2023; 11 (1): 00046. doi: https://doi.org/10.1525/elementa.2023.00046

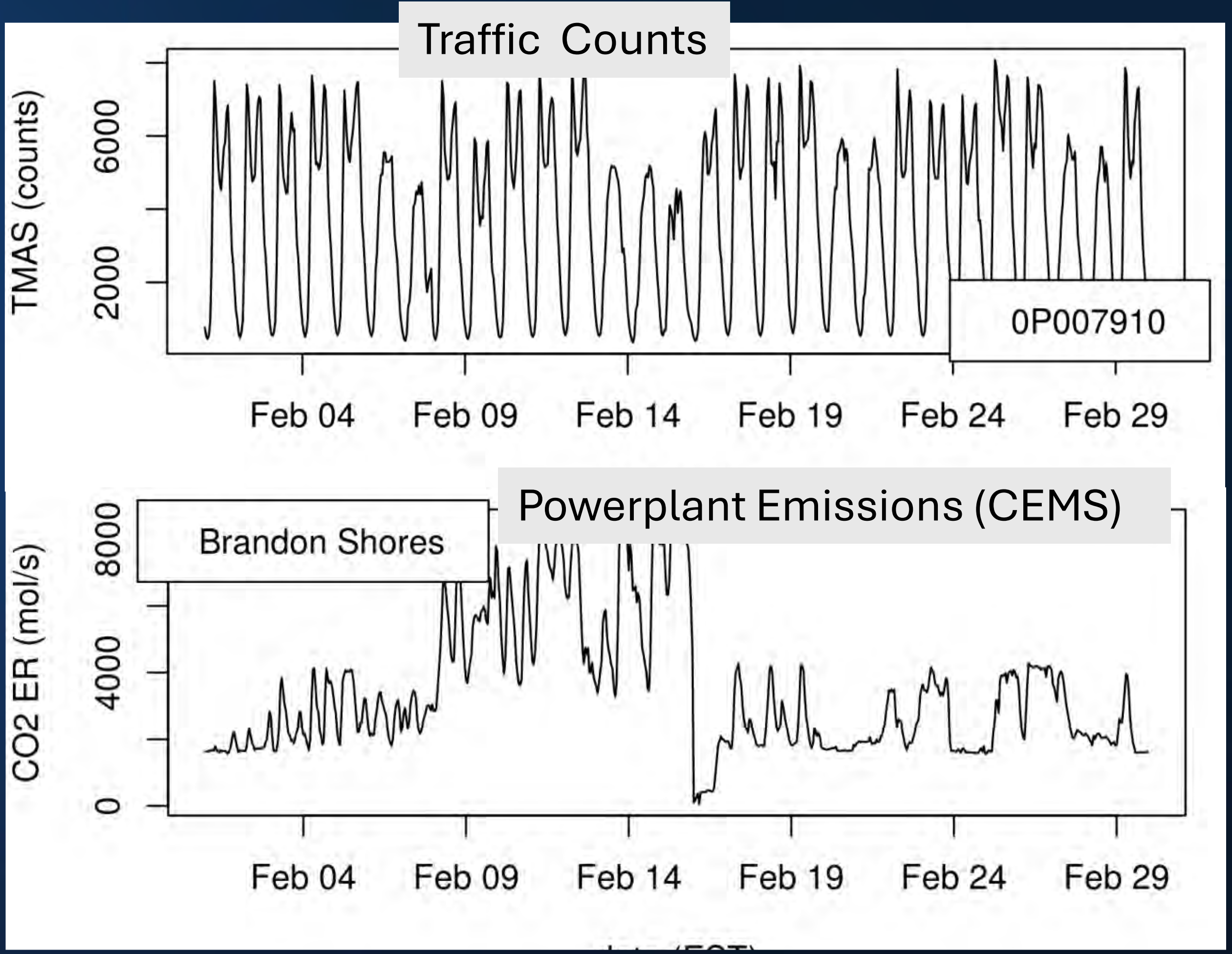
Airborne sampling temporal variability

Or: why do we need so many flights to get a good average?



Flight number in Feb 2016

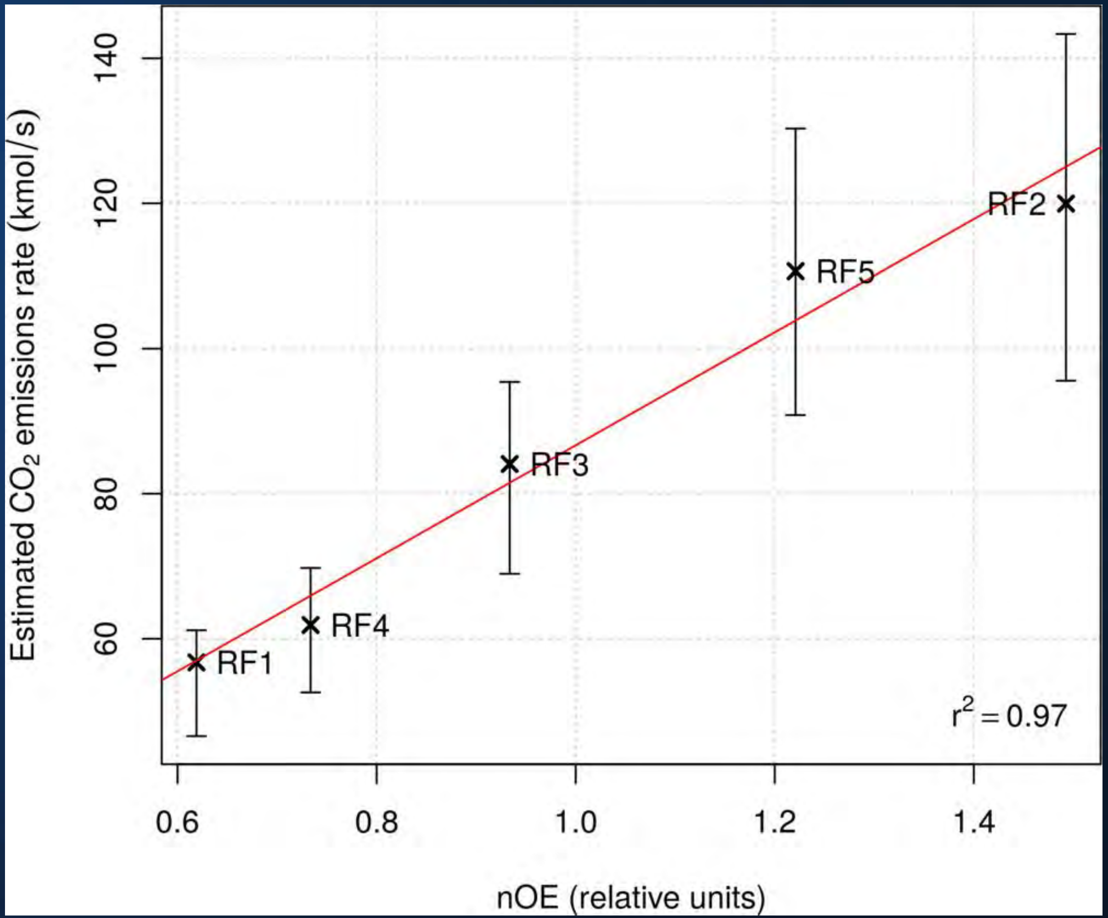
Large variability in posterior by flight



Lopez-Coto et al., ES&T, 2020, "Wintertime CO2, CH4, and CO Emissions Estimation for the Washington, DC–Baltimore Metropolitan Area Using an Inverse Modeling Technique".

Airborne sampling temporal variability

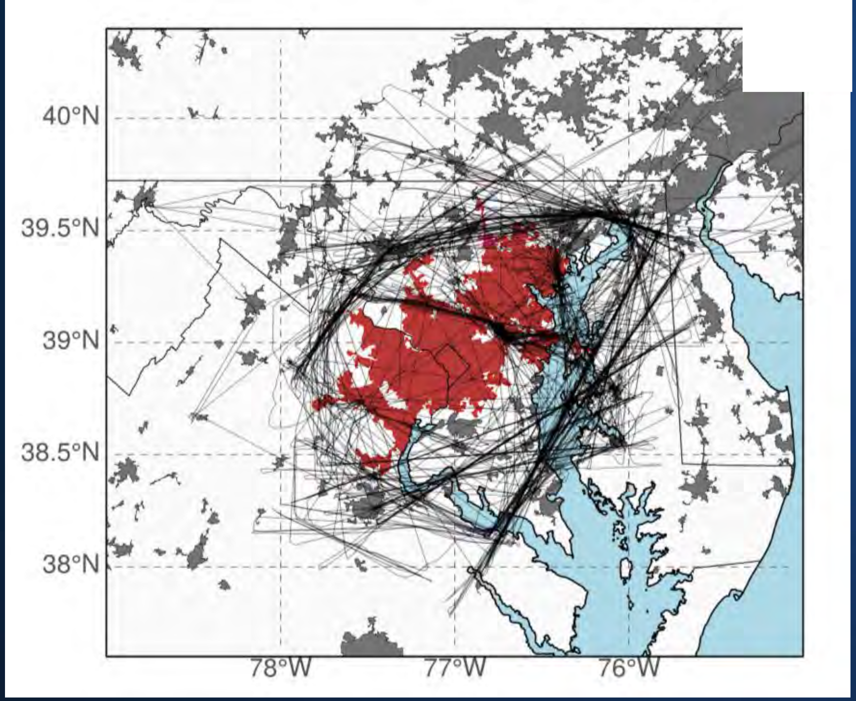
Flight-to-flight variability in posterior CO2 emissions is almost entirely explained by each flight's sampling spatio-temporally varying emissions from EGUs and traffic!



$$\mathrm{nOE}_i = f_\mathrm{e}\frac{\mathrm{CEMS}_i}{\langle \mathrm{CEMS} \rangle} + f_\mathrm{r}\frac{\mathrm{TMAS}_i}{\langle \mathrm{TMAS} \rangle} + 1 - (f_\mathrm{e} + f_\mathrm{r})$$

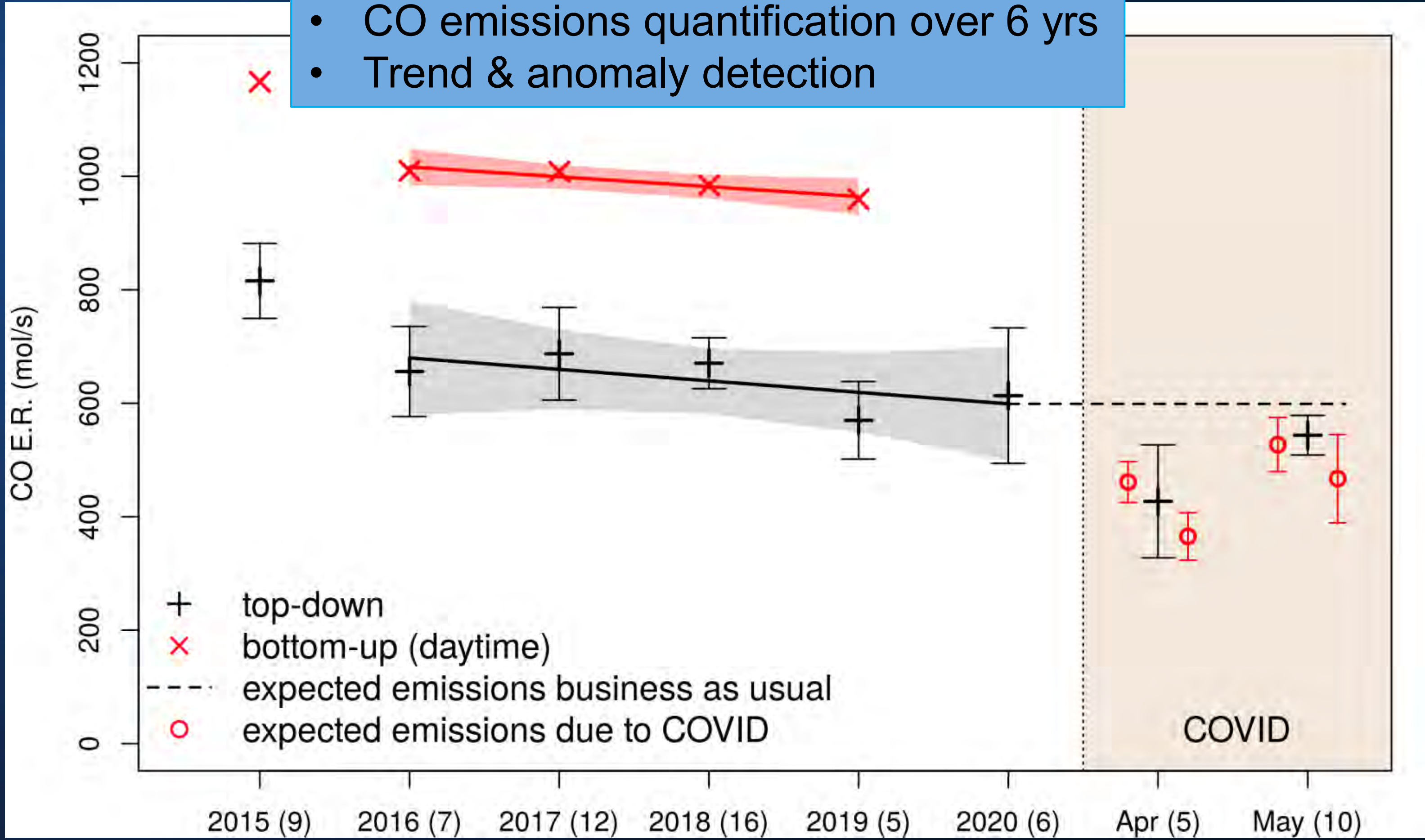
Lopez-Coto et al., ES&T, 2020, "Wintertime CO2, CH4, and CO Emissions Estimation for the Washington, DC–Baltimore Metropolitan Area Using an Inverse Modeling Technique".

Aircraft measurements: estimating city-scale emissions changes in Washington DC & Baltimore



Long-term aircraft campaign:
- 70 flights over 6 years
- Bayesian inversion framework

- CO emissions quantification over 6 yrs
- Trend & anomaly detection

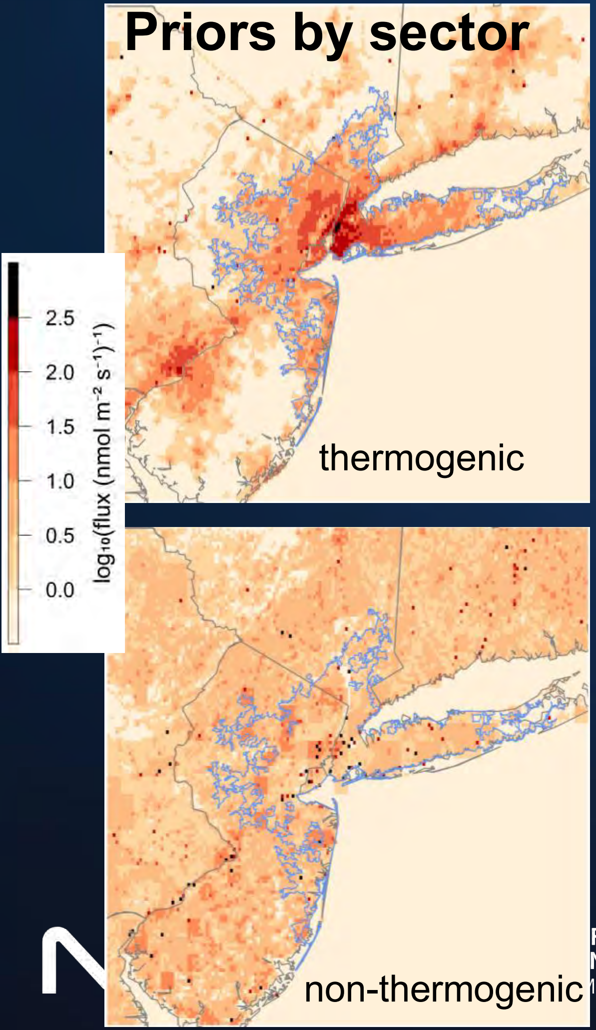


Airborne campaigns, when conducted regularly over multiple years, are an effective tool for trend and anomaly detection as well as absolute quantification of emissions.

Ref: Lopez-Coto et al., ES&T (2022)

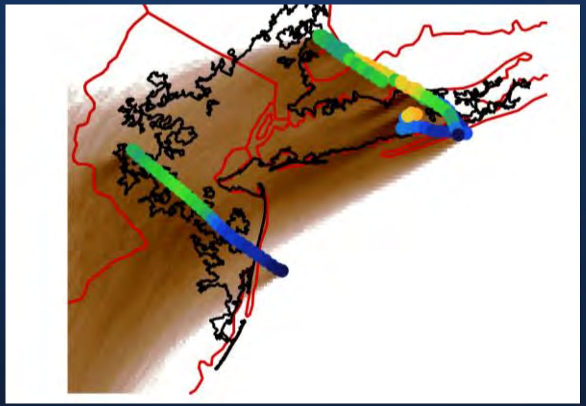
Aircraft measurements: estimating city-scale methane emissions by sector in NYC

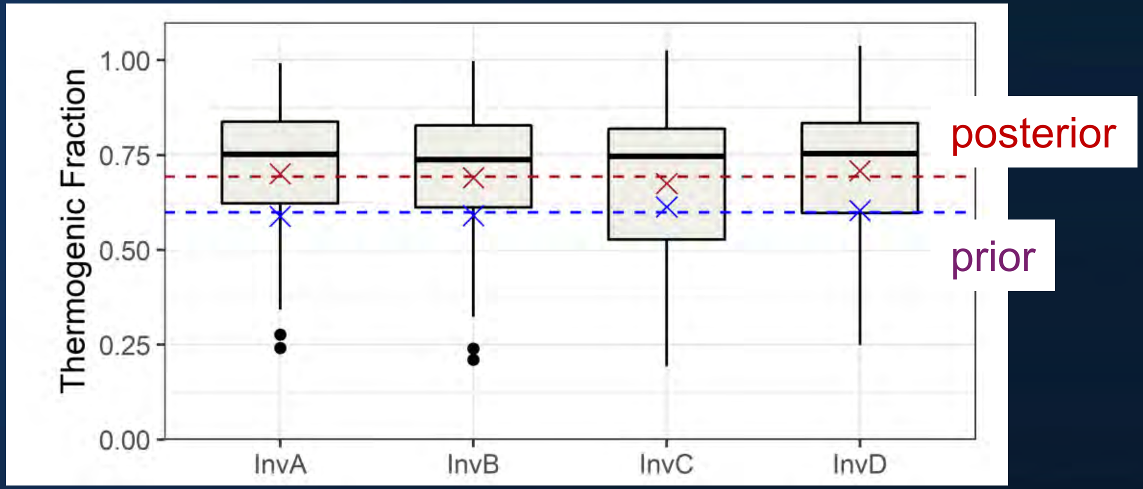
Leveraging the spatial distribution of thermogenic and non-thermogenic emissions



Airborne CH_4 measurements

Tagged-tracer transport modeling





New York Urban Area Thermogenic fraction:

Mean = 0.69
Median = 0.74

Ref: Pitt et al., ES&T (2024)

Moderate-Accuracy Sensor Station Network

3rd generation moderate accuracy GHG sensor station deployed on campus at NIST

- Measurements from moderately-accurate lower-cost CO_2 sensors can be beneficial to urban measurement networks (Lopez-Coto et al. 2017)
- Project Goals:
  - Deploy ~ 50 low-cost GHG sensor stations in the NEC urban testbed
    - Deploy 3 stations by September 2024
  - Characterize sensor uncertainties/validate measurement post-processing techniques
  - Design a standardized station infrastructure for a wide range of sensing applications (GHG, AQ, etc.)
  - Develop network infrastructure to support an autonomous and scalable network

Northeast Corridor Testbed

Collaboration with NOAA/GML: Measure multiple species in flask samples collected ~weekly at 4 tower stations ($^{14}CO_2$, hydrocarbons, CFCs, etc.)

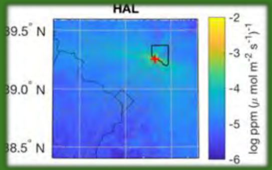
Routine Hysplit/STILT footprints for tower network using different meteorological products (NAM, ERA5, & custom WRF runs).

Aircraft campaigns
- U. Maryland
- Stonybrook/Purdue

Tower network
- Earth Networks
- NIST

Flask analysis
- NOAA / CU
- GNS Science

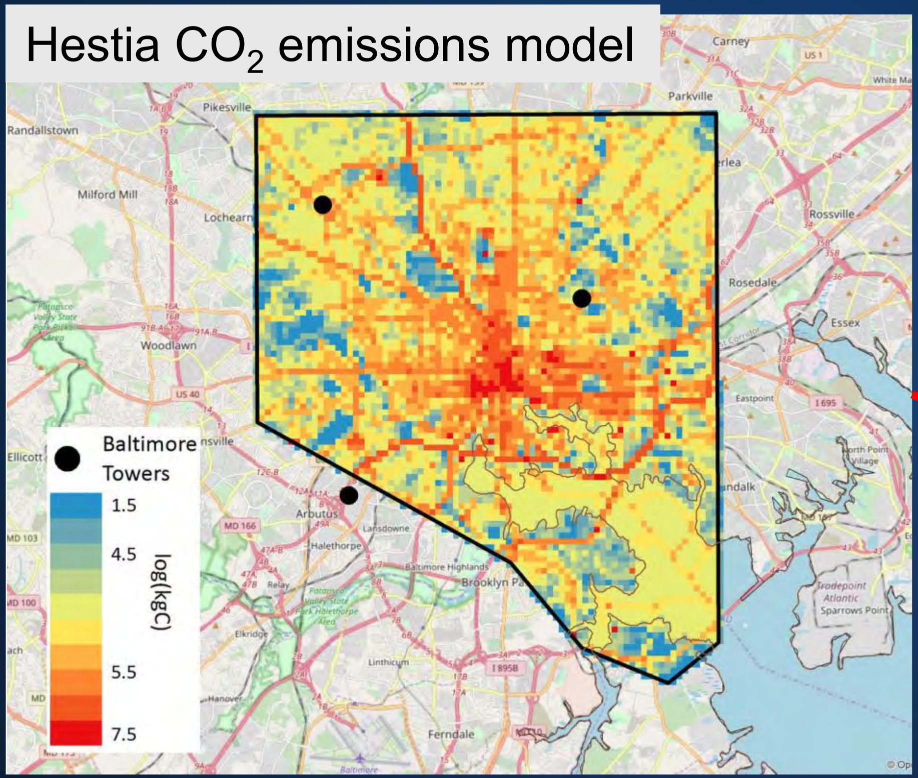
Emissions modeling
- NAU (Hestia)
- NOAA/CSL (GRA2PES)



Atmospheric modeling

Biosphere
- SIF Testbed
- VPRM
- Flux towers

Northeast Corridor Testbed



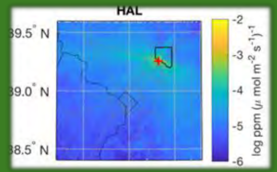
Hestia is an activity-based (bottom-up) estimate of hourly fossil fuel CO2 emissions. Currently for Baltimore it goes to 2015 at data.nist.gov, but is being updated for a larger area through 2022. (Kevin Gurney, NAU)

Aircraft campaigns
- U. Maryland
- Stonybrook/Purdue

Tower network
- Earth Networks
- NIST

Flask analysis
- NOAA / CU
- GNS Science

Emissions modeling
- NAU (Hestia)
- NOAA/CSL (GRA2PES)

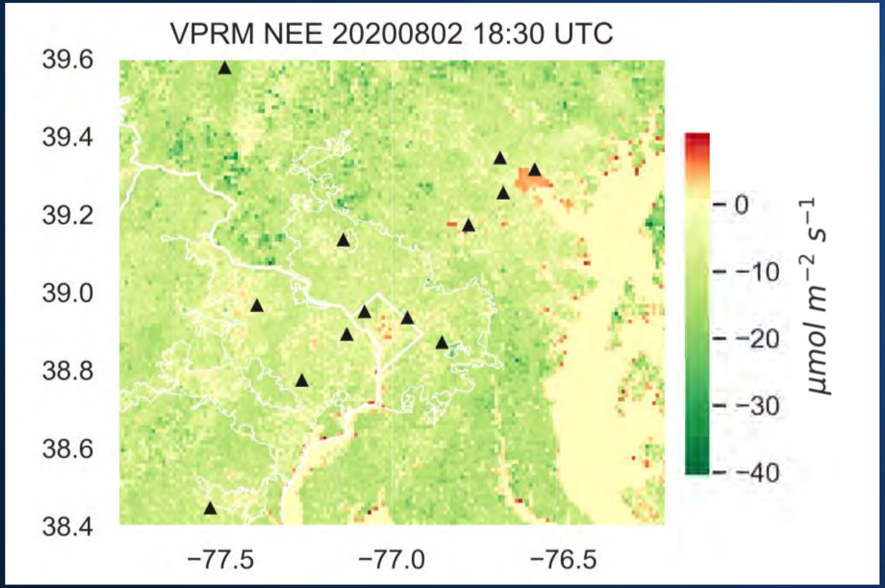


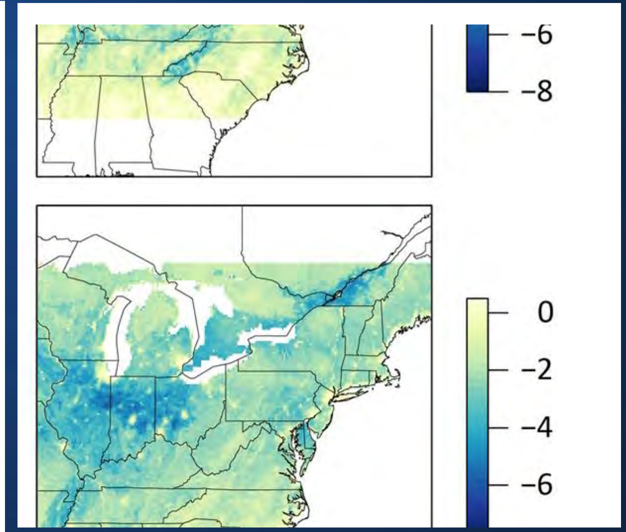
Atmospheric modeling

Biosphere
- SIF Testbed
- VPRM
- Flux towers

Northeast Corridor Testbed

VPRM CO_2 biosphere flux model





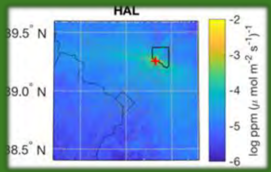
The Vegetation Photosynthesis and Respiration Model (based on Gourdji et al., 2021) is run routinely at NIST for the Northeastern US. Work is underway to improve and evaluate the fluxes in urban areas using scientific understanding from the NIST FOREST project (collab. with L. Hutyra @ BU)

Aircraft campaigns
- U. Maryland
- Stonybrook/Purdue

Tower network
- Earth Networks
- NIST

Flask analysis
- NOAA / CU
- GNS Science

Emissions modeling
- NAU (Hestia)
- NOAA/CSL (GRA2PES)

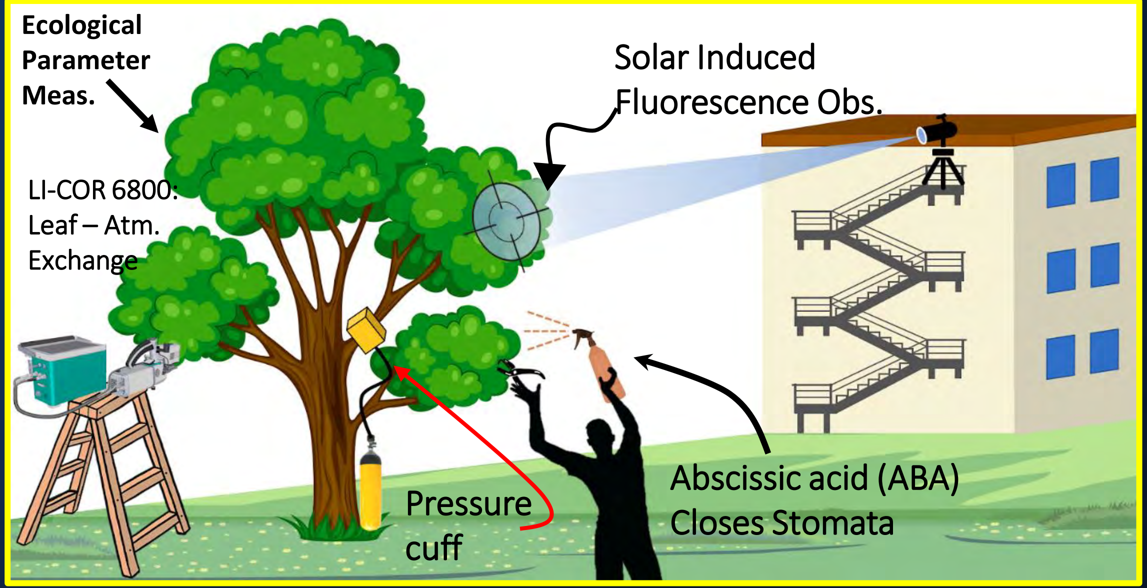


Atmospheric modeling

Biosphere
- SIF Testbed
- VPRM
- Flux towers

Additional testbed activities

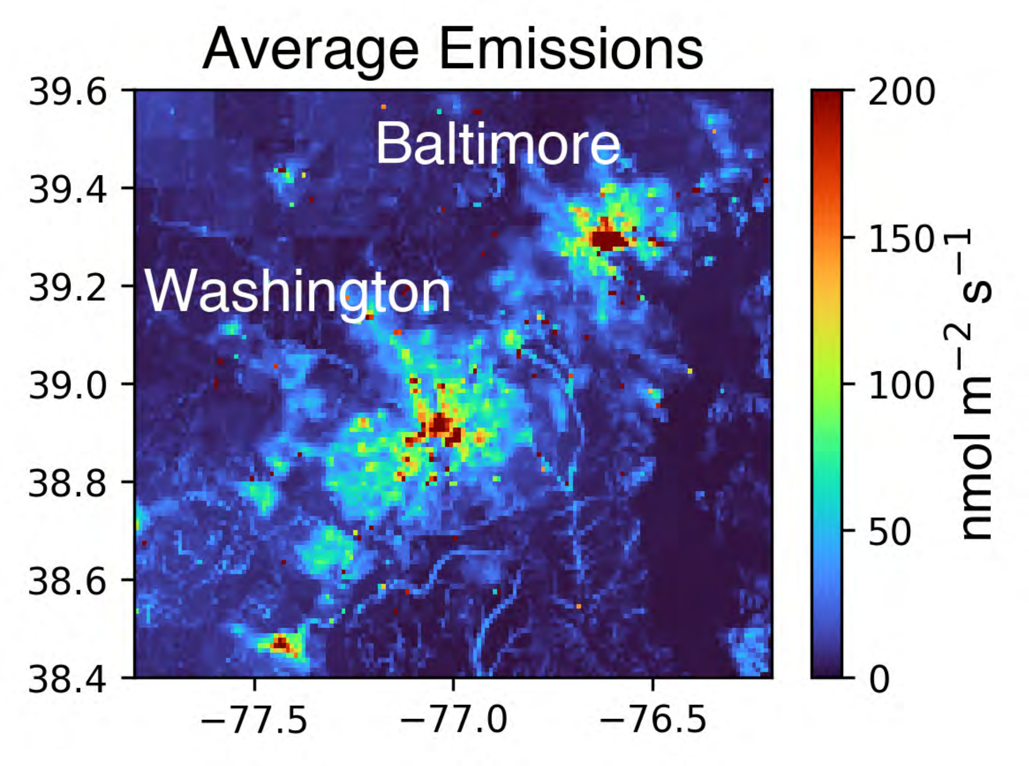
- Airborne turbulence measurements (Shepson group, Stonybrook U.) and high-resolution tracer modeling around powerplants using WRF-LES (e.g., Hope et al., 2024)
- **HALO (NOAA CSL wind/PBL lidar) for transport model evaluation**
- **Eddy covariance flux towers** (Davis group, Penn State) to diagnose CO_2 and CH_4 fluxes in cities (including suburban vegetation) (Wu et al., 2022).
- SIF-Biosphere testbed (FOREST) on NIST campus in Maryland, collab. w/ Boston U, Bowdoin & others. Goal to assess SIF measurements and linkage to GPP to improve biosphere modeling (Marrs, Hutyra, et al., GRL)
- Collaborate with new DOE-funded projects in Baltimore [Courage and BSEC].



https://www.nist.gov/greenhouse-gas-measurements/urban-test-beds

Contact: Anna.Karion@nist.gov

Findings



- Seasonal methane en… …ses are higher in winter when…
  - Distribution systen…
  - Leakage within ho… …l-the-meter leaks), e.g. … …f and start-up emissions
- Decline of 4% to 5% i…
  - About half could b…
  - Not clear if pipelin… …ntributing to the decline.
  - Other sectors (e.g., waste) could be a large factor.

Tower study example: Using atmospheric measurements to estimate emissions decline during COVID lockdowns

Geophysical Research Letters

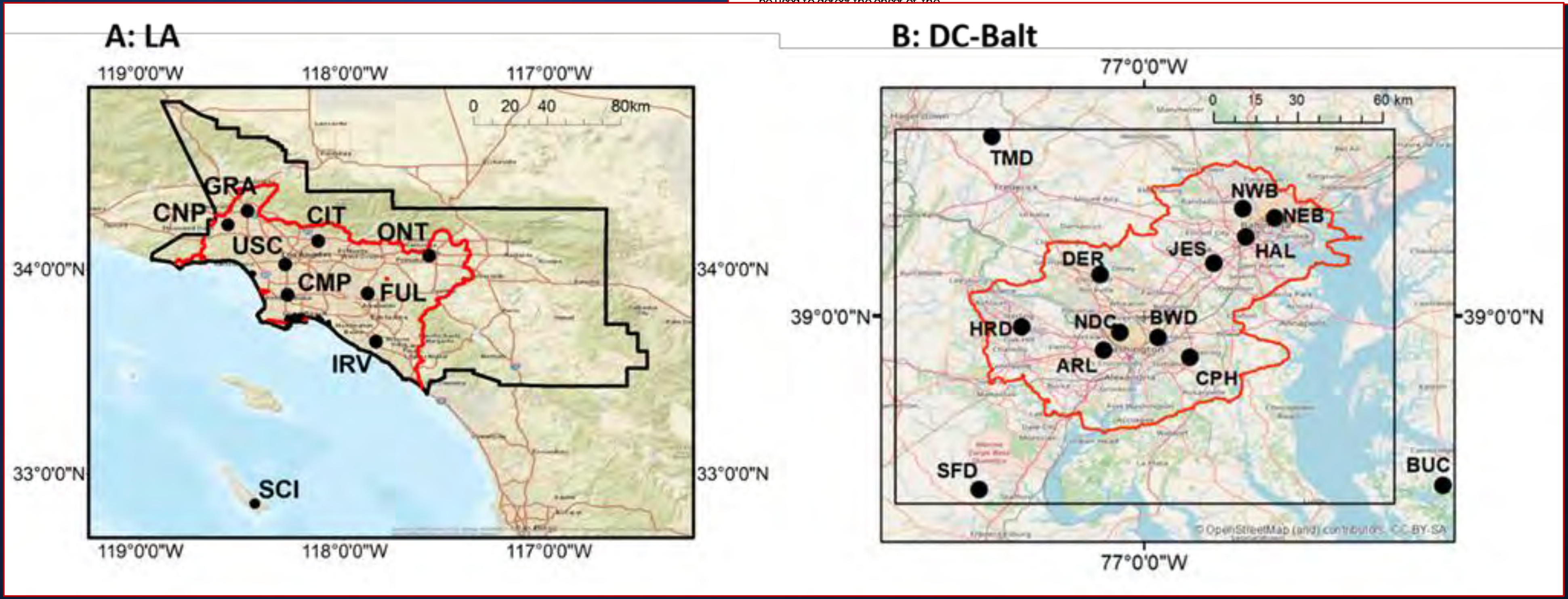
RESEARCH LETTER
10.1029/2021GL092744

Special Section:
The COVID-19 pandemic: linking health, society and environment

The Impact of COVID-19 on CO_2 Emissions in the Los Angeles and Washington DC/Baltimore Metropolitan Areas

Vineet Yadav[1], Subhomoy Ghosh[2,3], Kimberly Mueller[3], Anna Karion[3], Geoffrey Roest[4], Sharon M. Gourdji[3], Israel Lopez-Coto[3], Kevin R. Gurney[4], Nicholas Parazoo[1], Kristal R. Verhulst[1], Jooil Kim[5], Steve Prinzivalli[6], Clayton Fain[6], Thomas Nehrkorn[7], Marikate Mountain[7], Ralph F. Keeling[5], Ray F. Weiss[5], Riley Duren[8], Charles E. Miller[1], and James Whetstone[3]

Key Points:
- Atmospheric CO_2 observations can



NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Urban in-situ networks estimate similar relative reductions associated with COVID-19 in both the Washington and Los Angeles metropolitan areas

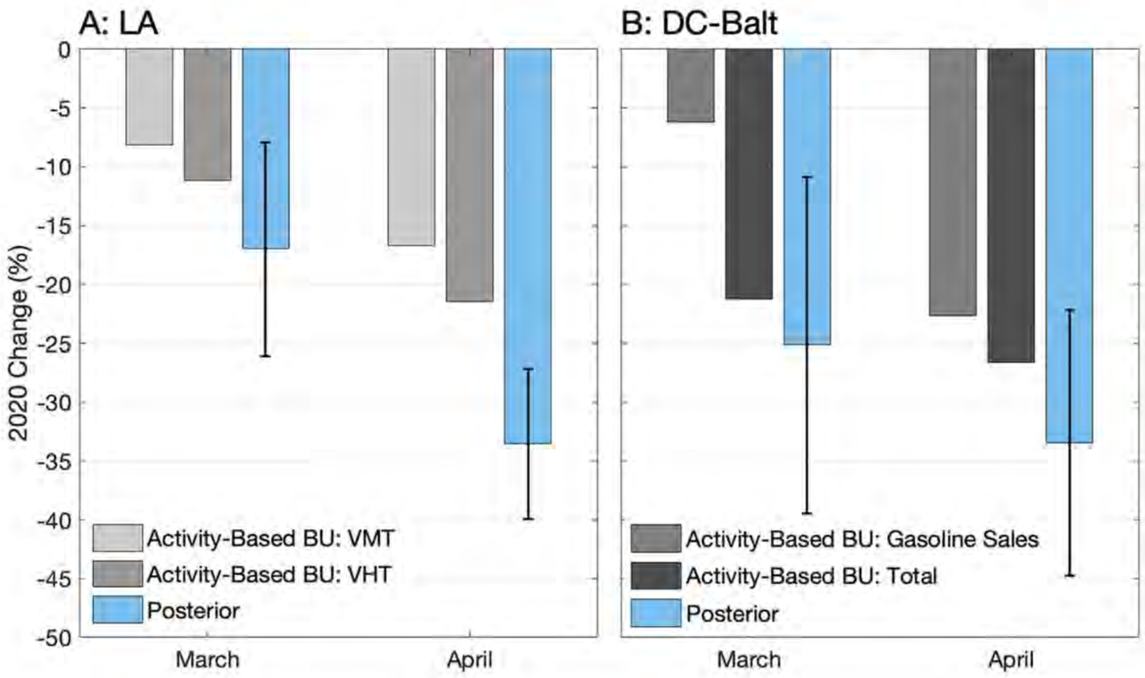


Figure 3. Changes in monthly mean emissions for April and March 2020 relative to 2018/2019 means for (a) LA and (b) DC-Balt. Blue bars represent the decrease estimated from the atmospheric inversion posteriors, with error bars representing the 95% CI. Various shades of gray bars represent the decrease for each month using different activity-based adjusted bottom-up totals, as indicated in the legend and described in the text.

Yadav et al., GRL, 2021

- LA: Mar 17% +/- 9%; Apr 34% +/- 6%
- Baltimore-Washington DC: Mar 25% +/- 14%; Apr 33% +/- 11%
- Assessing declines depends on baseline choice.
- Differences from month to month and year to year are real, and can be caused by various drivers.
- In this case we were successful in using activity information to isolate and attribute the changes due to the lockdown, by looking at the variability in activity associated with CO_2 emissions.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE