Towards the quantification of emission ratios between CO$_2$ and CO: what can we learn about sectoral activities?


Research questions

1. How can we more accurately quantify the emission ratios between CO$_2$ and CO using satellite observations?
2. What can we learn about the combustion efficiency within an urban area and across cities?

Extracting emission signals for every sector from satellites can be challenging; but we can extract industrial signals from cities with independent info →
Motivation

• SAMs facilitate the emission estimate within a city from space
• Emission control for locations with poor combustion efficiency
• Emission ratio of CO-to-\(\text{CO}_2\) (ER\(_{\text{CO}}\)) serves as an indicator of combustion efficiency; varies across types of activities but cities, and remains uncertain in emission inventories

Objective

1. Generate spatial ER\(_{\text{CO}}\) and investigate their variations
2. Extract industrial signals without using emission inventories

• Technically, we accounted for factors that impact the derivation of ER\(_{\text{CO}}\) using OCO-3 SAMs and TROPOMI XCO
  - Satellite footprint sizes -> aggregate OCO-2/3 soundings according to TROPOMI polygons
  - Averaging kernel profiles
  - Overpass time -> upwind met conditions
  - Possible biogenic and pyrogenic impact

• Total 5 cities with 3 in China and 4-6 satellite overpasses per city (no tracks in JJA)

Estimates of mean upwind emissions and emission ratios

For each satellite polygon, normalize the derived \(X_{\text{FF}}\) enhancements [ppm] by the total X-STILT footprint [ppm / (\(\mu\text{mol m}^2\text{ s}^{-1}\))] (see explanations below)

\[
E_{\text{gas}} = \frac{X_{\text{gas}} - X_{\text{bg}}}{\text{sum (XFoot}_{\text{gas}})}
\]

- Background \(X_{\text{bg}}\)
  - Plume detection using forward-mode of STILT (solid black curve)
  - Mean \(X_{\text{gas}}\) outside the plume towards the upwind direction as \(X_{\text{bg}}\)
  - Each satellite swath in a SAM gets a unique \(X_{\text{bg}}\)

- \(X_{\text{FF}}\) enhancements and XFoot\(_{\text{gas}}\)
  - Column footprint from X-STILT (XFoot\(_{\text{gas}}\)) describes the concentration anomalies at downwind atmospheric columns given potential upwind sources and sinks

- Why use XFoot? To minimize the impact of the diff in AK and wind speed between sensors; as well as to examine the urban-rural diff in \(X_{\text{fire}}\) and \(X_{\text{bio}}\) (with SMUrF and GFAS)

(Lin et al., 2003; Fasoli et al., 2018; Mitchell et al., 2018; Wu et al., 2018, 2020, 2021) [Wu et al., in prep]
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\]

Fluxes \(E_{\text{gas}}\) [\(\mu\text{mol m}^{-2}\text{ s}^{-1}\)] and \(ER_{\text{CO}}\) [ppb ppm\(^{-1}\)]

- Only use soundings within modeled urban plumes in emission estimates
- \(E_{\text{gas}}\) contains info of emission over the upwind region with respect to each TROPOMI polygon
- Each \(ER_{\text{CO}}\) will be tied to each TROPOMI polygon \((= ECO / ECO_{2})\)

*** However, possible wind shift between OCO-3 and TROPOMI overpass time can cause inaccurate \(ER_{\text{CO}}\) → see sensitivity test below

Wind directional shift impact

- We calculated the normalized 2D kernel density based on the air parcels distribution during either OCO or TROPOMI overpass time (purple-yellow) to infer downwind influence area (red curve during OCO time; blue curve during TROPOMI time)
- In general, cases with 1) large overpass time difference (\(\geq 3\) hrs), 2) larger mean wind speed, 3) complex terrain, or 4) relatively smaller TROPOMI footprint sizes, are more affected by the wind shift issue.

**Good cases** where urban plumes during OCO and TROPOMI overpass durations are identical; Or their mismatch is small compared to TROPOMI footprint size
(e.g., Baotou, Oct 8, 2019, no need to shift)

**Cases used with cautions** where two urban plumes were shifted large enough compared to TROPOMI footprint sizes
- > manually re-match OCO-3 vs. TROPOMI polygons
(e.g., Shanghai, Feb 20, 2020, shift by ~1 grid)

**!! Cases as outliers** where urban plumes change dramatically
- > no way to fix via a simple polygon shifting/rematch
(e.g., LA, March 3, 2020, excluded from results, see page 5)

\([Wu et al., \text{in prep}]\)
Industrial signals over Shanghai

- Obs-based estimates per satellite coincidence
  - Temporal variations in ER ↔ changes in upwind regions (e.g., SW part of Shanghai on Feb 24, 2020, but Northern part for the remaining cases)

- Leverage **heavy industry** from WUDAPT and obs-based spatial ER$_{CO}$
  - Temporal variations in ER ↔ changes in upwind regions (e.g., SW part of Shanghai on Feb 24, 2020, but Northern part for the remaining cases)
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ER tendency towards the higher end for satellite polygons with stronger industrial influences*

Northern part of Shanghai
(Iron & steel prod & coal-fired PP)

* Further defined by the coupling of column footprint and heavy industry land fraction with 50 or 75% tiles

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(Ching et al., 2018)

White symbols denote power plants with different primary fuel types
Industrial signals over Los Angeles

- Obs-based estimates per satellite coincidence
  - **3 outliers** were removed as their plumes at OCO and TROPOMI times change dramatically → a simple polygon shift won’t work (see bottom right panel on page 3)

- Leverage **heavy industry** from WUDAPT and obs-based spatial ER$_{\text{CO}}$

![Diagram showing industrial signals over Los Angeles with outliers and ER tendency slightly towards the lower end for satellite polygons with stronger industrial influences.]

*Further defined by the coupling of column footprint and heavy industry land fraction with 50 or 75%tiles*

Port of LA (diesel engines)

(Ching et al., 2018)
Ongoing work

1. Uncertainty estimates of ER
2. Evaluate our LA results with CLARS-FTS data
3. Apply to more cities when OCO-3 B10 is available
4. Move forward to examine TROPOMI tropospheric NO$_2$ (the accurate quantification of NO$_x$ lifetime is challenging, thus, we started with CO first)

Distribution of spatial ER across cities

- Spread in ERs also matters!
  - More concentrated with lower values for LA vs. more spread-out with higher values for the rest
  - Outliers where urban plumes significantly change over time have been removed

- Pie chart to indicate the FF sectoral and wildfire contributions from BU inventories
  - % calculated from the coupling of footprint with EDGAR (latest year of 2015) + GFAS
  - Minimal wildfire contributions for the 4 cases over Mexico City

Share [% , Xsect in ppm / (Xfire + Xff) in ppm] based on EDGAR and GFAS

Literneres on city-integrated CO-to-CO$_2$ ratios

- Comparable to ours despite the approach and obs
  - Diff obs platforms (ground/airborne/satellite, X or not)
  - Diff ways of background accounting (or no bg..)
  - Diff statistical metric (slopes, mean, median, etc..)

[Crippa et al., 2019; Kaiser et al., 2012]