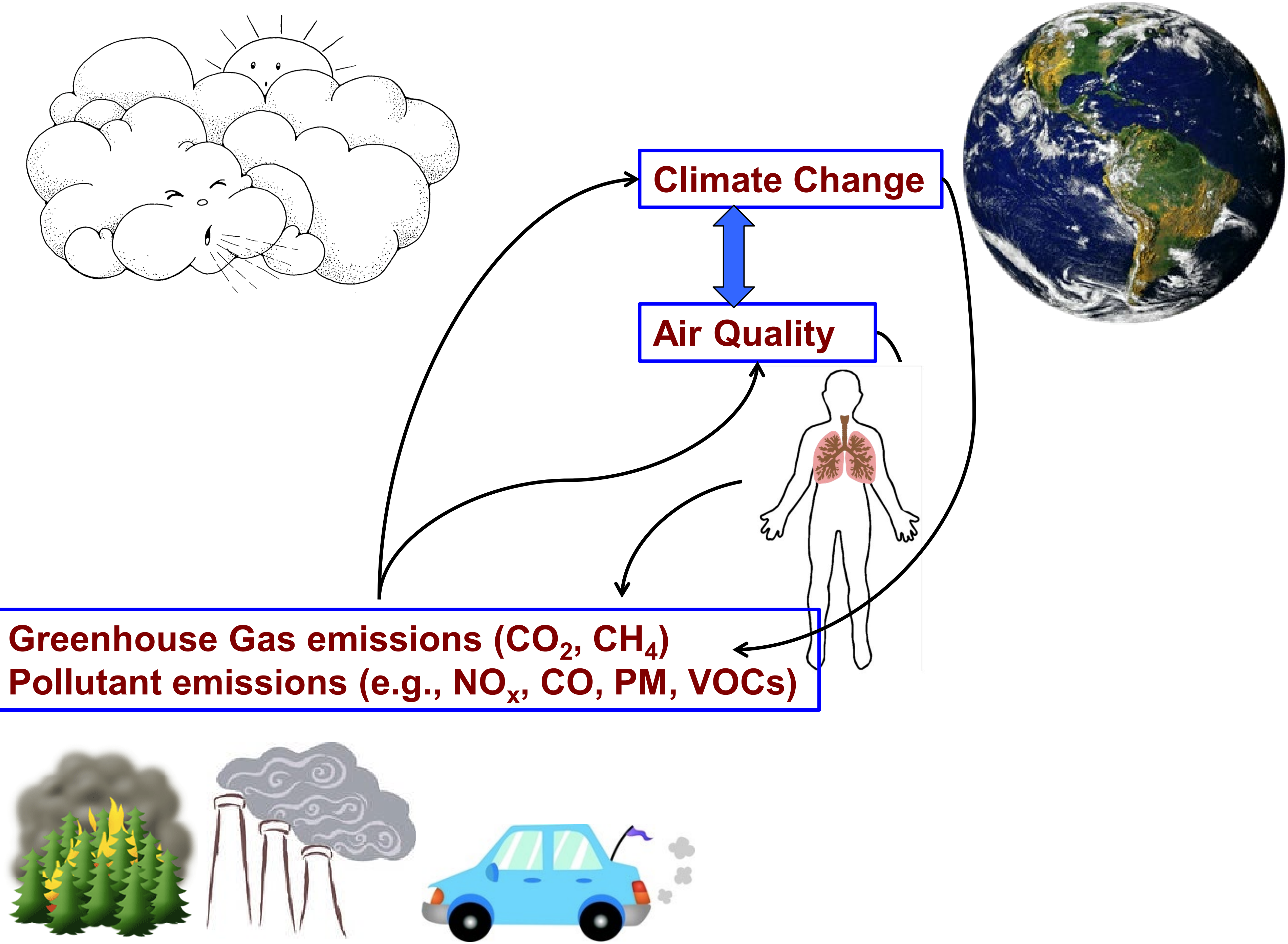
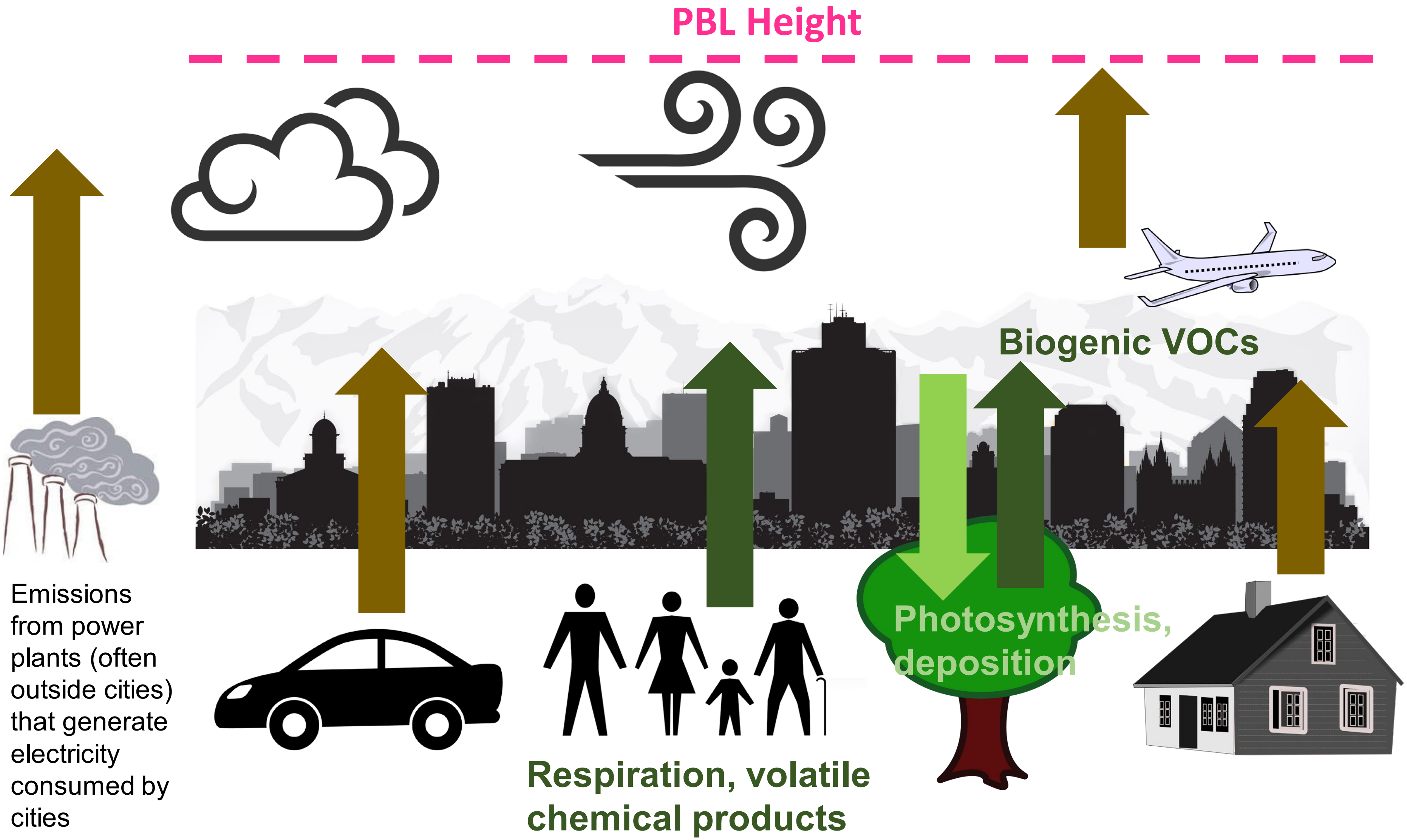
Changing emissions of greenhouse gases and chemically reactive pollutants: implications for urban atmospheric composition

John Chun-Han Lin (John.Lin@utah.edu)
Ryan Bares
Logan Mitchell
Ben Fasoli

Department of
ATMOSPHERIC SCIENCES
MINES AND EARTH SCIENCES | THE UNIVERSITY OF UTAH


Climate Change
Air Quality
Greenhouse Gas emissions (CO_2, CH_4)
Pollutant emissions (e.g., NO_x, CO, PM, VOCs)



Modified from Lin et al. (BAMS, 2018)

Emission Estimation in Inventories

"The general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100)$$

where:

- E = emissions;
- A = activity rate; **related to energy usage (fossil fuel combustion!); constrained with GHG data**
- EF = emission factor; **constrained with pollutant:GHG ratio obs**
- ER =overall emission reduction efficiency, %"

https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification

Urban Atmospheric Composition is Changing

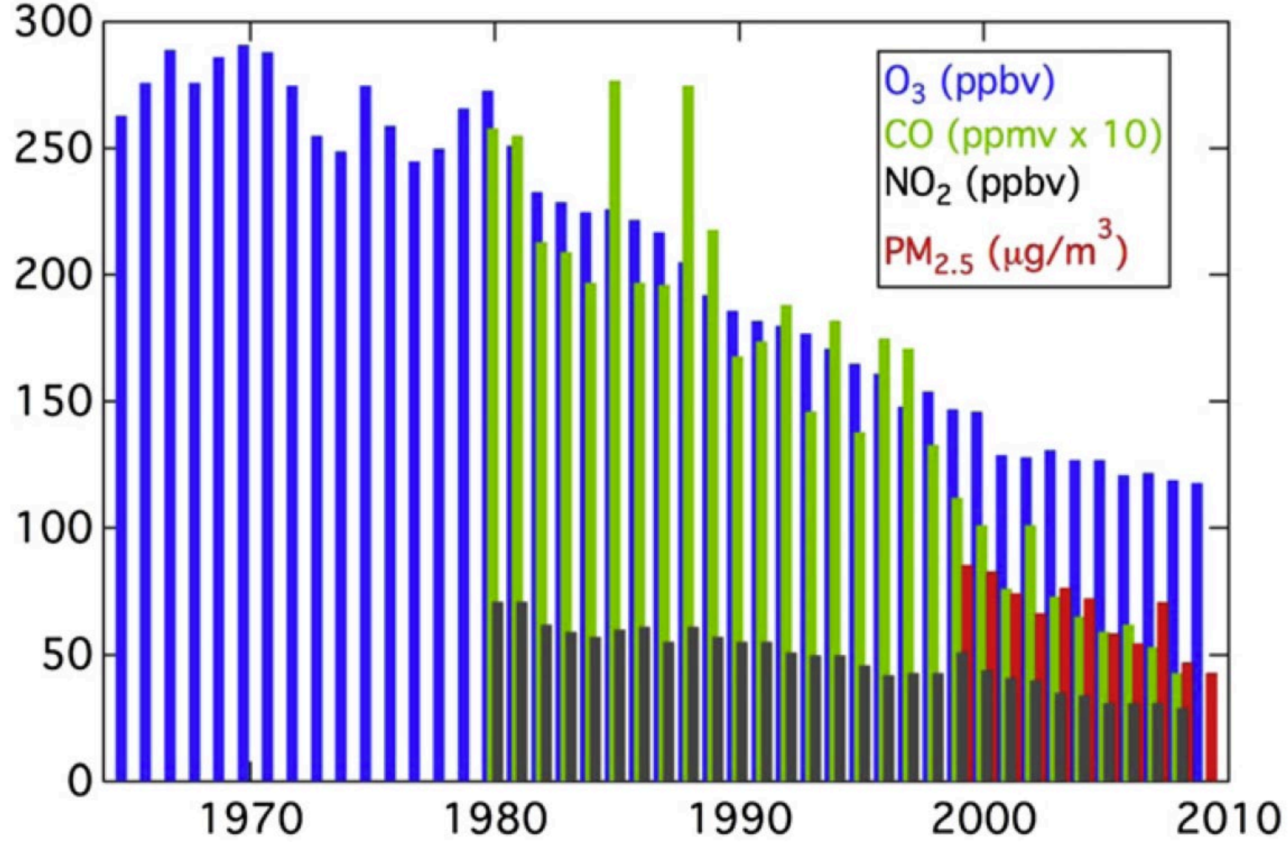
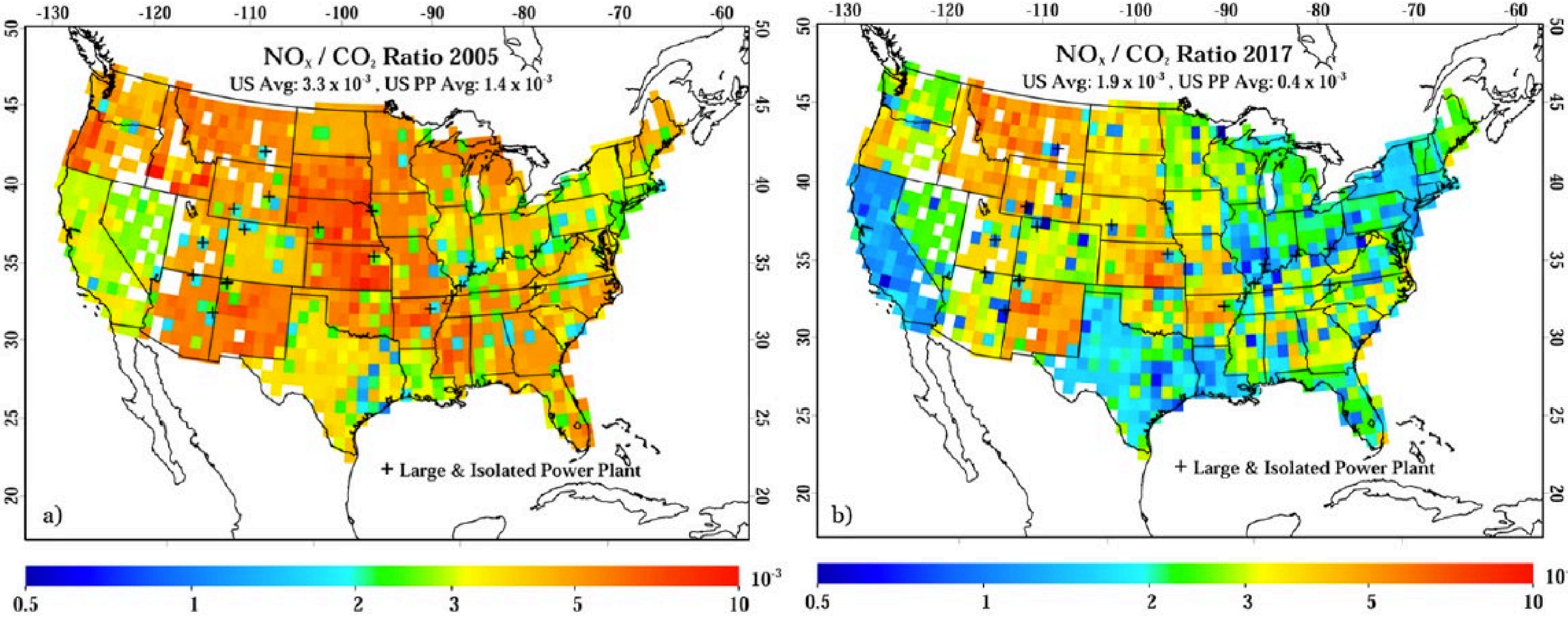


Fig. 1. Air quality trends in the Los Angeles urban area of California. As per national standards, the O_3 data (8-h average) are 3-yr averages of the 4th highest annual maxima, the CO data (8-h average) are annual maxima, the NO_2 data are annual averages, and the $PM_{2.5}$ data (24-h average) are annual 98th percentiles. Data are derived from monitoring stations in the SoCAB region (Alexis et al., 1999; Cox et al., 2009; http://www.arb.ca.gov/adam/cgi-bin/db2www/polltrendsb.d2w/Branch).

Parrish, D. D., H. B. Singh, L. Molina, and S. Madronich, 2011: Air quality progress in North American megacities: A review. *Atmos. Environ.*, **45**, 7015–7025, doi:https://doi.org/10.1016/j.atmosenv.2011.09.039.

Pronounced spatial variations even within the Western U.S.: will we see with aircraft?



NOx-to-CO_2 emission ratios (inferred from emission inventories) have decreased by ~40% nationwide between 2006 to 2017

Catalytic converters:
NOx => NH_3?

Science of the Total Environment 695 (2019) 133805

Contents lists available at ScienceDirect

Science of the Total Environment

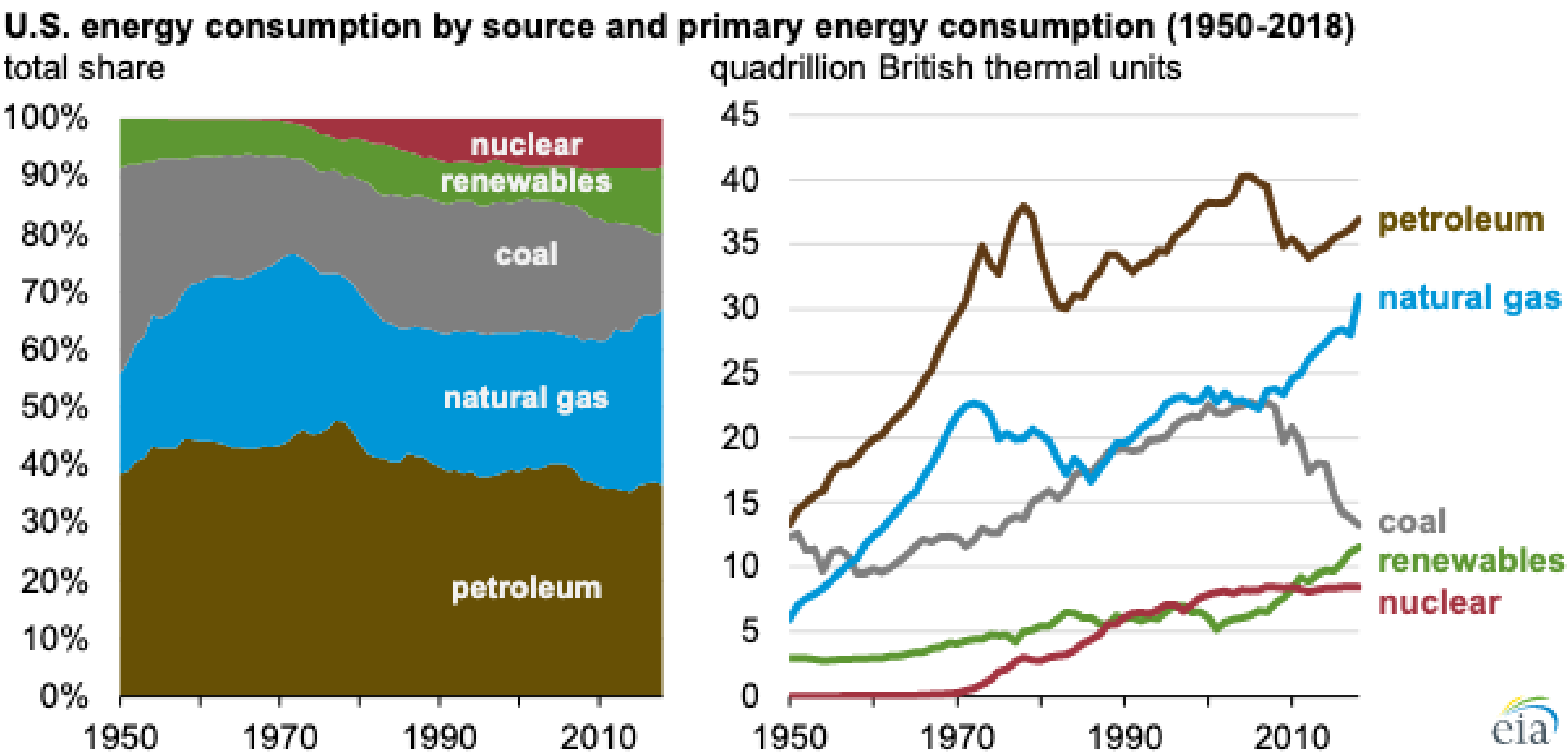
journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

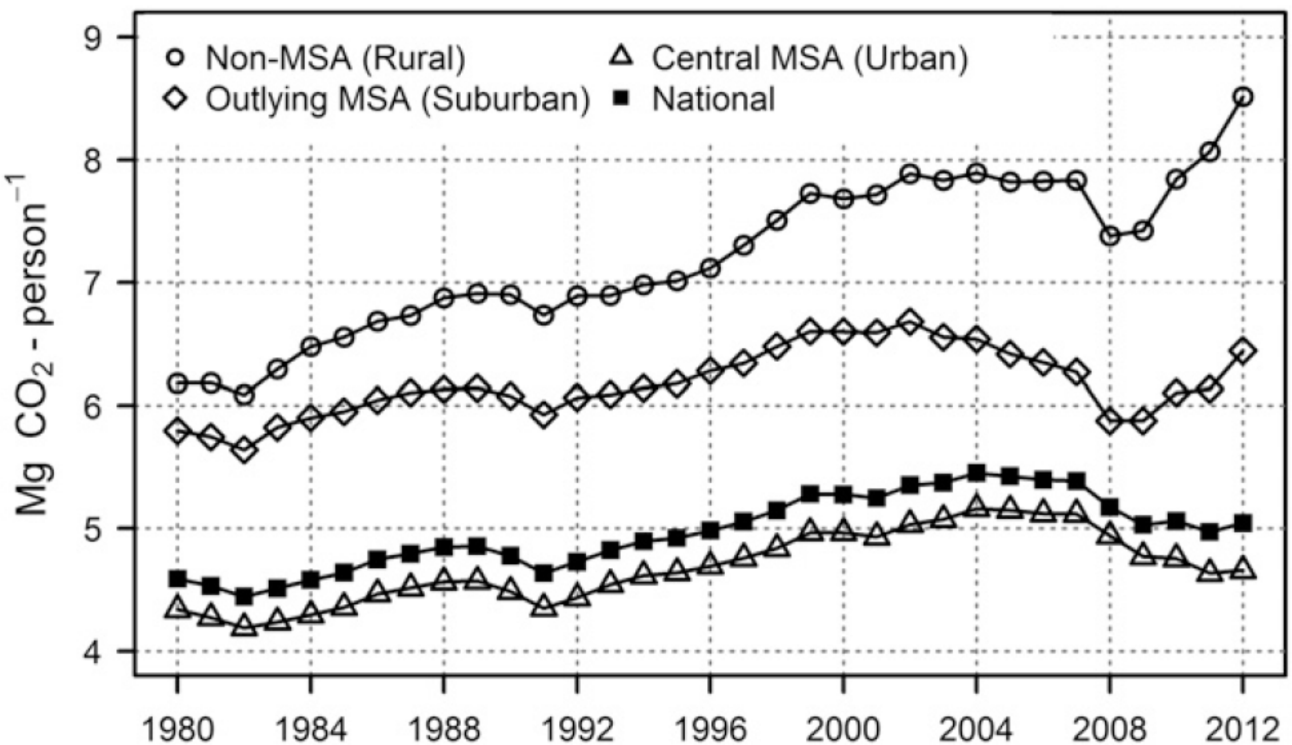
Exploiting OMI NO_2 satellite observations to infer fossil-fuel CO_2 emissions from U.S. megacities☆

Daniel L. Goldberg [a,b,*], Zifeng Lu [a,b], Tomohiro Oda [c,d], Lok N. Lamsal [c,e], Fei Liu [c,e], Debora Griffin [f], Chris A. McLinden [f], Nickolay A. Krotkov [e], Bryan N. Duncan [e], David G. Streets [a,b]

U.S. fuel mixture—changes over years

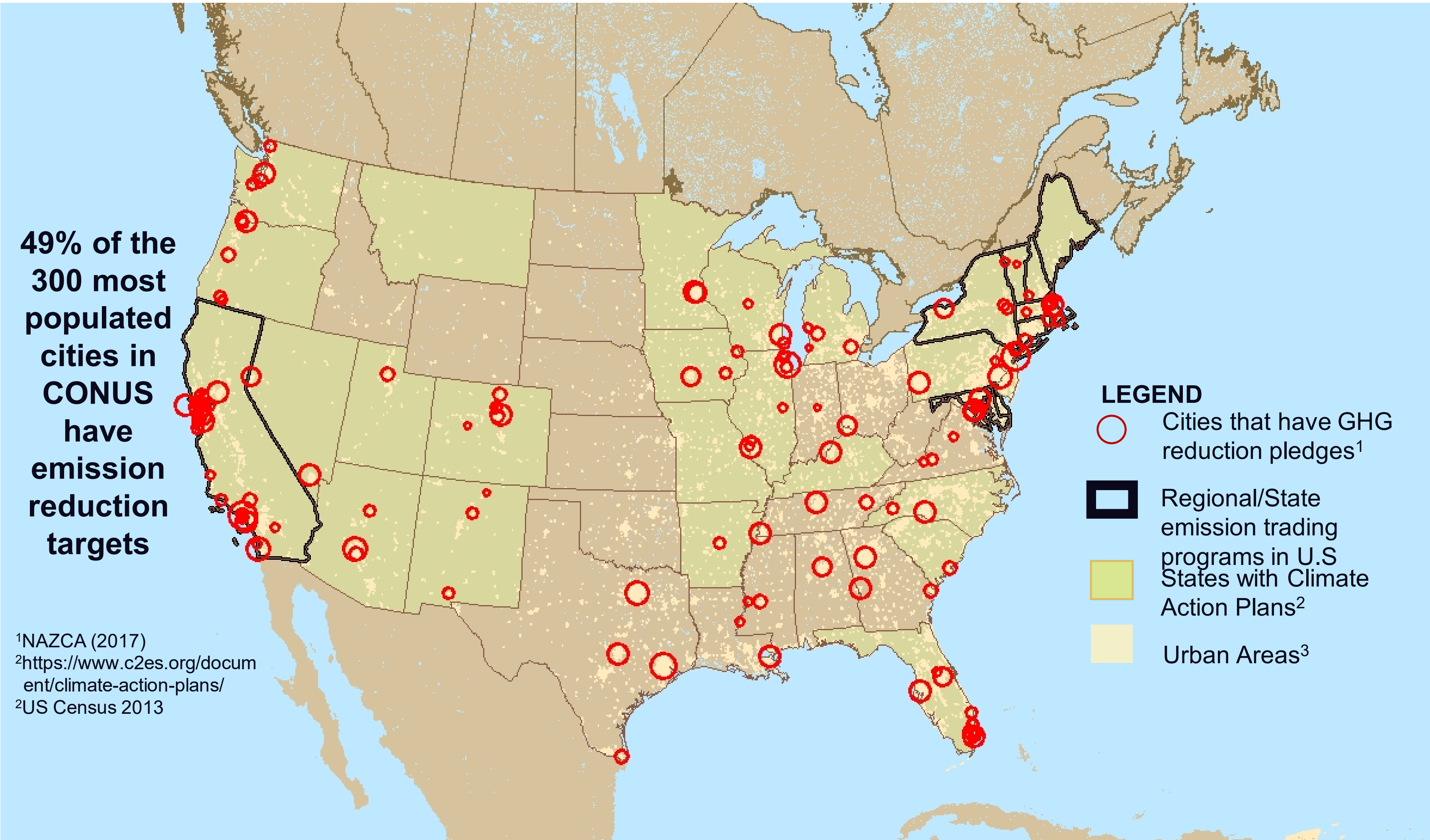


Time Series of U.S. Per capita ON-ROAD CO_2 Emissions by County



(Gately et al., 2015)

“Demand” for Localized GHG Emission Information
ex. GHG mitigation policies/pledges



(from Kim Mueller)

“Our city. . . is committed to powering 50% of municipal operations with renewables by 2020. We have set another goal of transitioning the entire community's electricity supply to 100 percent clean energy by 2032, followed by an overall reduction of community greenhouse gas emissions 80% by 2040. “
--Jackie Biskupski, mayor of Salt Lake City

SALT LAKE CITY

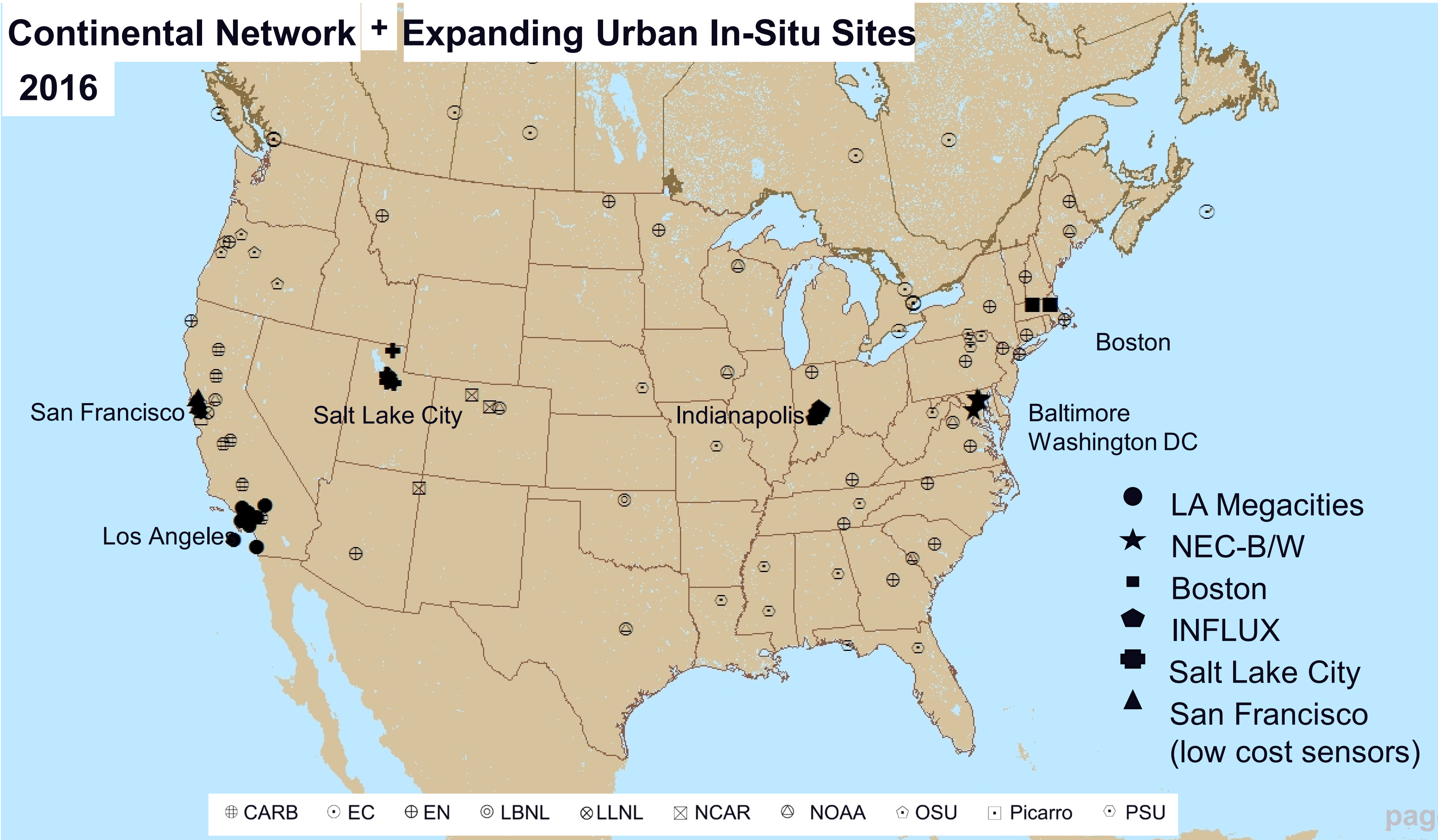
SLCgreen

Continental Network + Expanding Urban In-situ Sites

2016

Data Expansion

ex. in-situ obs. for top-down models



(from Kim Mueller)

CO2 Urban Synthesis and Analysis Network

CO_2-USA Project Website

GHG Data Registry

Workshops Working Groups Inventory Urban Biosphere Atmospheric Transport Modeling Resources for Cities

“CO_2-USA” Network

http://sites.bu.edu/co2usa

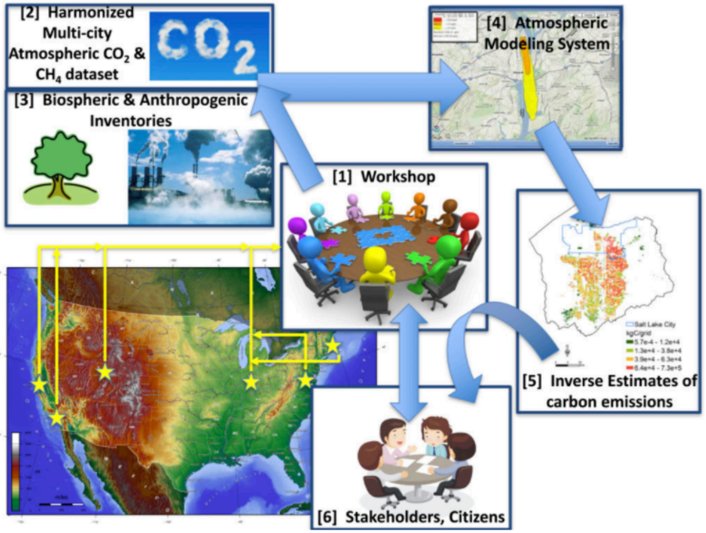
Principal Investigators: John Lin, Lucy Hutyra, Steven Wofsy, Christopher Loughner

Project Summary

Next workshop in Boston: Oct. 7th~8th, 2019

Cities have emerged as leaders in US efforts to reduce greenhouse gas emissions, but the scientific knowledge to quantitatively track emissions and assess the efficacy of mitigation is lacking. As the global population increasingly resides in urban regions, scientific knowledge about *how much, where,* and *why* a particular city emits carbon becomes increasingly important. This workshop launches a collaborative network to exchange information on community standards and common measurements, facilitate data sharing, and create analysis frameworks and cross-city syntheses to catalyze a new generation of researchers and enable new collaborations tackling important objectives that are difficult to address in isolation. Specifically this synthesis effort seeks to:

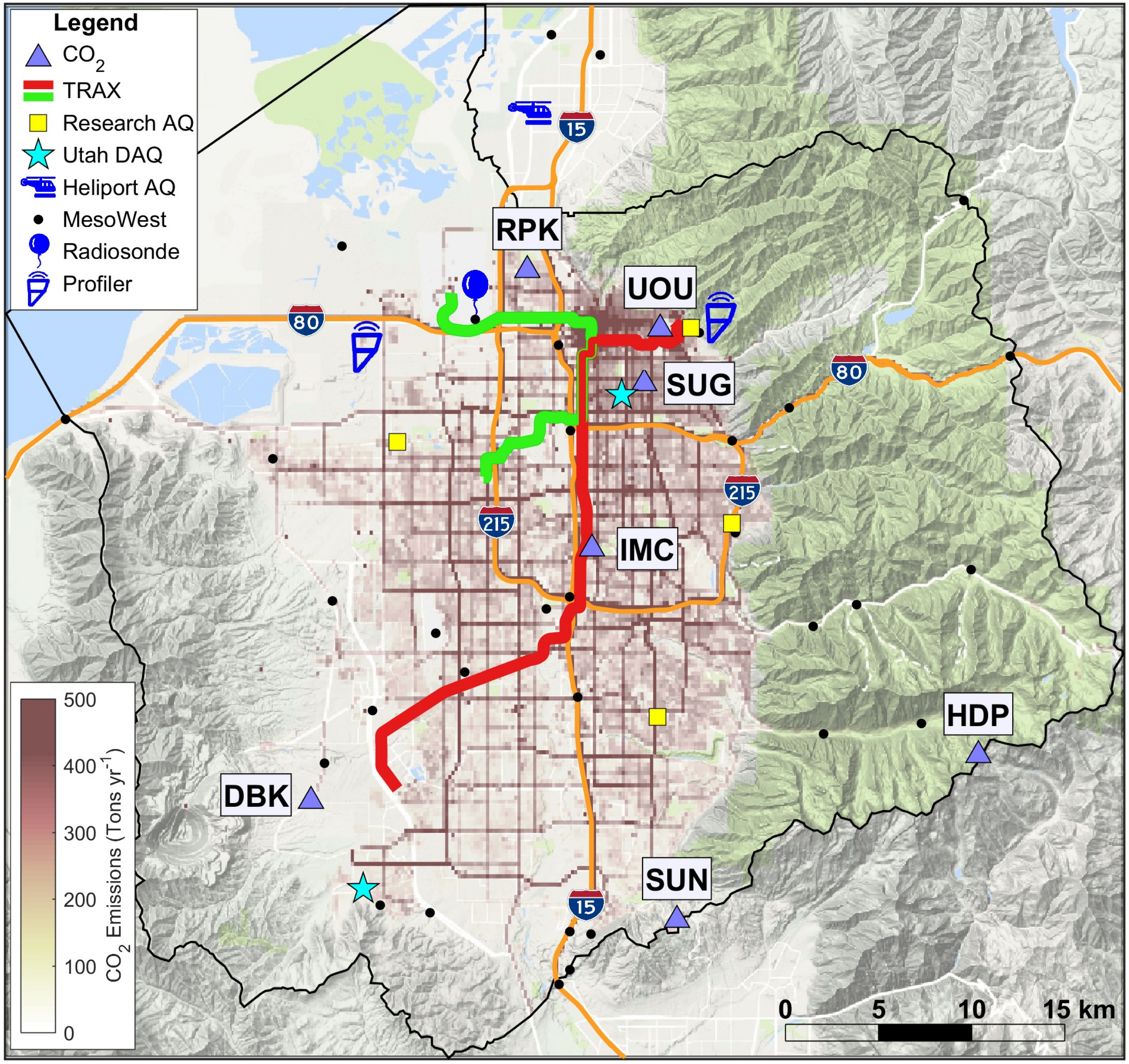
- Quantify & understand similarities/differences in CO_2 and CH_4 fluxes across cities;
- Develop harmonized CO_2 and CH_4 mixing ratio datasets that are readily useable, traceable, and accessible by the research community and the public;
- Construct an atmospheric modeling system that is scalable and transferable between cities;
- Compare & understand similarities/differences between anthropogenic emission inventories;
- Improve estimates of biospheric fluxes across cities;
- Foster a community of urban carbon cycle researchers and generate collaborative studies;
- Engage stakeholders to link them with data, syntheses, and insights into urban emissions.

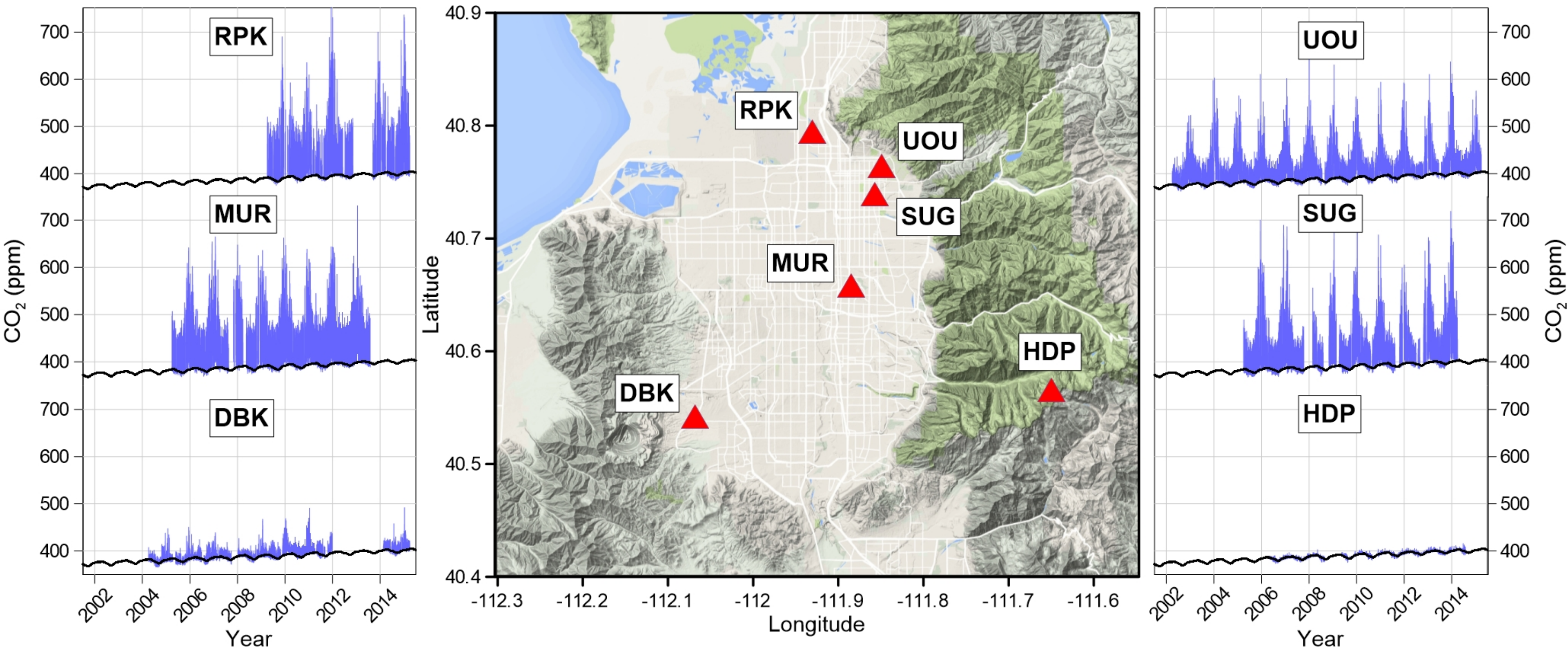


Supported through NOAA AC4 with workshop support from NIST

Salt Lake Area Greenhouse Gas Monitoring System

https://air.utah.edu/; Lin et al., BAMS, Nov. 2018.





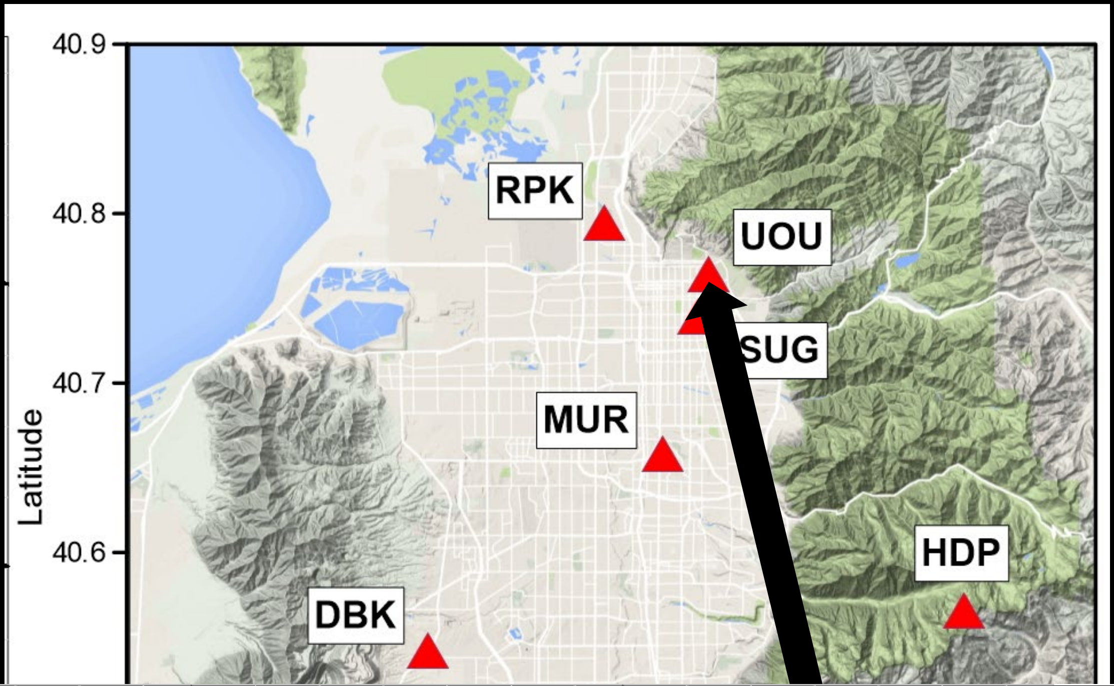
Long-term urban carbon dioxide observations reveal spatial and temporal dynamics related to urban characteristics and growth

Logan E. Mitchell[a,1], John C. Lin[a], David R. Bowling[b], Diane E. Pataki[b], Courtenay Strong[a], Andrew J. Schauer[c], Ryan Bares[a], Susan E. Bush[b], Britton B. Stephens[d], Daniel Mendoza[a], Derek Mallia[a], Lacey Holland[a,e], Kevin R. Gurney[f], and James R. Ehleringer[b]

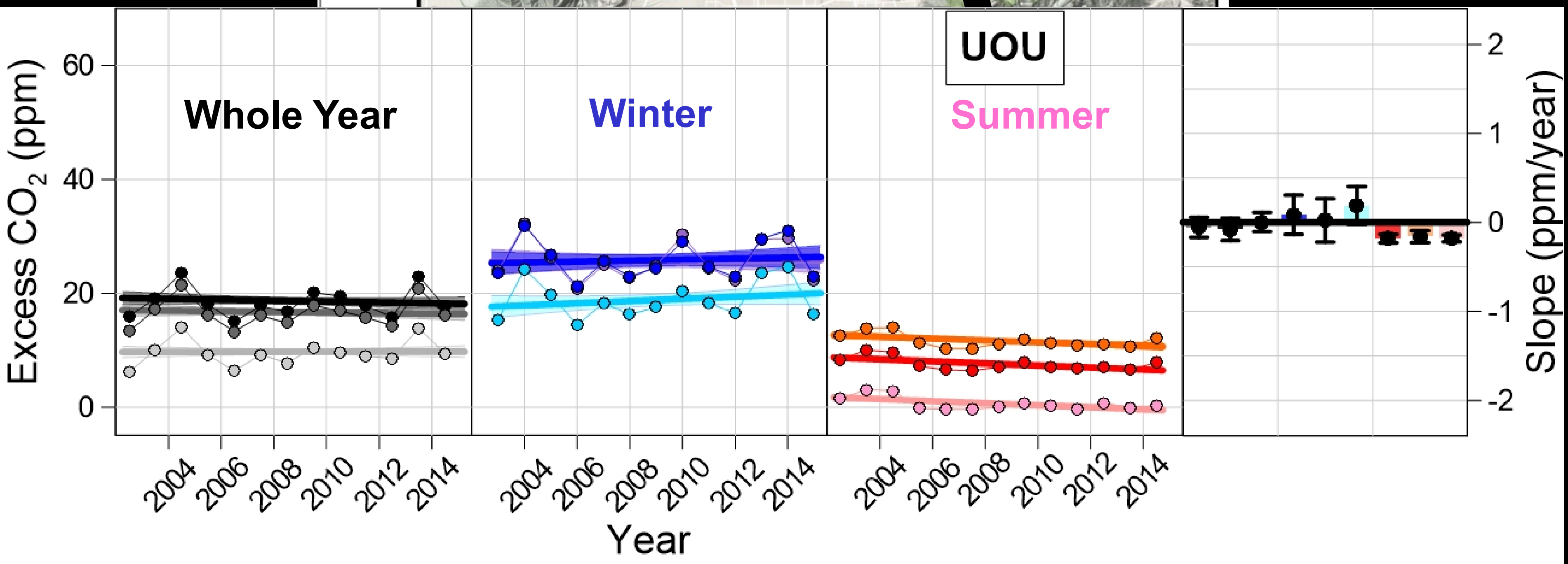
[a]Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT 84112; [b]Department of Biology, University of Utah, Salt Lake City, UT 84112; [c]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195; [d]National Center for Atmospheric Research, Boulder, CO 80307; [e]Department of Atmospheric Sciences, University of Hawaii at Manoa, Honolulu, HI 96822; and [f]School of Life Sciences, Arizona State University, Tempe, AZ 85287

SLC CO_2 Long-term trends results

Trends vary across the urban area!

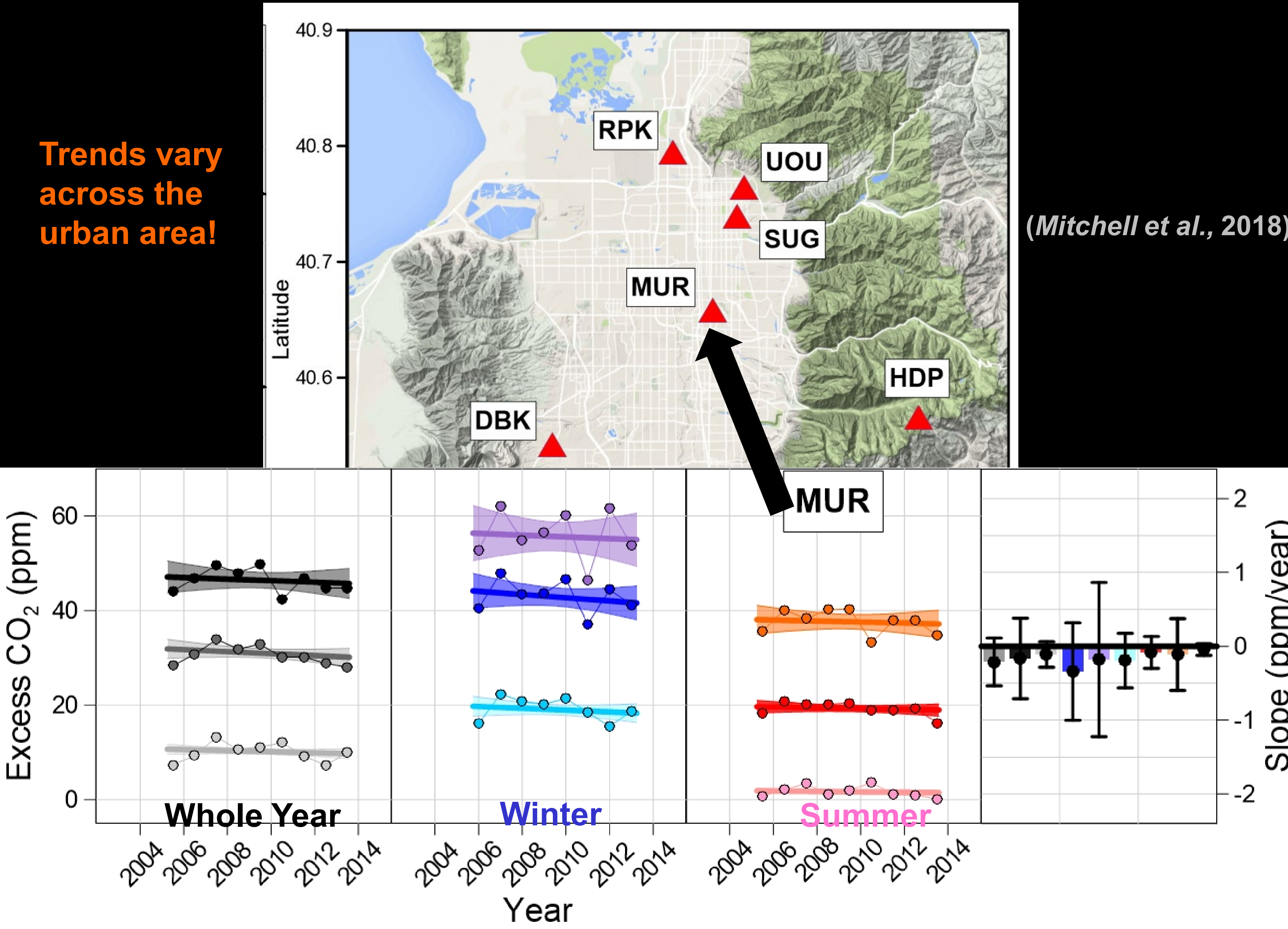


(*Mitchell et al.*, 2018)



SLC CO_2 Long-term trends results

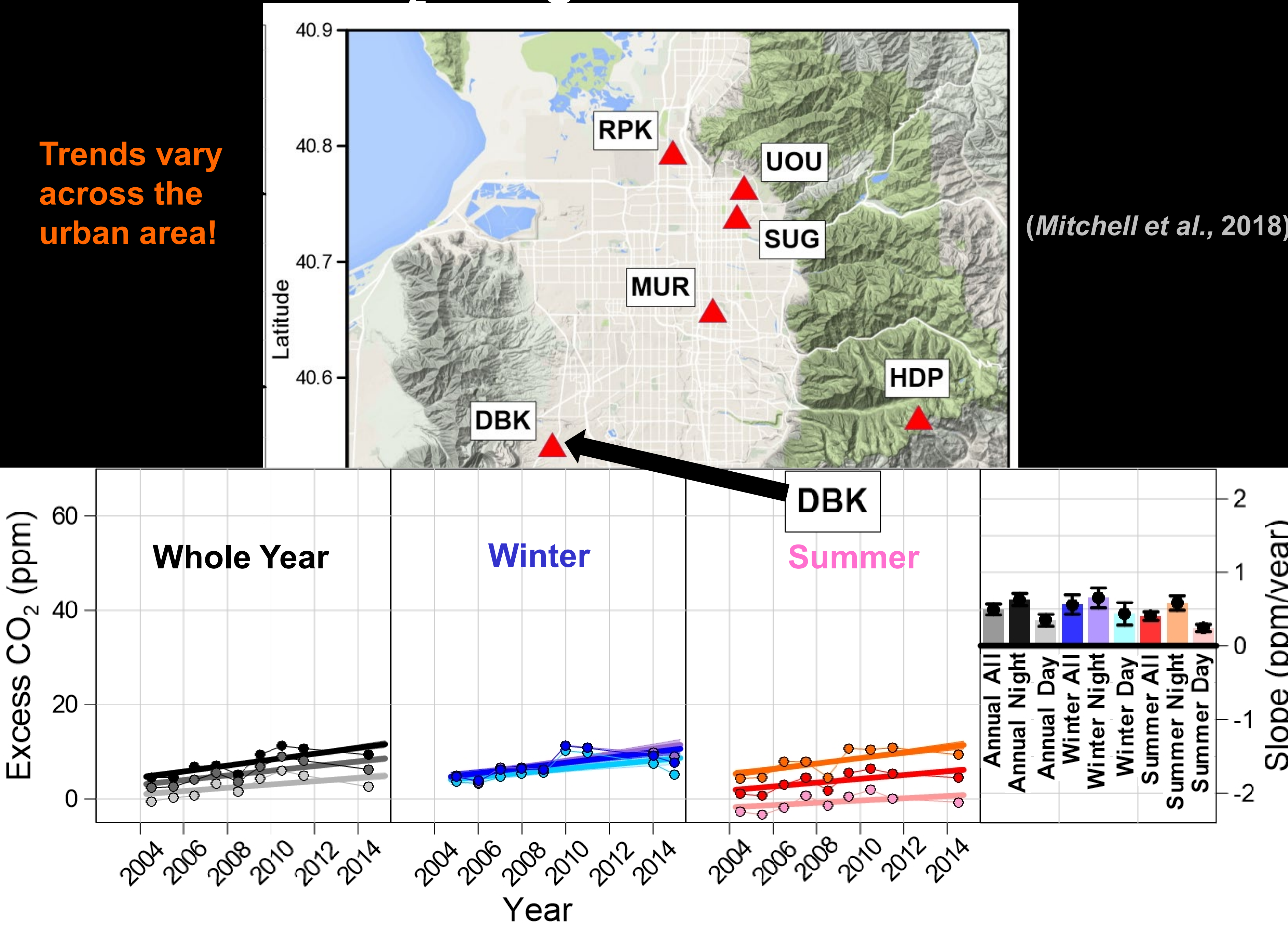
Trends vary across the urban area!



(*Mitchell et al.*, 2018)

SLC CO_2 Long-term trends results

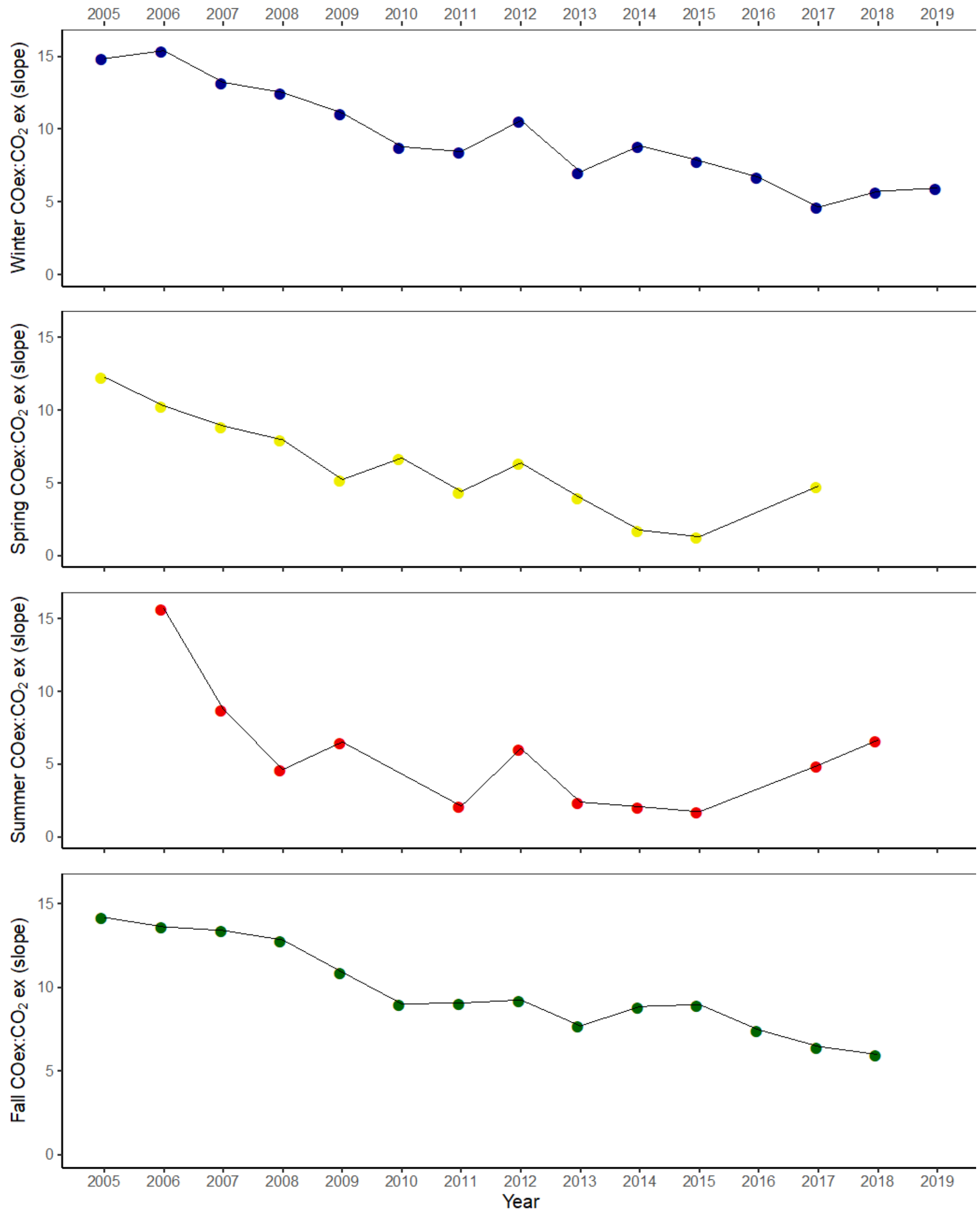
Trends vary across the urban area!



(*Mitchell et al.*, 2018)

$CO:CO_2$ Trends over Multiple Years in different seasons

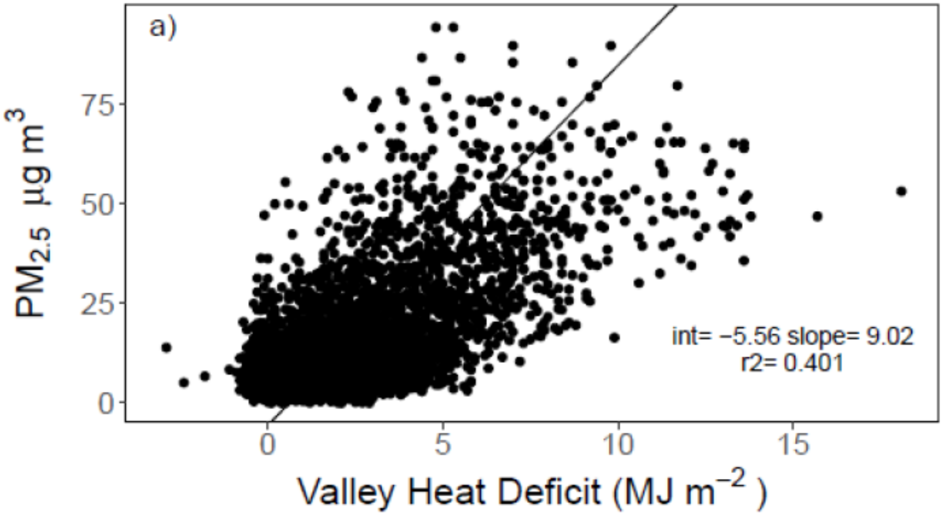
Hawthorne elementary school (Fri field trip)

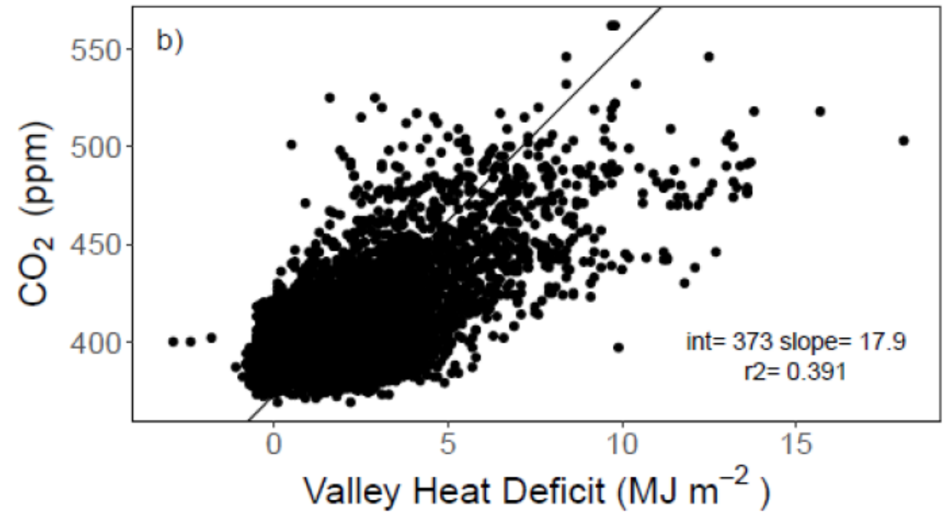


(R. Bares)

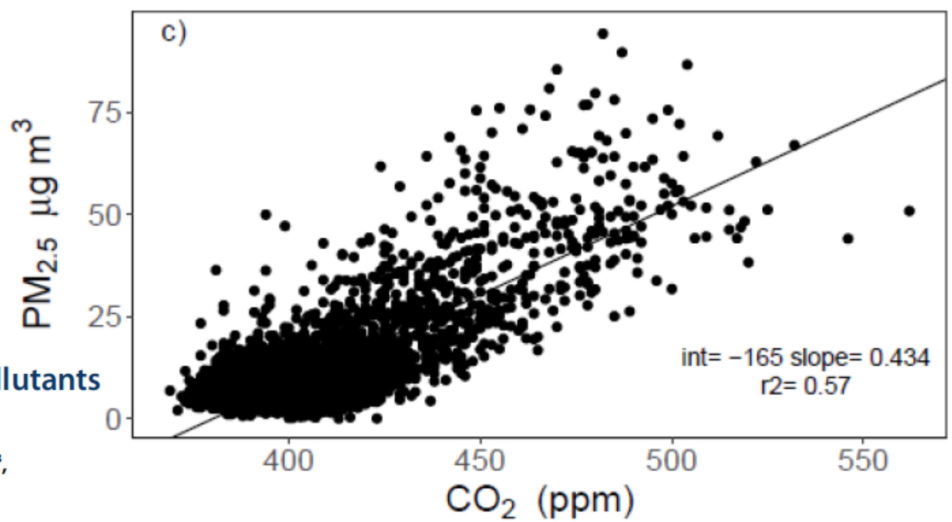
Close Relationship between CO_2 & $PM_{2.5}$ (daily)

(Years: 2003~2013)





VHD is measure of atmospheric stability (Whiteman et al., 2014)

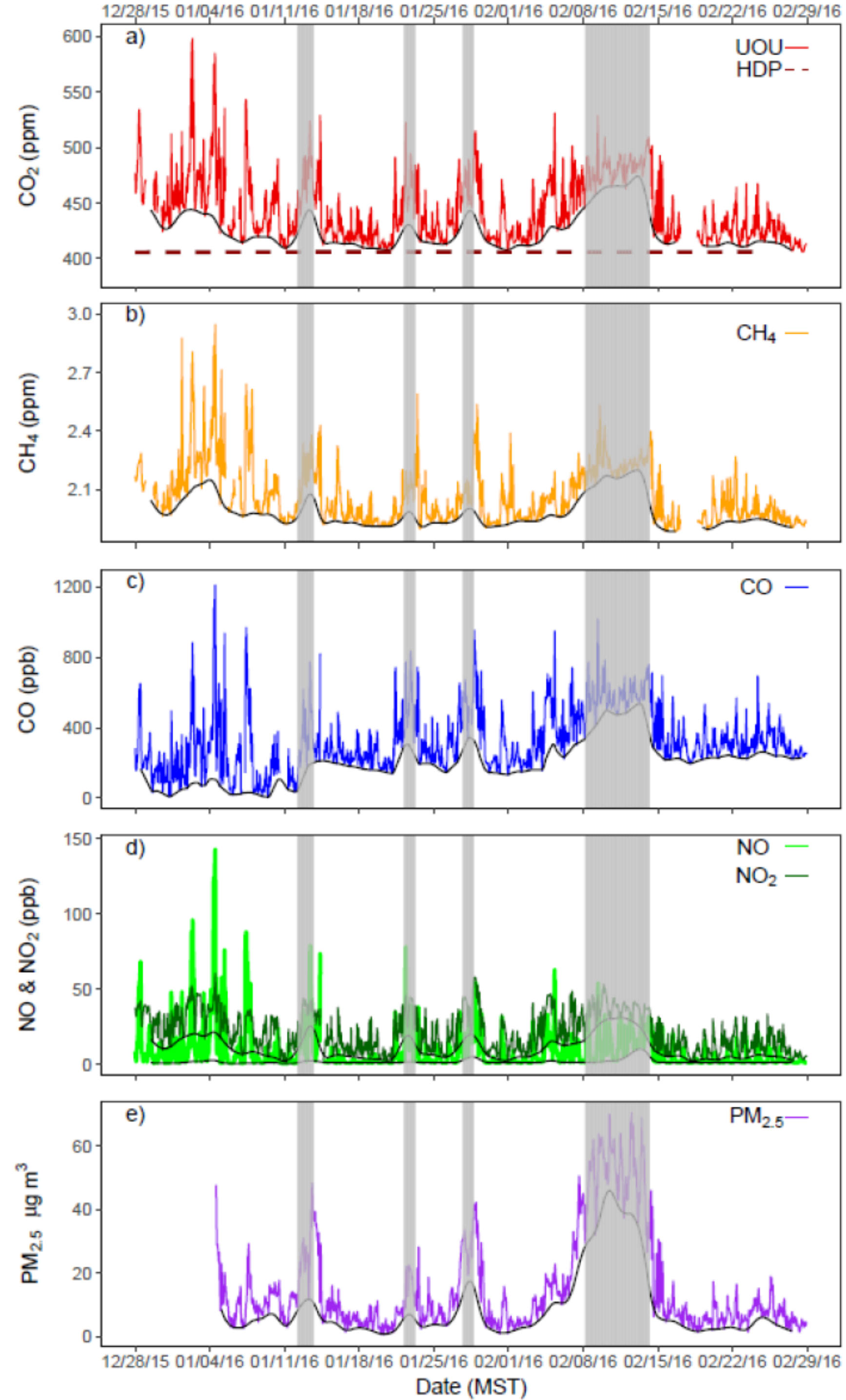


The Wintertime Covariation of CO_2 and Criteria Pollutants in an Urban Valley of the Western United States

Ryan Bares[1,2], John C. Lin[1,2], Sebastian W. Hoch[1], Munkhbayar Baasandorj[1,3], Daniel L. Mendoza[1], Ben Fasoli[1,2], Logan Mitchell[1], Douglas Catharine[1,2], and Britton B. Stephens[4]

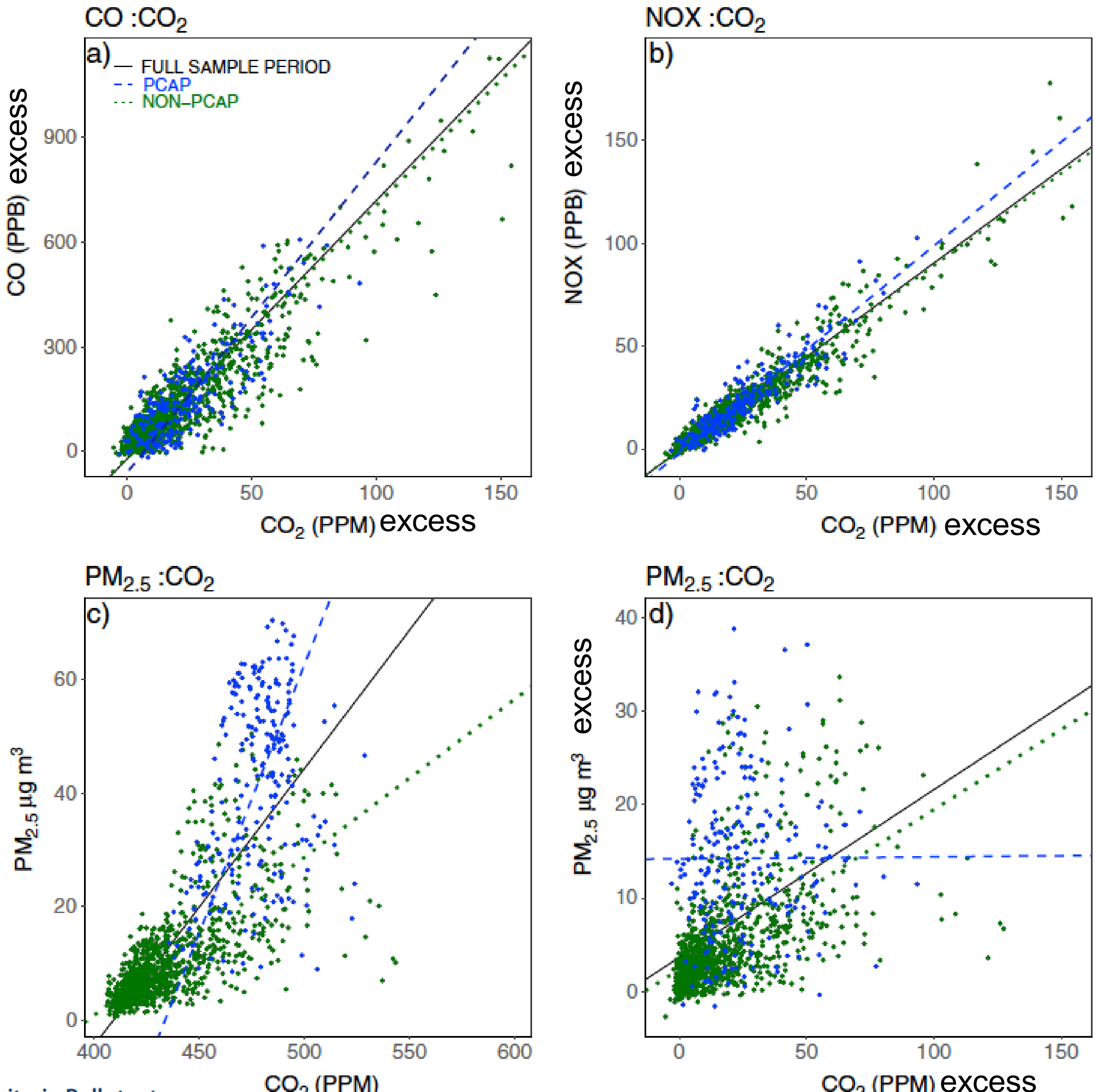
Observations on Univ. of Utah Campus of Greenhouse Gases and Criteria Pollutants

U-ATAQ Lab



(Bares et al., 2018)

Emission inventories overestimate $CO:CO_2$ and $NOx:CO_2$ ratios (factor of ~3 overestimation for $NOx:CO_2$)



The Wintertime Covariation of CO_2 and Criteria Pollutants in an Urban Valley of the Western United States

Ryan Bares[1,2], John C. Lin[1,2], Sebastian W. Hoch[1], Munkhbayar Baasandorj[1,3], Daniel L. Mendoza[1], Ben Fasoli[1,2], Logan Mitchell[1], Douglas Catharine[1,2], and Britton B. Stephens[4]

TRAX Monitoring of Air Quality and Greenhouse Gases in the Salt Lake Valley

UTA TRAX

THE UNIVERSITY OF UTAH

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
AIR QUALITY

Atmospheric Environment 187 (2018) 9–23

Contents lists available at ScienceDirect

Atmospheric Environment

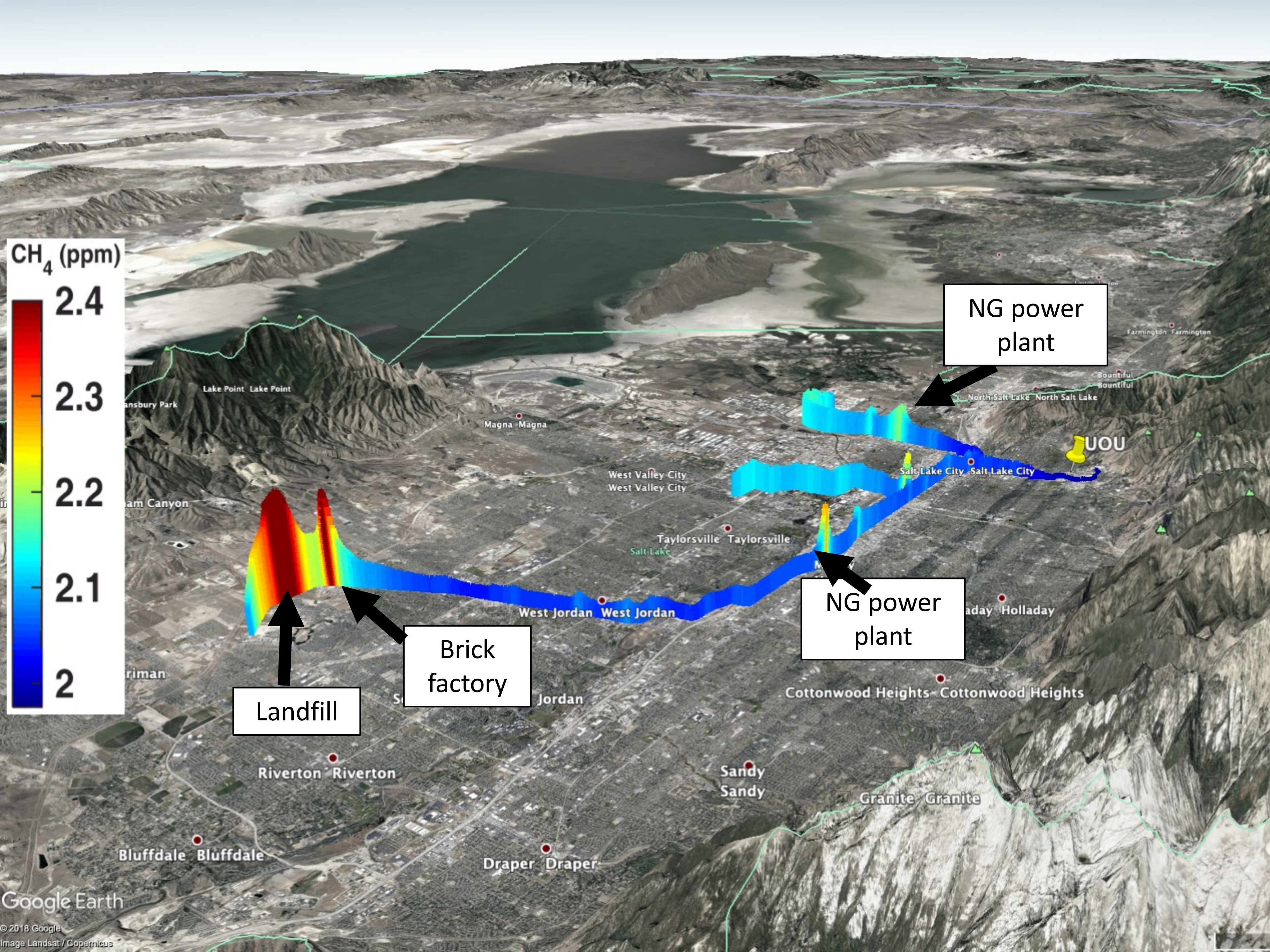
journal homepage: www.elsevier.com/locate/atmosenv

ELSEVIER

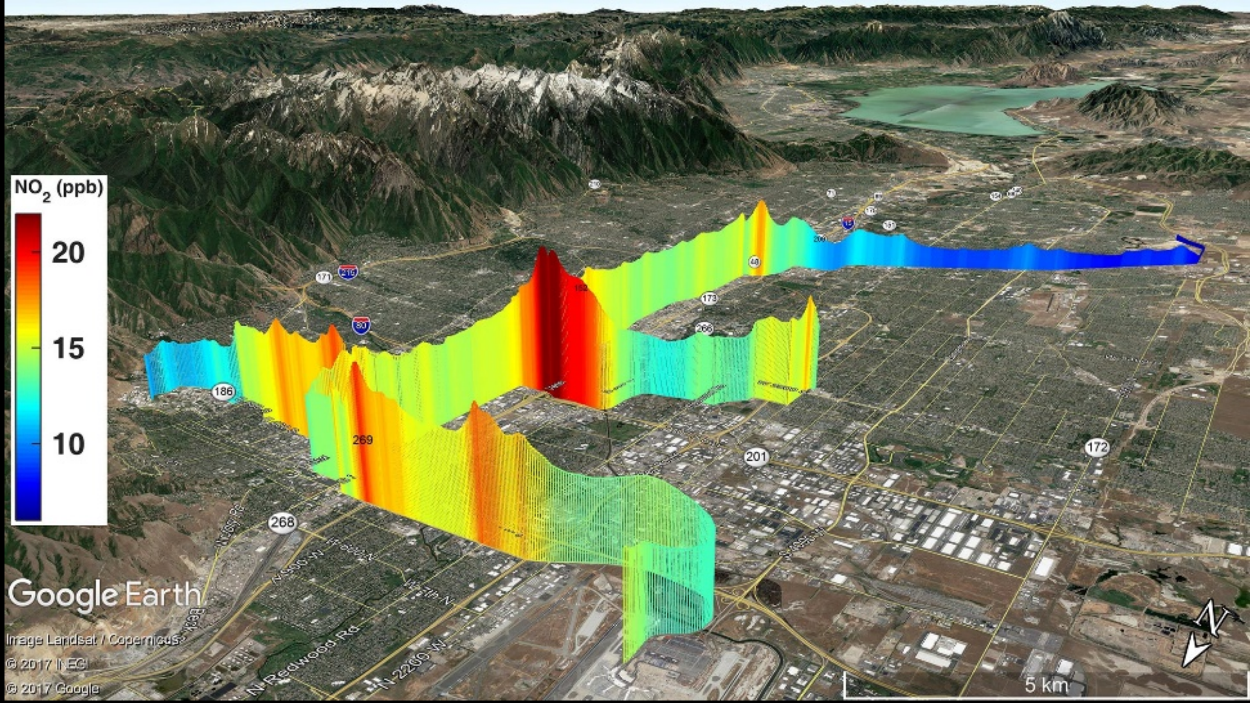
Monitoring of greenhouse gases and pollutants across an urban area using a light-rail public transit platform

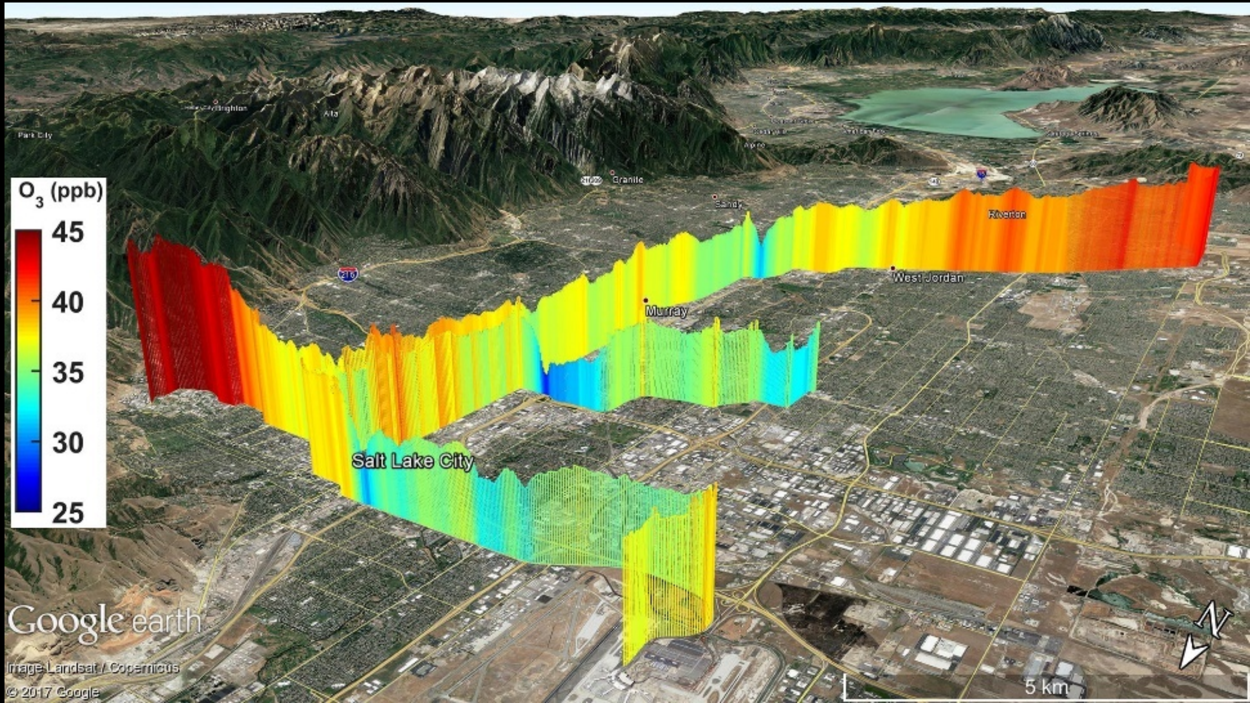
Logan E. Mitchell[a,*], Erik T. Crosman[a], Alexander A. Jacques[a], Benjamin Fasoli[a], Luke Leclair-Marzolf[a], John Horel[a], David R. Bowling[b], James R. Ehleringer[b], John C. Lin[a]

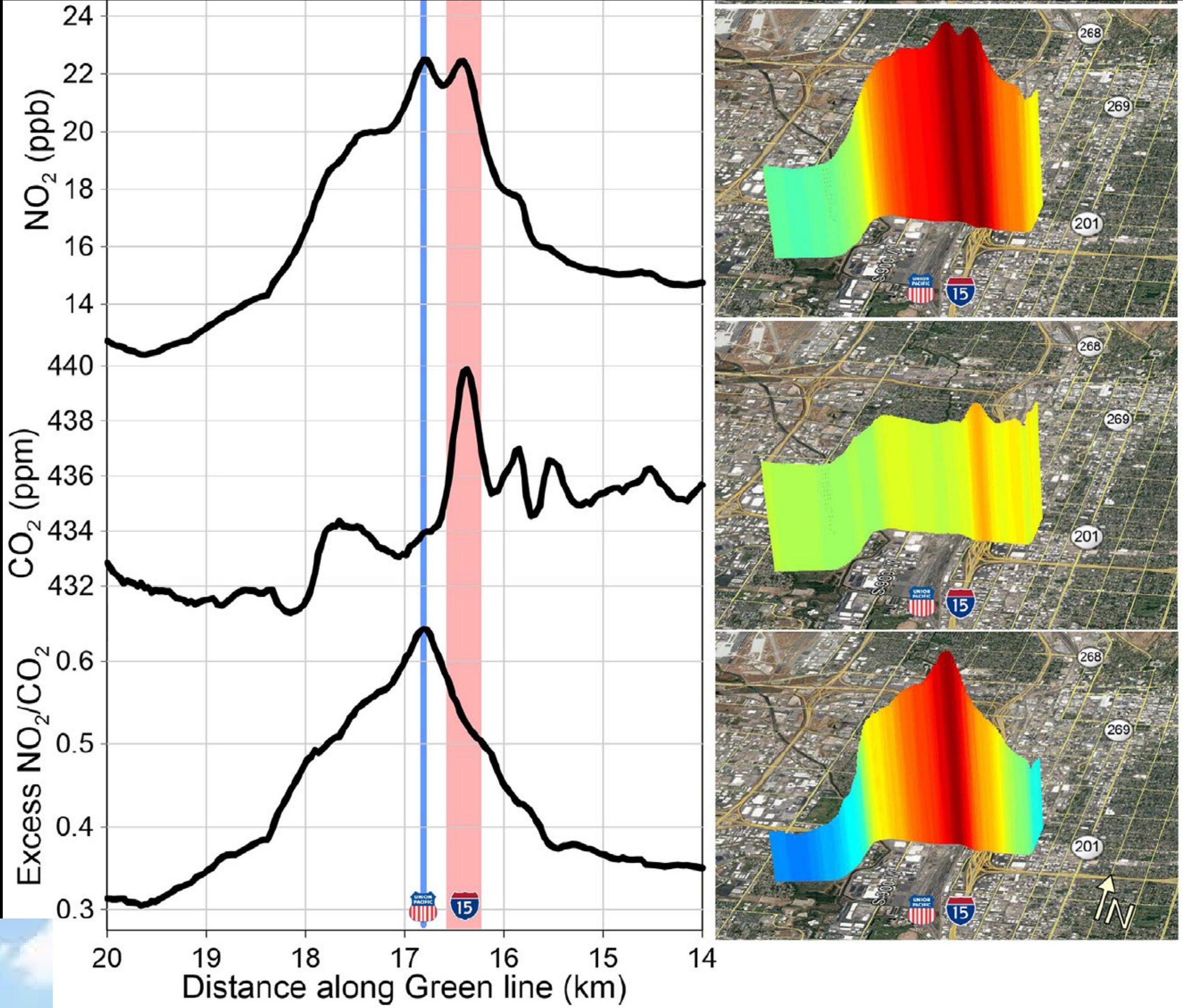
[a] Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT, United States
[b] Department of Biology, University of Utah, Salt Lake City, UT, United States


CH$_4$ (ppm)
2.4
2.3
2.2
2.1
2
NG power plant
NG power plant
Brick factory
Landfill
UOU
Lake Point Lake Point
Magna Magna
West Valley City
West Valley City
Salt Lake City Salt Lake City
North Salt Lake North Salt Lake
Bountiful
Bountiful
Farmington Farmington
Taylorsville Taylorsville
Salt Lake
West Jordan West Jordan
Holladay
Jordan
Cottonwood Heights Cottonwood Heights
Riverton Riverton
Sandy
Sandy
Granite Granite
Bluffdale Bluffdale
Draper Draper
Google Earth
© 2018 Google
Image Landsat / Copernicus

- NO_2 and O_3 are related through atmospheric photochemistry.
  - Strong correlation ($r = -0.96$)
- Illustrates the complex signature of fossil fuel combustion on urban atmospheric composition and air quality.





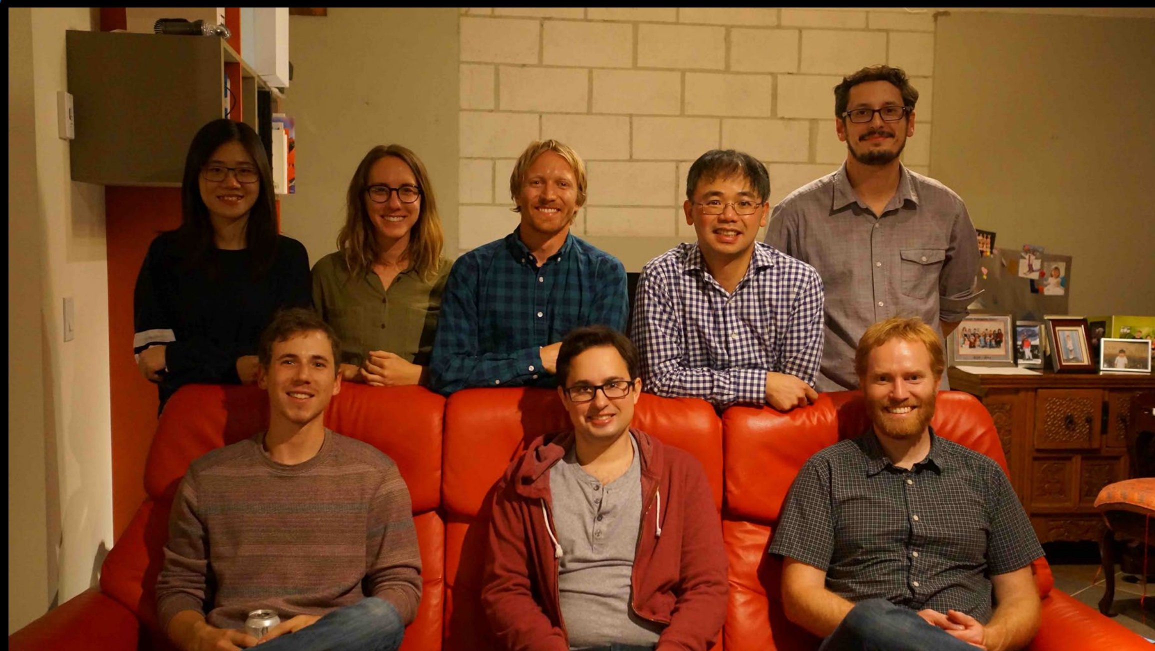

NO$_2$ (ppb)
24
22
20
18
16
14
CO$_2$ (ppm)
440
438
436
434
432
Excess NO$_2$/CO$_2$
0.6
0.5
0.4
0.3
15
20
19
18
17
16
15
14
Distance along Green line (km)
268
269
201
N

Acknowledgements

NASA

Global Change & Sustainability Center
THE UNIVERSITY OF UTAH

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE



UTAH DEPARTMENT OF ENVIRONMENTAL QUALITY

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

NSF

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

Key Questions

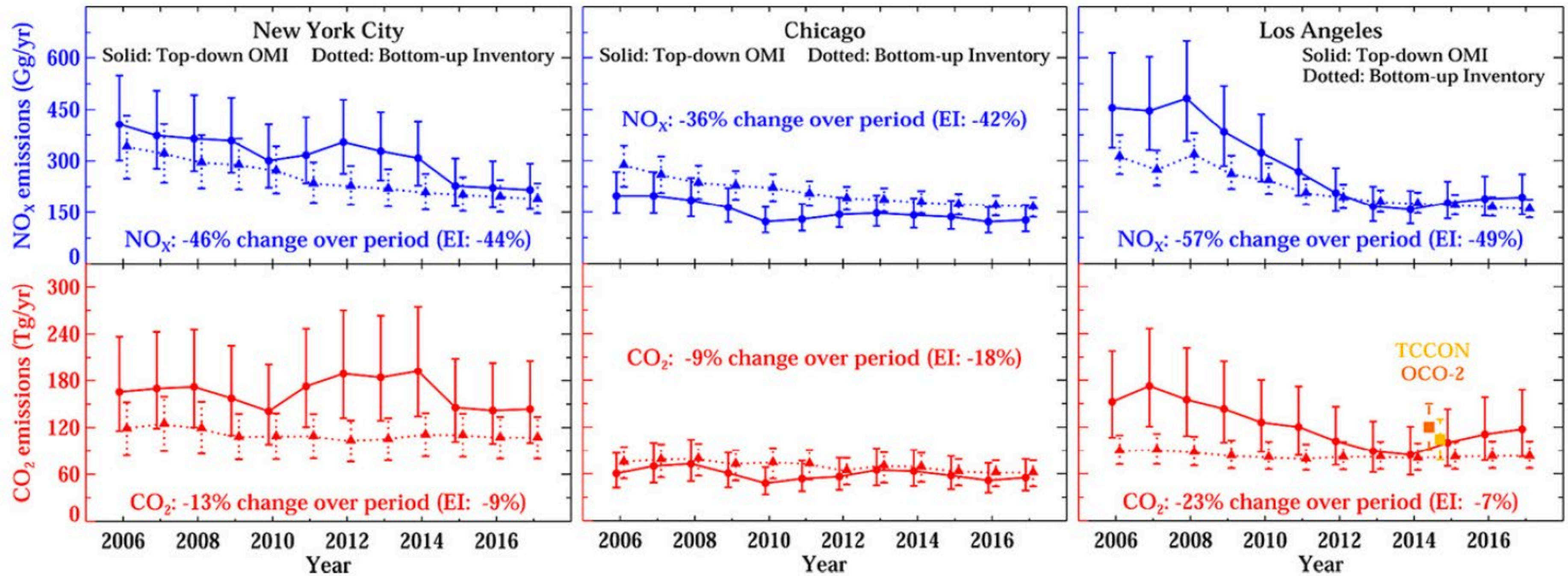
Overall question: How are urban GHG emissions changing in the western U.S., which sectors are responsible for the changes, and how are shifts in GHG emissions associated with changes in short-lived pollutants?

- How should aircraft and other datasets (e.g., surface stations) be combined to constrain GHG emissions and source attribution?
- Changes in mobile sector (cleaner cars) leading to both reduced GHG and chemically-active pollutant emissions?
- Changes in CO_2 and CH_4 composition due to decarbonization efforts and switch from one fossil fuel (coal, petroleum) to another (natural gas)
- What kind of role, if any, does the urban biosphere play as sources and sinks of both GHG and short-lived pollutants (and their precursors)?
- What kind of “co-benefits” can be realized in terms of climate mitigation and improved air quality?
- Key climate “penalties” for air quality
- Potential scenarios for things to “backfire”?
- Insights for policy measures or measures under discussion by policymakers

Other Slides

Salt Lake City Google Street View-based Air Quality Sampling (since April 2019)

EDF
ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work



NOx-to-CO2 emission ratios have decreased by ~40% nationwide between 2006 to 2017

Science of the Total Environment 695 (2019) 133805

Contents lists available at ScienceDirect

Science of the Total Environment

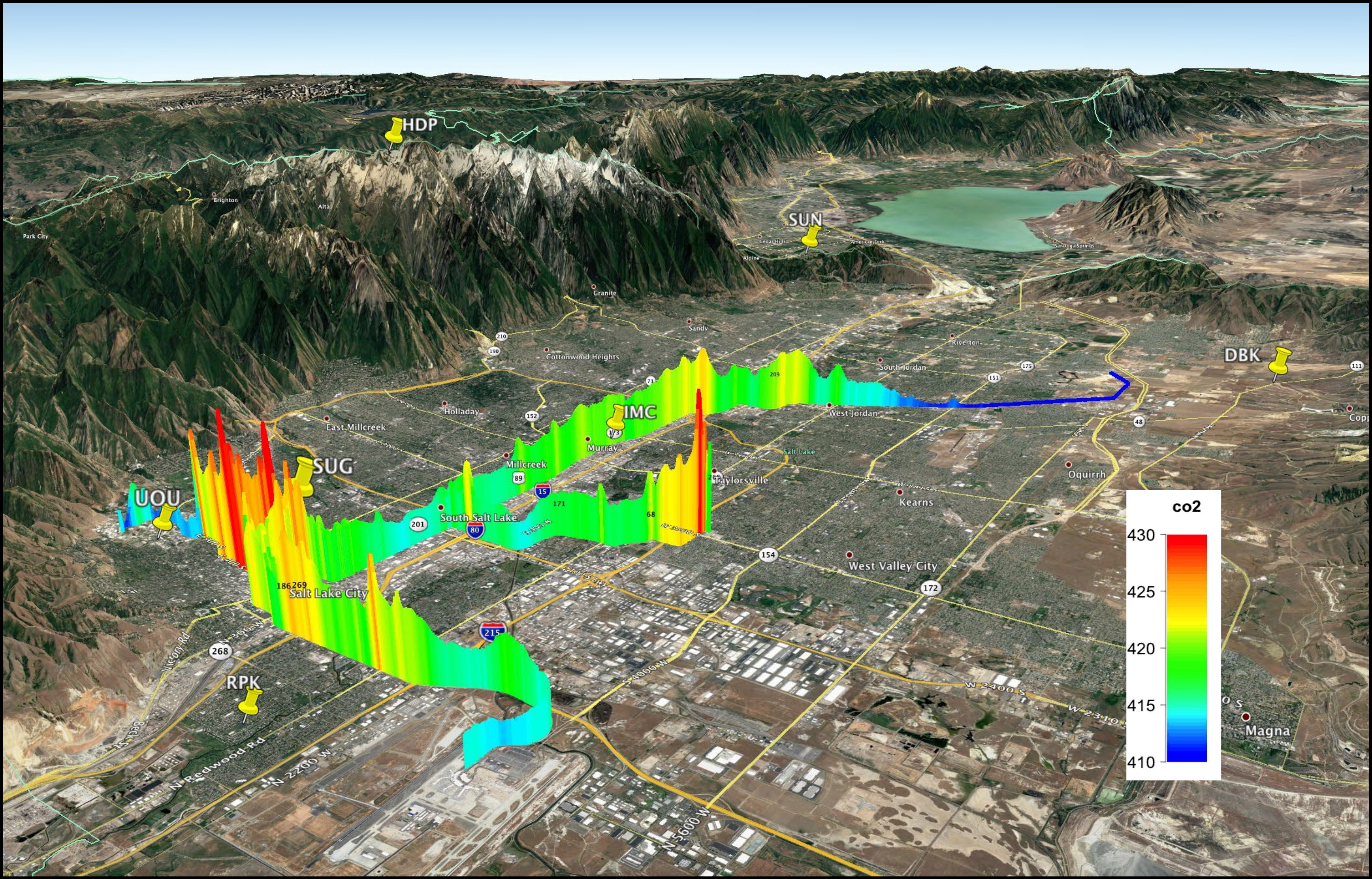
journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Exploiting OMI NO_2 satellite observations to infer fossil-fuel CO_2 emissions from U.S. megacities☆

Daniel L. Goldberg [a,b,*], Zifeng Lu [a,b], Tomohiro Oda [c,d], Lok N. Lamsal [c,e], Fei Liu [c,e], Debora Griffin [f], Chris A. McLinden [f], Nickolay A. Krotkov [e], Bryan N. Duncan [e], David G. Streets [a,b]

Light Rail-based CO_2 Observations



(Lin et al., BAMS, 2018)

Light Rail-based $PM_{2.5}$ Observations

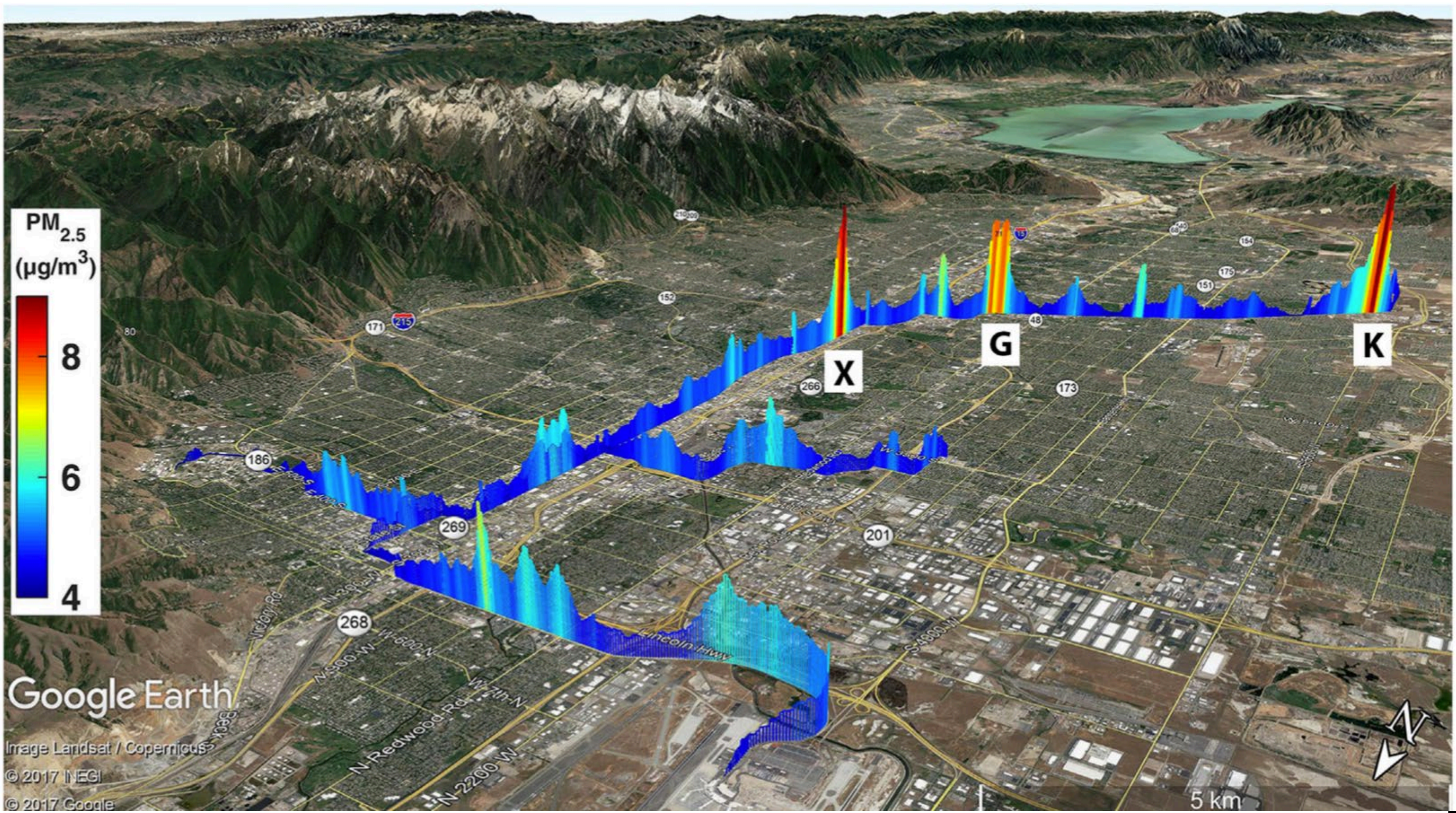


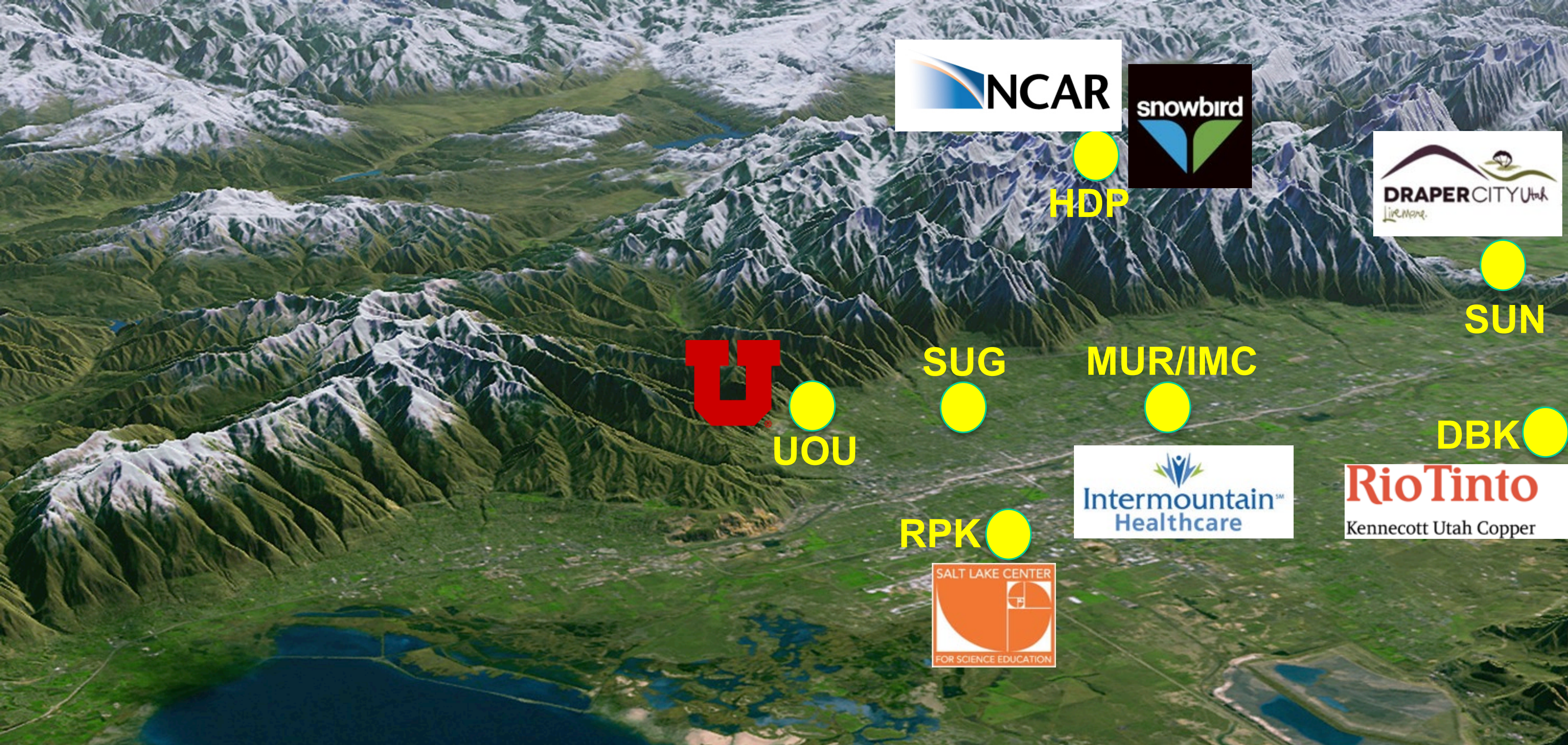
Fig. 8. $PM_{2.5}$ averaged over the summer of 2016 (May through September). The 'G', 'K', and 'X' indicate the locations of the gravel pit shown in Fig. 7a, the brick factory shown in Fig. 5 and 6, and an unidentified $PM_{2.5}$ source, respectively.

(Mitchell et al., Atmospheric Environment, 2018)

"If you can't measure it, you can't improve it."
- Peter Drucker

Salt Lake Valley CO_2 Observational Network—(among the longest-running urban CO_2 networks in the world)

https://air.utah.edu/



Salt Lake Valley CO_2 Observational Network—hosted at sites owned by numerous partner organizations

http://co2.utah.edu

(one of longest-running urban CO_2 networks in the world)

Thanks to D. Pataki, D. Bowling, J. Ehleringer