Towards the quantification of emission ratios between CO_2 and CO: what can we learn about sectoral activities?

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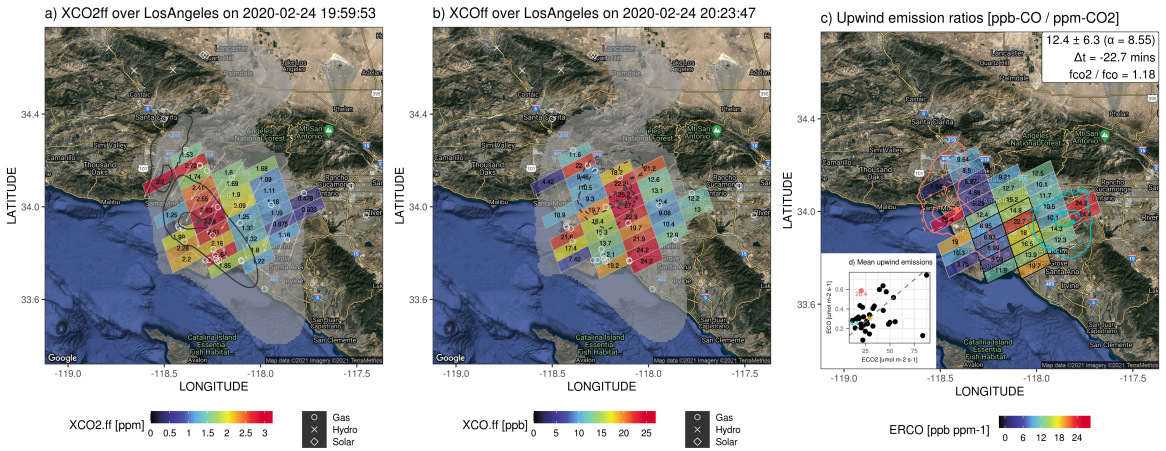
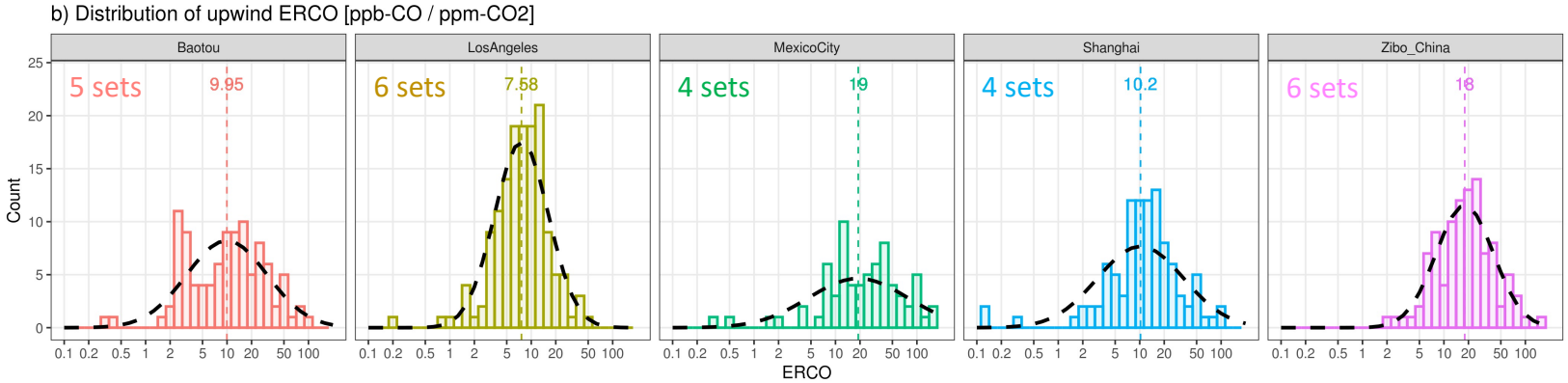
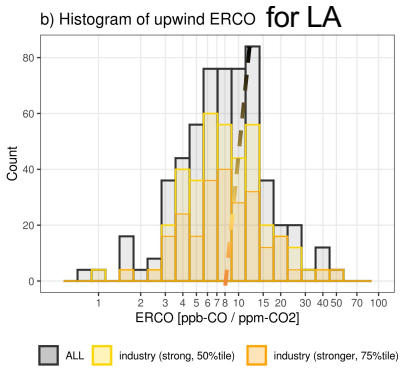


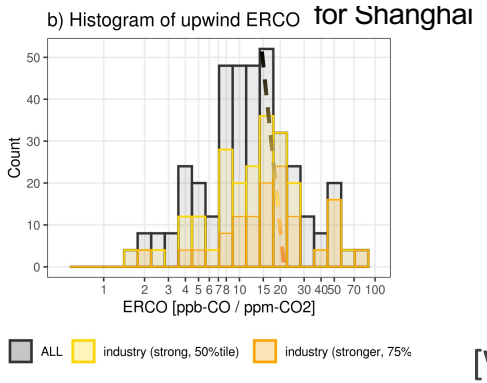
Research questions

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→



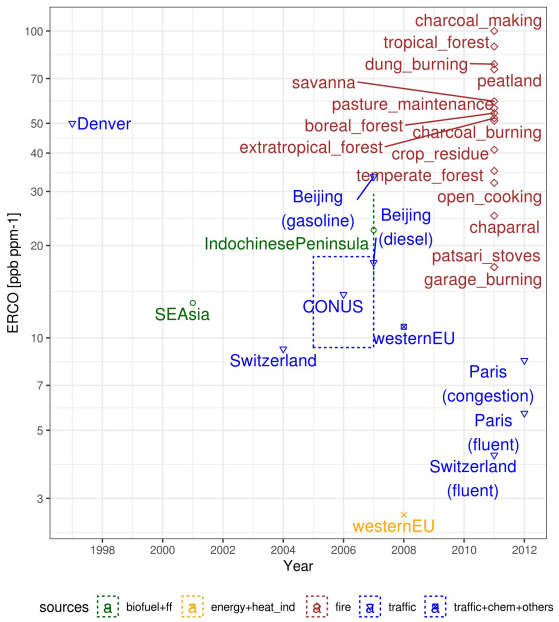


[Wu et al., in prep]

Motivation

- SAMs facilitate the emission estimate within a city from space
- Emission control for locations with poor combustion efficiency
- Emission ratio of CO-to-CO_2 (ER_{CO}) serves as an indicator of combustion efficiency; varies across types of activities but cities, and remains uncertain in emission inventories

Summary fig for type-specific ER_{CO}



Objective

1. Generate spatial ER_{CO} and investigate their variations
2. Extract industrial signals **without** using emission inventories

- Technically, we accounted for factors that impact the derivation of ER_{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

  Resolved by adopting an atmospheric transport model (X-STILT)
- Total 5 cities with 3 in China and 4-6 satellite overpasses per city (no tracks in JJA)

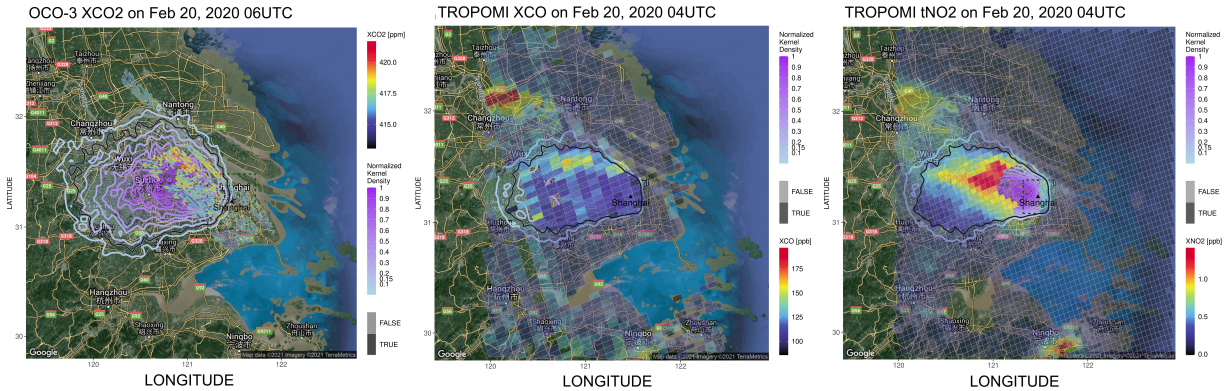
Estimates of mean upwind emissions and emission ratios

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

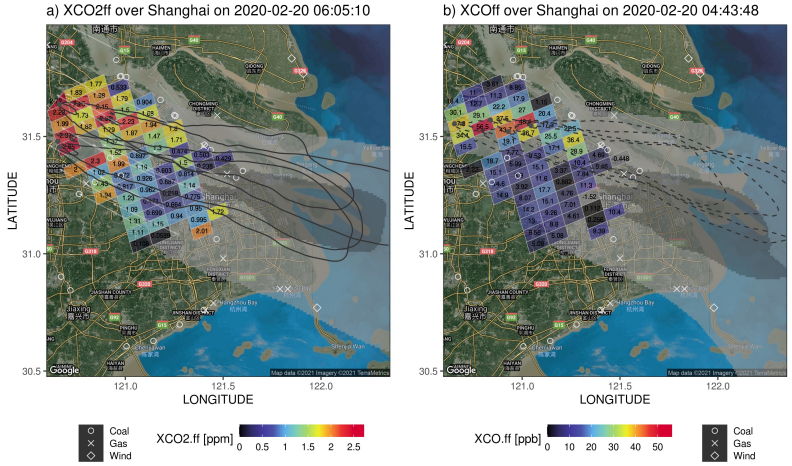
$$E_{gas} = (X_{gas} - X_{bg}) / \text{sum}(XFoot_{gas})$$

Background X_{bg}

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



X_{FF} enhancements and $XFoot_{gas}$



- Column footprint from X-STILT ($XFoot_{gas}$) 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_{fire} and X_{bio} (with SMUrF and GFAS)

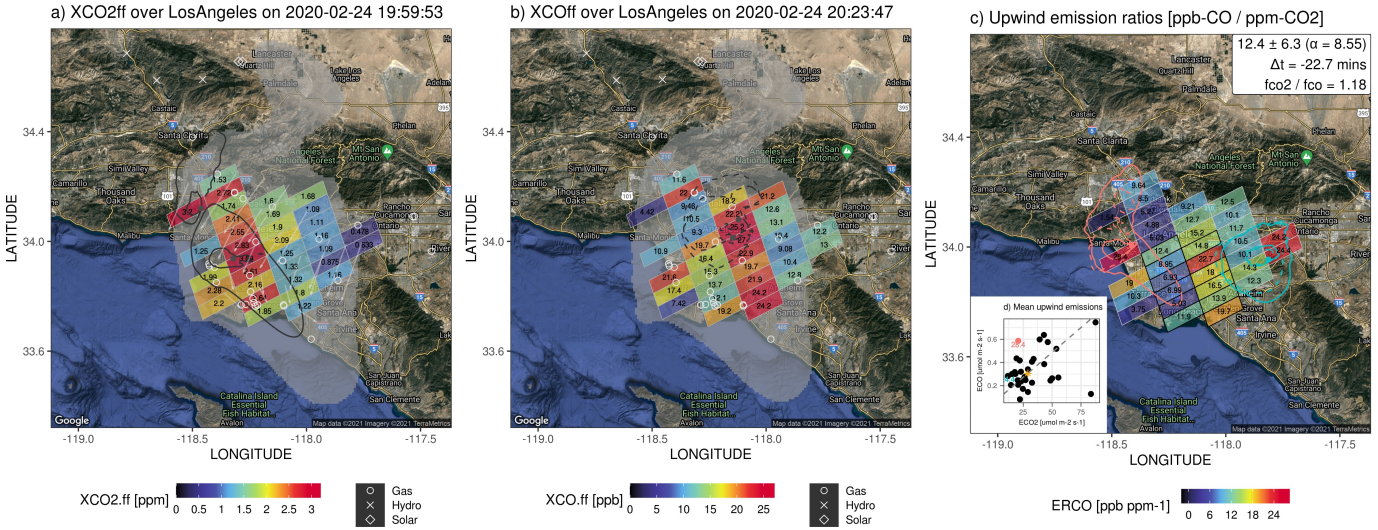
(Lin et al., 2003; Fasoli et al., 2018; Mitchell et al., 2018; Wu et al., 2018, 2020, 2021) [Wu et al., in prep]

$$E_{gas} = (X_{gas} - X_{bg}) / \text{sum}(Foot_{gas})$$

❖ Fluxes E_{gas} [μmol m^{-2} s^{-1}] and ER_{CO} [ppb ppm^{-1}]

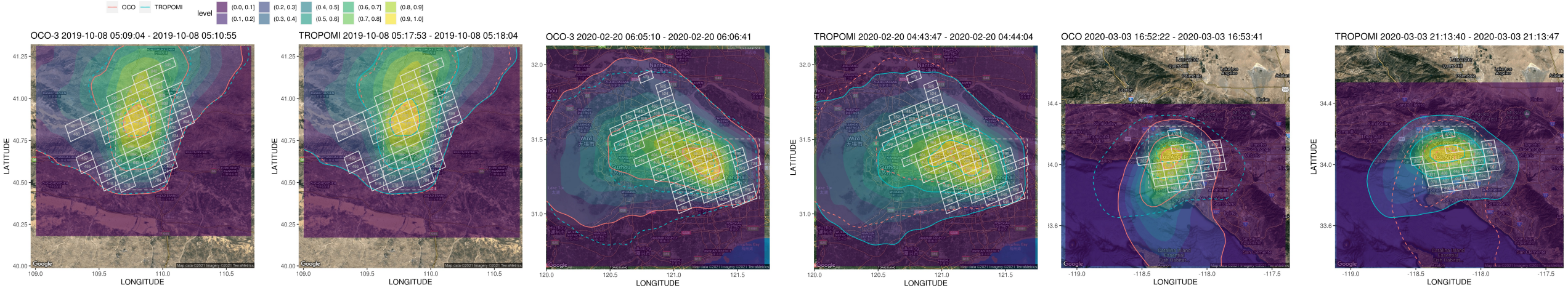
- Only use soundings within modeled urban plumes in emission estimates
- E_{gas} contains info of emission over the upwind region with respect to each TROPOMI polygon
- Each ER_{CO} will be tied to each TROPOMI polygon (= ECO / ECO_2)

**** However, possible wind shift between OCO-3 and TROPOMI overpass time can cause inaccurate ER → 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 (>= 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

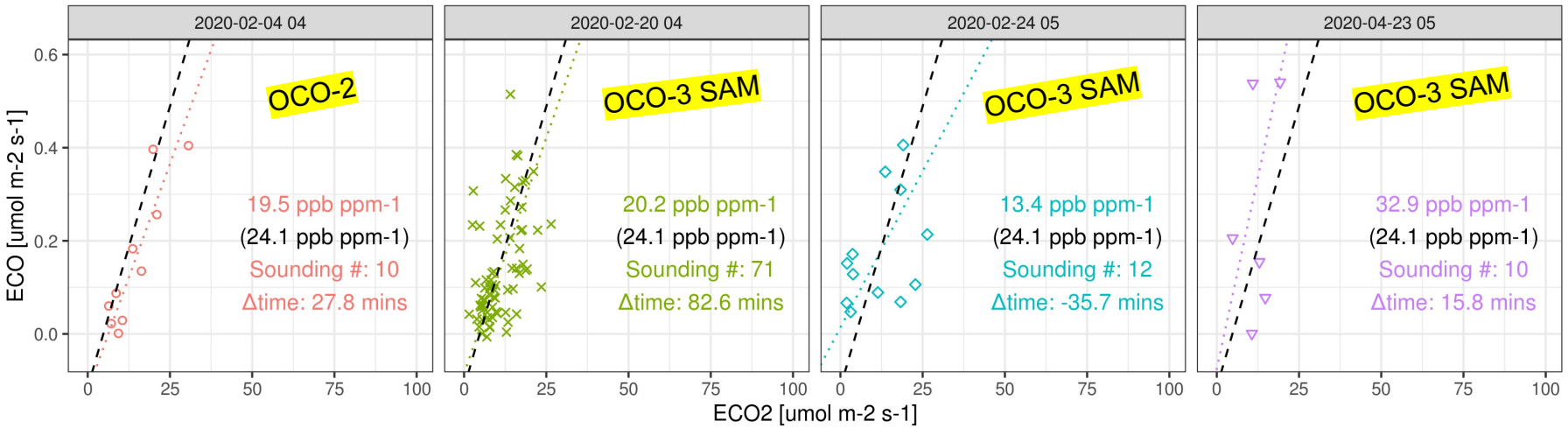
(e.g., LA, March 3, 2020, excluded from results, see page 5)

[Wu et al., in prep]

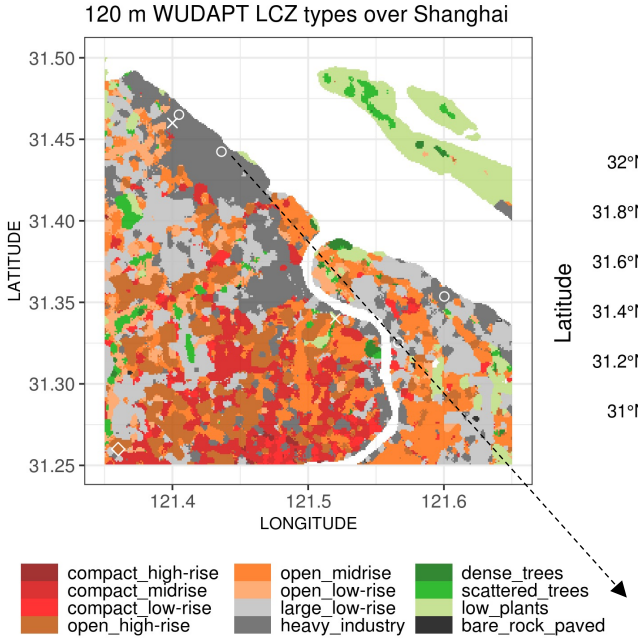
Industrial signals over Shanghai

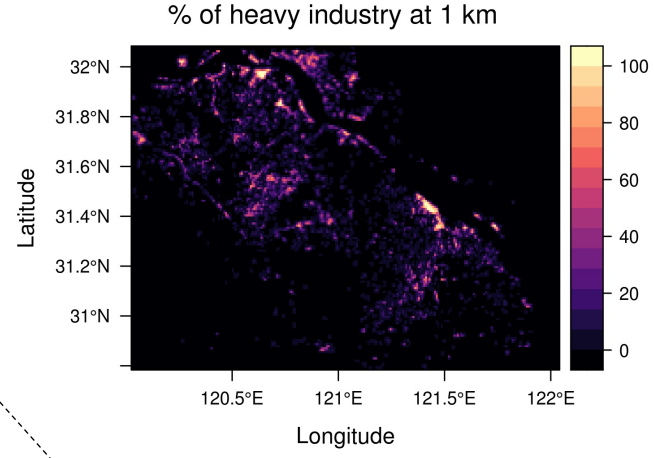
- Obs-based estimates per satellite coincidence
- Temporal variations in ER ← changes in upwind regions (e.g., SW part of Shanghai on Feb 24, 2020, but Northern part for the remaining cases)

a) Mean upwind ECO2 and ECO over upwind regions in Shanghai wrt. TROPOMI time [UTC]



- Leverage ***heavy industry*** from WUDAPT and obs-based spatial ER_{CO}
  (since locations of sectoral emissions from inventories can be off...)

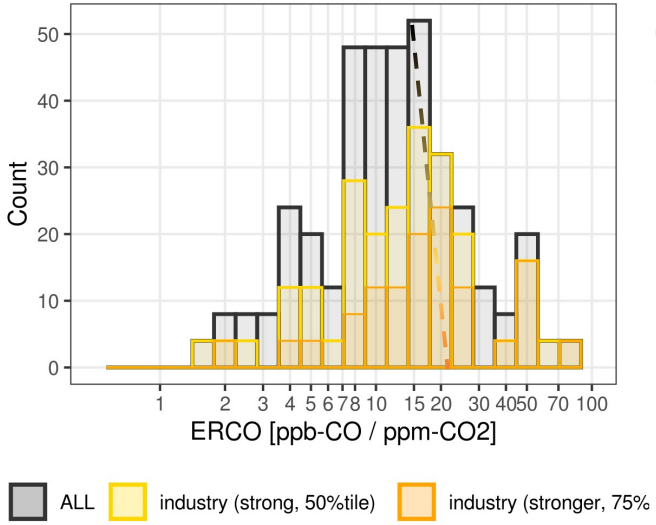




White symbols denote power plants with different primary fuel types

(Ching et al., 2018)

b) Histogram of upwind ERCO



ER tendency towards **the higher end** for satellite *polygons with stronger industrial influences**

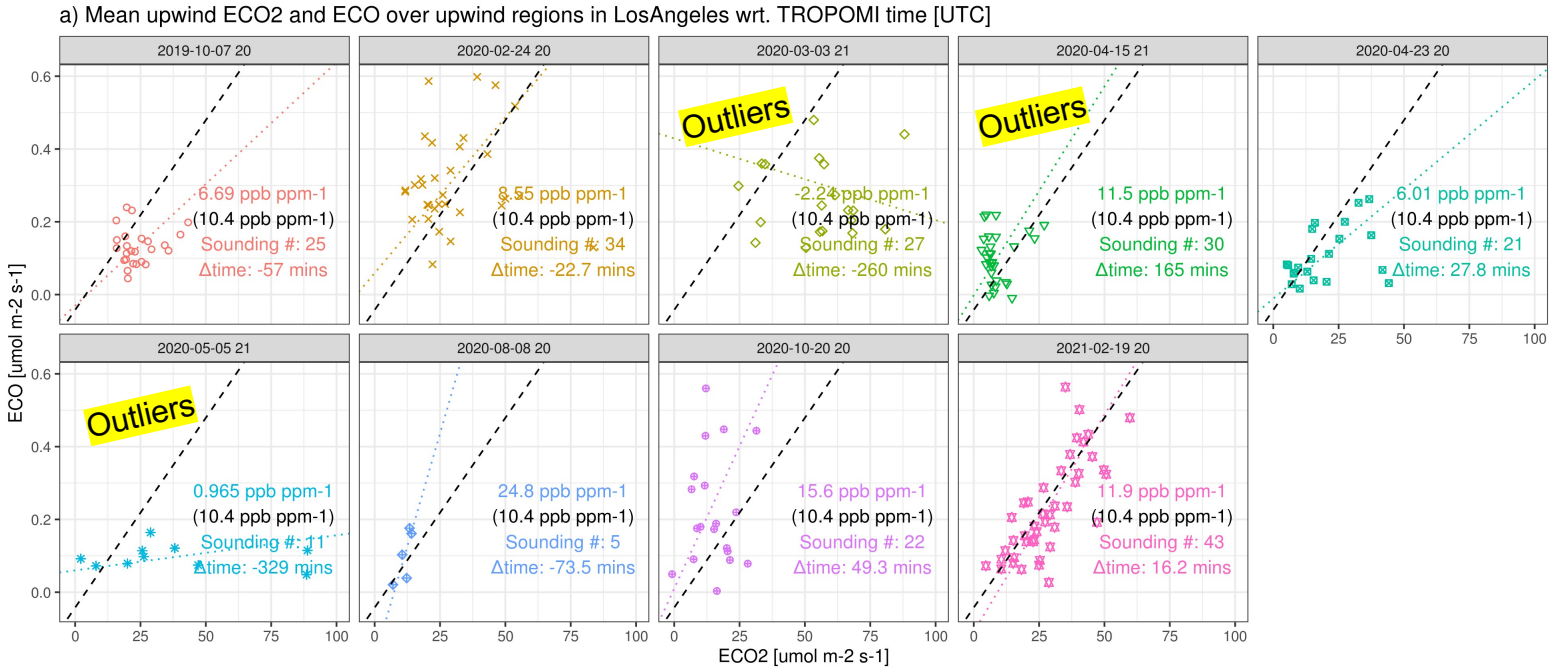
Northern part of Shanghai
(Iron & steel prod & coal-fired PP)

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

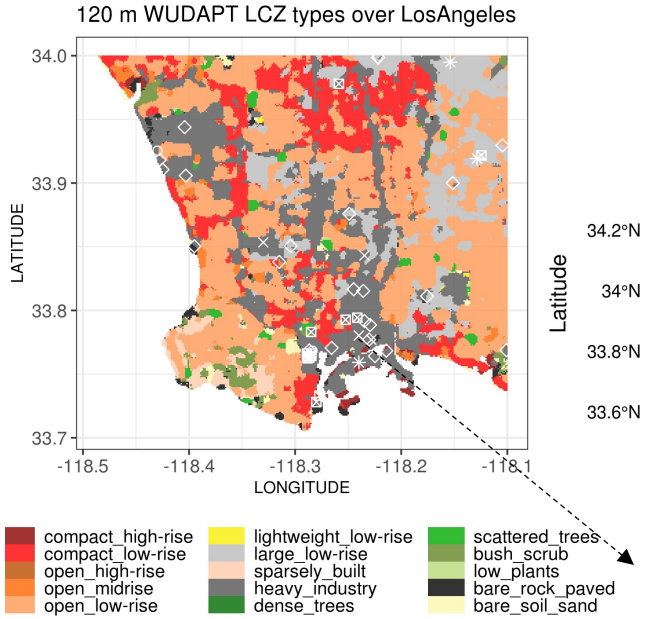
[Wu et al., in prep]

Industrial signals over Los Angeles

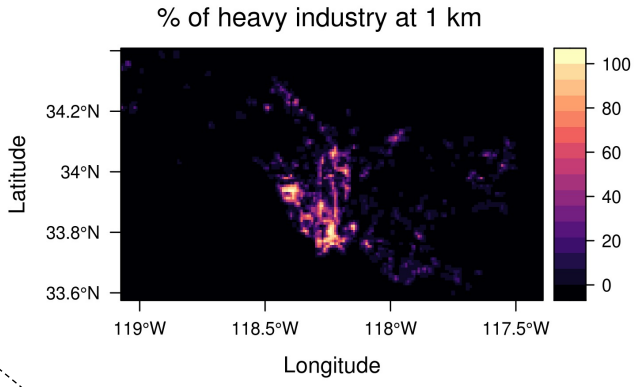
- Obs-based estimates per satellite coincidence
- 3 outliers were removed as their plumes at OCO and TROPOMI times change dramatically → a simple polygon shift won't work (see bottom right panel on page 3)



- Leverage ***heavy industry*** from WUDAPT and obs-based spatial ER_{CO}



(Ching et al., 2018)



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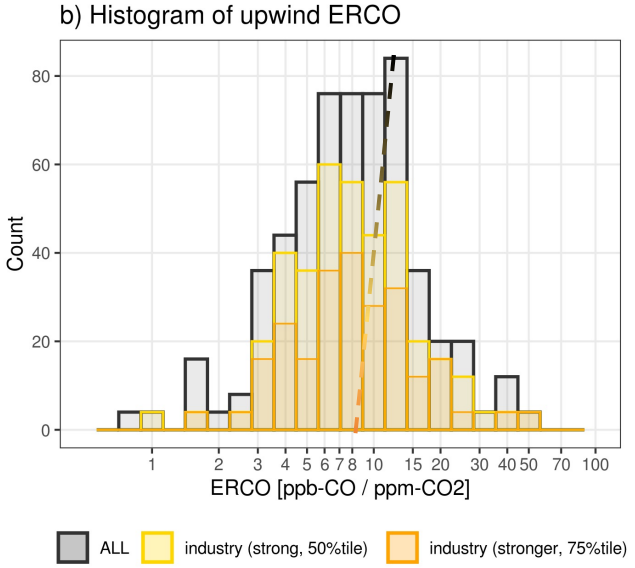


ER tendency *slightly* towards **the lower end** for satellite *polygons with stronger industrial influences**

Port of LA (diesel engines)

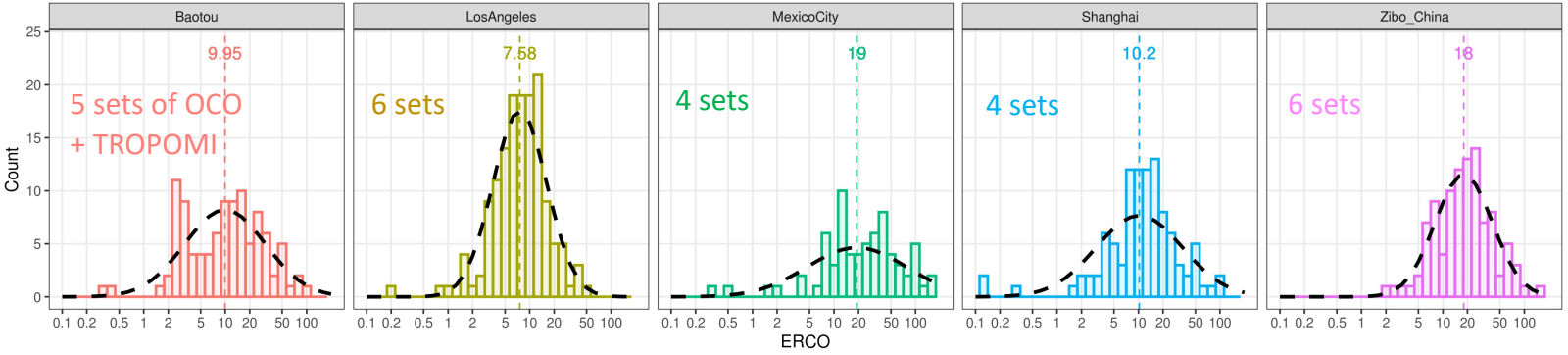
** Further defined by the coupling of column footprint and heavy industry land fraction with 50 or 75%tiles*

[Wu et al., in prep]

Distribution of spatial ER across cities

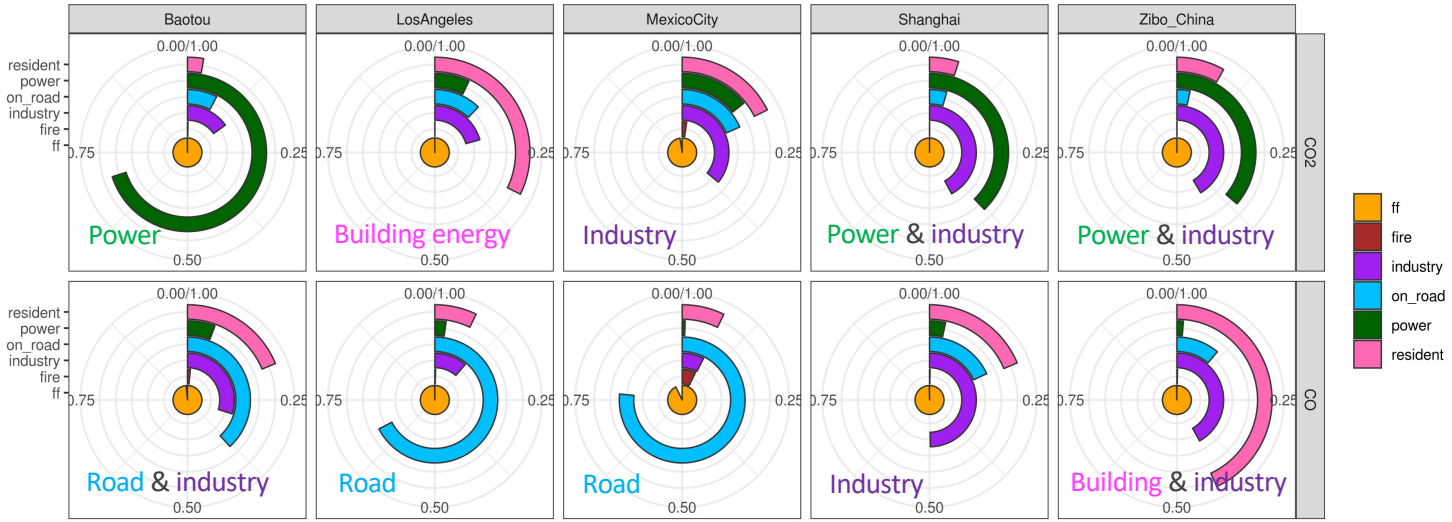
- Spread in ERs also matters!
  - More concentrated with lower values for LA vs. more spread-out with higher values for the rest
  - Outliers where urban plumes significantly change over time have been removed

b) Distribution of upwind ERCO [ppb-CO / ppm-CO2]



- 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

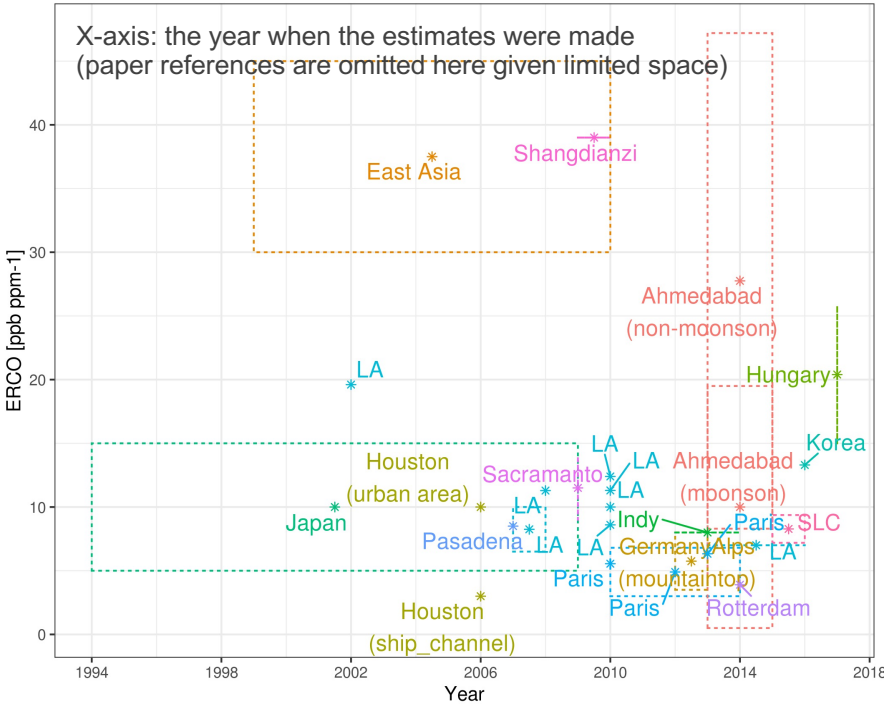
Share [%, Xsect in ppm / (Xfire + Xff) in ppm] based on EDGAR and GFAS



(Crippa et al., 2019; Kaiser et al., 2012)

Literatures 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..)



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)*

[Wu et al., in prep]