Statistical Partitioning of Net Carbon Dioxide Fluxes Over a Heterogeneous Urban Landscape

Olaf Menzer, Joe McFadden

University of California, Santa Barbara

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Urban CO$_2$ Fluxes

>70% of anthropogenic CO$_2$ emissions generated in cities

(Canadell et al., 2009)
Eddy Covariance Method

Eddy covariance

- Non-destructive, non-invasive
- Multiple-time scales ($10^5-10^9$)
- Carbon and water, and energy fluxes
- Biogeophysics and biogeochemistry
- Fast response
- Temporal high resolution (half hourly)

- Only net fluxes
- Stochastic data, gaps
- Biases if theory not met
- Confined to flat terrain
Eddy Covariance in Urban Areas

- growing number of eddy covariance sites
- useful for e.g., emission inventory validation
- synthesis studies by Velasco & Roth 2010 and Nordbo et al. 2012; modeling studies e.g., Christen et al. 2011

- means to account **Net** CO$_2$ emissions, i.e., including all emission components, both **anthropogenic** and **biogenic**
Suburban Study Site

- tall radio tower site in a suburban neighborhood in Minneapolis, MN, USA.
- LCZ 6
- Instruments at two levels (40m and 80m)

(Peters et al. 2011, Menzer et al. 2015)
Observed Sources and Sinks

- Diurnal time courses, $Net CO_2 Flux F_c$

1.) Photosynthesis – daily and seasonal patterns
2.) Traffic – rush hour, weekday vs. weekend
3.) Other influences: space heating, respiration

⇒ More (variable) sources & sinks make flux modeling (e.g. for gap-filling, partitioning) a complex problem
Spatial heterogeneity

- Gap-filling model predictions, for different wind sectors

(Menzer et al. 2015, AtmEnv 101)
Urban Flux Partitioning Challenges

(1) Multiple emission sources and sinks
(2) Spatial variability of emissions and uptake throughout tower footprint
(3) Complexity and noise in the observed net flux

Previously developed partitioning approaches in urban environments:
- modeling fluxes based on surface fractions in the changing turbulent source area (Crawford and Christen, 2014),
- Data fusion with bottom up emission inventories (Christen et al. 2011)
Modeling Approach (I)

\[ F_c = F_{\text{anthrop}} + F_{\text{biog}} \]

- During Winter (DJF), \( F_{\text{biog}} \approx 0 \) (for, \( T < -1 \) deg C)
- (Minnesota has very cold winters...)
- ~ approximately 3,000 high quality data points available for modeling

Preliminary Results

- Winter Flux correlation with traffic: \( r = 0.68 - 0.91 \)
- Winter Flux correlation with heating fuel emissions from space heating (e.g., using model by Sailor and Lu 2004)
  - \( r = 0.27 \) at the half hourly scale; \( r = 0.55 - 0.92 \) at the daily level
Modeling Approach (II)

\[ F_c = F_{\text{anthrop}} + F_{\text{biog}} \]

1. Develop response model \( F_{\text{anthrop}} = f(\text{traffic}) + f(T) + \epsilon \)
2. Extrapolate \( F_{\text{anthrop}} \) to the rest of the year as needed
3. Calculate \( F_{\text{biog}} = F_c - F_{\text{anthrop}} \)
4. Run standard Nighttime based partitioning approach on \( F_{\text{biog}} \)

Parameters & Filters
- Residential and recreational sector
- High quality data (qc = 0)
- \( f(T) \) is a composite of a Moving Average and a Lag temperature variable
- \( f(T) = 0 \) for \( T > 18 \) deg C

Air Temperature

\[ \text{half hourly vehicle counts} \]
Anthropogenic Flux Response Function, residential sector

$$F_C^{\text{hat}} = 0.0072 \times \text{traf} + (-0.1942) \times T_{\text{MA18+6}} + (-0.5097) \times T_{\text{lag6}} + 3.2880$$

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Recreational Sector

Anthropogenic Flux Response Function, recreational sector

\[ F_{C\hat{}} = 0.0053 \times \text{traf} + (-0.0474) \times T_{\text{air}_{MA18+6}} + (-0.5232) \times T_{\text{air}_{lag6}} + 4.3522 \]
Relative model parameters

<table>
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<th></th>
<th>$b_{veh}$</th>
<th>$p$</th>
<th>$b_{Tma}$</th>
<th>$p$</th>
<th>$b_{Tlag}$</th>
<th>$p$</th>
<th>$b_0$</th>
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<tr>
<td>residential sector (A)</td>
<td>1.385</td>
<td>&lt;0.001</td>
<td>-0.928</td>
<td>&lt;0.001</td>
<td>-0.813</td>
<td>&lt;0.001</td>
<td>7.870</td>
<td>&lt;0.001</td>
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<tr>
<td>recreational sector (B)</td>
<td>1.053</td>
<td>&lt;0.001</td>
<td>-0.231</td>
<td>0.353</td>
<td>-0.967</td>
<td>&lt;0.001</td>
<td>6.066</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

(A) residential sector

(B) recreational sector

*(Anthropogenic Flux Response Function, residential sector)*

*(Anthropogenic Flux Response Function, recreational sector)*
Validation of biogenic components

Calculated $F_{\text{anthrop}}$ → Now, estimate (3) $F_{\text{biog}} = F_{\text{C}} - F_{\text{anthrop}}$

- e.g., comparing to turf fluxes (mobile tower over a lawn in footprint (T))
- e.g., comparing to bottom up modeling of $F_{\text{VegSoil}}$ (Peters et al. 2012)
Nighttime Flux Partitioning

- Reichstein et al. (2005) method
- Based on temperature response function of ecosystem respiration (sum of heterotrophic and autotrophic respiration)

\[ R_{\text{eco}} = R_{\text{ref}}e^{E_0(1/(T_{\text{ref}}-T_0)-1/(T-T_0))} \]

(Lloyd & Taylor 1994)

- Assuming nighttime fluxes to be independent of photosynthesis

Therefore, nighttime \( F_C \sim= R_{\text{eco}} \)

Then, extrapolate to the daytime, calculate GPP as the difference

\[ \text{GPP} = R_{\text{eco}} - F_C \]
Validation of biogenic components

- e.g., comparing to turf fluxes from a mobile tower over a lawn in the footprint (T)
- e.g., comparing to bottom up modeling of $F_{\text{VegSoil}}$ (Peters et al. 2012)
- no significant relationship between turf tower Reco and modeled tall tower flux

- Significant relationship between turf tower Reco and modeled tall tower flux
- tall tower Reco also includes tree respiration and residual fluxes
Comparison to bottom up C estimates

Statistical partitioning result:

\[ F_{\text{biogenic}} = GPP - R_{\text{eco}} \]

(Peters et al. 2012)
Conclusions

(1) Highly variable **urban emission processes represented well** in the Eddy Covariance data at this suburban neighborhood site

(2) Several sources and sinks can be estimated through filtering and statistical modeling based on a multi-year data set

(3) Representation through **multiple regression models is significant**

(4) Provide **C component estimates** independent of e.g., footprint data

Impact & Applications

▶ (1) **Anthropogenic** emission component estimates: can be used to validate *building energy and traffic models*

▶ (2) **Biogenic fluxes**: useful to identify areas with *emission-reduction potentials* and establish *emission baselines*.
Outlook

- Carbon budgeting of all components presented today
- Cross comparison of models parameters for other sites
  → !!!interested in your urban flux data!!!
- Uncertainties need a more detailed assessment
  (1) Spatiotemporal residual assessment, (using flux footprint maps overlayed on Quickbird landcover map)
  (2) error propagation: e.g. Flux data uncertainty and biogenic partitioning model uncertainty

- Final study ongoing: **Up-scaling** of fluxes based on land cover fractions