Detection of local-scale changes in urban greenhouse gas emissions using micrometeorological methods and comparison to high-resolution inventory

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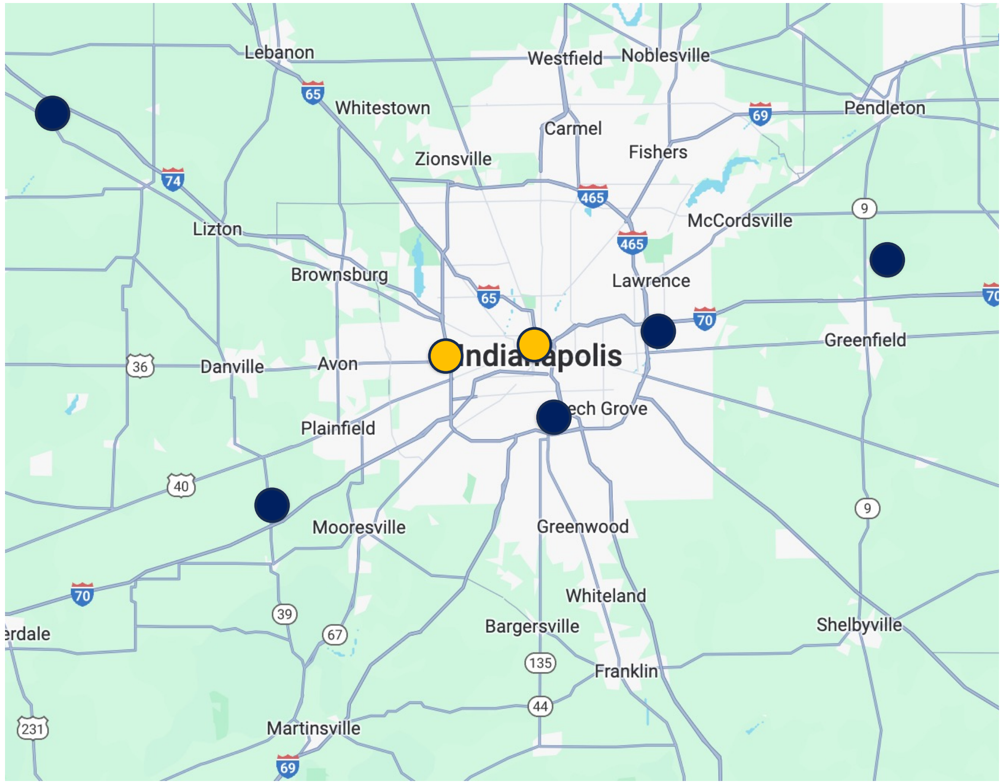
Motivation

- Urban areas account for a large fraction of emissions (Birol et al. 2008)
- Greenhouse gas (GHG) emissions sources must be understood for planning mitigation strategies
- Emissions inventories
  - Bottom-up estimates of GHG emissions based on human activity data
  - Large differences when compared to one another (Gately and Hutyra 2017; Gurney et al. 2021)
- Atmospheric emissions monitoring
  - Emissions monitoring networks, such as Indianapolis Flux Experiment (INFLUX) (Davis et al. 2017)

INFLUX monitoring network



Google Maps

● = Mole fraction monitoring site

● = EC & mole fraction monitoring site

- 7 mole fraction monitoring sites (Miles et al. 2017)
  - Used for large scale GHG emissions estimation (inversions)
    - Inversions have been used to evaluate inventories on a large scale (e.g., Lauvaux et al. 2020)
- 2 eddy covariance (EC) sites
  - Directly measure GHG emissions (flux) on a local scale
  - A few sites complement inversions
- Most inventory evaluations focus on large scale – what if we could use mole fraction sites to produce small scale flux estimates?

Monin-Obukhov Similarity Theory (MOST)

Scalar standard deviation

$$\left|\left(\overline{w'c'}\right)_0\right| = \frac{\sigma_c u_*}{\phi_\theta}$$

Scalar flux

Empirical function of atmos. stability

- **Flux-variance relationship**: relate variance with flux, stability (Kaimal and Finnigan 1994)

Monin-Obukhov Similarity Theory (MOST)

CO_2 mole fraction (concentration) standard deviation

$$\left|\left(\overline{w'c'}\right)_0\right| = \frac{\sigma_c u_*}{\phi_\theta}$$

CO_2 flux (emissions)

Empirical function of atmos. stability

- **Flux-variance relationship**: relate variance with flux, stability (Kaimal and Finnigan 1994)
- Can be used to approximate urban GHG emissions from mole fraction measurements (Kenion et al., submitted)
- Hourly, local-scale emissions
- This study:
  - Carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) flux estimation
  - Combination with tracer ratio to get fossil fuel CO_2 flux (CO_2ff) using CO

Methods: MOST at three sites

Los Angeles Megacities Carbon Project in Los Angeles, CA (Verhulst et al. 2017)

- **COM**: CO, CO_2, CH_4; 25m AGL

Photo: Jooil Kim; Map: Google Maps

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Indianapolis Flux Experiment (INFLUX) in Indianapolis, IN

- **Site 3**: CO, CO_2, CH_4; 30m AGL

Google Maps

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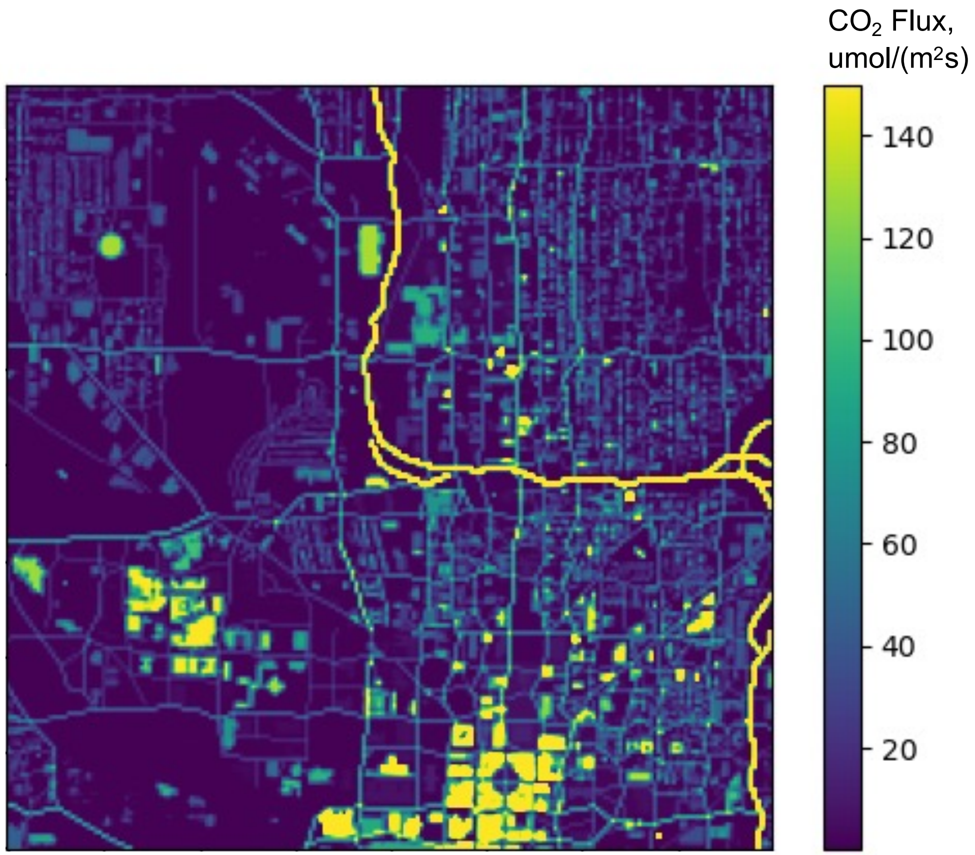
- Site 3: CO, CO_2, CH_4; 30m AGL
- **Site 7**: CO, CO_2, CH_4; 54m AGL

Google Maps

Inventory: Hestia CO_2 emissions product

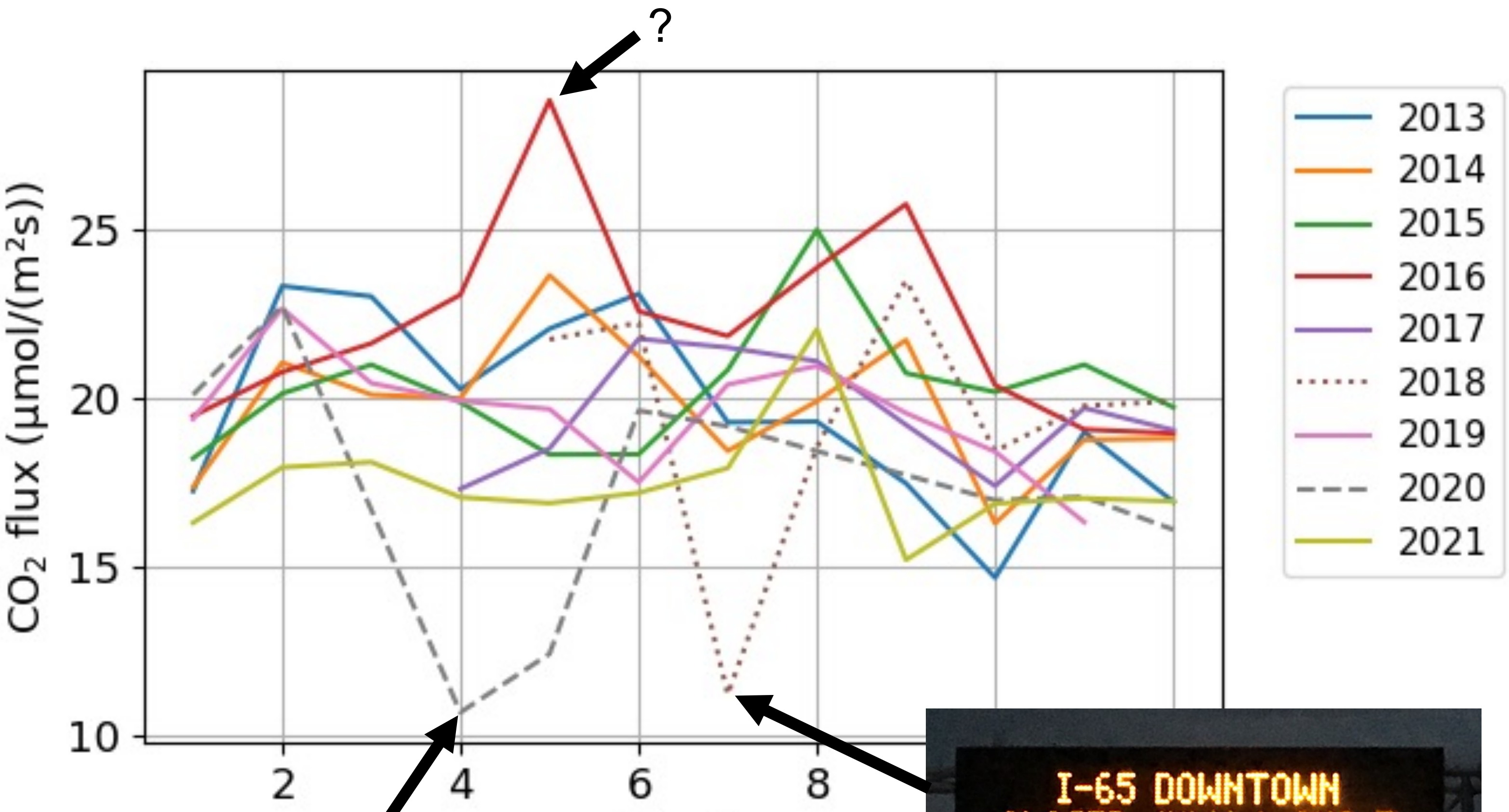
- Developed by Gurney lab at NAU for Indianapolis and LA (Gurney et al. 2012, 2019)
- Activity-based CO_2 emissions estimate
  - Building energy models, traffic data, reported power plant emissions, etc.
- 2 sub-domains in Indianapolis surrounding sites 3 and 7 (Roest et al. 2023)
  - 20m spatial resolution
  - Hourly temporal resolution
  - Entire 2020 year



Key research questions

- **Using MOST, can temporal changes in GHG emissions be detected and quantified?**
- **What can we learn from trends in urban fluxes inferred using MOST methods? Can we identify the causes of changes in emissions?**
- Do the CO_2 fluxes calculated using MOST agree with bottom-up (inventory) emissions estimates across time at individual sites?

Abrupt changes in emissions can be detected and quantified using MOST



Pandemic stay-at-home order

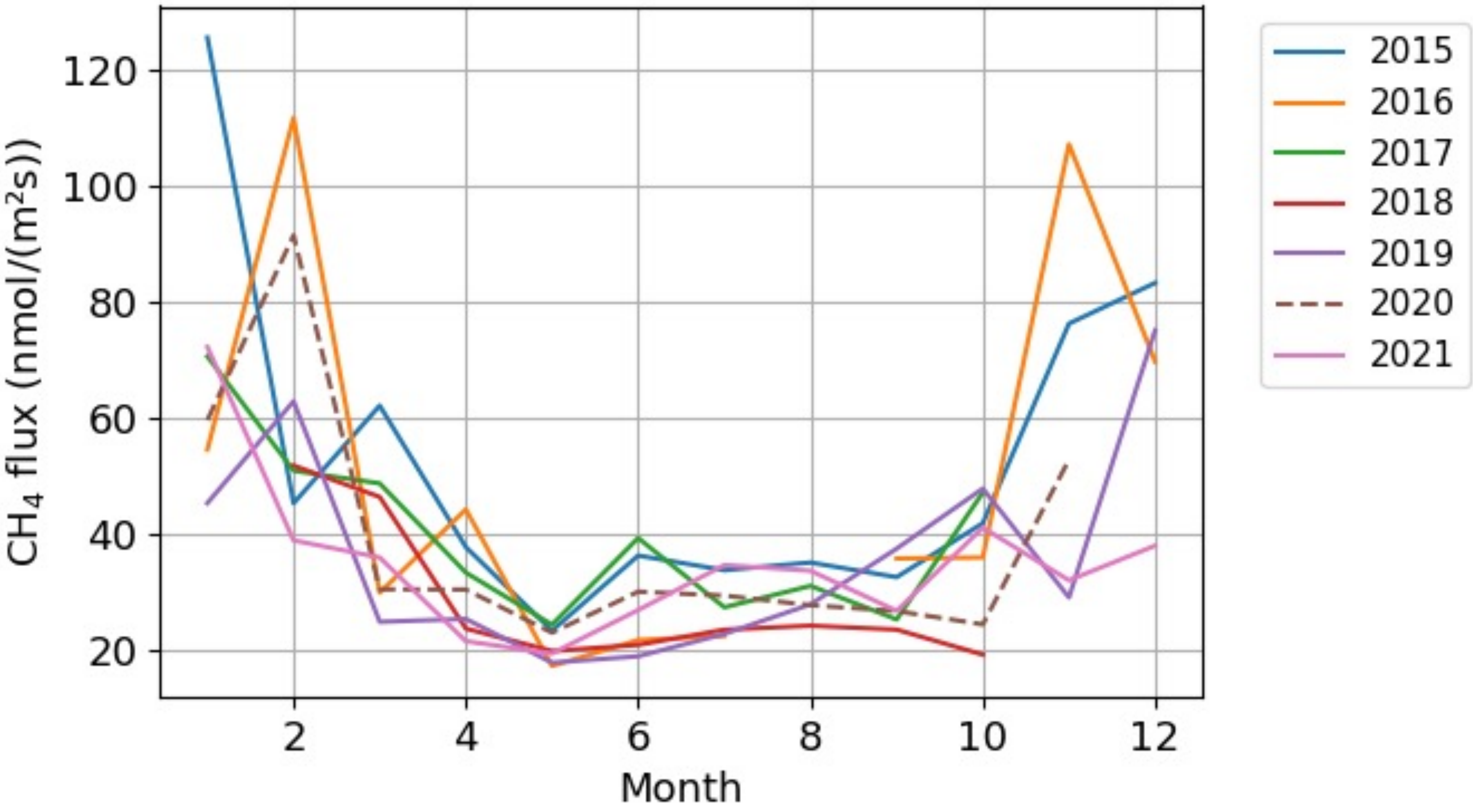
Photo: Indiana State Police Twitter, June 2018

Site 3 monthly median weekday **CO_2** fluxes

- April 2020: **46% lower** than previous years
- July 2018: **45% lower** than previous years

April 2020 decreases also detected in CO and CO_2 flux at COM, CO flux at Site 7

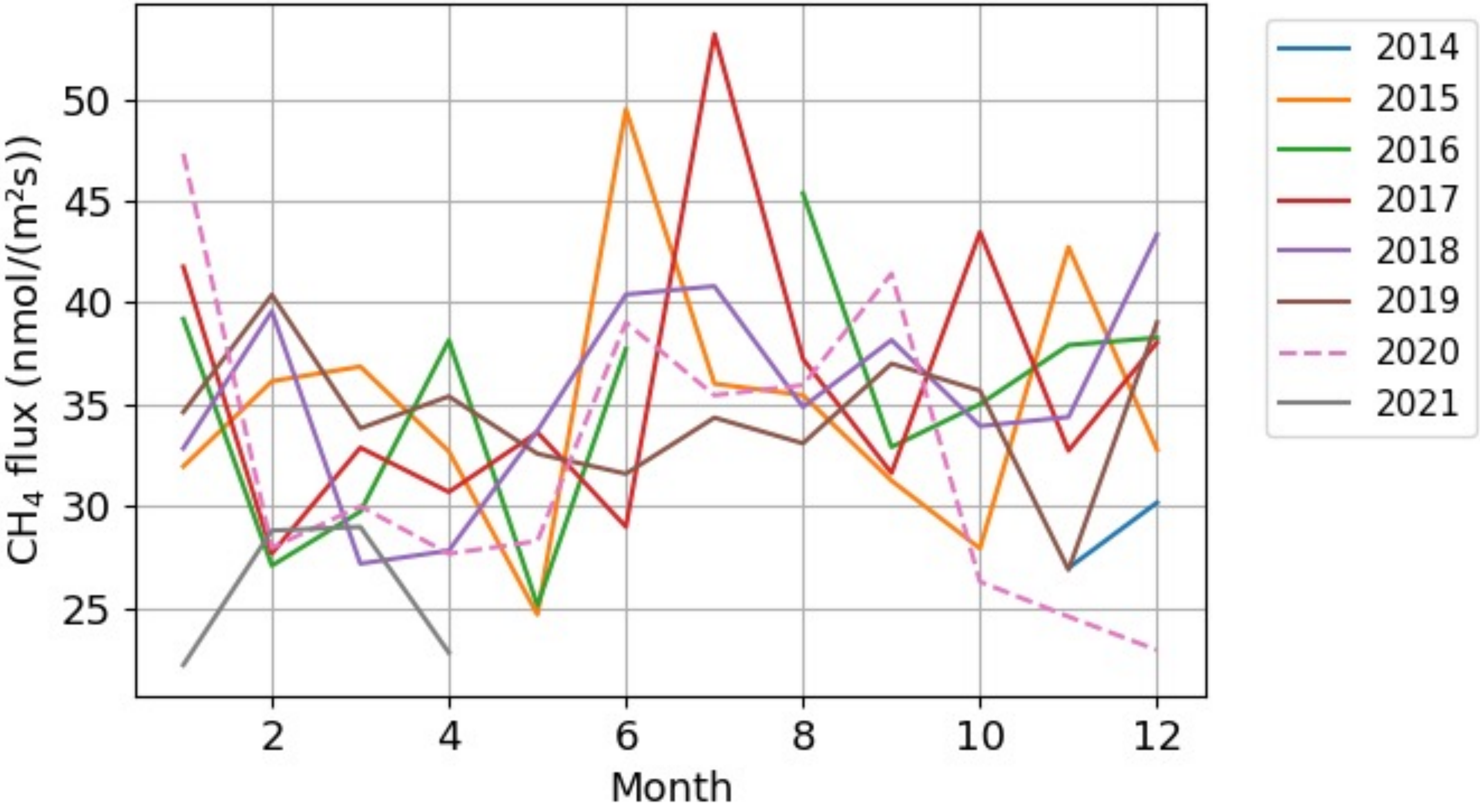
Seasonal changes in emissions can be detected using MOST



COM monthly median weekday **CH_4** fluxes

- Clear seasonal pattern
- Cause unknown

Seasonal changes in emissions can be detected using MOST



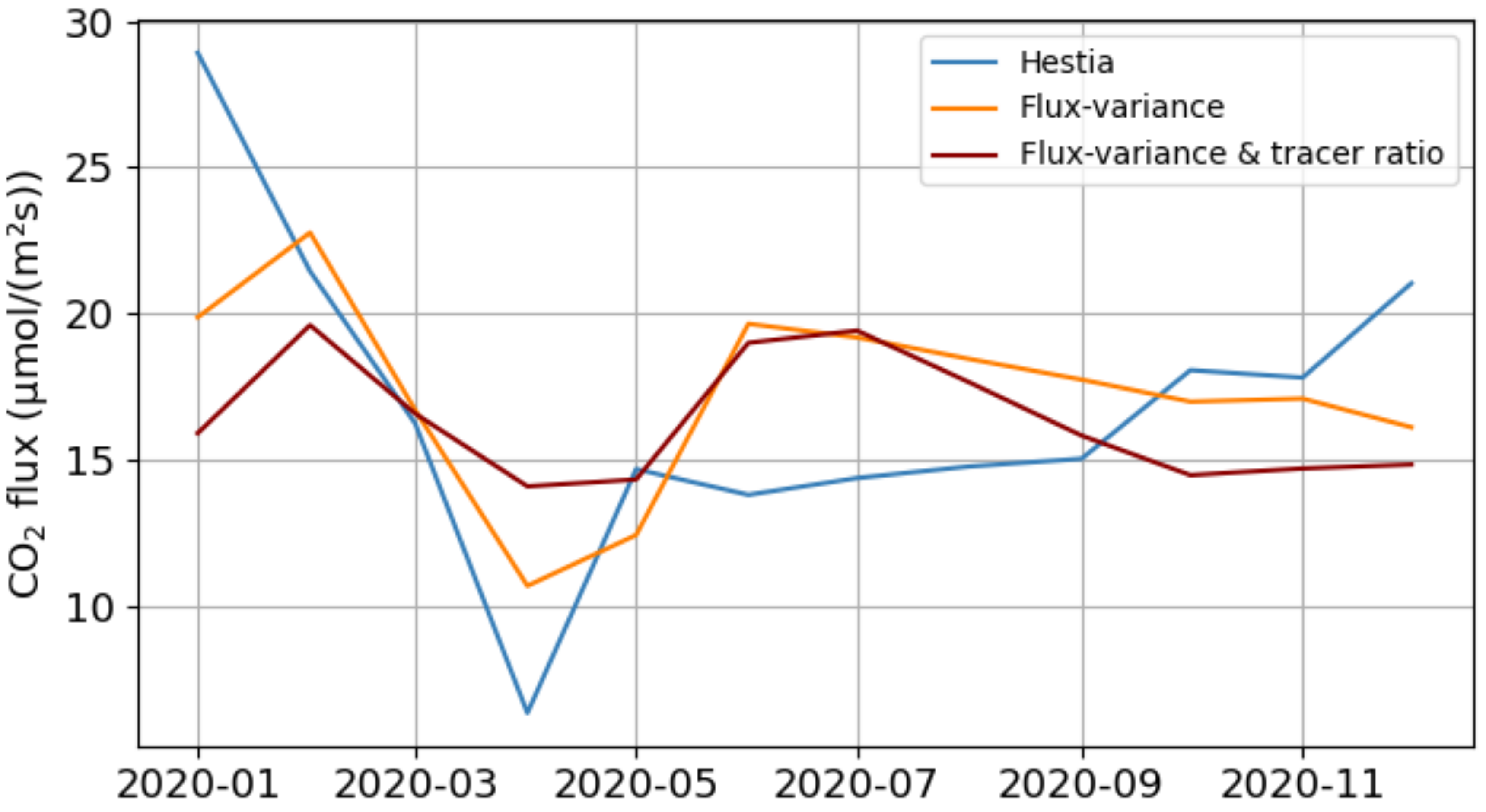
Site 7 monthly median weekday **CH_4** fluxes

- No clear seasonal pattern

Key research questions

- Using MOST, can temporal changes in GHG emissions be detected and quantified?
  - MOST can be used to quantify abrupt changes in emissions
  - MOST can be used to monitor seasonal trends in emissions
- What can we learn from trends in urban fluxes inferred using MOST methods? Can we identify the causes of changes in emissions?
  - Some changes correlate with changes in human activity
  - Can provide important clues about emissions sources
- **Do the CO_2 fluxes calculated using MOST agree with bottom-up (inventory) emissions estimates across time at individual sites?**

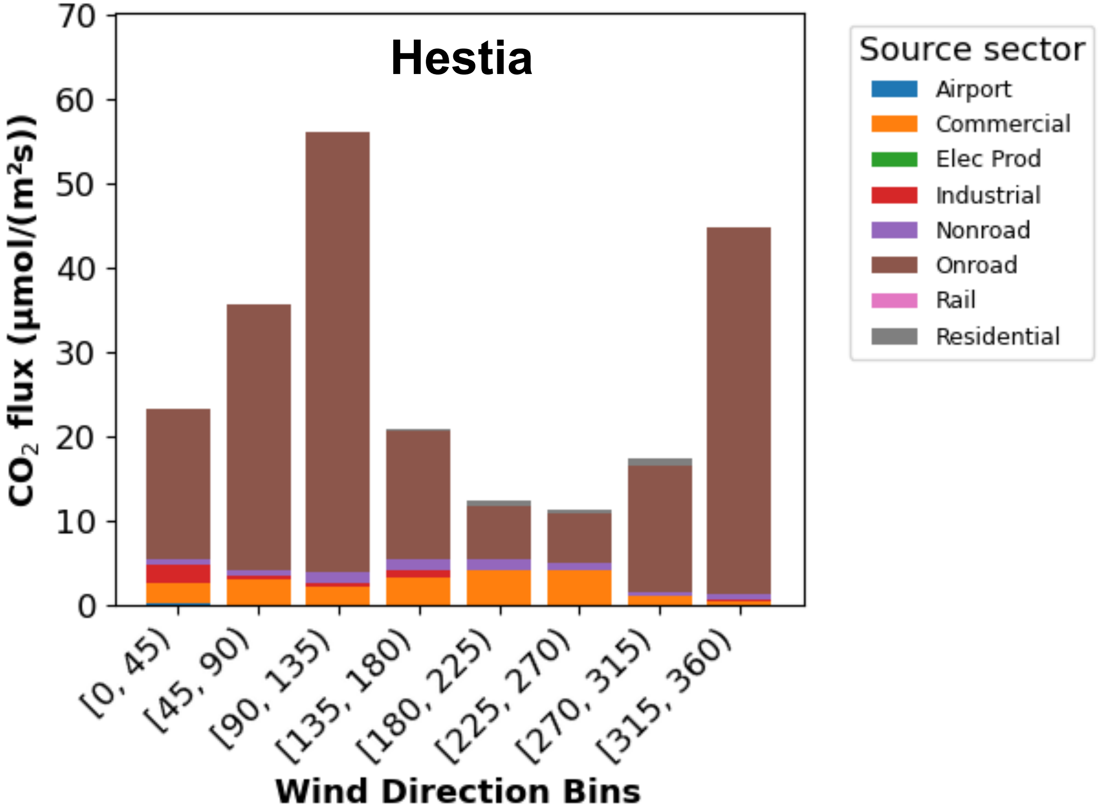
Methods are close in magnitude at Site 3, agree there is decrease in CO_2 emissions April 2020

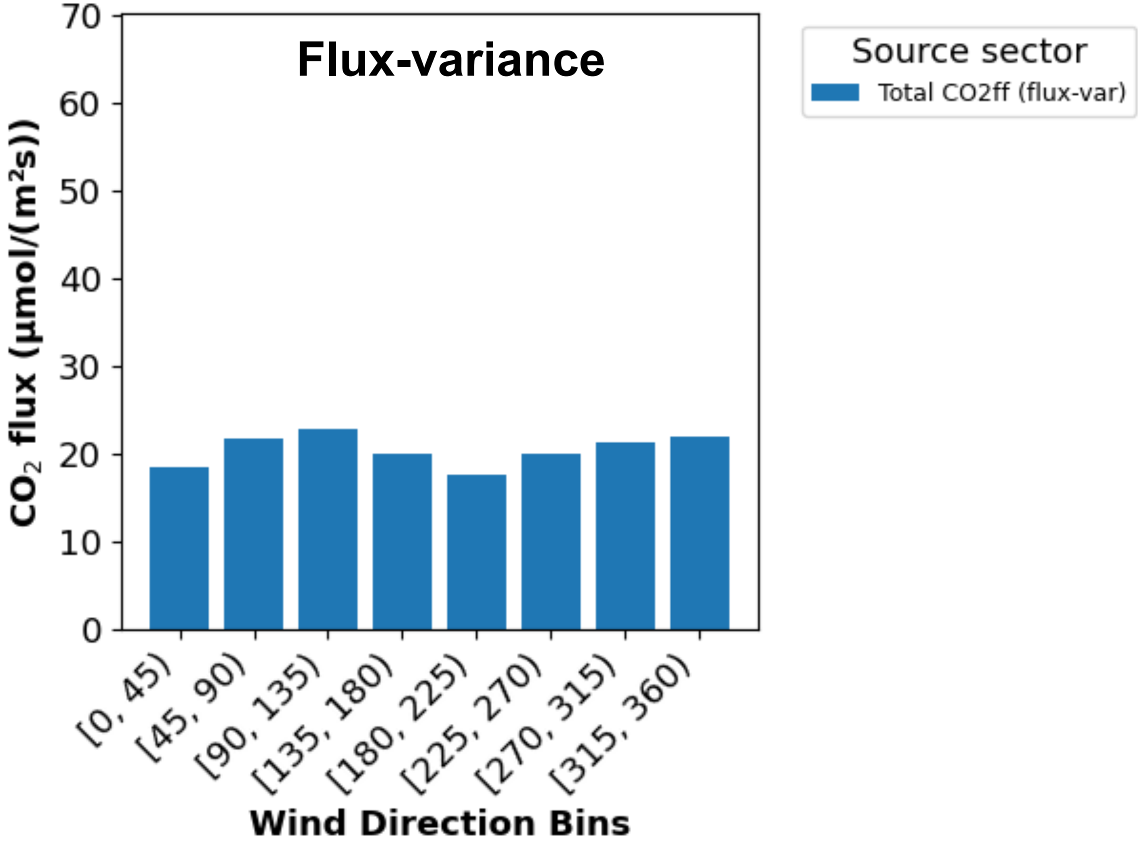


Site 3 monthly median weekday **CO_2** fluxes in 2020

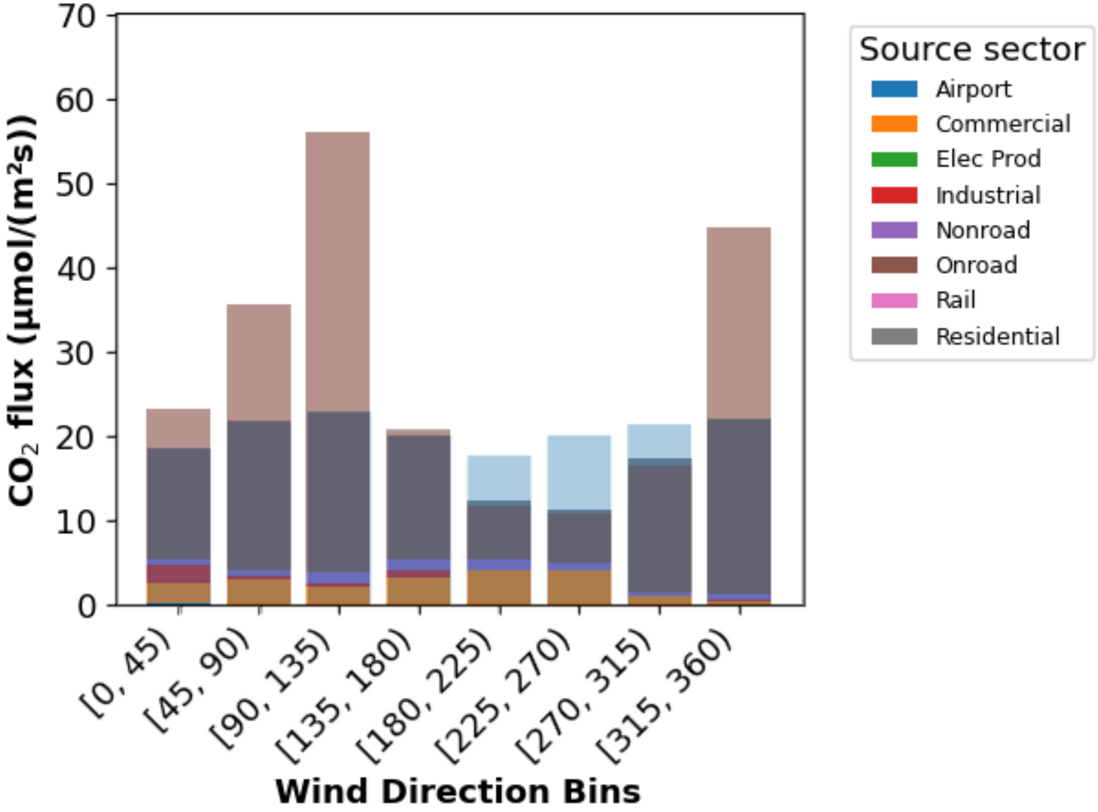
- Methods are close in magnitude
- Agree there was a drop in April
- Some discrepancies

Atmospheric estimates help identify potential errors in spatial distribution

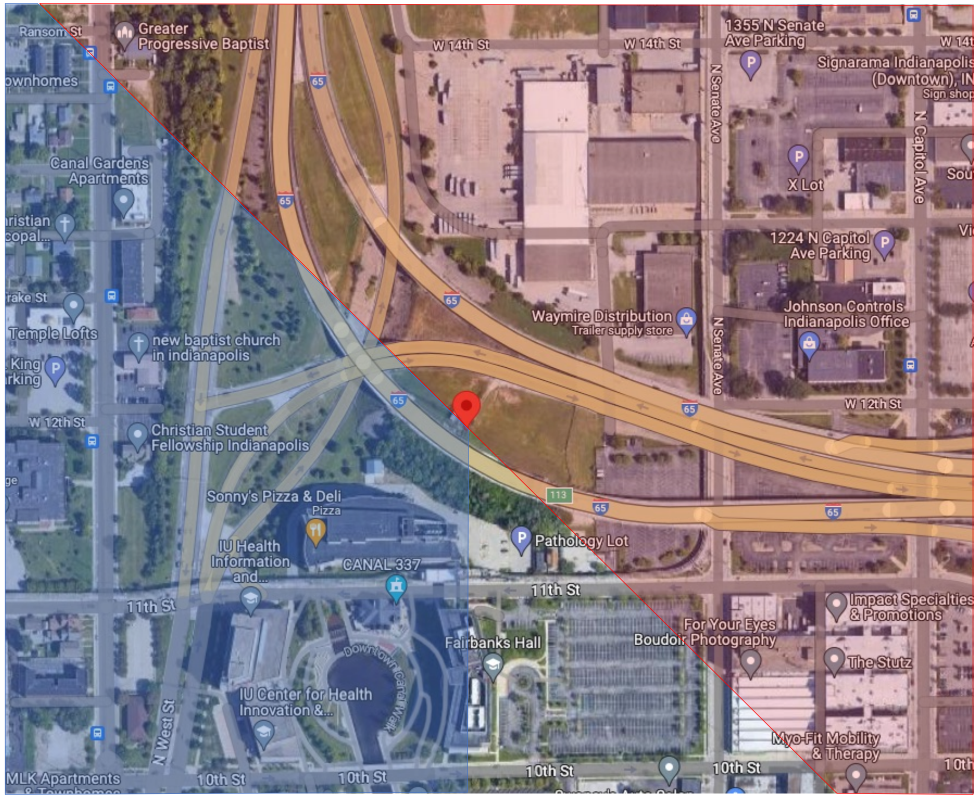




Atmospheric estimates help identify potential errors in spatial distribution



Hestia > Flux-var



Hestia < Flux-var

Potential cause: Onroad emissions attribution in Hestia

Conclusions

- Using MOST, can temporal changes in CO_2 emissions be detected and quantified?
  - MOST can be used to quantify abrupt changes in emissions
  - MOST can be used to monitor seasonal trends in emissions
- What can we learn from trends in urban fluxes inferred using MOST methods? Can we identify the causes of changes in emissions?
  - Some changes correlate with changes in human activity
  - Can provide important clues about emissions sources
- Do the CO_2 fluxes calculated using MOST agree with bottom-up (inventory) emissions estimates across time at individual sites?
  - MOST is a useful tool to evaluate inventories at high spatial and temporal resolution

Acknowledgements

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