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
Greenhouse Gas emissions (CO₂, CH₄)
Pollutant emissions (e.g., NOₓ, CO, PM, VOCs)

Climate Change

Air Quality
Emissions from power plants (often outside cities) that generate electricity consumed by cities

Respiration, volatile chemical products

Photosynthesis, deposition

Biogenic 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 \( \text{O}_3 \) data (8-h average) are 3-yr averages of the 4th highest annual maxima, the \( \text{CO} \) data (8-h average) are annual maxima, the \( \text{NO}_2 \) data are annual averages, and the \( \text{PM}_{2.5} \) 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/polltrendsb2w/Branch).

NO\textsubscript{x}-to-CO\textsubscript{2} emission ratios (inferred from emission inventories) have decreased by ~40% nationwide between 2006 to 2017.

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

Catalytic converters: NO\textsubscript{x} => NH\textsubscript{3}?
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

49% of the 300 most populated cities in CONUS have emission reduction targets

LEGEND
- Cities that have GHG reduction pledges
- Regional/State emission trading programs in U.S
- States with Climate Action Plans
- Urban Areas

1NAZCA (2017)
2https://www.c2es.org/document/climate-action-plans/
3US Census 2013

(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
Continental Network + Expanding Urban In-situ Sites 2016

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

Continental Network + Expanding Urban In-Situ Sites

2016

(from Kim Mueller)
“CO₂-USA” Network

Project Summary

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 CO₂ and CH₄ fluxes across cities;
- Develop harmonized CO₂ and CH₄ 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.

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

Supported through NOAA AC4 with workshop support from NIST
Salt Lake Area Greenhouse Gas Monitoring System

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

SLC CO₂ 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)
Trends vary across the urban area!

SLC CO₂ Long-term trends results

(Mitchell et al., 2018)
CO:CO$_2$ Trends over Multiple Years in different seasons

Hawthorne elementary school (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$^{1,2}$, Daniel L. Mendoza$^1$, Ben Fasoli$^{1,2}$, Logan Mitchell$^3$, Douglas Catharine$^{1,2}$, and Britton B. Stephens$^4$
Observations on Univ. of Utah Campus of Greenhouse Gases and Criteria Pollutants

(Bares et al., 2018)
Emission inventories overestimate CO:CO$_2$ and NO$_x$:CO$_2$ ratios (factor of ~3 overestimation for NO$_x$:CO$_2$)
Monitoring of greenhouse gases and pollutants across an urban area using a light-rail public transit platform


Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT, United States
Department of Biology, University of Utah, Salt Lake City, UT, United States
• 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.
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)
NOx-to-CO2 emission ratios have decreased by ~40% nationwide between 2006 to 2017.
Light Rail-based CO₂ 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 CO₂ Observational Network—(among the longest-running urban CO₂ networks in the world)

https://air.utah.edu/
Salt Lake Valley CO₂ Observational Network—hosted at sites owned by numerous partner organizations

http://co2.utah.edu

(one of longest-running urban CO₂ networks in the world)

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