Cornell University

Residential Wood Combustion (RWC): Near-Source Characterization, Source Estimation and Emission Surrogate

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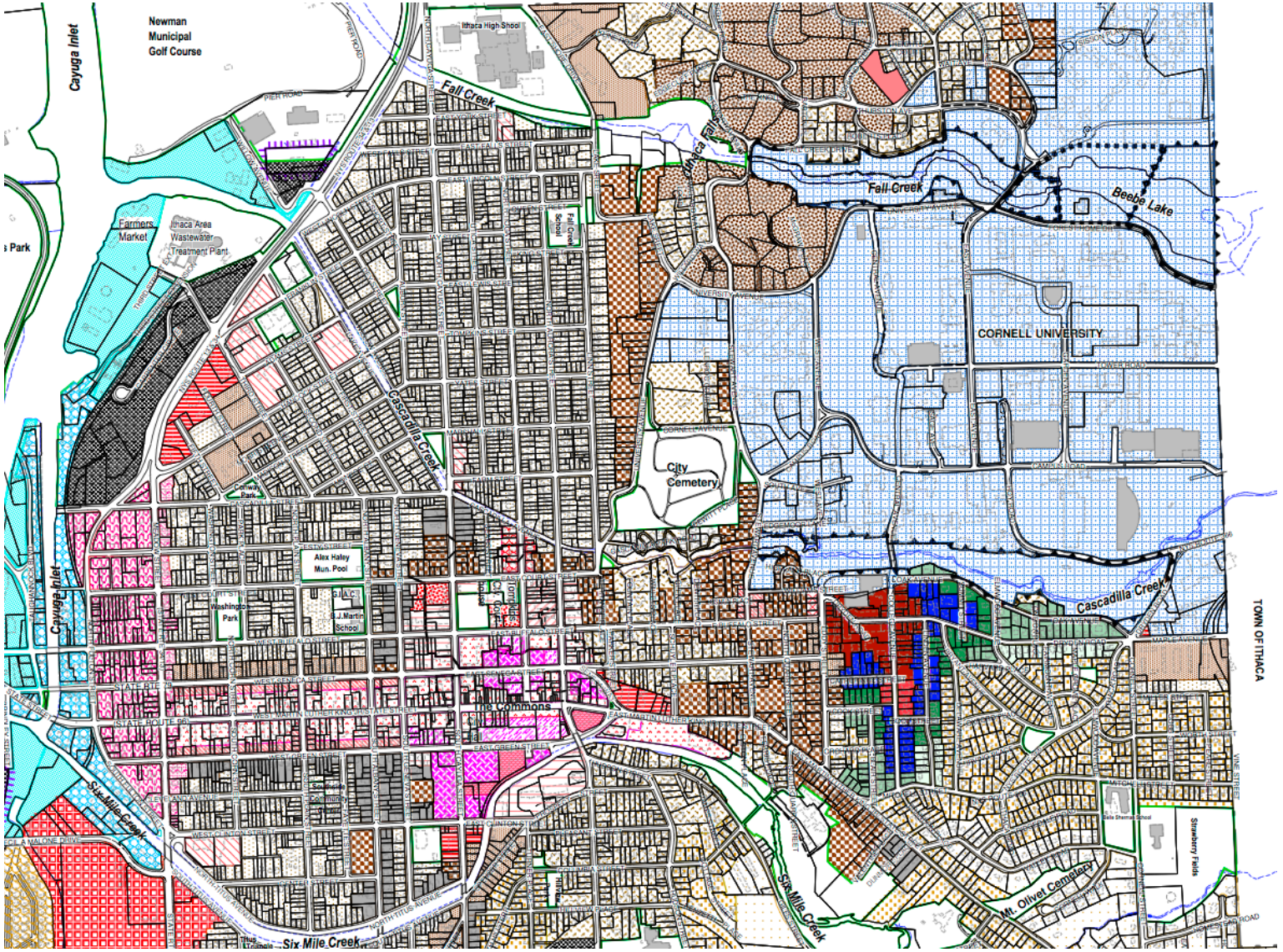
City of Ithaca, NY

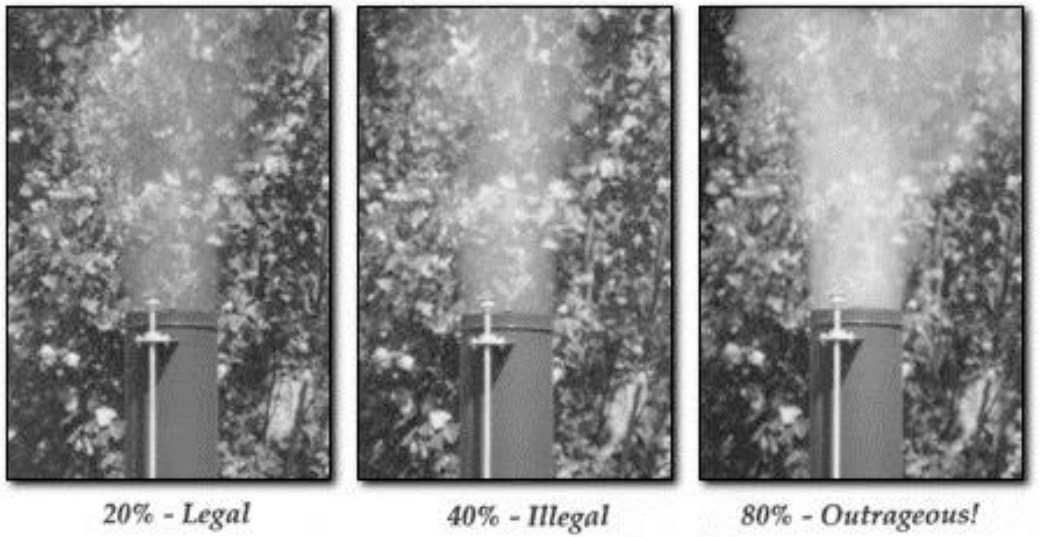


Woodsmoke as an **urban** problem

Policy-relevant research questions

- Impact assessment
  - How localized is the local air pollution problem?
- Regulations
  - Local ordinances rarely exist
  - Basis: Concentration or Emissions?
  - Enforcement mechanism inadequate
- Emission Inventory
  - Heavily relying on survey data.
  - Lack of alternative surrogates

How do we respond to woodsmoke complains?



Enforcement Kit ?

- Near-source measurement
- Data processing
- Estimating emission rates

Policy-relevant research questions

- Impact assessment
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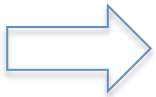
- Conducting near-source woodsmoke monitoring



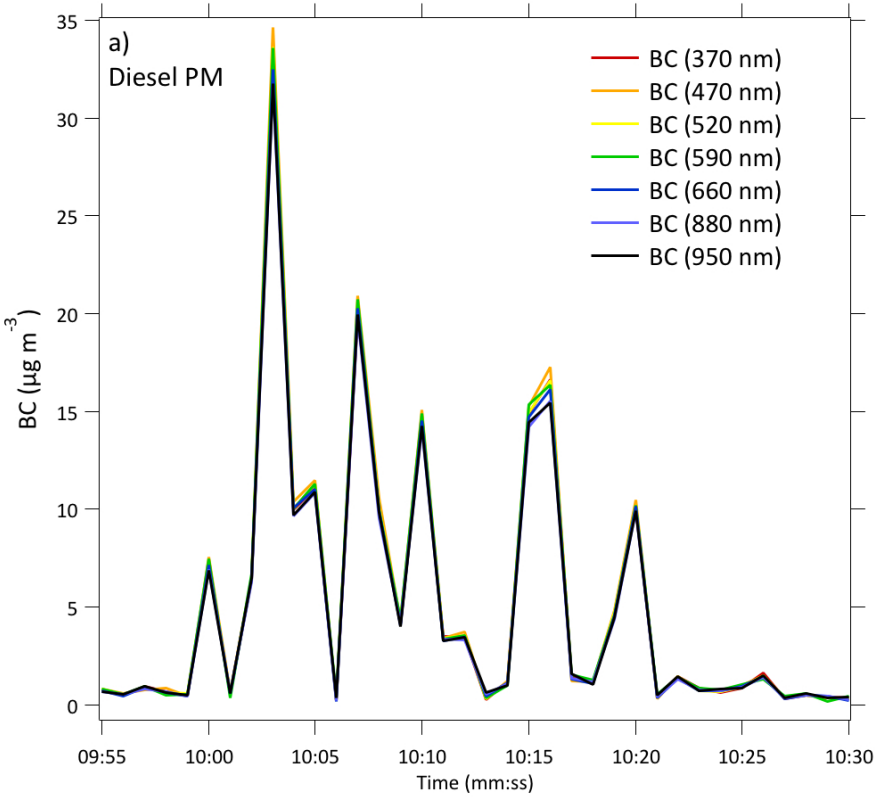
- Developing source estimation techniques

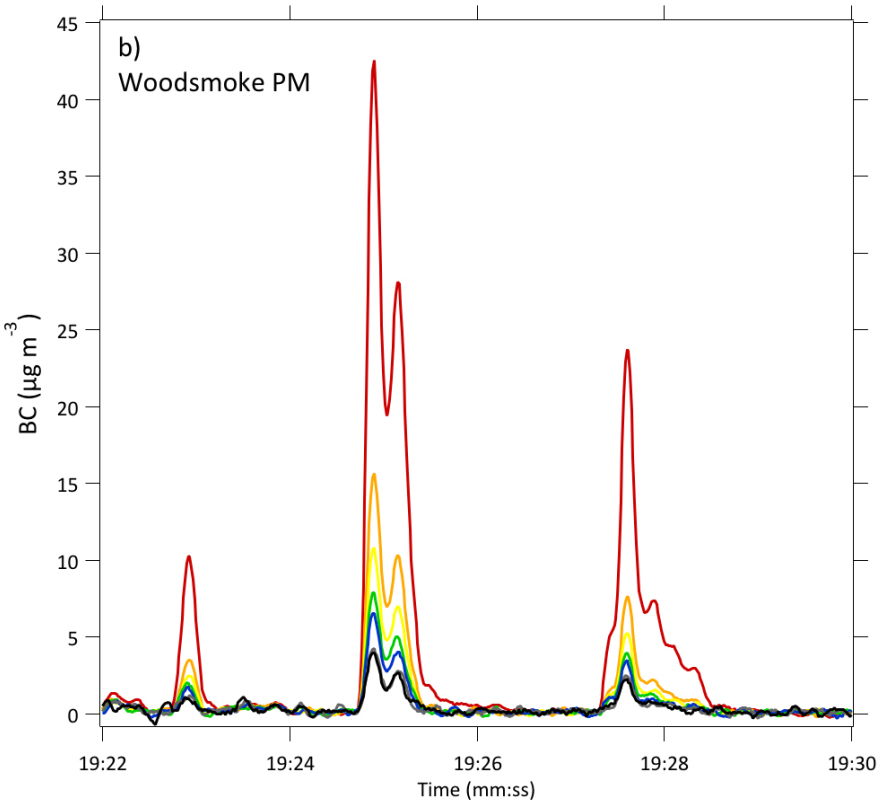
- Evaluating a potential woodsmoke emissions surrogate

Hybrid mobile and fixed site monitoring in Ithaca

- pDR-1500: $PM_{2.5}$
- AE-33: seven-wavelength Aethalometer™ (370 nm, 470 nm, 520 nm, 590 nm, 660 nm, 880 nm, and 950 nm)
  - DC= BC (370) – BC (880) as a woodsmoke marker
- GMP343: CO_2
- Mobile platform: a hybrid electric vehicle (HEV), probes mounted one feet above the sunroof of the HEV
- Fixed site monitoring at the property line for reoccuring hotspots
- A total of 20 mobile monitoring runs and fixed site monitoring were done on the following dates (low temperature and low wind speed):
  - December: 16, 20
  - January: 5, 6, 7, 22-AM, 22-PM, 24, 27
  - February: 9, 12, 14, 18, 26
  - March: 3, 4, 5, 6, 19, and 20

Wavelength-dependent responses





Diesel PM: No enhancement for UV absorption

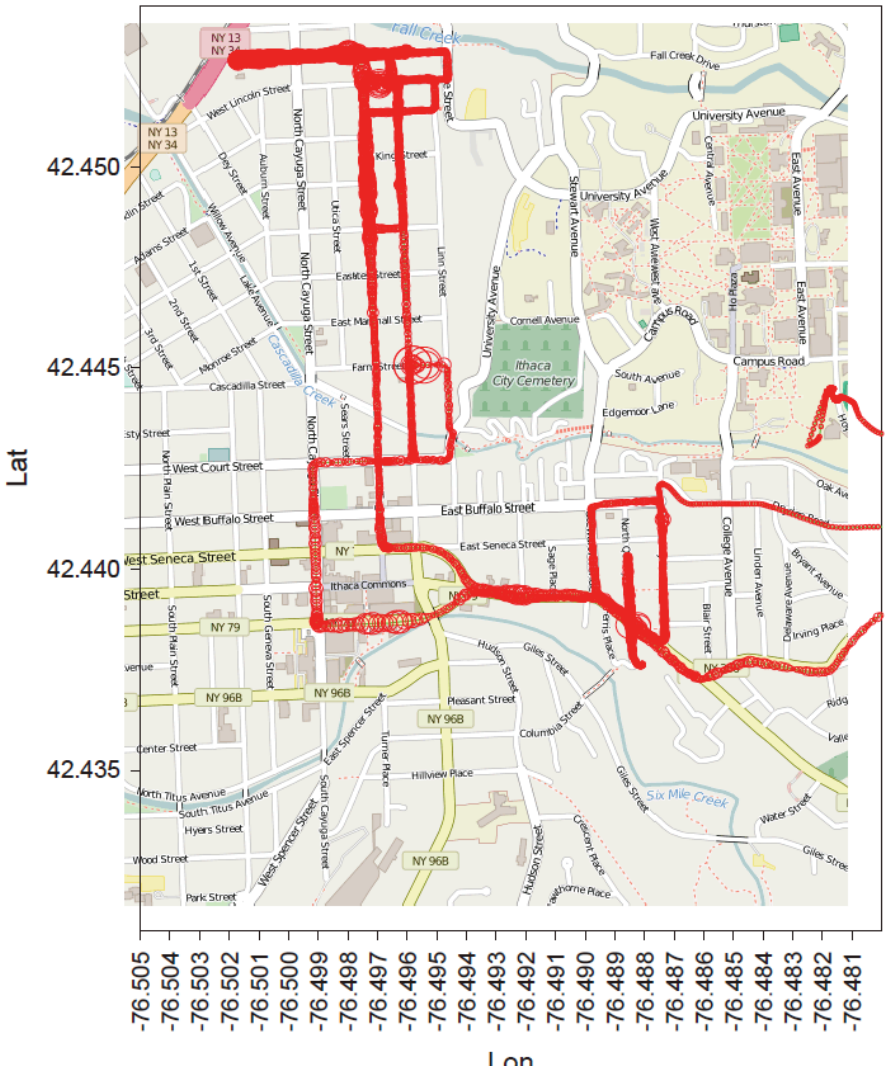
Woodsmoke PM: Strong enhancement at shorter wavelength

DC= BC (370) – BC (880) as a woodsmoke marker

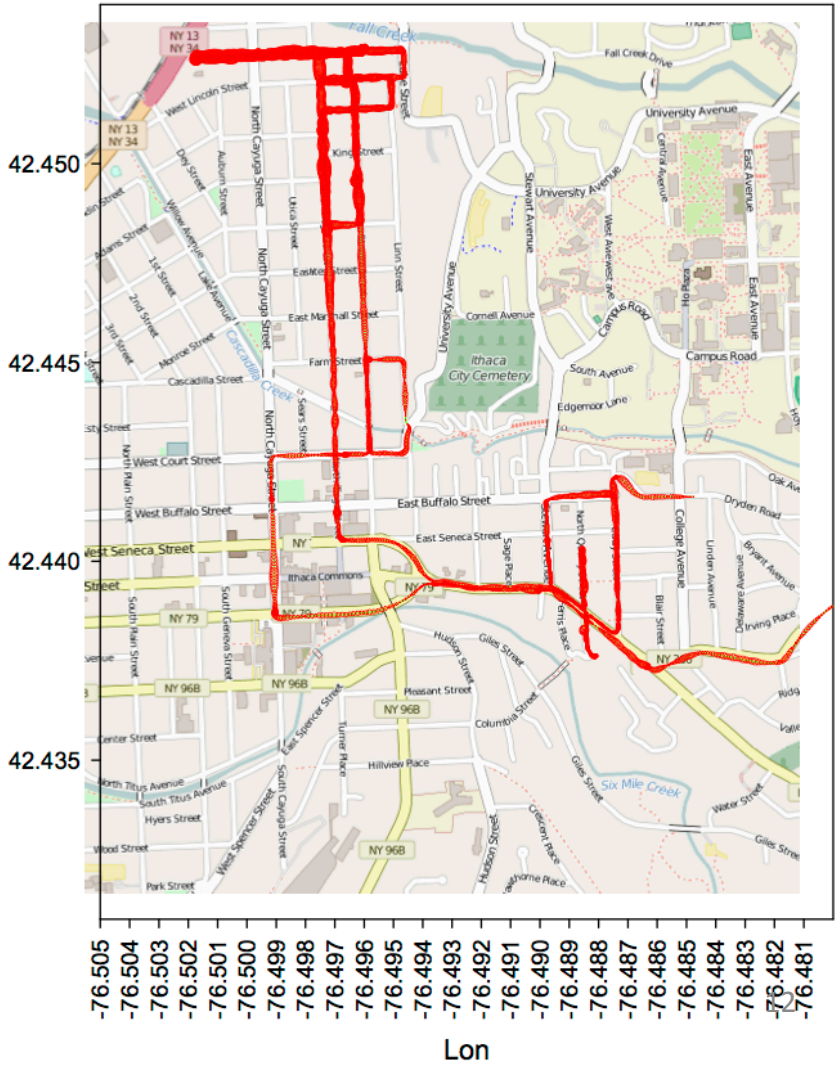
Near-source monitoring

Examples of mobile run results

Ithaca 06Jan16 Trip 1 Red Circle is pDR PM2.5; Green is GPS Track When PM=0

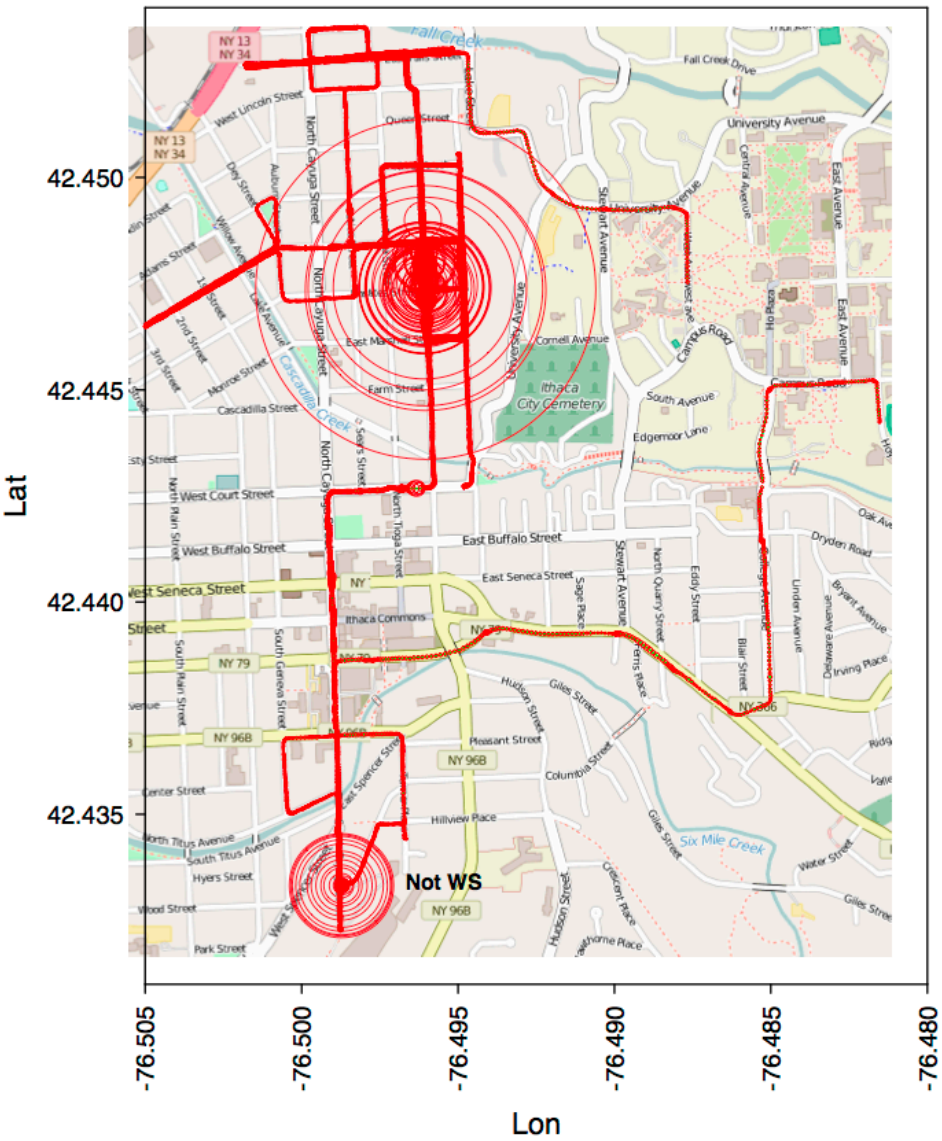


Ithaca 06Jan16 Trip 1 Woodsmoke Red Circle is Delta-C; Green is GPS Track When DC=0



Near-source monitoring

Ithaca 22Jan16-am Red Circle is pDR PM2.5;
Green is GPS Track When PM=0



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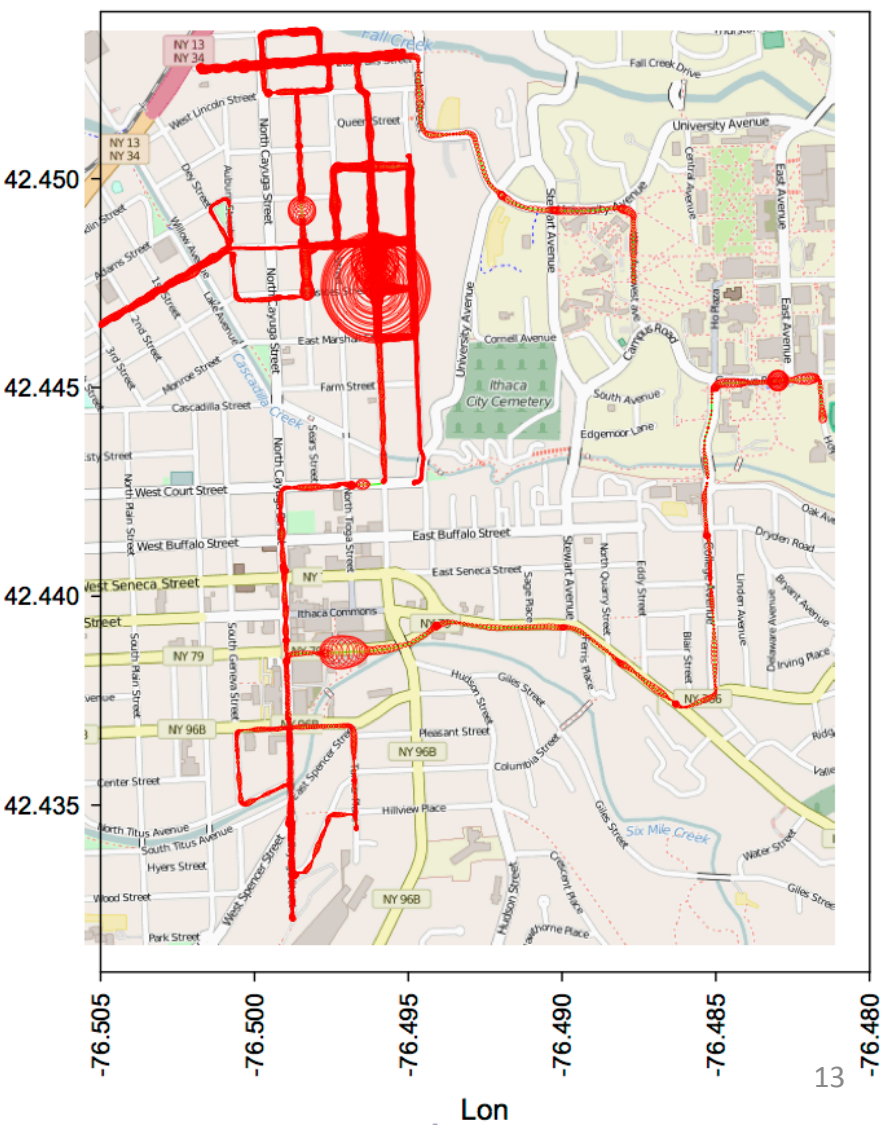
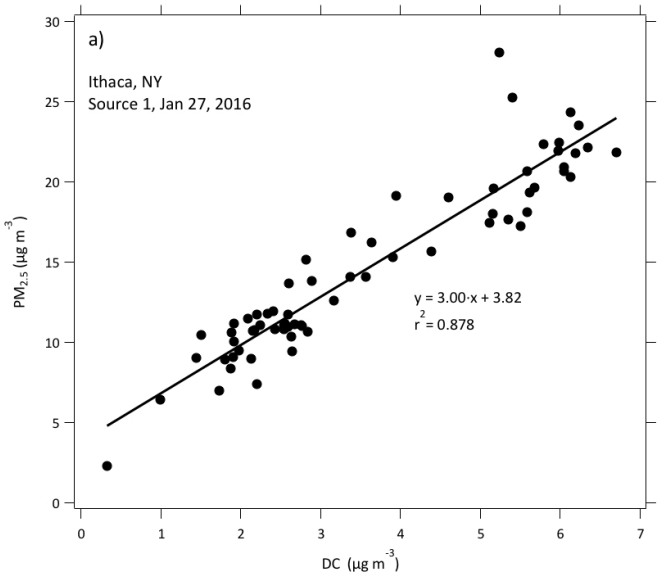
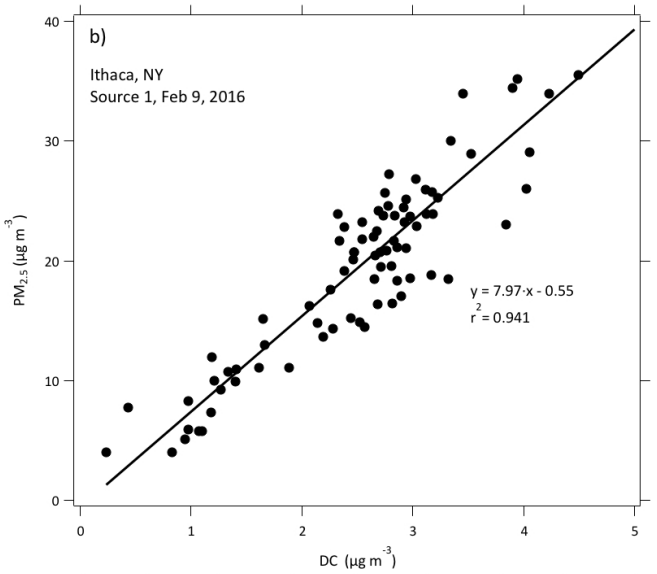
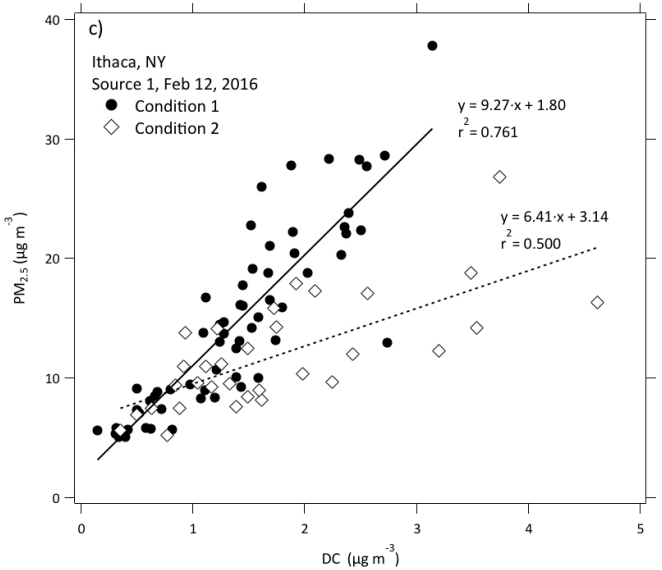
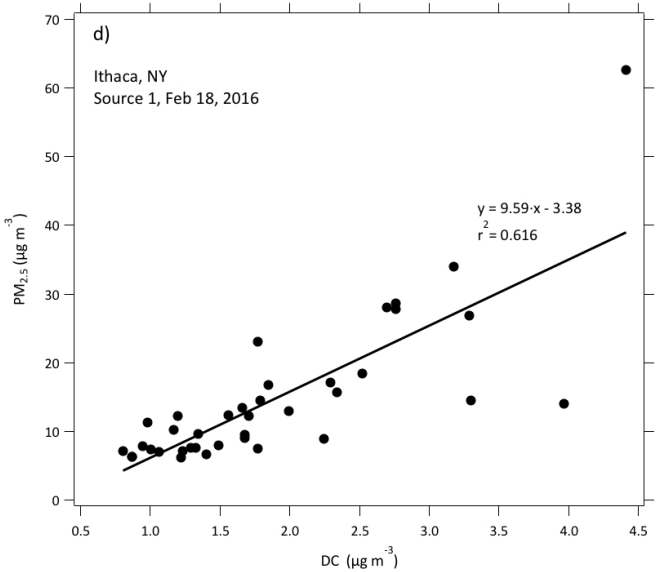


Fixed site: Source 1

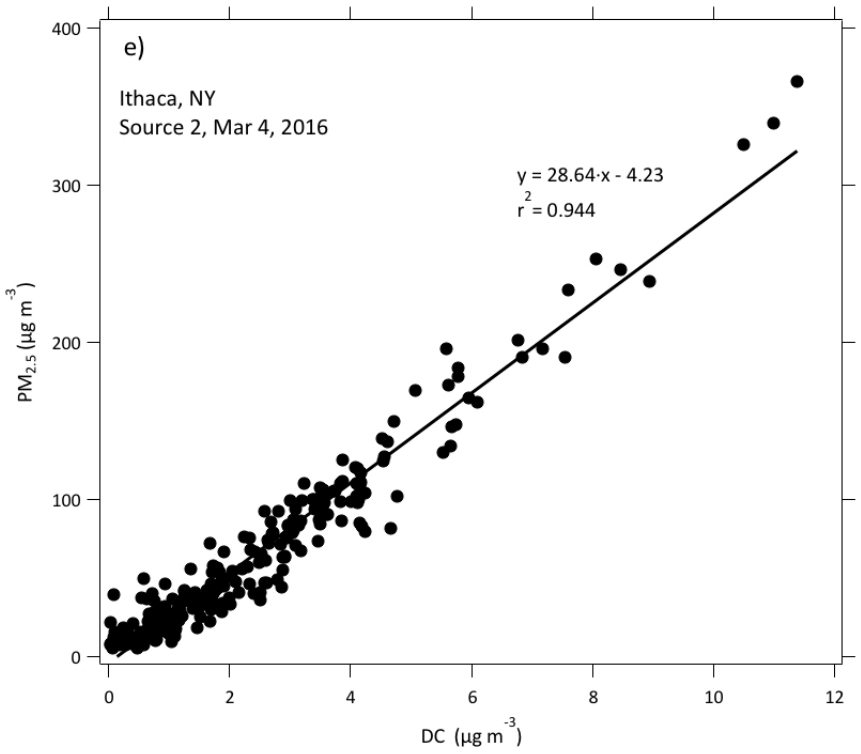


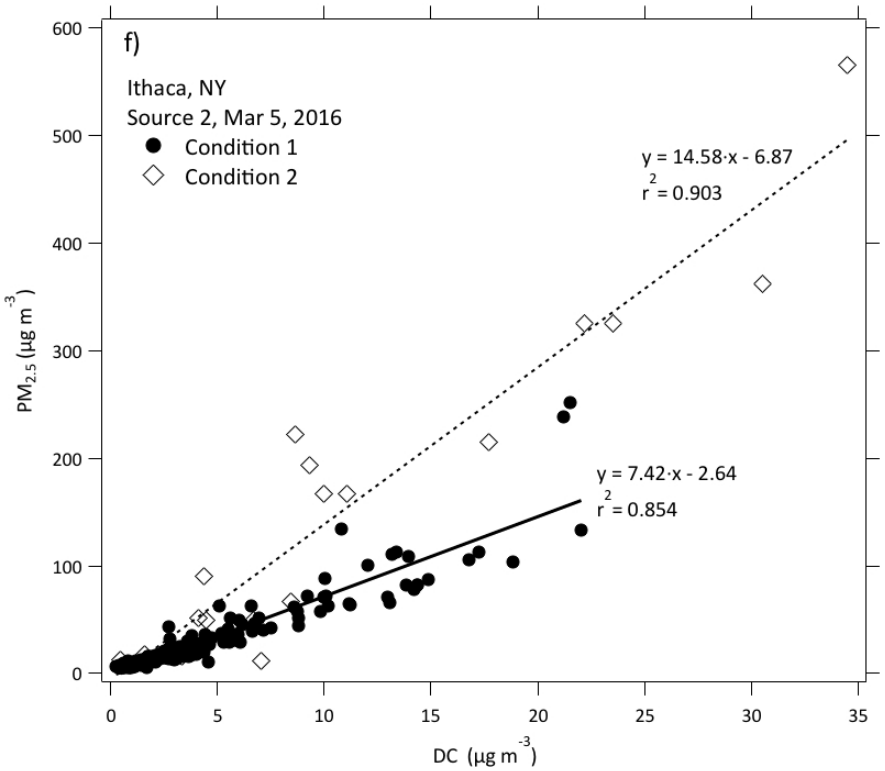






Fixed site: Source 2





Different PM vs. DC relationships indicate different combustion conditions

Source Estimation

Dispersion Modeling

source

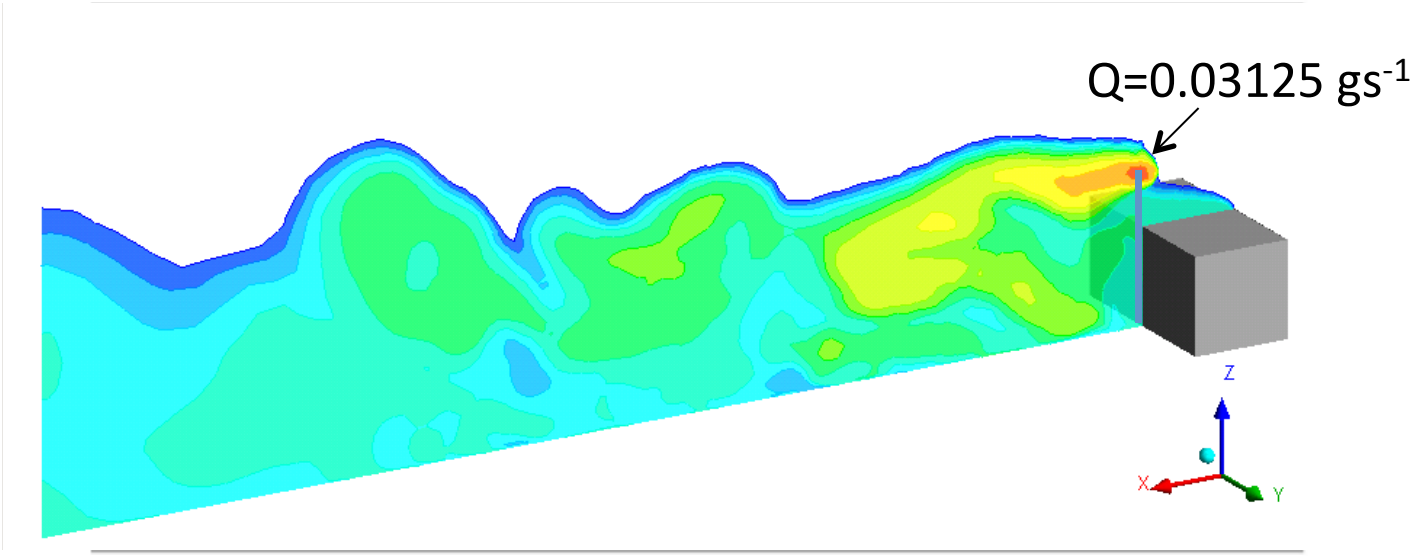
receptor

Source Estimation

Approaches adopted in the literature

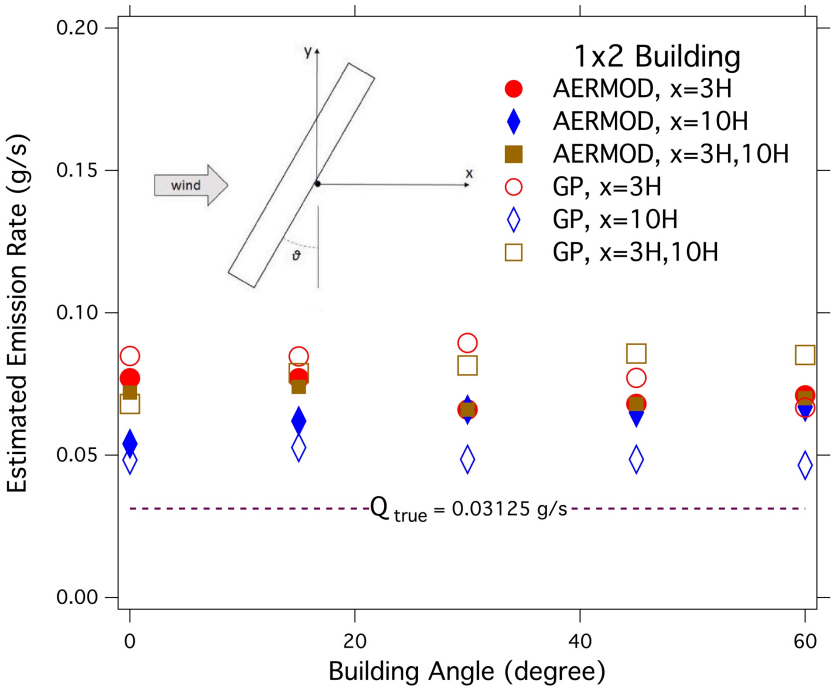
- **Bayesian Inference**
- Variational Data Assimilation
  - Tangent Linear Model and its Adjoint
  - Direct differentiation
  - Surrogate-assisted optimization
- ……

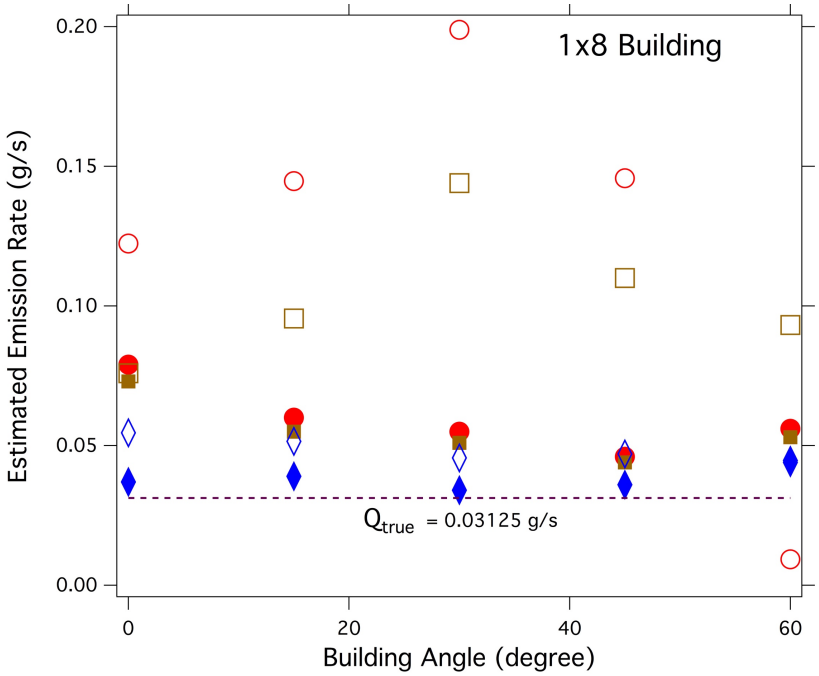
Testbed for woodsmoke source estimation methods



- Wind tunnel experiment conducted by EPA
  - Controlled environment for testing different methods
  - Foundation for source estimation based on real-world woodsmoke data
- Low momentum point source with low stack
  - Mimicking a residential woodsmoke source
- Various conditions
  - Different building aspect ratios and wind angles

Gaussian Plume (GP) Equation vs AERMOD





Model 1: Gaussian Plume (GP) Equation Use the Dynamically Dimensioned Search (DDS) algorithm to fit the equation with measurements to determine the parameters Q (emission rate), σ_y and σ_z (vertical and lateral dispersion coefficients), h_{eff} (effective height) and δy (lateral offset).

Model 2: AERMOD Regulatory dispersion model by EPA, equipped with PRIME downwash mechanism. Use the direct differentiation to find best Q to fit the observation data.

Method 3: Bayesian Inference

Bayes' Formula:

Likelihood Function

$$P(Q|C) \sim P(C|Q)P(Q)$$

Posterior Prior

Recall that: $C_i = C_{FM,i} + \varepsilon$, where $\varepsilon \sim N(\mu, \sigma^2)$

Then the likelihood function is:

$$P(C|Q) = \prod_i P(C_i|Q)$$

where: $$P(C_i|Q) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(C_i - C_{FW,i}(Q) - \mu)^2}{2\sigma^2}\right]$$

Emission Surrogate

Woodsmoke surrogate for emission inventory

- Motivation
  - Currently, wood combustion emissions in the National Emission Inventory (NEI) are estimated based on survey data.
  - Extensive surveys on residential wood combustion (RWC) are difficult to conduct; current RWC emissions are likely to be under-estimated.
- Opportunities
  - A growing number of routine air monitoring sites include dual-wavelength black carbon (BC) instruments, in addition to those for criteria pollutants
  - *Rochester, NY* (2008-present)
  - *Springfield, MA* (2006-present)
  - …

Emission Surrogate

Proposed woodsmoke surrogate

- DC = BC370 - BC880,
  - which has been shown to be a good marker for woodsmoke concentration.
- BC' = BC880 – DC*WS_BCfac
  - Representing "non-woodsmoke" BC.
  - WS_BCfac is set to 0.1
- DC/BC' is proposed as a surrogate for woodsmoke **emissions**
  - BC' act as a dilution indictor to normalize DC, transforming *from concentration to emission*.

Policy Implications

- Compact Growth vs. RWC air pollution
  - Unintended consequence?
- Human behaviors
  - In terms of mitigating excessive emissions from RWC, our study suggests that responsible wood burning practice is equally important as upgrading wood stoves.
- Regulations
  - Science-based local ordinances on woodsmoke are needed
  - Effective enforcement of those ordinances is necessary
- Outreach and Education
  - Cooperative extension as trusted community partner

Some thoughts on how to address RWC problems

NYSERDA