Quantifying the spatial distribution of urban methane emissions using tower-based atmospheric measurements

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MOTIVATION

- Methane (CH_4) is a potent greenhouse gas whose leakage from the natural gas system and biological sources contributes to climate change
- Top-down estimates of CH_4 emissions (from atmospheric measurements) are typically greater than bottom-up estimates (from source inventories)[1]
- Results from the Indianapolis Flux Experiment (INFLUX) indicate that the disparity between top-down and bottom-up estimates in the city may be due to low-level, widespread diffuse sources not accounted for in the source inventory[2]

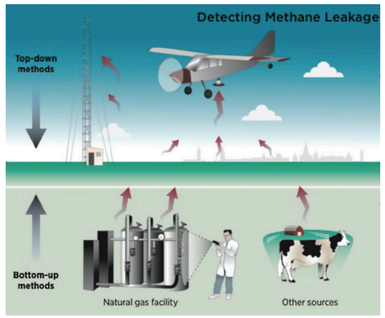


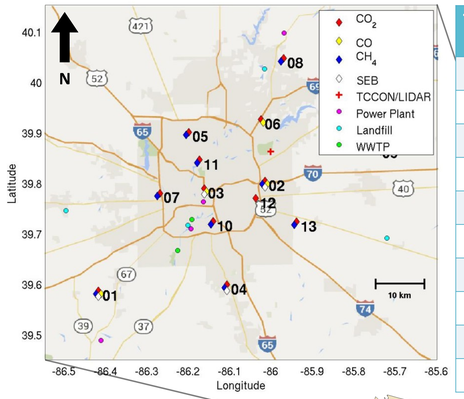
Fig. 1. Illustration of top-down and bottom-up methods for estimation of CH_4 emissions (Image by John Bellamy, Stanford University)

RESEARCH QUESTIONS:

1. What is the spatial distribution of CH_4 emissions in Indianapolis, Indiana?
2. Do low-level CH_4 emissions estimated from tower measurements and boundary layer budget methods account for earlier estimate disparities?

LOCATIONS AND DATA

- Hourly average CH_4 mole fractions from INFLUX tower-based continuous measurements using Cavity Ring Down Spectroscopy (PICARRO, INC.)
- In 2015, CH_4 measured on 9 towers in Indianapolis, Indiana, USA



Tower Pair	Typical Wind Dir.	Distance (km)	Heights (m)
2-8	S-SSW	27	136, 41
7-11	SW	11	58, 130
1-4	W	27	121, 60
2-13	NW	11	136, 87
4-13	SW	19	60, 87
5-8	SW-WSW	25	125, 41
5-11	NNW	6	125, 130
7-5	SSW	15	58, 125
1-7	SSW-SW	25	121, 58
10-13	W	17	40, 87

Fig. 2. Atmospheric CH_4 concentrations measured from 9 towers with a range of max sample heights between 40 and 136 m AGL in Indianapolis, Indiana. A large landfill to the west of tower 10 accounts for 35% of estimated emissions.[2]

- Hourly wind speed and direction from Indianapolis airport weather data
- Data evaluated for the afternoon hours of 12-5 pm LT (16-21 or 17-22 UTC) when the boundary layer is assumed to be well-mixed, and for wind speeds above 3 m/s and changes in wind direction less than 30 degrees

METHODS

- Calculated difference in CH_4 concentration between pairs of towers when wind blowing across both towers
- Estimated CH_4 flux (F_c) using boundary layer budget approach:

$$F_c \sim \frac{U \times Z_i \times \Delta[CH_4]}{L}$$

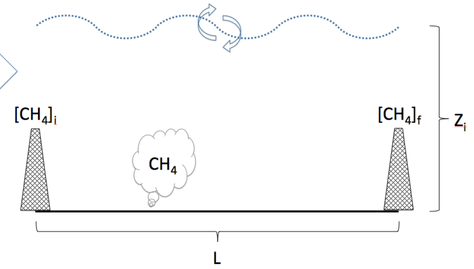


Fig. 3. Equation and diagram of boundary layer budget approach of estimating flux between two towers using differences in CH_4 concentration

- Assumed boundary layer depth (Z_i) = 1,000 m and wind speed (U) = 5 m/s
- Estimate total emissions for city's 1,855 km^2, compare to estimates by Lamb et al.[2]

RESULTS

Fig. 4. Distribution of Differences in Hourly Average CH_4 Concentration

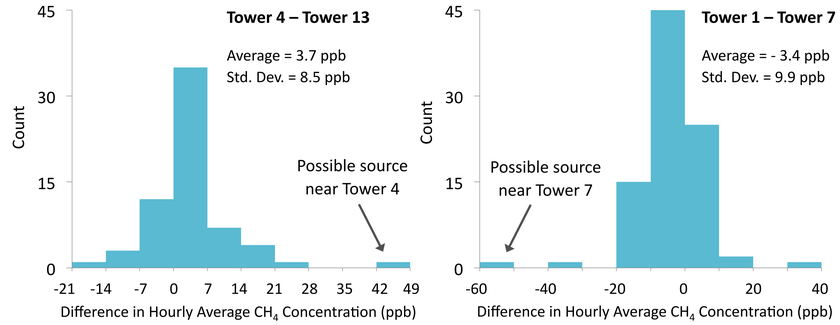


Fig. 5. CH_4 Flux for Tower Pairs

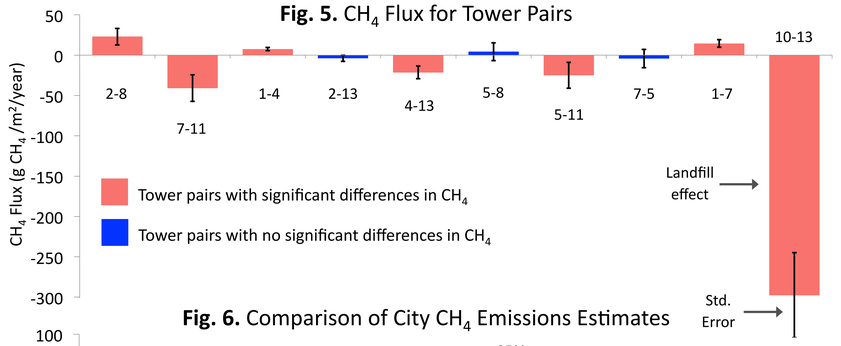
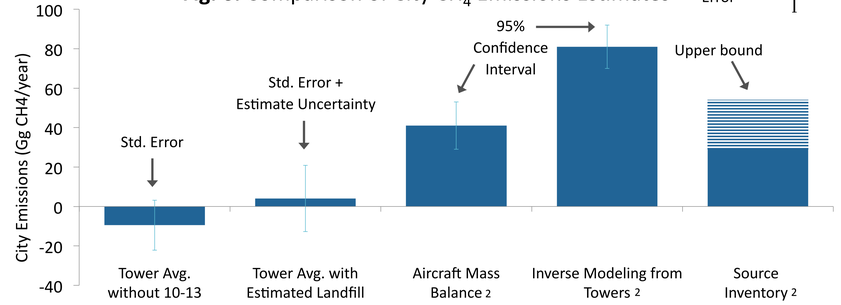


Fig. 6. Comparison of City CH_4 Emissions Estimates



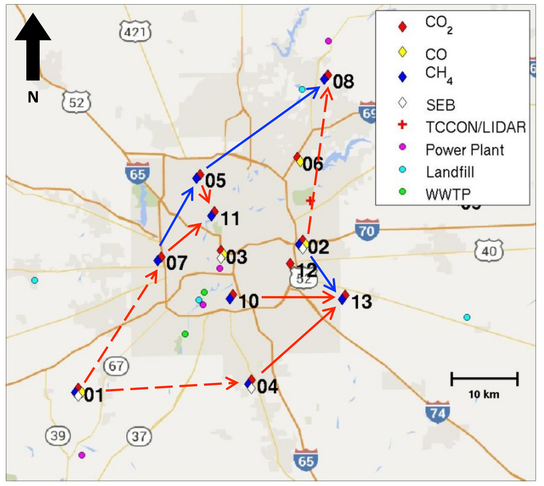
CONCLUSIONS

Fig. 7. Map of Indianapolis showing:

Evidence of emissions between towers when wind blowing in arrow's direction

Evidence of sinks between or emissions near towers when wind blowing in arrow's direction

No evidence of emissions between or near towers when wind blowing in arrow's direction



- There may be local CH_4 sources close to towers 1, 4, 7, and 5
- Clear evidence of high CH_4 emissions from the landfill close to tower 10
- Evidence of CH_4 emissions between towers 2 and 8, 1 and 4, 1 and 7, and evidence of sinks between or emissions near 7 and 11, 4 and 13, 5 and 11
- Total city emission estimate from diffuse sources and previous landfill estimates not within range of Lamb et al.
- Tower-based estimate from low, diffuse fluxes using this method gives no clear evidence of widespread emissions and does not account for the difference between earlier top-down and bottom-up estimates

FUTURE WORK

- Incorporate data available for 2014 and 2013, and all tower combinations
- Calculate CH_4 flux more accurately using average wind speed from weather data and average boundary layer depth from Lidar measurements
- Incorporate time lag into calculation of concentration differences
- Analyze the relationship between differences in concentration/flux estimates and tower heights

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