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Acknowledgments

• Guillermo Metz at Tompkins County Cooperative Extension
• Pat Fritz, Tom Wainman and Judy Abbott at DOH
• NYSERDA (PM: Ellen Burkhard) for funding support
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 complaints?

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 reoccurring 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
**Diesel PM**: No enhancement for UV absorption
**Woodsmoke PM**: Strong enhancement at shorter wavelength
**DC** = BC (370) – BC (880) as a woodsmoke marker
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
Near-source monitoring

Fixed site: Source 1

a) Ithaca, NY
   Source 1, Jan 27, 2016
   \[ y = 3.00x + 3.82 \]
   \[ r^2 = 0.878 \]

b) Ithaca, NY
   Source 1, Feb 9, 2016
   \[ y = 7.97x - 0.55 \]
   \[ r^2 = 0.941 \]

c) Ithaca, NY
   Source 1, Feb 12, 2016
   \[ y = 9.27x + 1.80 \]
   \[ r = 0.761 \]

   Condition 1
   \[ y = 6.41x + 3.14 \]
   \[ r = 0.500 \]

   Condition 2

d) Ithaca, NY
   Source 1, Feb 18, 2016
   \[ y = 9.59x - 3.38 \]
   \[ r^2 = 0.616 \]

DC (µg m⁻³) vs. PM₂.₅ (µg m⁻³)
Different PM vs. DC relationships indicate different combustion conditions
Approaches adopted in the literature

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

Source Estimation

Dispersion Modeling

Source Estimation
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
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), $\sigma_y$ and $\sigma_z$ (vertical and lateral dispersion coefficients), $h_{\text{eff}}$ (effective height) and $\delta_y$ (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:

\[ P(Q|C) \sim P(C|Q)P(Q) \]

Likelihood Function

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:

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