NIST SPECIAL PROGRAMS OFFICE

NIST's Northeastern Corridor Project

Linking R&D with Stakeholder Needs

Kim Mueller
https://www.nist.gov/greenhouse-gas-measurements

ICOS Annual Meetin: March 2023

NIST SPO personnel: Israel Lopez-Coto, Kim Mueller, Subhomoy Ghosh, Tyler Boyle, Annmarie Eldering, James Whetstone
+ NIST and outside collaborators

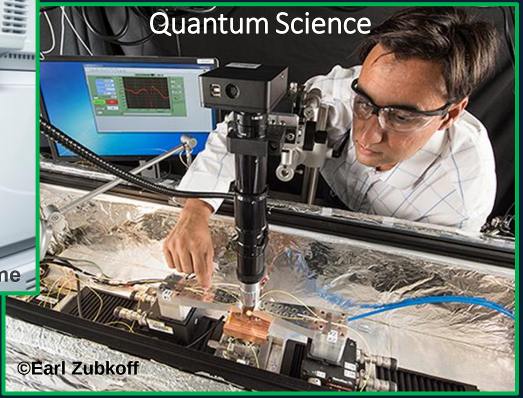
Outline

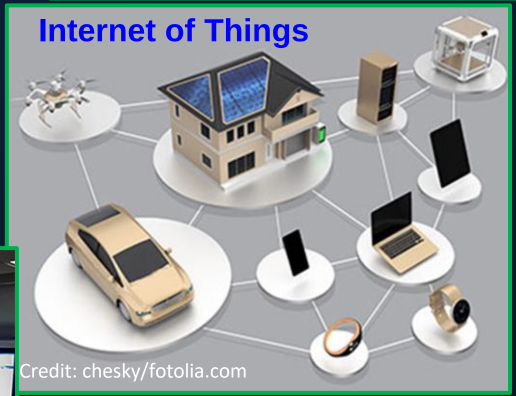
- A word about NIST
- Northeast Corridor (NEC)
  - Activities
  - Recent results
- Policy value?
- Stakeholder engagement in the NEC
- Where next?

NIST: The US National Metrology Institute

Mission: To promote US innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

- A non-regulatory Department of Commerce Agency
- Develops unbiased, state-of-the-art measurement science and standards advancing the nation's technology infrastructure
- Often provides standards and standard methods to private sector to aid in commerce (e.g. financial community and green financing).





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NIST's Greenhouse Gas Measurement Program

Purpose: Develop internationally recognized, greenhouse gas emissions measurements and standards for reliable and accurate mapping of urban to regional greenhouse gas emissions that inform timely and effective mitigation actions, science-based policy decisions, and enable trade and commerce.

Components:

– Urban GHG Measurements Testbed System, Tools, and Methods

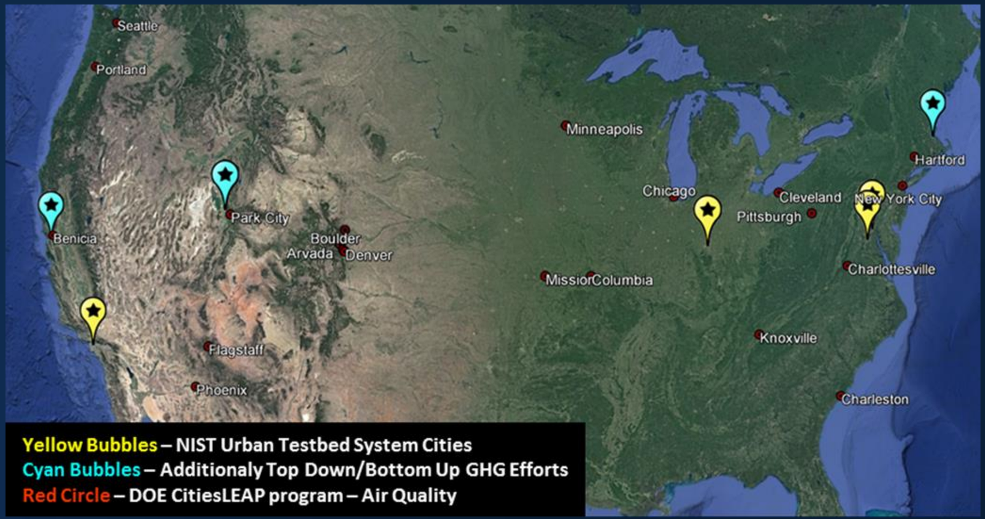
– Stationary or Point Source Emission Metrology
(advances in smokestack Continuous Emissions Monitoring (CEMs) technology)

– Satellite Calibration and Atmospheric Carbonaceous Aerosols Measurements & Standards

– Measurement Tools, Standards and Reference Data

– International Documentary Standards Development for Urban GHG Flux Measurements

NIST's Urban GHG Testbed System



Objective: To develop & demonstrate urban GHG measurement methods.

2010

The initial testbed

Indianapolis Flux Experiment (INFLUX)

9 public & private actors +

2013

2nd testbed

LA Megacities Project

12 public, non-govt., & private actors +

2014

Latest testbed

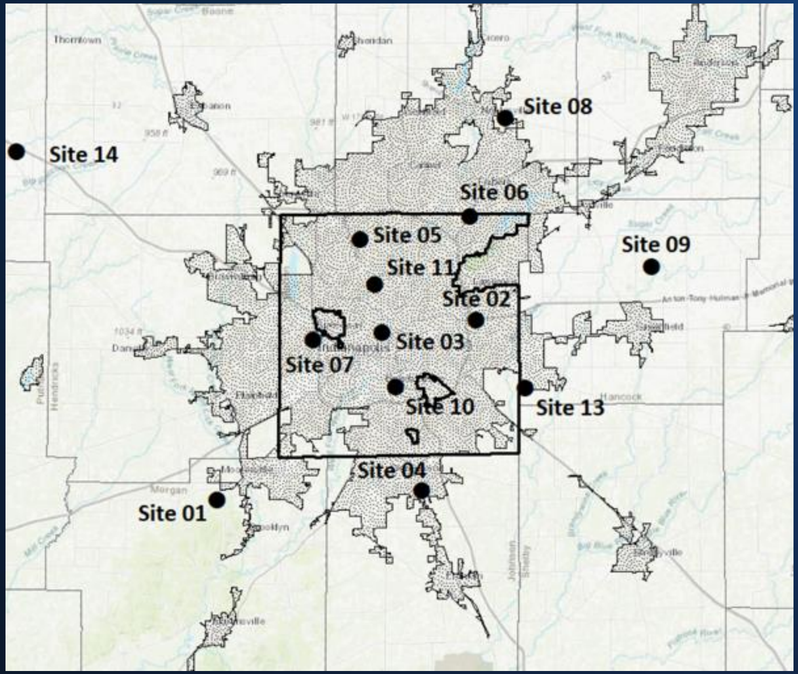
Northeast Corridor/Baltimore – Washington DC (NEC/BW)

5 public & private actors +

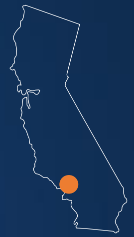
Three urban testbeds have been established (Indianapolis, Los Angeles, and Washington/Baltimore). These are collaborative multi-institution projects (including federal agencies, universities, and the private sector), combining atmospheric measurements and analysis to estimate urban GHG emissions and related uncertainties.

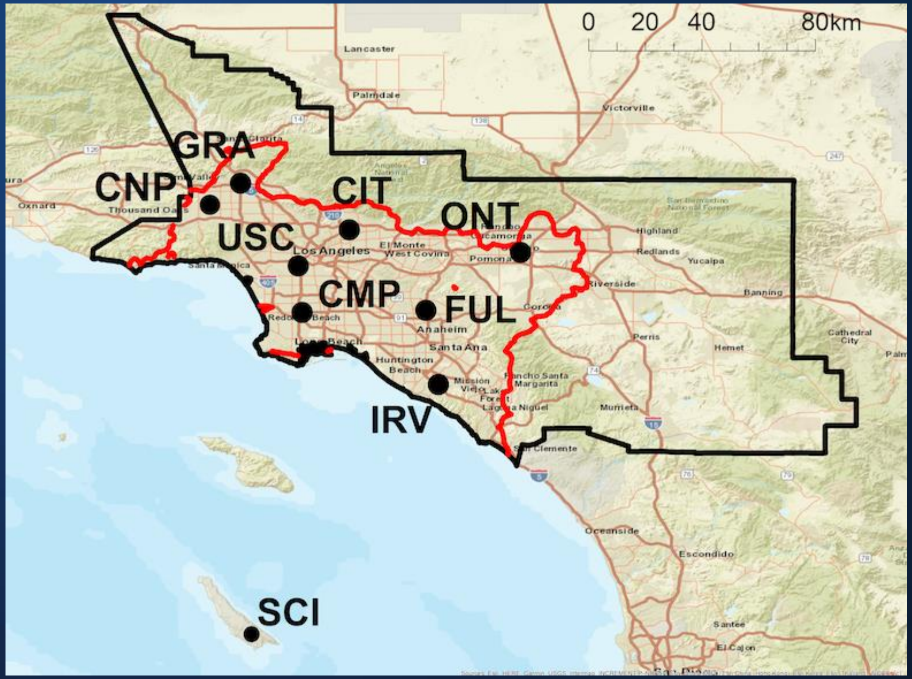
NIST's Three Urban Testbeds

Indianapolis

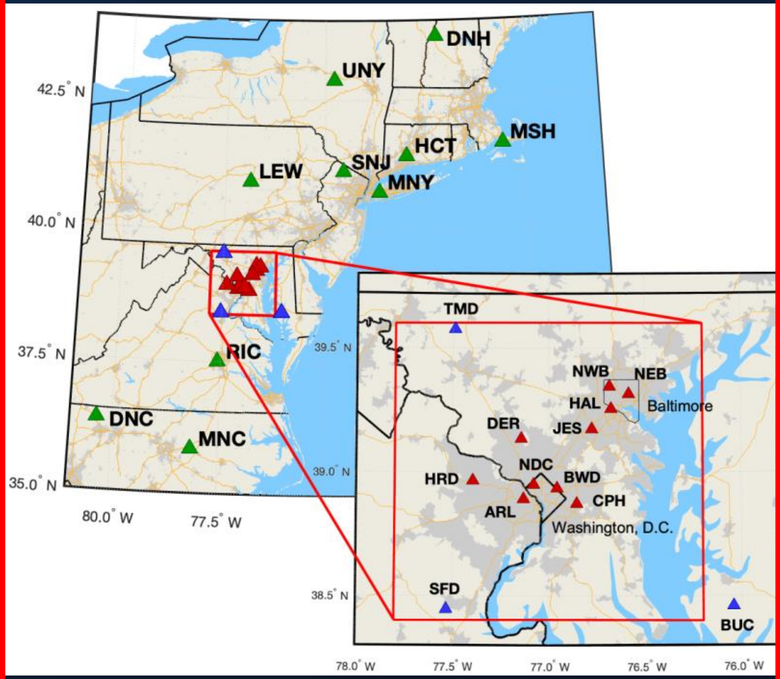


Los Angeles Megacity

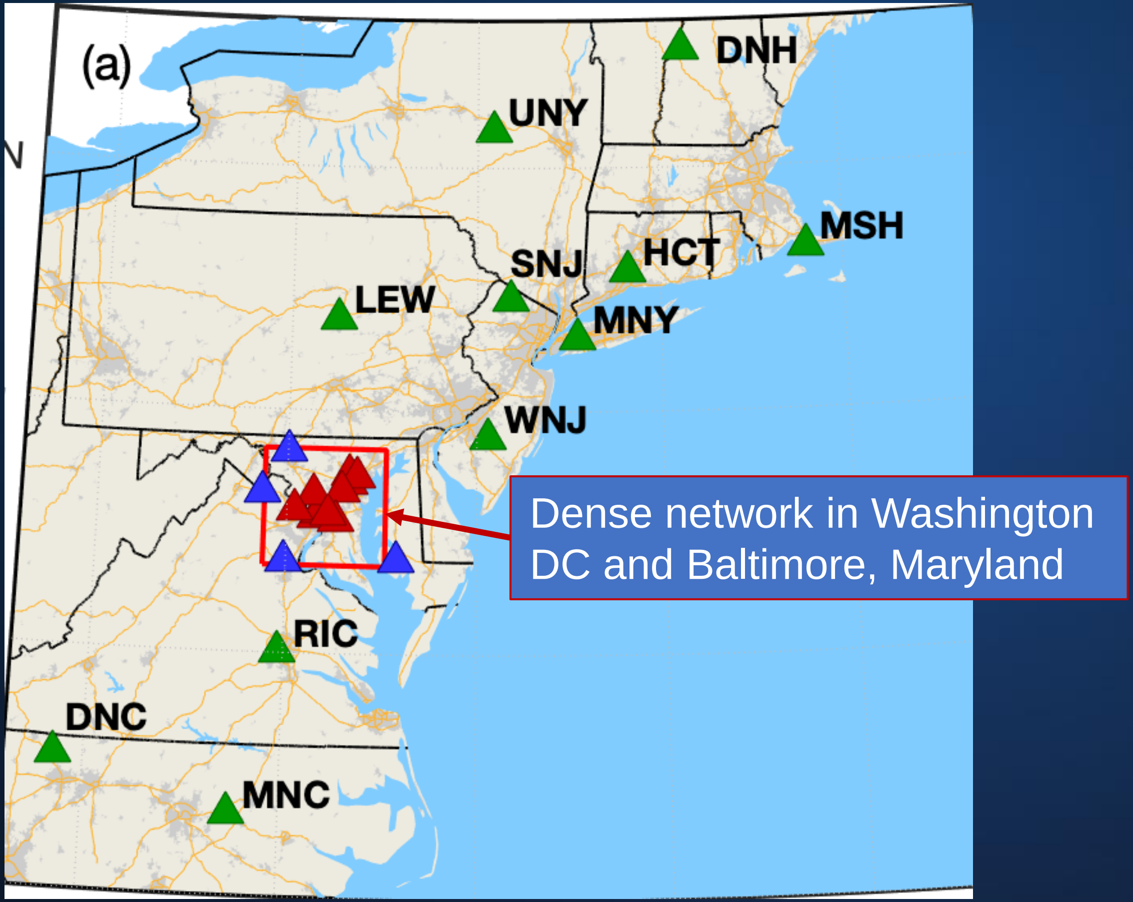




Northeast Corridor



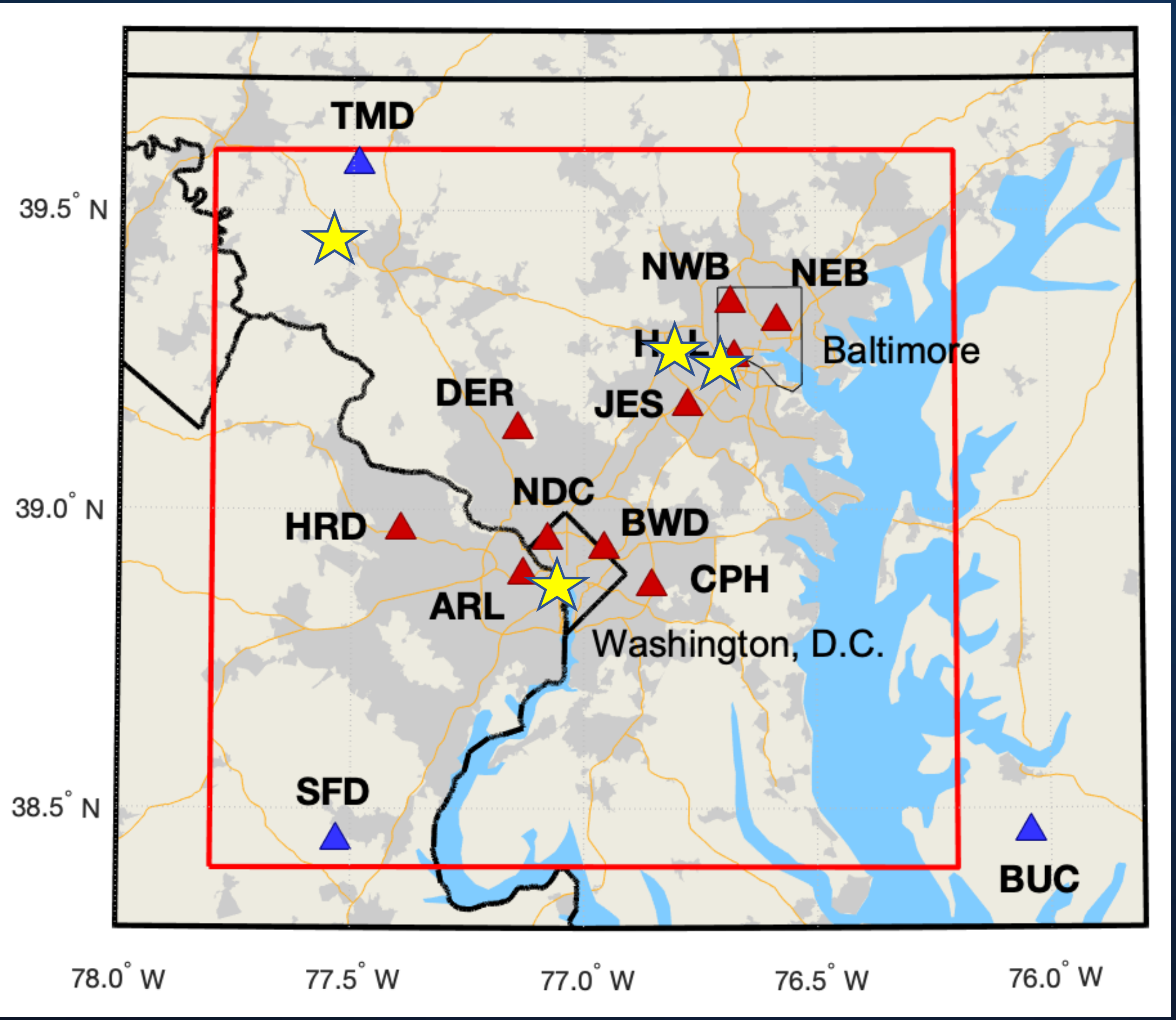
Northeast Corridor Tower Network



- Partnership with Earth Networks
- High-accuracy CO_2 / CH_4 / CO concentrations reported on WMO scales
- High density in the DC/Baltimore area
- Plans to extend to Philadelphia & NYC
- Include regional non-urban sites to characterize background conditions (i.e. incoming CO_2/CH_4 concentrations)
- Data available at data.nist.gov

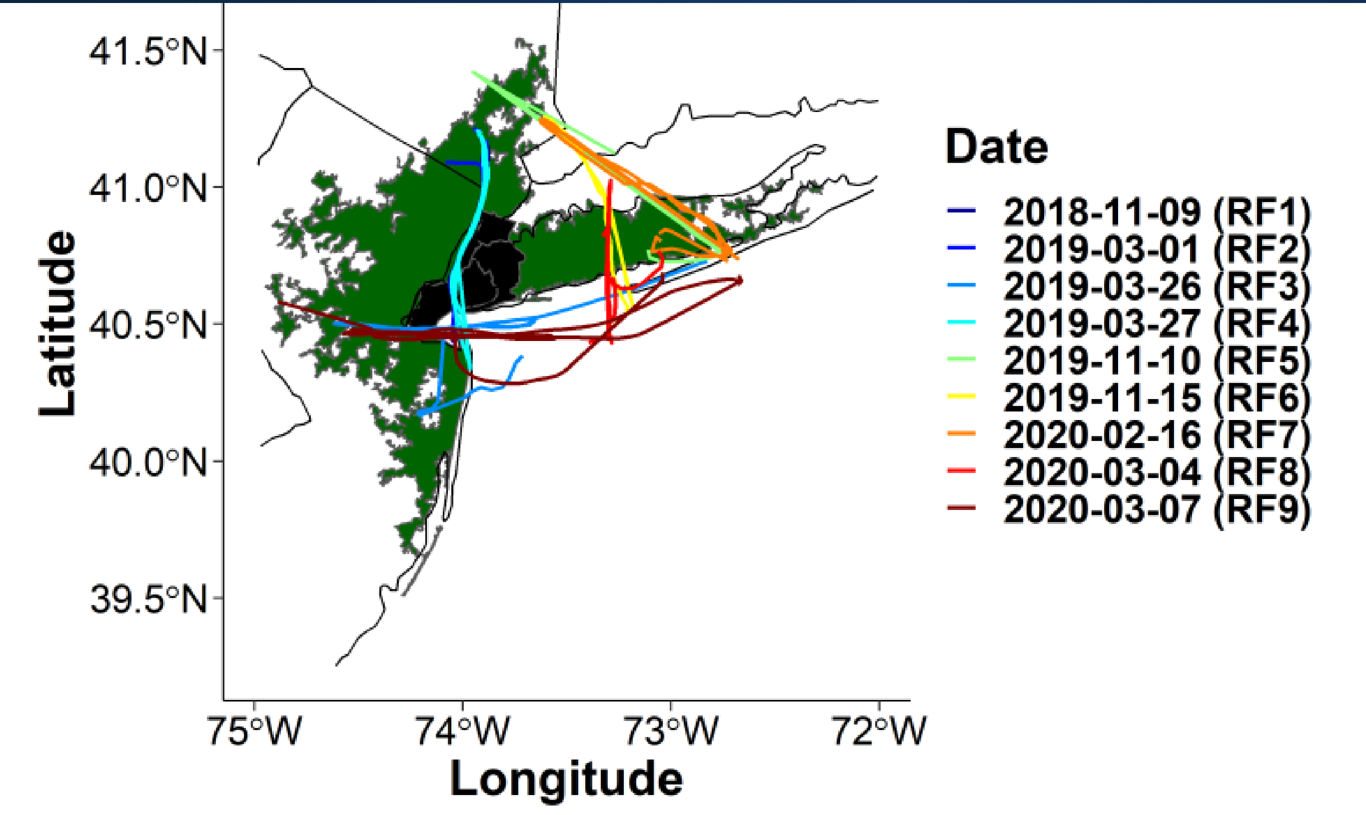
Karion, A., Callahan, W., Stock, M., Prinzivalli, S., Verhulst, K. R., Kim, J., Salameh, P. K., Lopez-Coto, I., and Whetstone, J.: Greenhouse gas observations from the Northeast Corridor tower network, Earth Syst. Sci. Data, 12, 699–717, https://doi.org/10.5194/essd-12-699-2020, 2020.

Flask Measurements



- 4 sites with NOAA flask packages (integrator systems)
- 55+ trace gases
- $^{14}CO_2$ (radiocarbon)
- Flasks are sampled at the same time/date through the DC network
- TMD values are subtracted as background

Airborne sampling



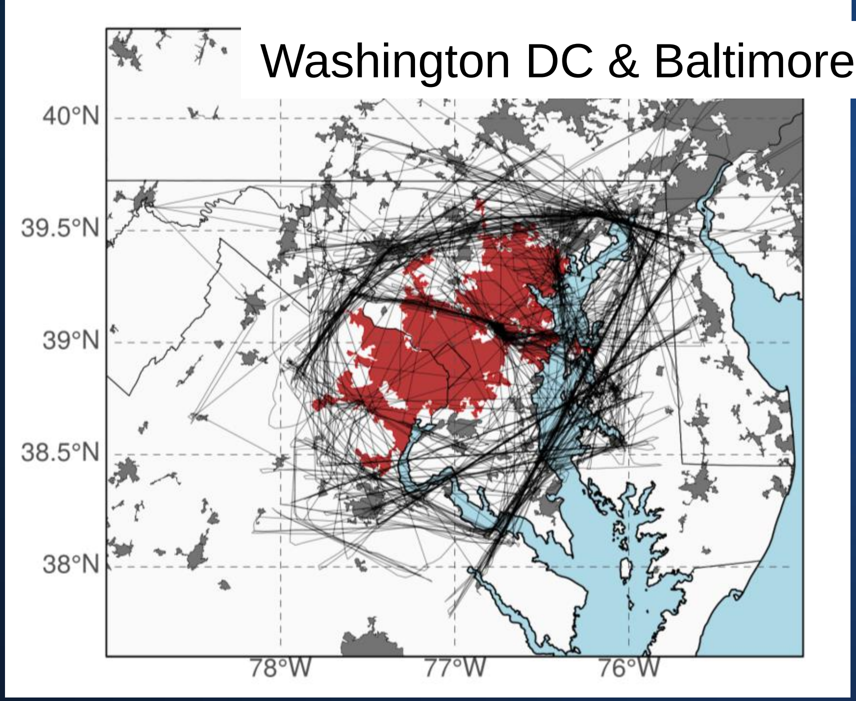
Stonybrook U./Purdue U. flight tracks used for GHG flux estimation. Figure from Hajny et al, 2022.

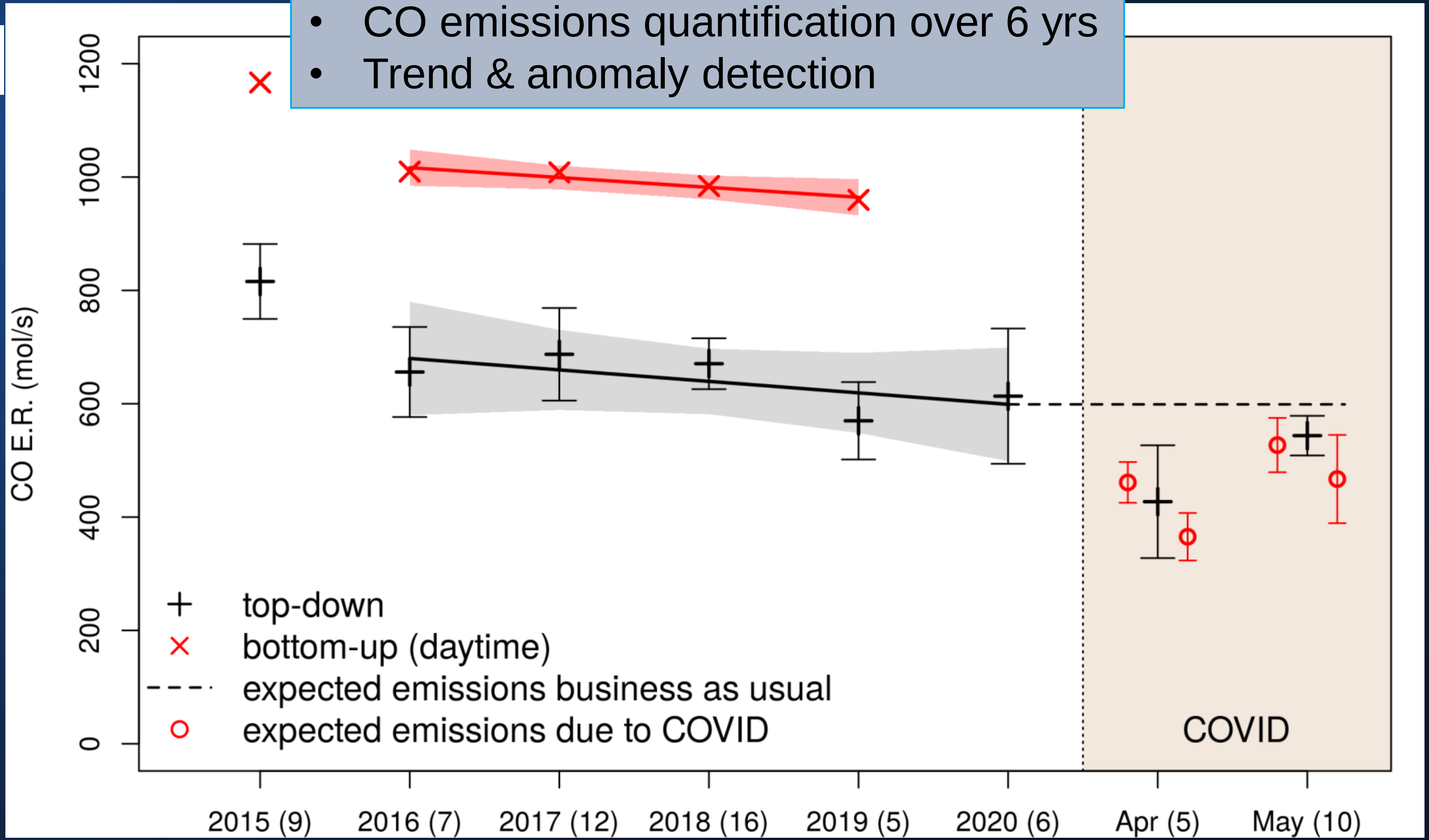
- University of Maryland, Purdue, & Stonybrook University conducting flight campaigns in Indianapolis, DC/Baltimore, and NYC areas
- Measurements of CO_2, CH_4; sometimes include CO, O_3, NO_2, & turbulence / meteorology
- Mass balance, scaling factor, and full model inversion analyses using flight GHG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

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

Aircraft measurements: estimating city-scale emissions

Lopez-Coto, I., et al. (2022). "Carbon Monoxide Emissions from the Washington, DC, and Baltimore Metropolitan Area: Recent Trend and COVID-19 Anomaly." Environmental Science & Technology **56**(4): 2172-2180.



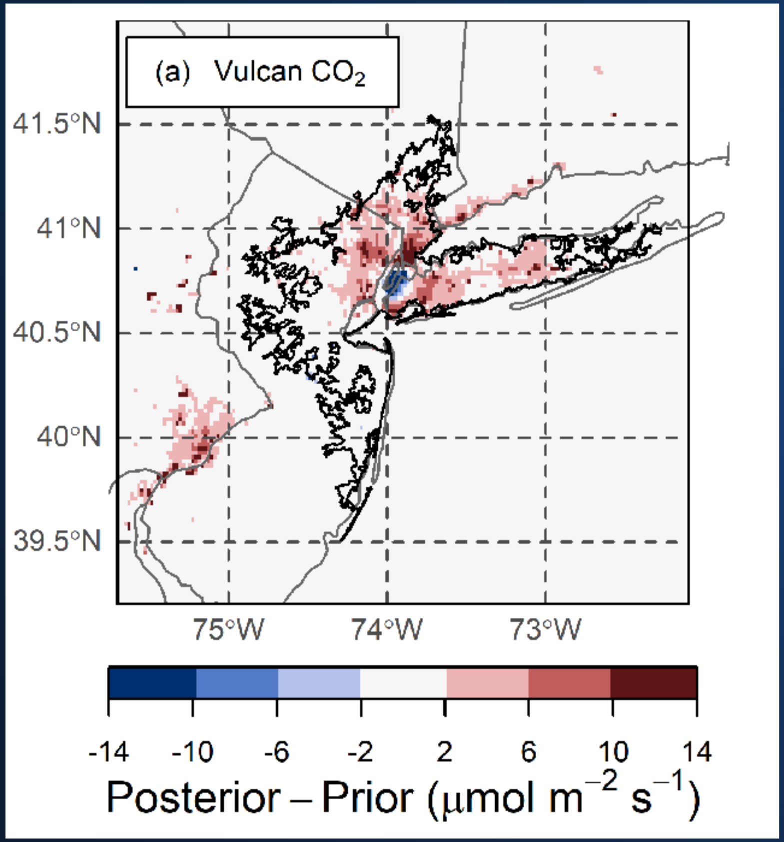


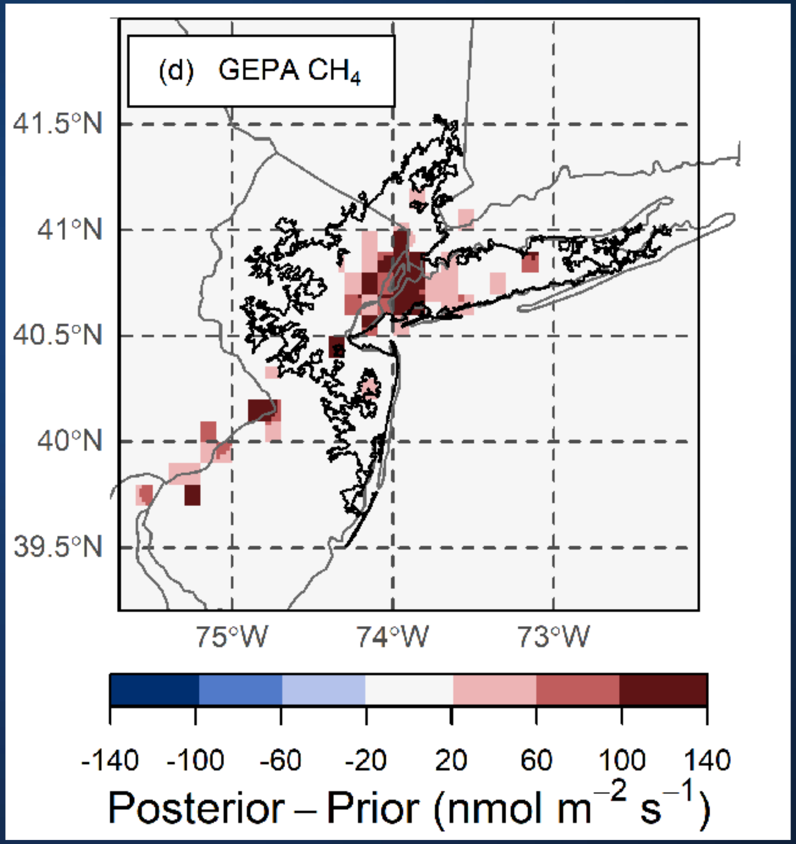
- CO emissions quantification over 6 yrs
- Trend & anomaly detection

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

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

Aircraft Measurements: Estimating City-Scale





Pitt, J. R., et al. (2022). "New York City greenhouse gas emissions estimated with inverse modeling of aircraft measurements." Elementa-Science of the Anthropocene **10**(1).

See also:

Hajny, K. D., et al. (2022). "A spatially explicit inventory scaling approach to estimate urban CO2 emissions." Elementa-Science of the Anthropocene **10**(1).

Lopez-Coto, I., X. Ren, O. E. Salmon, A. Karion, P. B. Shepson, R. R. Dickerson, A. Stein, K. R. Prasad and J. Whetstone (2020). "Wintertime CO2, CH4 and CO emissions estimation for the Washington DC / Baltimore metropolitan area using an inverse modeling technique." Environmental Science & Technology.

Ren, X. R., et al. (2018). "Methane Emissions From the Baltimore-Washington Area Based on Airborne Observation: Comparison to Emissions Inventories." Journal of Geophysical Research-Atmospheres 123(16): 8869-8882.

Multiple methods all using **airborne** measurements to estimate emissions in the recent literature

Aircraft Measurements: Estimating City-Scale CO_2 & CH_4 Emissions

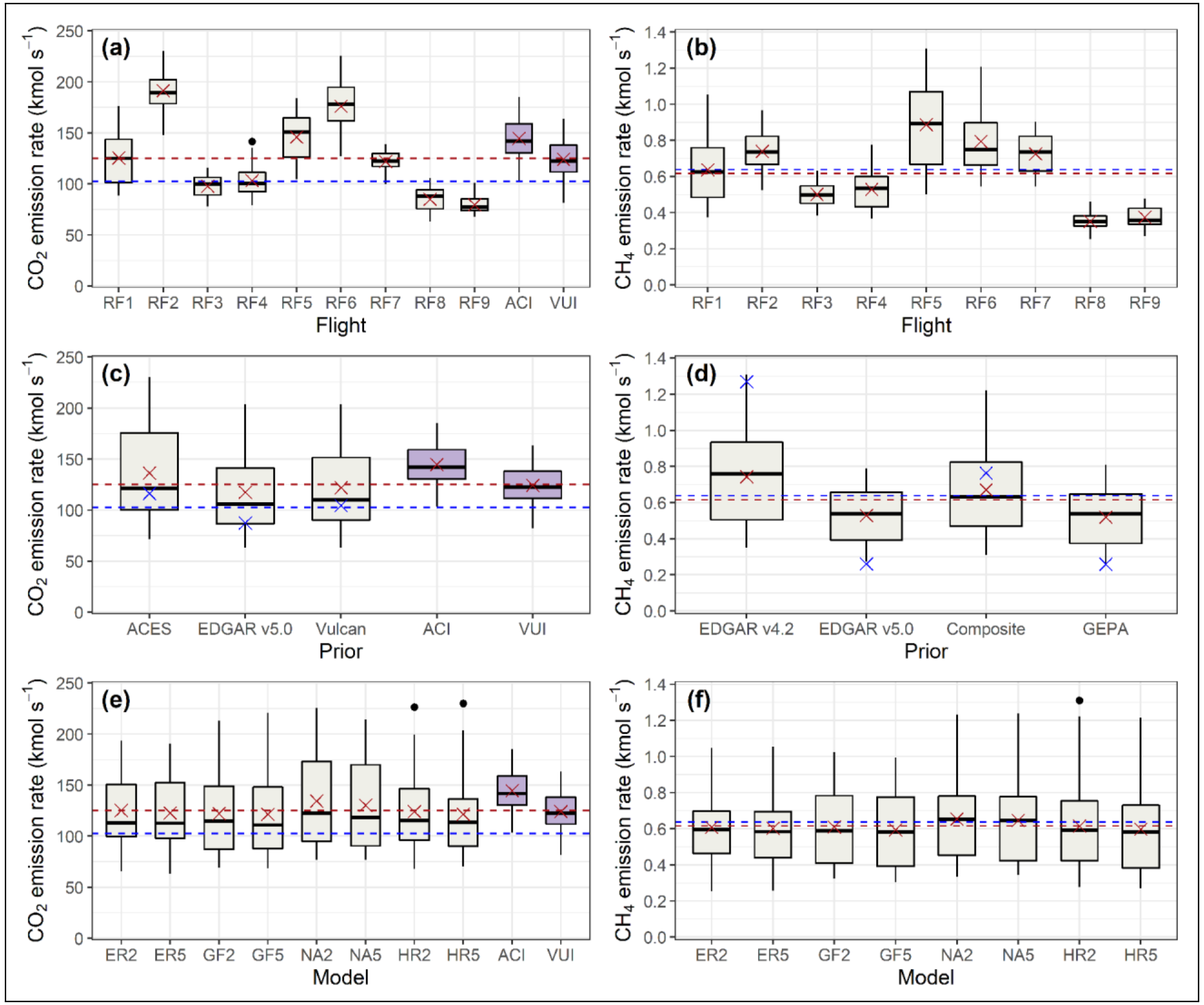


Figure 1. Boxplots of the total posterior emission rates for the New York–Newark urban area. Results are shown

Pitt, J. R., et al. (2022). "New York City greenhouse gas emissions estimated with inverse modeling of aircraft measurements." Elementa-Science of the Anthropocene **10**(1).

Variability by flight date

Inverse methods investigate impact of different model choices, such as the prior or the transport model

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High-resolution (NYC) inventory

New inventory focussed on NYC and surrounding areas with:

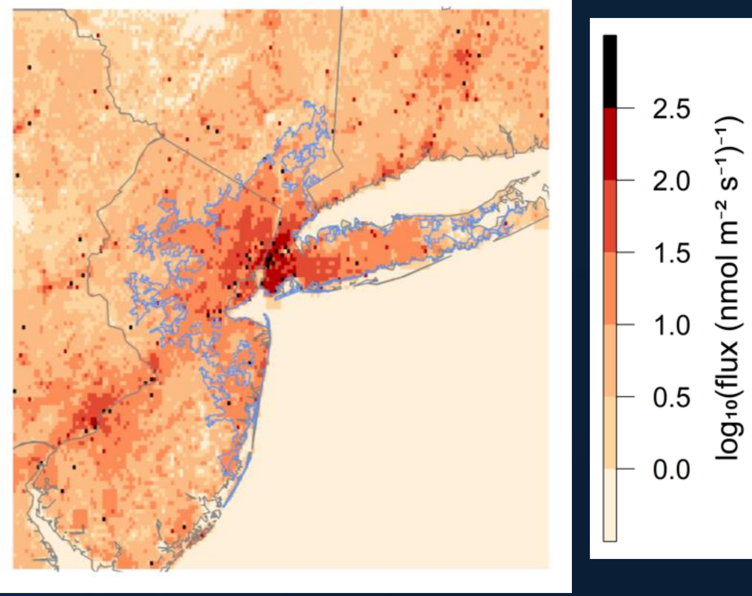
- Higher spatial resolution (0.02°)
- Updated activity data (for the year 2019)
- Updated emission factors
- Updated spatial proxies
- Natural emissions (wetlands, rivers, lakes)

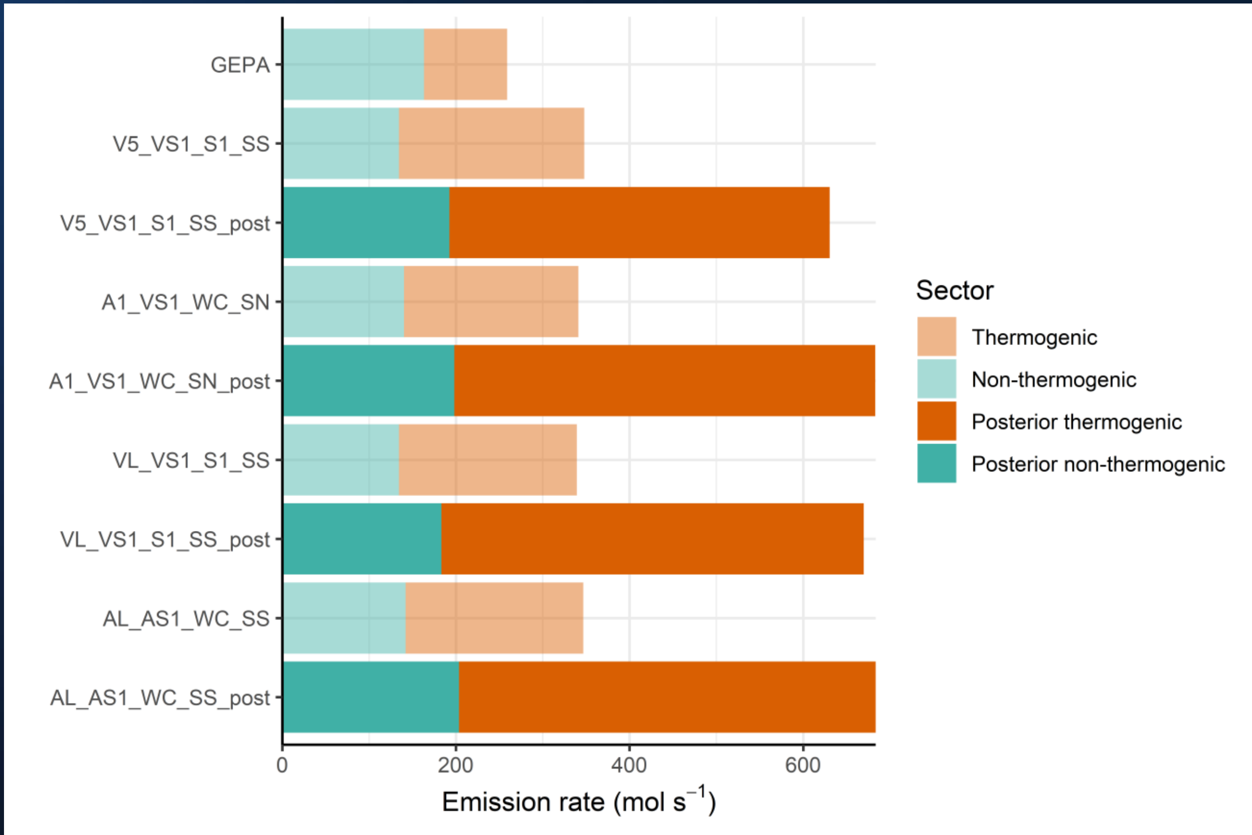
Key Results:

All 4 versions of high-res inventory have larger thermogenic emissions than the GEPA

An inversion using aircraft data (9 flights) with the high-res inventory as a prior still yields much larger posterior emissions (especially thermogenic)

High res prior:





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Pitt et al., (submitted), ES&T

Tower study example (CO_2):

Using atmospheric measurements to estimate emissions decline in March / April 2020.

Geophysical Research Letters

RESEARCH LETTER
10.1029/2021GL092744

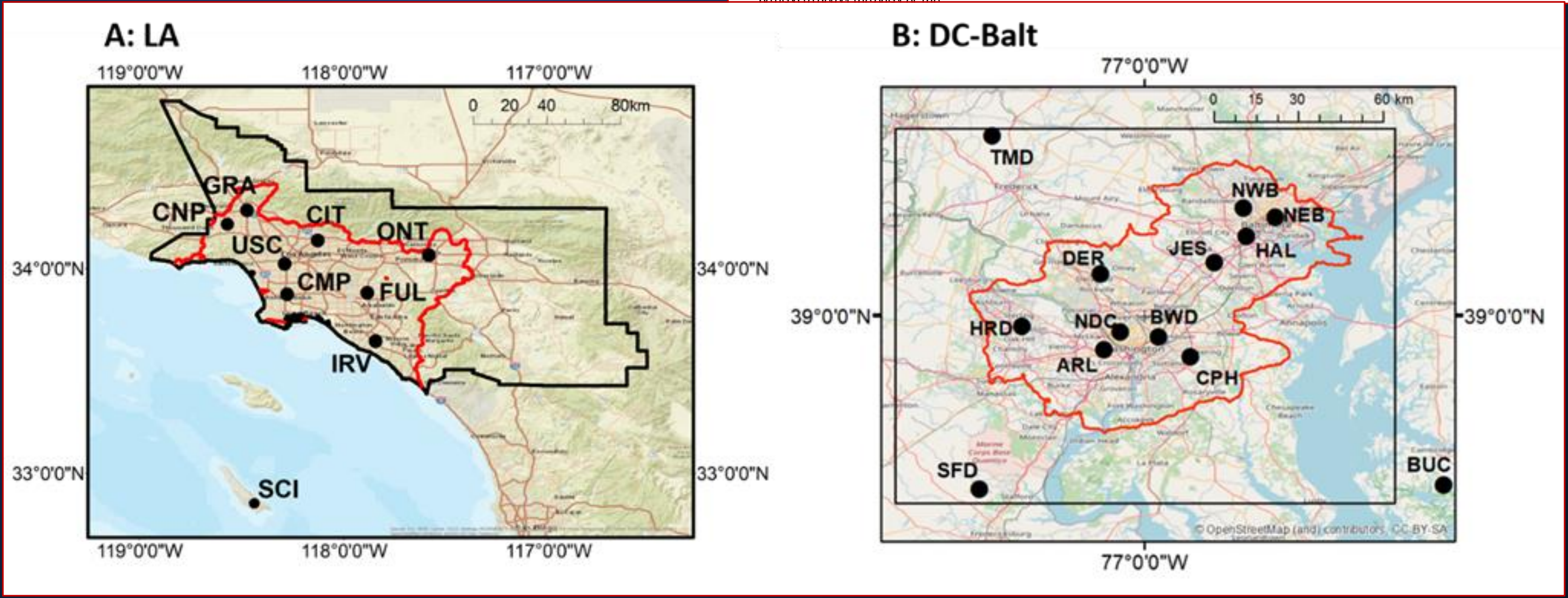
Special Section:
The COVID-19 pandemic: linking health, society and environment

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



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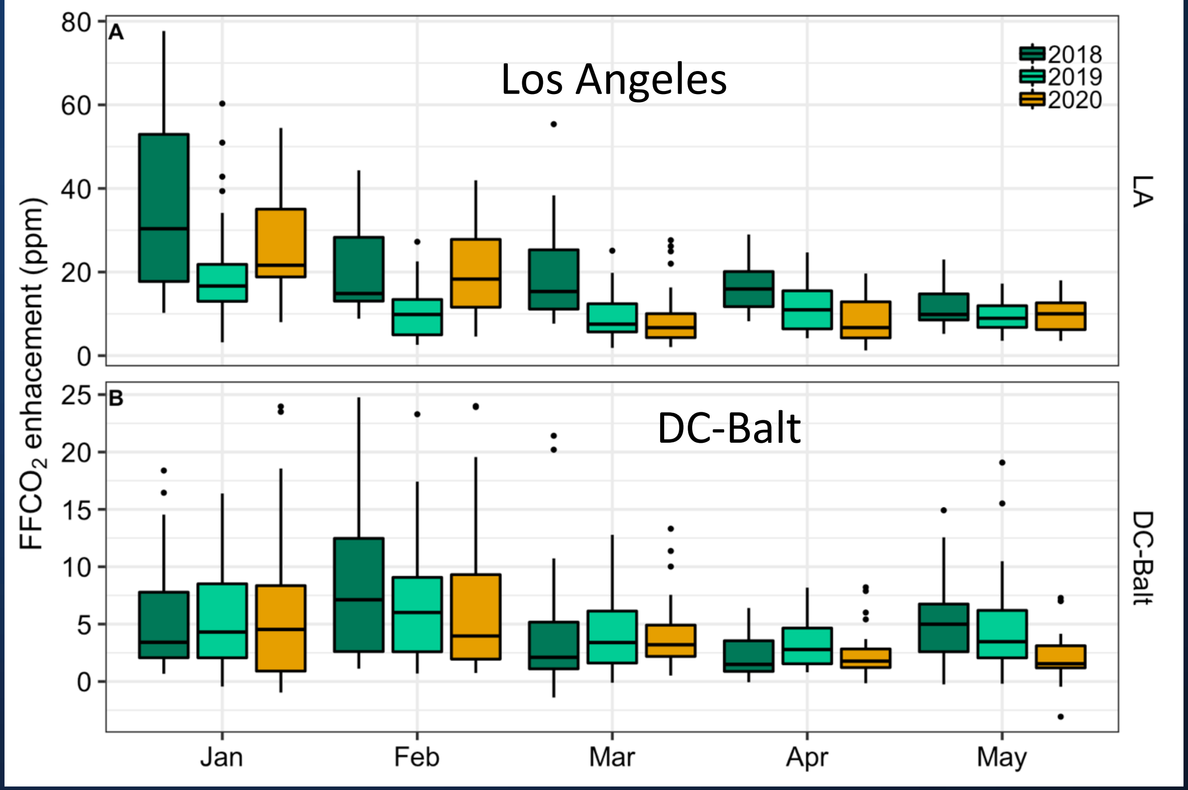
Do CO_2 enhancements show a change?

Box plots of afternoon daily mean network-averaged $FFCO_2$ enhancements ($\mathbf{y}_{FFCO_2}$) in LA (A) and DC-Balt (B) for 2018 through 2020.



Yes, sort of.

Kind of / not really

Yadav et al., GRL, 2021

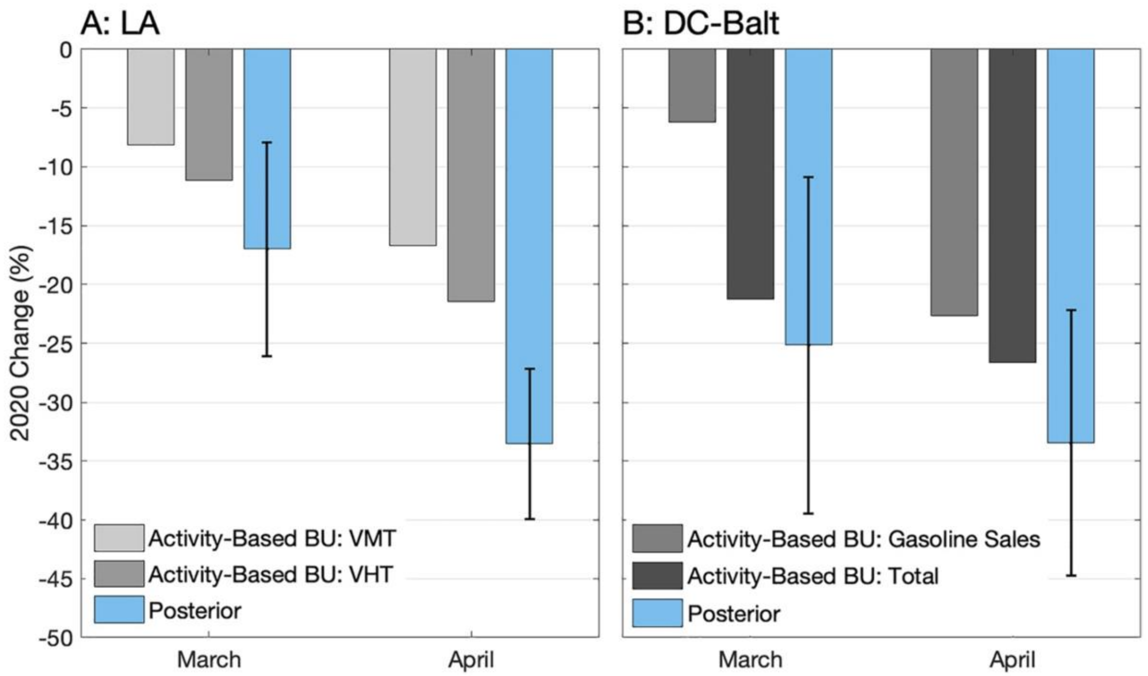


Figure 3. Changes in monthly mean emissions for April and March 2020 relative to 2018/2019 means for (a) LA and (b) DC-Balt. Blue bars represent the decrease estimated from the atmospheric inversion posteriors, with error bars representing the 95% CI. Various shades of gray bars represent the decrease 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

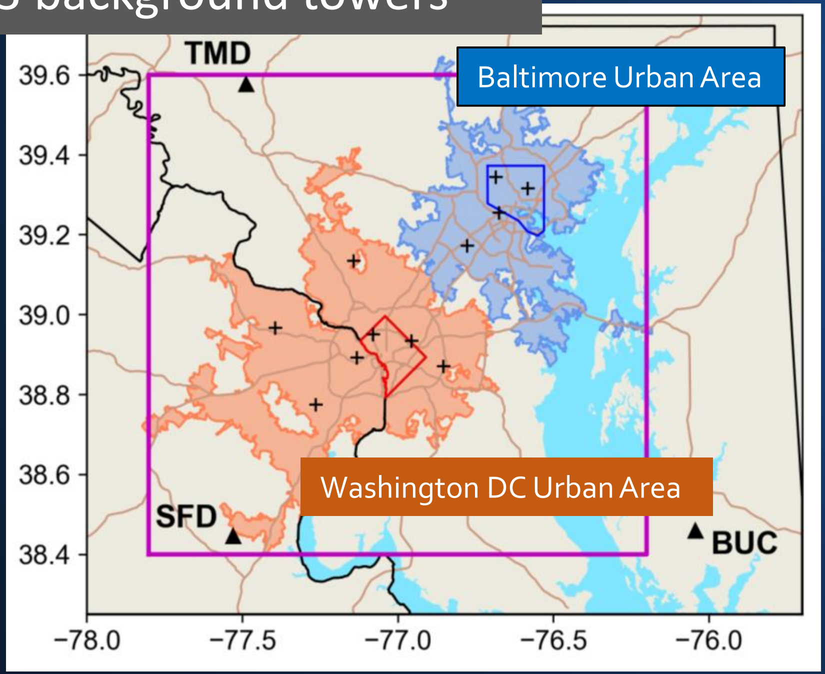
- Assessing declines depends on baseline choice.
- Differences from month to month and year to year are real, and can be caused by various drivers.
- In this case we were successful in using activity information to isolate and attribute the changes due to the lockdown, by looking at the variability in activity associated with CO_2 emissions.

For LA:
March: 17% ± 9% (0.57 MtC ± 0.30 MtC, 95% CI)
April: 34% ± 6% (1.09 MtC ± 0. 21 MtC, 95% CI)

For DC-Balt:
March: 25% ± 14% (0.45 MtC ± 0.25 MtC, 95% CI)
April: 33% ± 11% (0.43 MtC ± 0.15 MtC, 95% CI)

Tower study example (CH_4): Using atmospheric measurements to estimate CH_4 emissions for multiple years

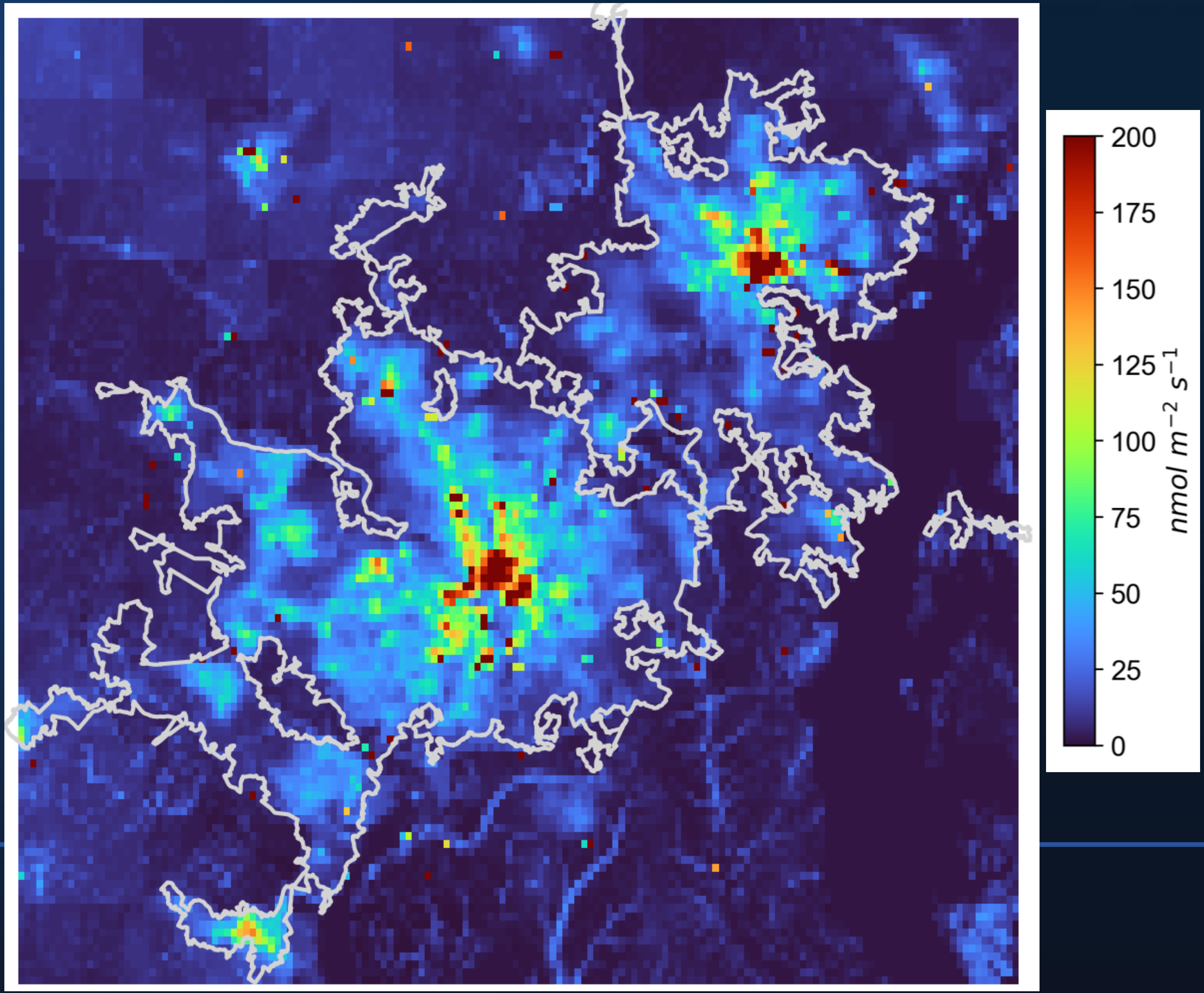
6 to 11 urban towers (+)
3 background towers



US census-designated urban areas

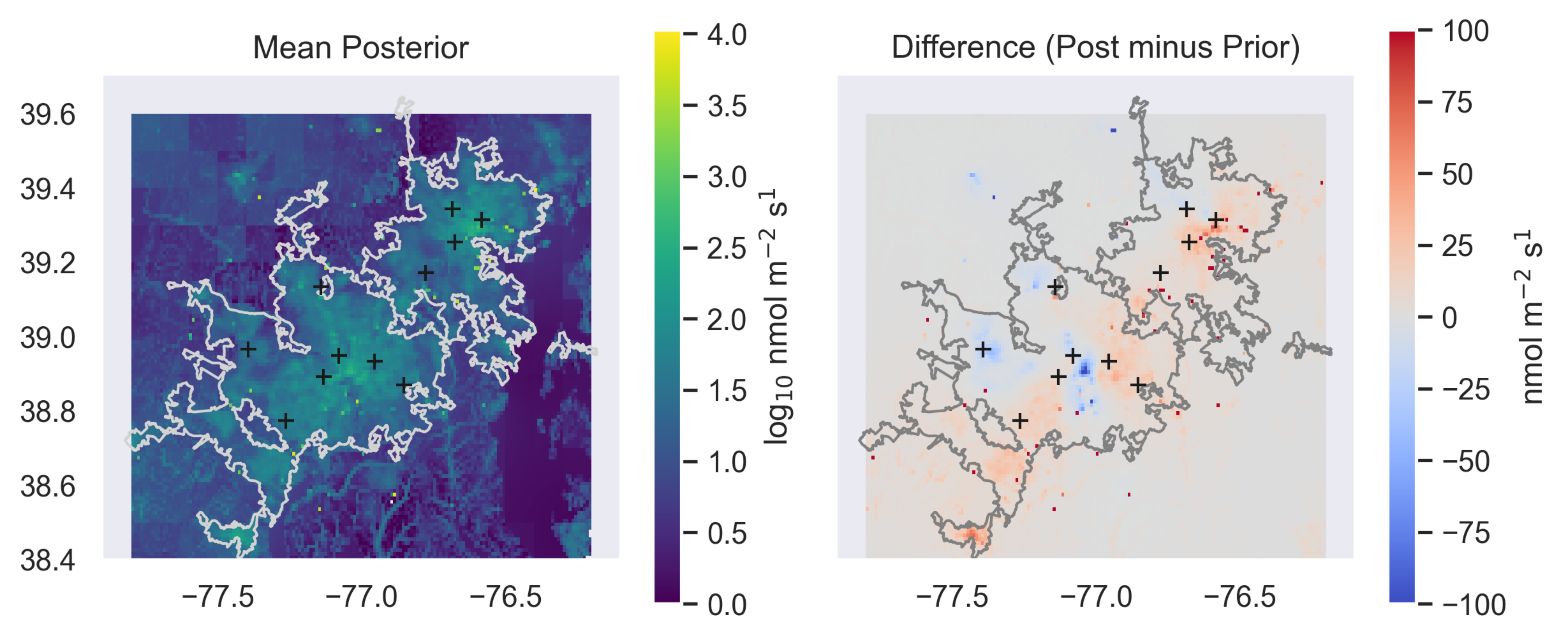
Network Design :
Lopez-Coto et al., 2017 & Mueller et al., 2018.

High res prior:



Karion et al., (in prep.)

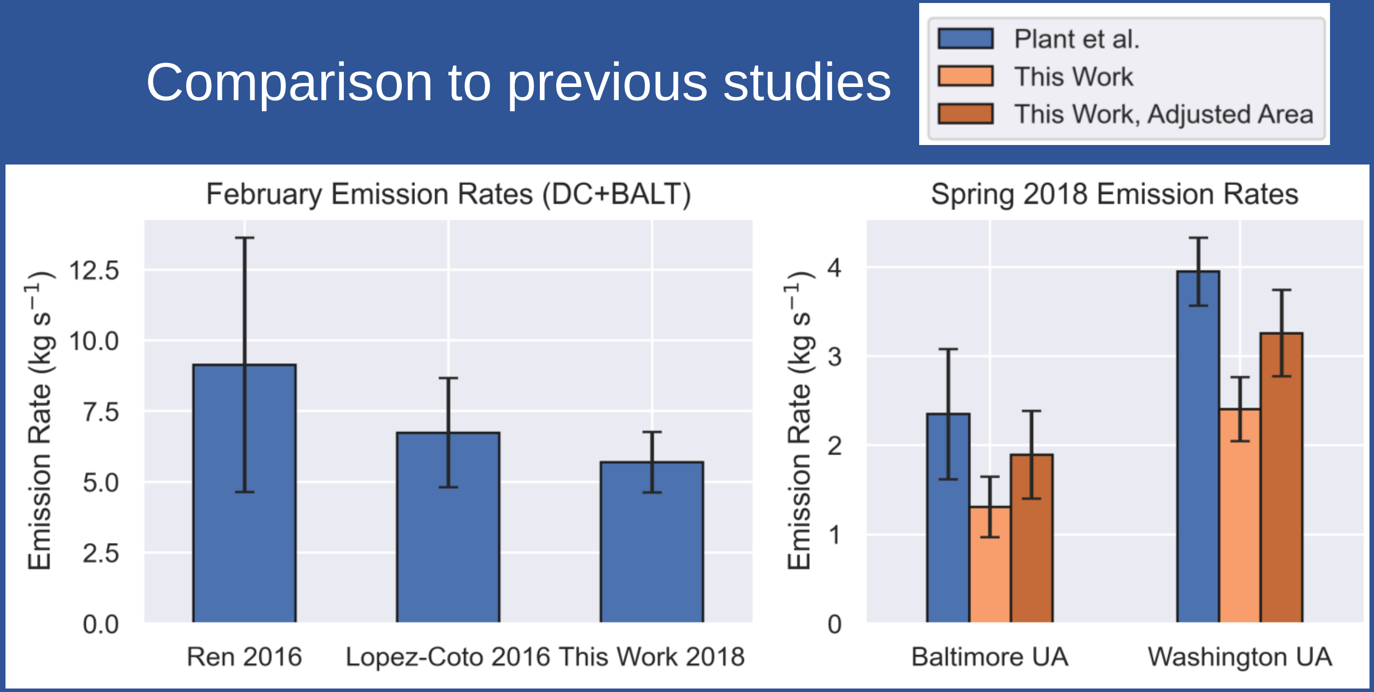
Results: ensemble average of posteriors



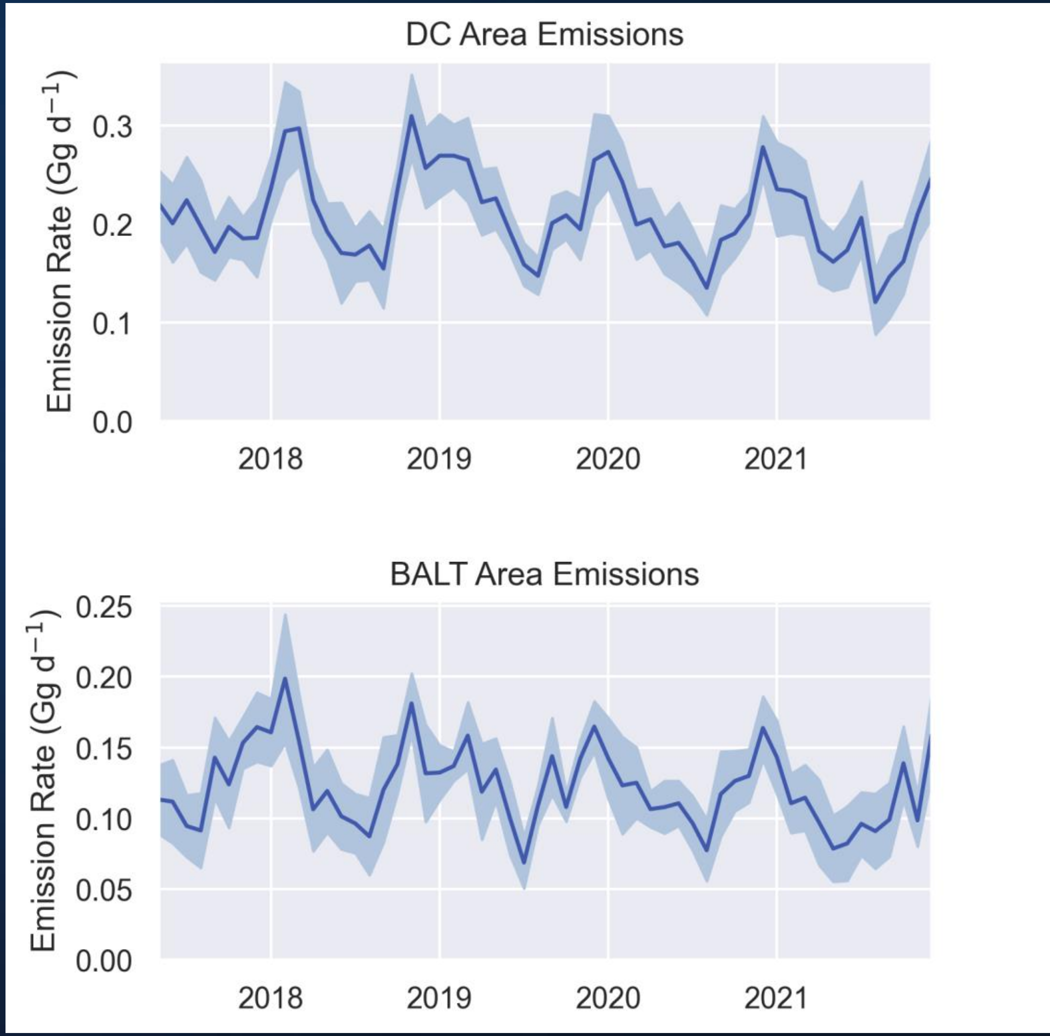
Karion et al., (in prep.)

Results: ensemble average of posteriors

Comparison to previous studies



Overall emissions in both cities are higher than our bottom-up estimate. Ongoing work to point to the reason for the under-estimate



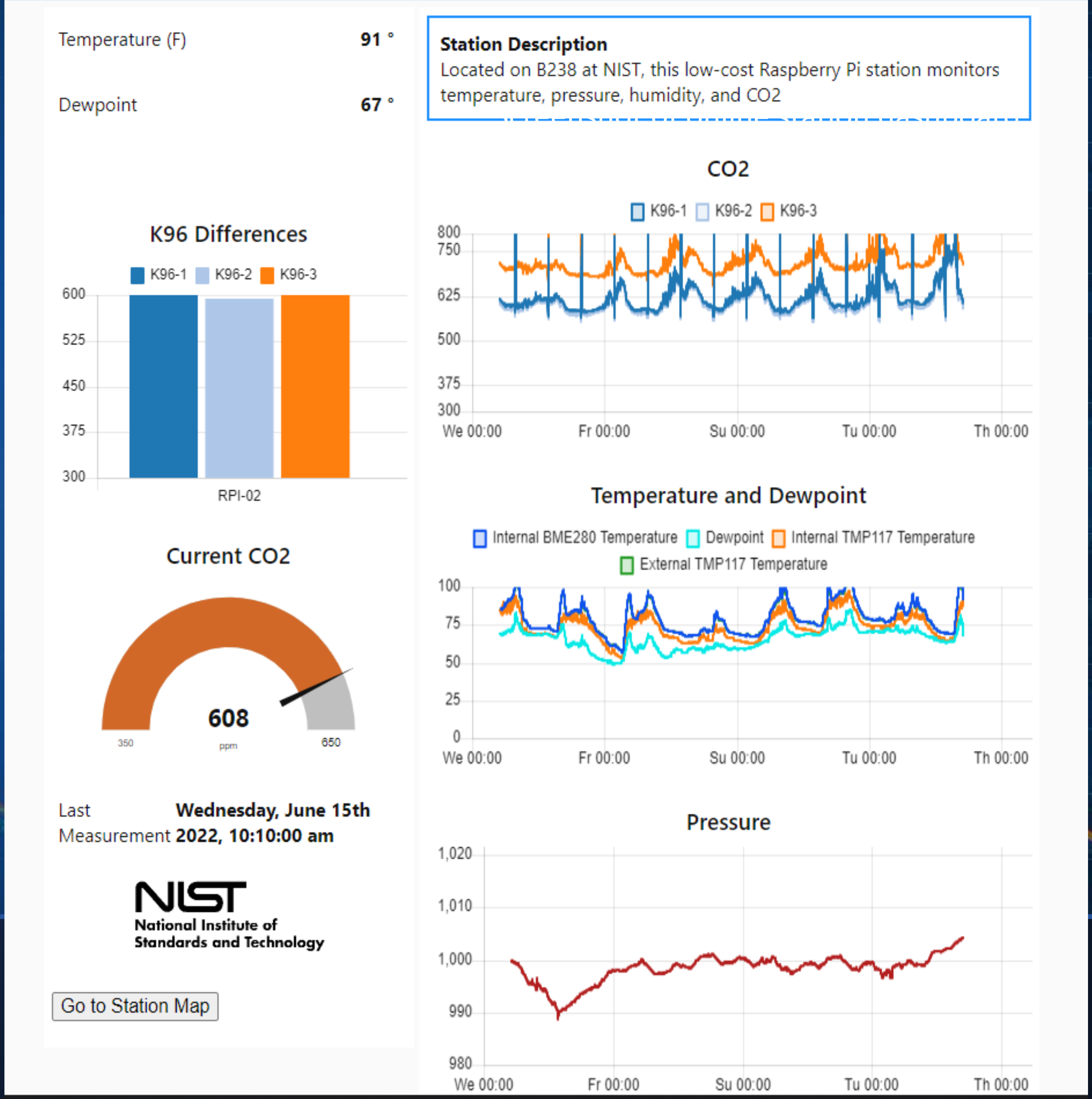
Time series of posterior emissions indicates seasonality

Karion et al., (in prep.)

Low-cost sensors

- Even with enhanced measurement uncertainties, low-cost sensor measurements can be beneficial to urban measurement networks (Lopez-Coto et al. 2017)
- Goals:
  - Characterize sensor uncertainties over ideal conditions
  - Develop and deploy a network supporting ~50 low-cost GHG sensor stations in the Northeast Corridor (NEC) corridor to augment measurements from high-accuracy analyzers
- Currently working with commercial CO_2 sensors
- Building flexible framework for other future sensors

NIST: Building 238 Screenshot courtesy of Tyler Boyle



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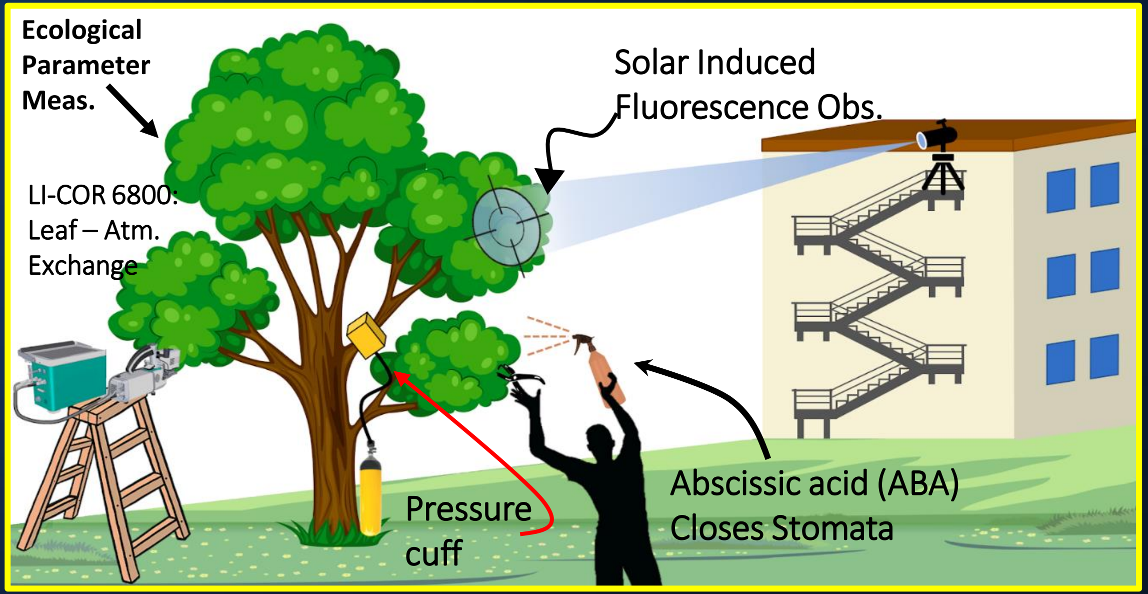
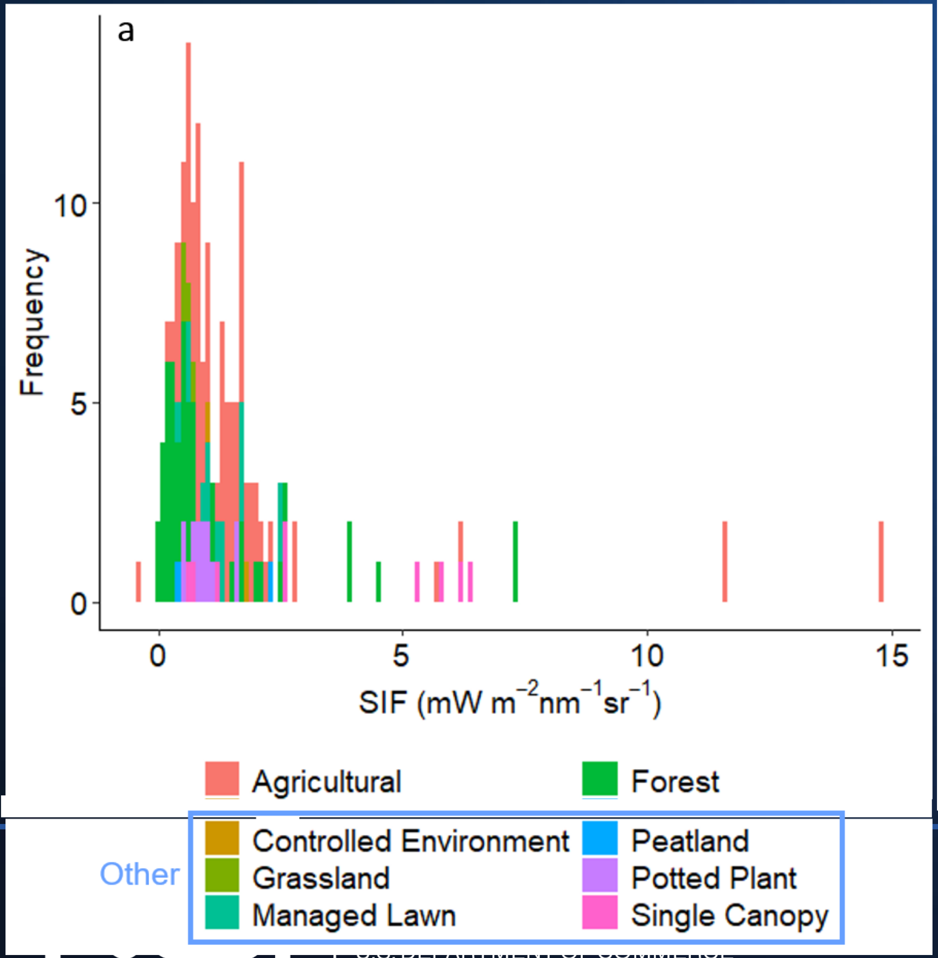
Additional testbed activities

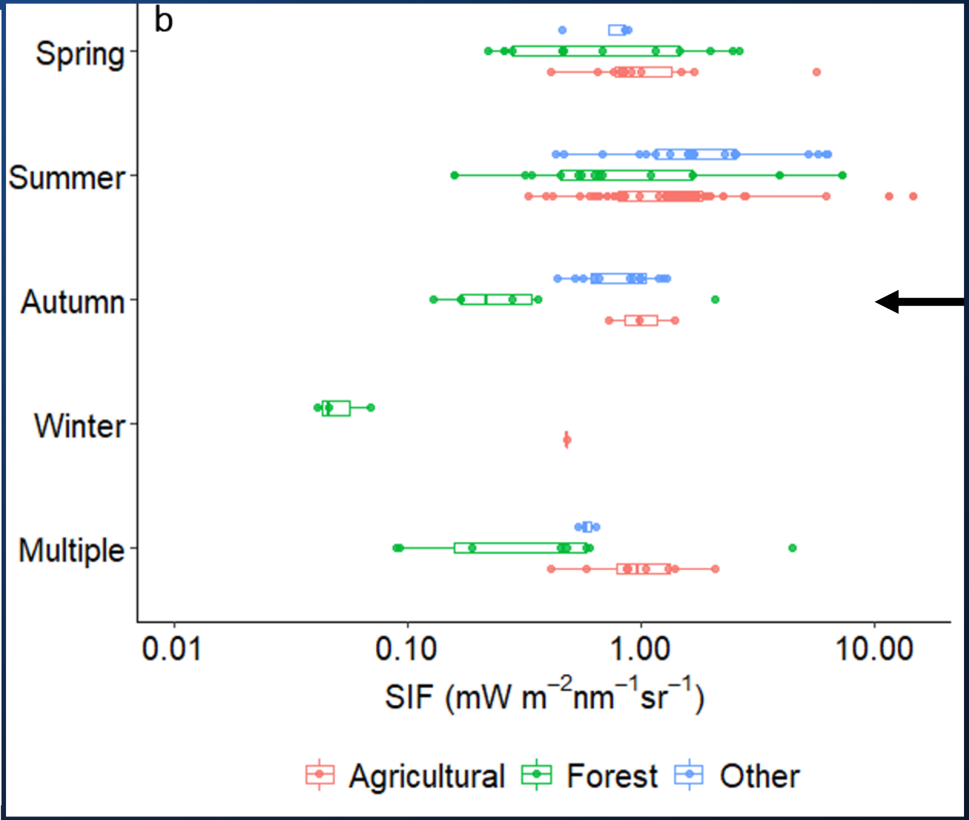
- Airborne turbulence measurements (Stonybrook U.) and high-resolution tracer modeling around powerplants using WRF-LES
- HALO (wind/PBL lidar) & Mini-MPL (Lidar)
- Eddy covariance flux towers (Penn State) in Indianapolis and in the Washington area to diagnose CO_2 and CH_4 fluxes in cities (including suburban vegetation) (Wu et al., 2022).
- SIF-Biosphere testbed (FOREST project) on NIST campus in Maryland, collab. w/ BU, Bowdoin & others. Goal to assess SIF measurements and linkage to GPP to improve biosphere modeling (Marrs et al., GRL)



SIF Retrievals:
Can span three orders of magnitude!

Instrument calibration & characterization effects may help to explain limitations





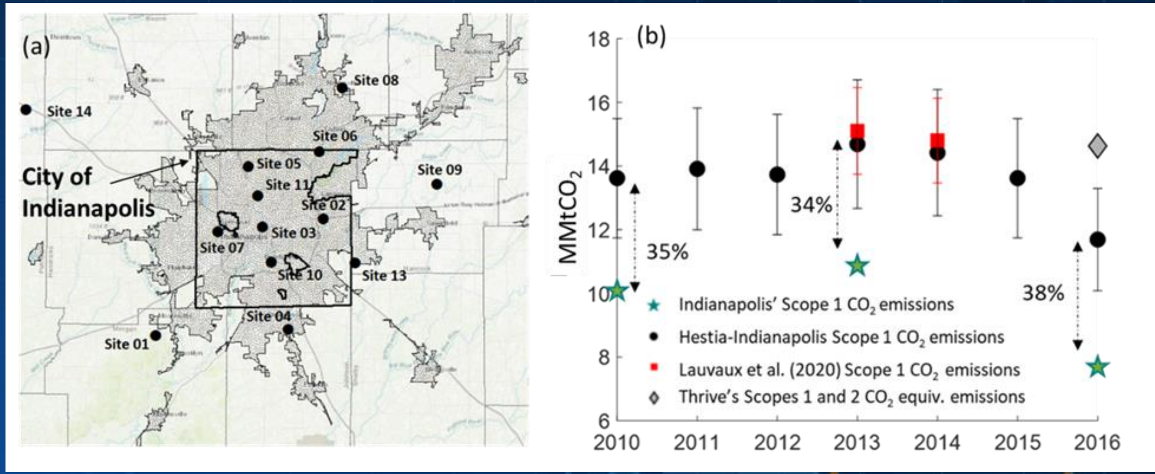
Two orders of magnitude within a single season and vegetation type

Marrs et al. 2021 *RSE*
https://doi.org/10.1016/j.rse.2021.112413

Relevance → Stakeholders

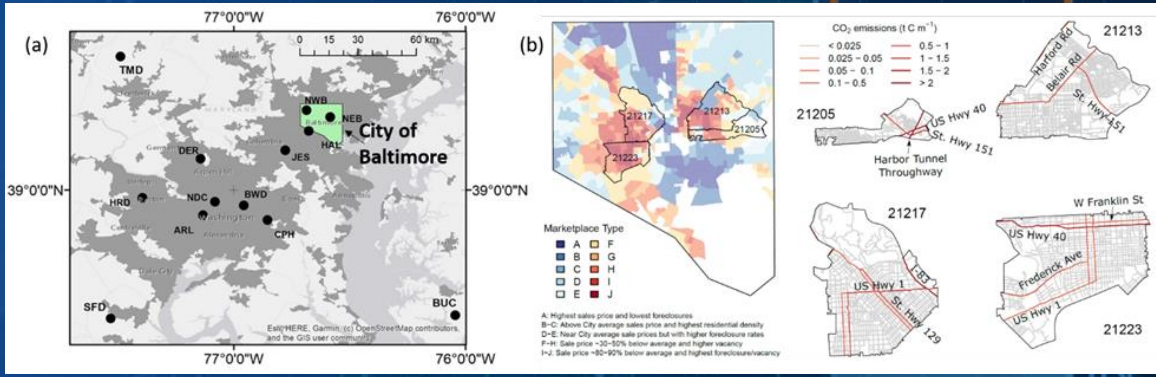
Indianapolis

City comparisons with reported emissions



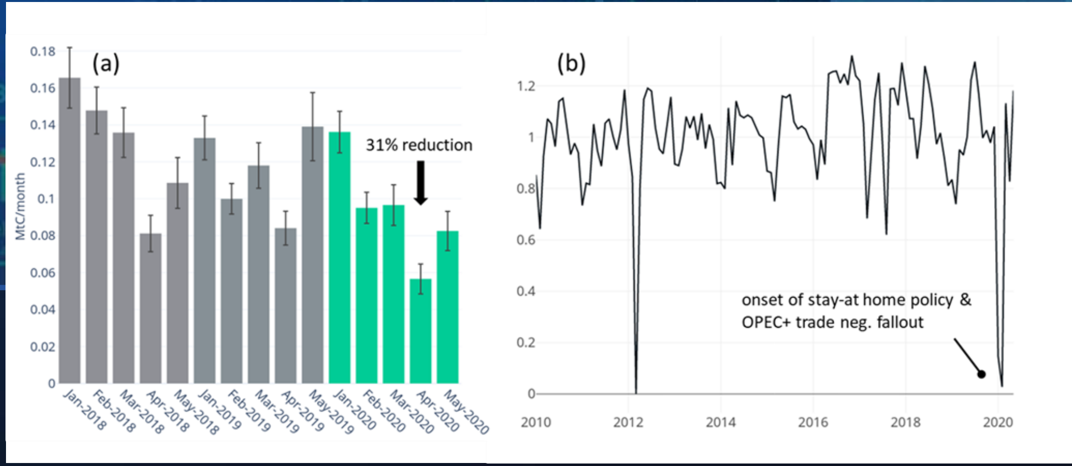
Northeast Corridor

Combining with correlated problems (e.g., air quality and environmental equity)



Northeast Corridor

Investigating drivers (e.g., behavioral shifts due to COVID-19 or market forces)



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Mueller et al. (2021) An Emerging GHG estimation approach can help cities achieve their climate and sustainability goals. Env. Research Letters

Relevance → Stakeholders (Brown Station Landfill, Maryland)

Relevance → Stakeholders

Urban Integrated Field Laboratories
U.S. Department of Energy | Office of Science | Biological and Environmental Research Program

BSEC
The Baltimore Social-Environmental Collaborative

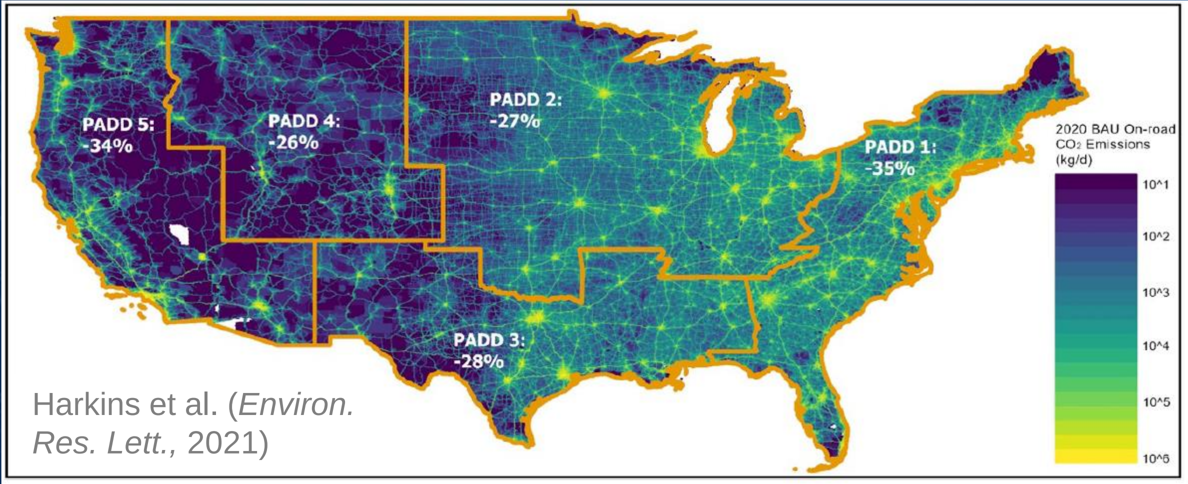
Baltimore. Baltimore is representative of the climate challenges faced by many midsized industrial cities in the United States, and in particular with eastern "rust belt" cities that face interlinked challenges of aging infrastructure, stagnant populations, increased heat and flood risk, and inequitable burdens of air and water pollution.

- Baltimore is one of three cities selected for this project.
- Benjamin Zaitchik, Johns Hopkins University (Lead PI) – multi-institutional project (ex. Penn State playing a role) including minority serving universities
- NIST is collaborating with GHG portion (small role) - Scot Miller, John Hopkins University Lead
  - CO_2 observations + HALO measurements + WFF
- BUT much bigger than GHG (health , Environmental Justice)
- Community groups, City of Baltimore (Office of Sustainability)

Accelerate transparency and robustness of emission information to foster credible transactions, ESG information, etc. → improve US competitiveness

- Work with Department of Commerce International Trade Administration (ITA) to connect physical science to finance community
- **Continue technical focus** in calibration and measurement science
- Engage international organizations
- **Launch standards process** in greenhouse gas measurement methods
- Build capabilities in the USG that can provide information at a range of spatial scales by partnering with NOAA and others

GRA2PES (GReenhouse gas and Air Pollutants Emissions System)



Harkins et al. (*Environ. Res. Lett.*, 2021)

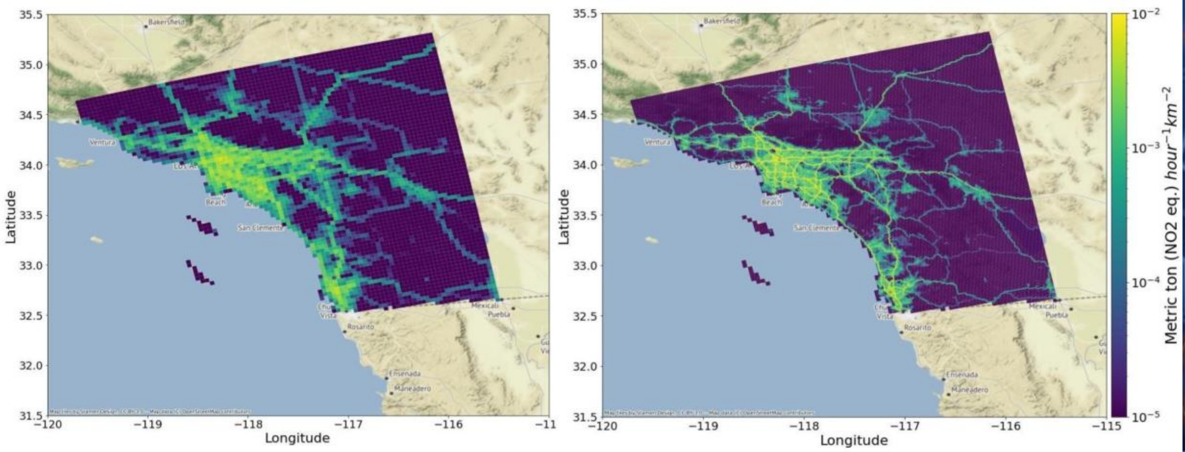


Figure provided by Katelyn Yu (UC-Berkeley/NOAA CSL)

Research Objectives

- Joint initiative between NIST Greenhouse Gas Measurement Program and NOAA Chemical Sciences Laboratory
- Measure, model, and map emissions of greenhouse gases and air pollutants in consistent spatial/temporal pattern
- Development of uncertainty analyses for emission inventories
- Enable nowcasting, forecasting, or hindcasting of GHGs and pollutants at multiple spatial scales – city, state and national

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NAU
NOAA Air Resources Laboratory
Global Monitoring Laboratory
Earth System Research Laboratories
CSL NOAA CHEMICAL SCIENCES LABORATORY

Thank you

https://www.nist.gov/greenhouse-gas-measurements/urban-test-beds
Contact: Kimberly.Mueller@nist.gov