Woodsmoke in Upstate NY: A New Technique for Improved Spatial Modeling

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Rationale

- Woodsmoke is an important contributor to PM during heating season
- Potential for increased use of biomass fuels
  - Renewable, GHG benefits
  - Relatively inexpensive
- Woodsmoke health impacts[1]
- Woodsmoke often not well-characterized with existing monitoring networks
- Woodsmoke has high intake fraction[2]

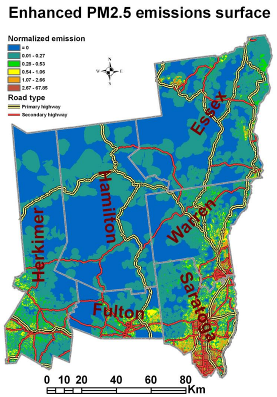
[1]Naeher et al. Woodsmoke health effects: A review. Inhalation Toxicology. 2007; 19:67-106.

[2]Ries et al. Intake fraction of urban wood smoke. Environmental Science and Technology. 2009. 43 (13): 4701–4706

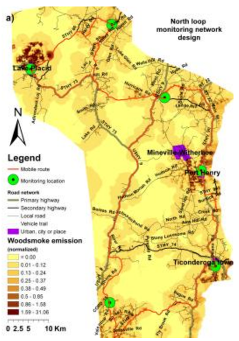
Goals

- Apply mapping/mobile monitoring approach developed in Pacific NW[1-3] to up-state NY
  - 7 county study area
  - Focus on evenings with meteorology conducive to woodsmoke build-up
- Improve understanding of spatial extent and patterns in woodsmoke
- Screening approach to locate potential woodsmoke hotspots in rural/semi-rural areas

[1]Larson et al. A Spatial Model of Urban Winter Woodsmoke Concentrations. Environmental Science and Technology. 2007; 41 (7): 2429 -2436.; [2]Su et al. Modeling spatial variability of airborne levoglucosan in Seattle, Washington. Atmospheric Environment 2008; 42(22):5519-5525: [3]Su et al. 2007. Spatial Modeling for Air Pollution Monitoring Network Design: Example of Residential Woodsmoke. Journal of the Air & Waste Management Association. 57: 893-900.

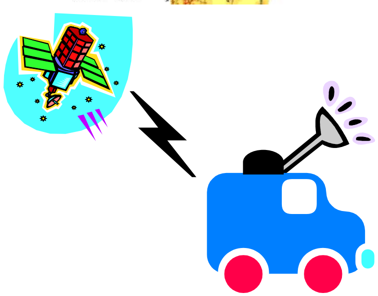


Emissions surface

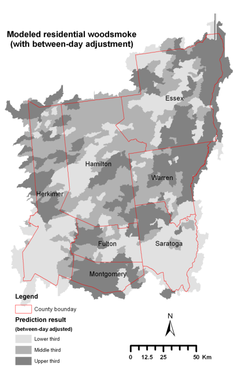


Fixed Site Sampler Location

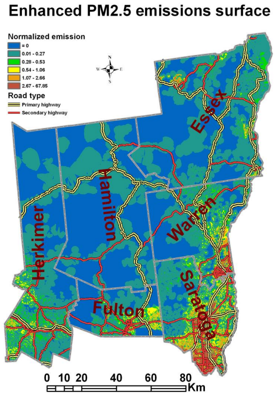
Design of Mobile Monitoring Routes



Mobile Monitoring



Spatial Modeling



Emissions surface

Fixed Site Sampler Location

Design of Mobile Monitoring Routes

Mobile Monitoring

Spatial Modeling

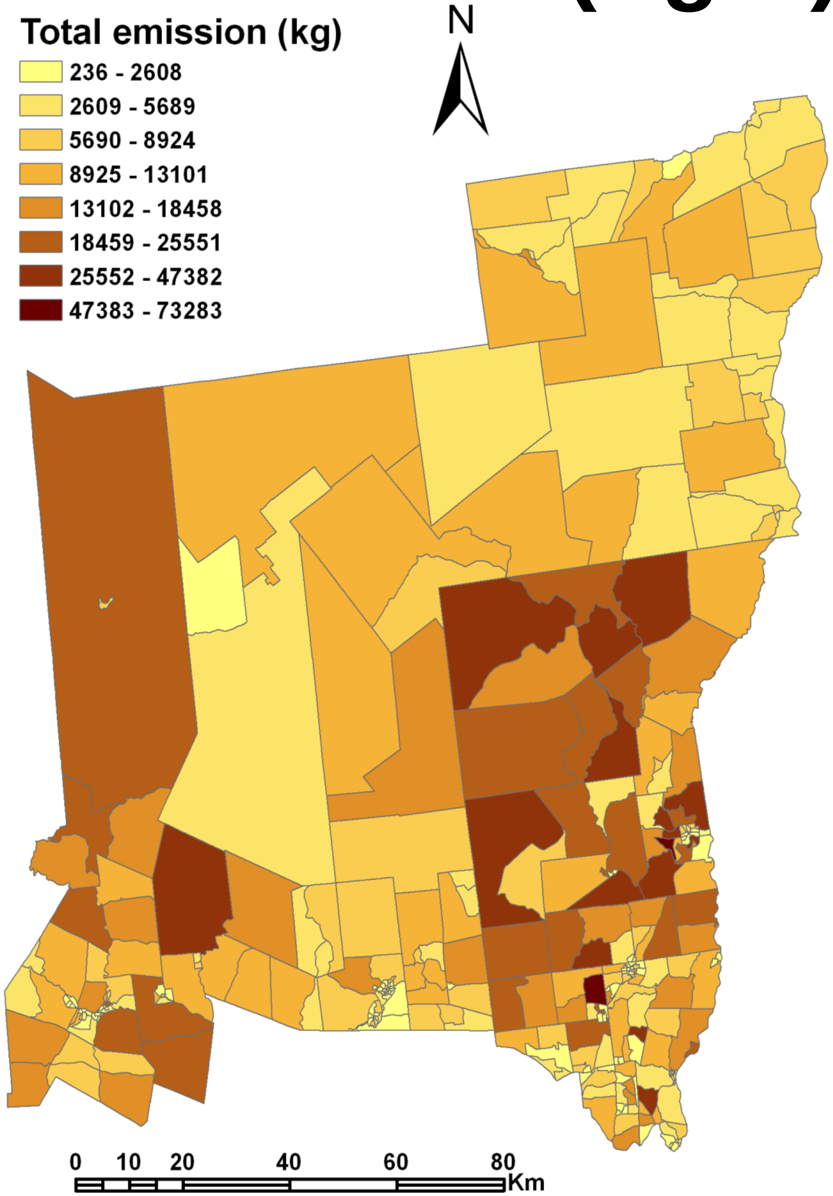
Spatial residential woodsmoke PM emissions mapping

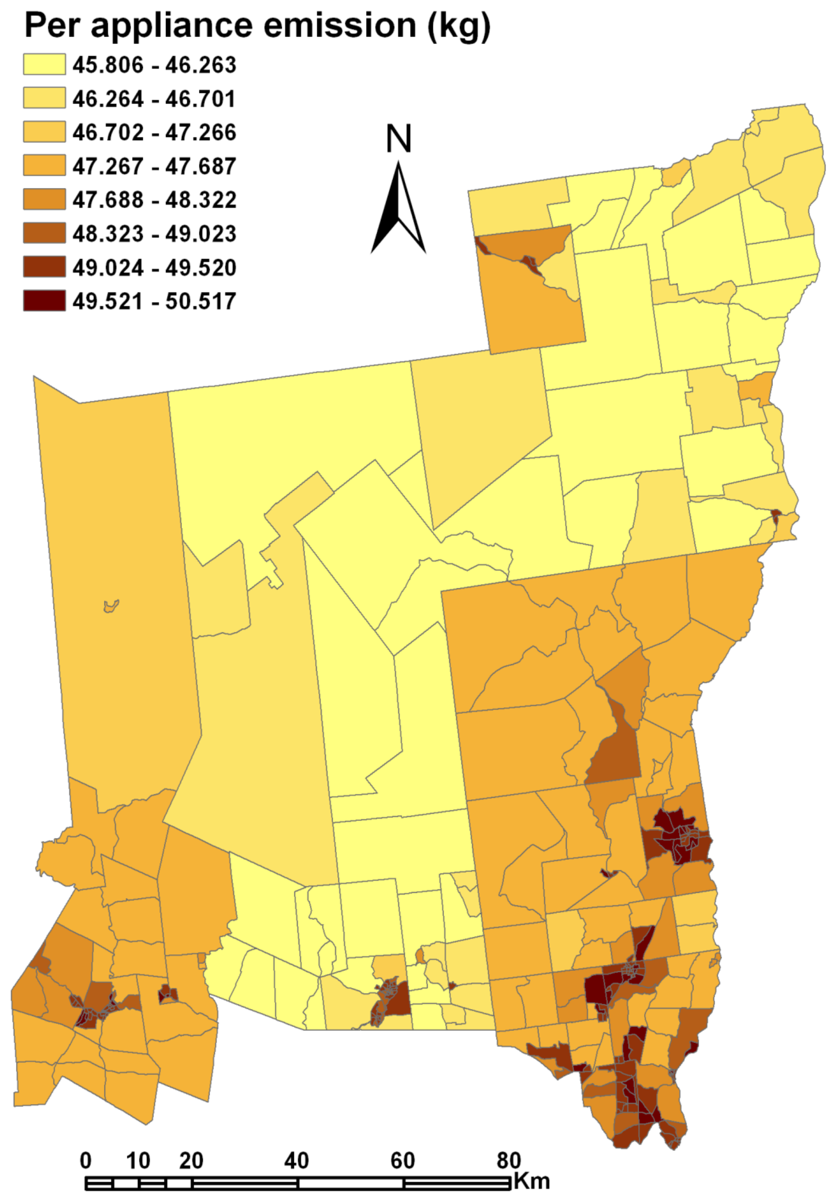
- Wood heating appliances
  - woodstoves
  - fireplaces with inserts
- Fireplaces w/o inserts
- Pellet heaters
- Centralized wood heaters (including outdoor wood boilers)

Estimating woodsmoke PM emissions at census block group level

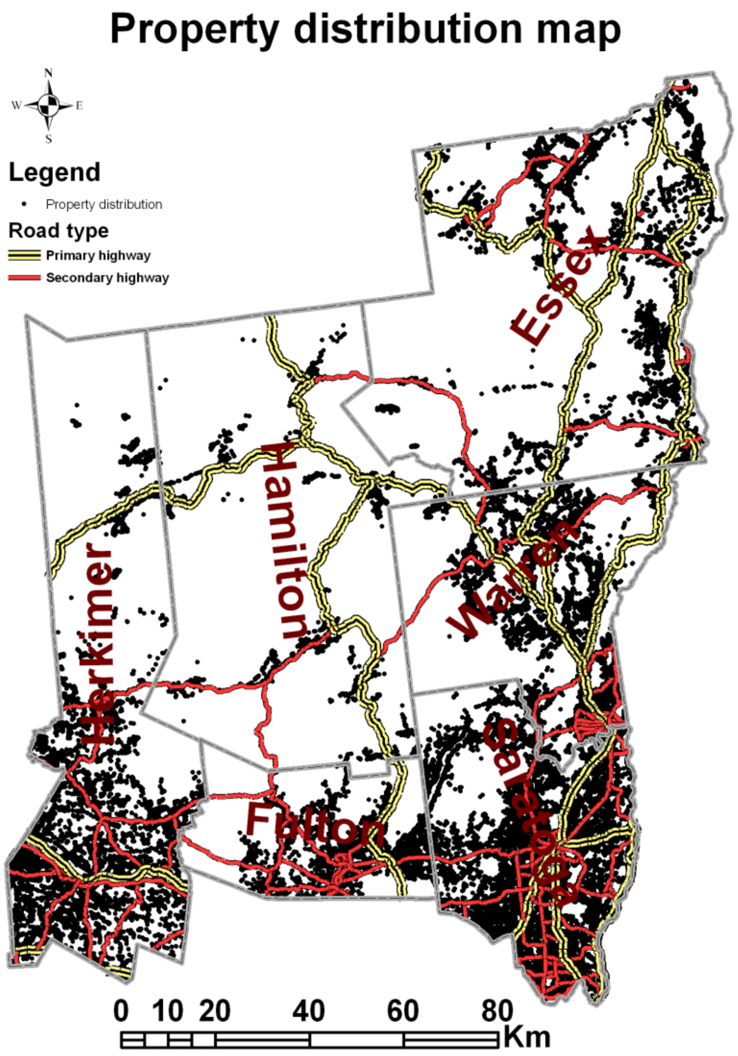
- Estimate total mass of wood burned for each source category
  - census and survey data
- Calculate block group emissions with AP-42 emissions factor
- Enhance (spatially disaggregate) woodsmoke emissions surface within each block group with property assessment data

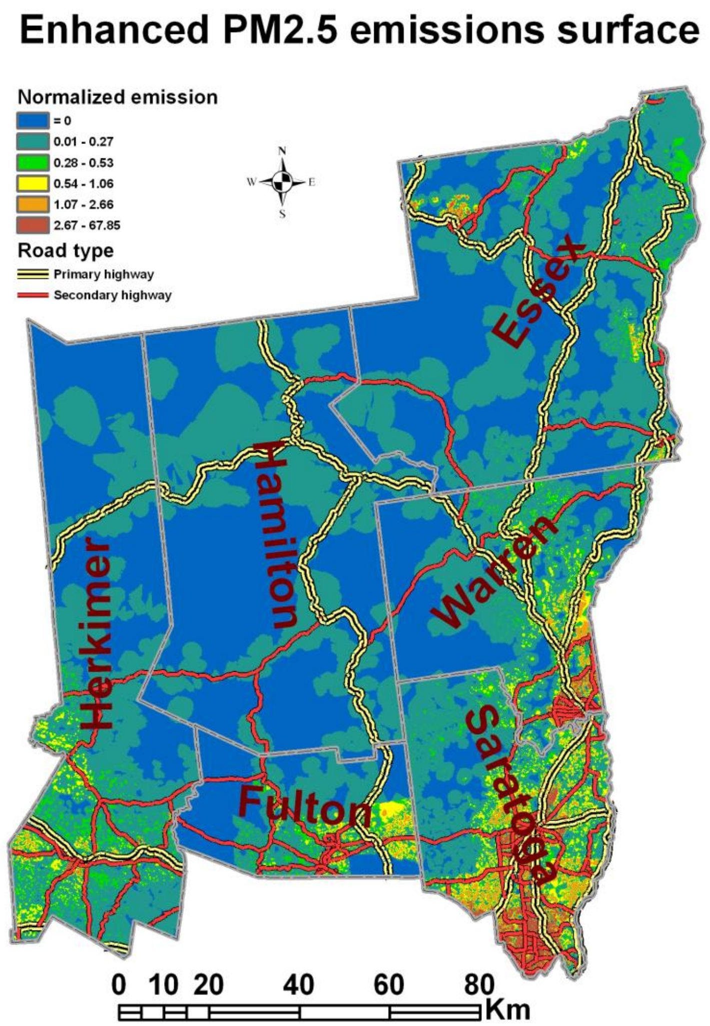
Estimating block group total (left) and mean (right) emissions



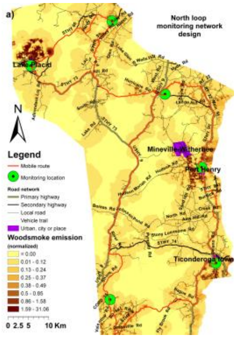


Property distribution map and woodsmoke emissions surface





Emissions surface



Fixed Site Sampler Location

Design of Mobile Monitoring Routes

Mobile Monitoring

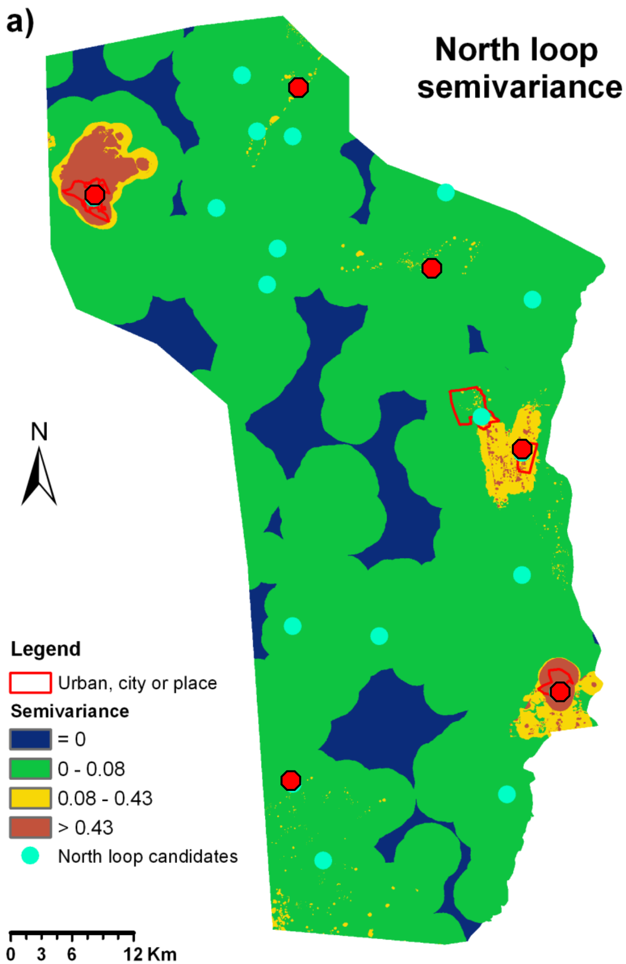
Spatial Modeling

Location of fixed site monitoring sites

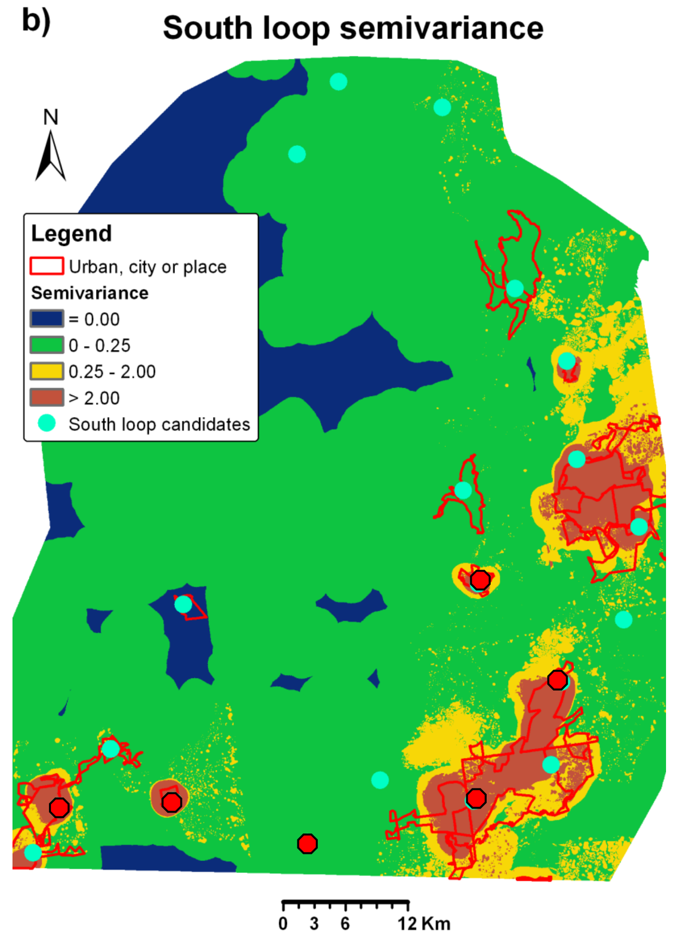
- Based on a location-allocation algorithm
  - Use predicted emissions map to optimally place limited number of samplers in study area to (semivariance surface)
    - efficiently provide information on woodsmoke spatial variability
    - incorporate additional constraints (e.g. locate in populated areas).
- Reflects the maximum gradients of change of woodsmoke

Estimated residential woodsmoke semi-variance surfaces and 20 monitoring location candidates

(north and south loops)



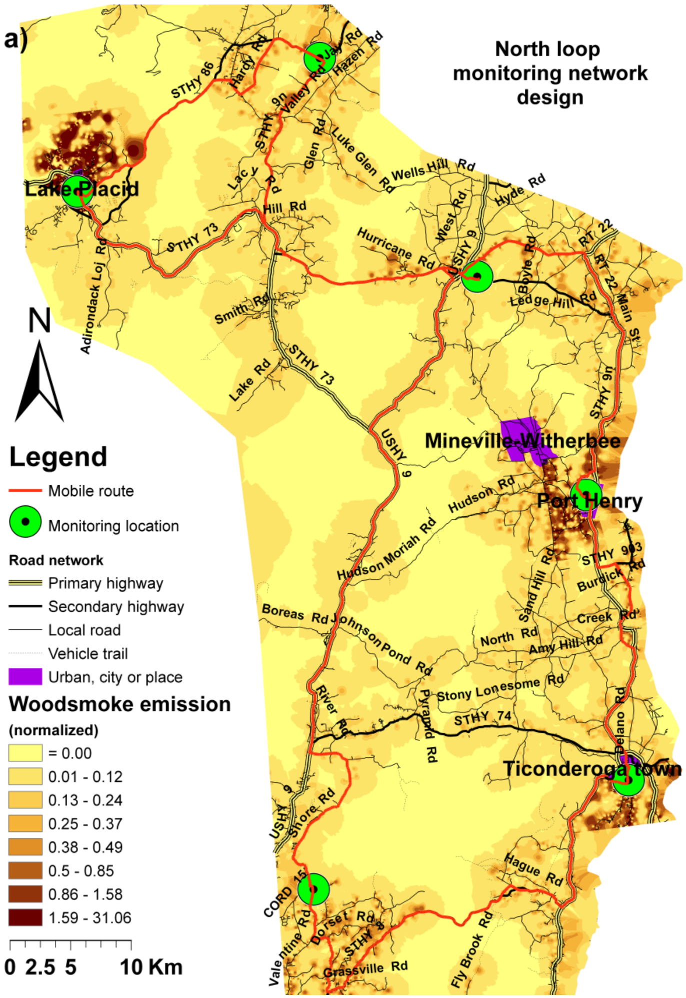
final **6 sites** in each loop chosen for coverage of high, intermediate and low woodsmoke emissions.

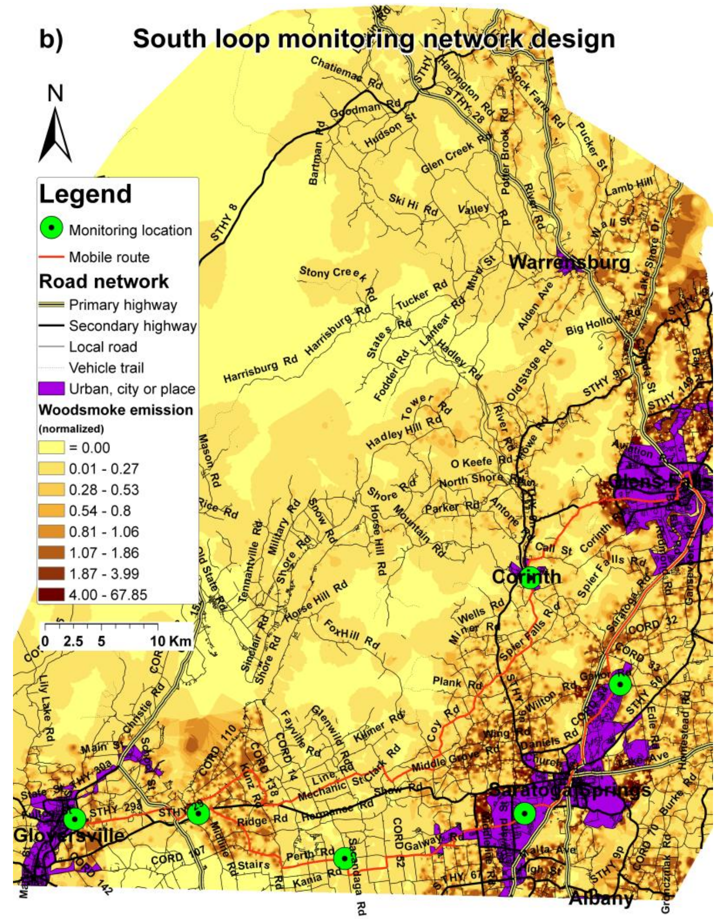


Design of mobile monitoring route(s)

- Application of network analysis algorithm to design mobile monitoring routes that
  - efficiently cover full range of **spatial variability** in woodsmoke emissions in study area
  - in a **limited amount of time** (i.e. by minimizing the distance of the route and therefore the required time spent sampling)
  - connect **fixed monitoring sites**

Six fixed-site monitoring locations (green) and corresponding mobile sampling route (red)





Emissions surface

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Fixed Site Sampler Location

Design of Mobile Monitoring Routes

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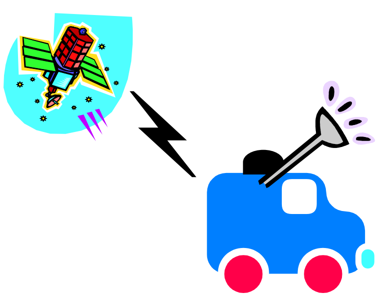
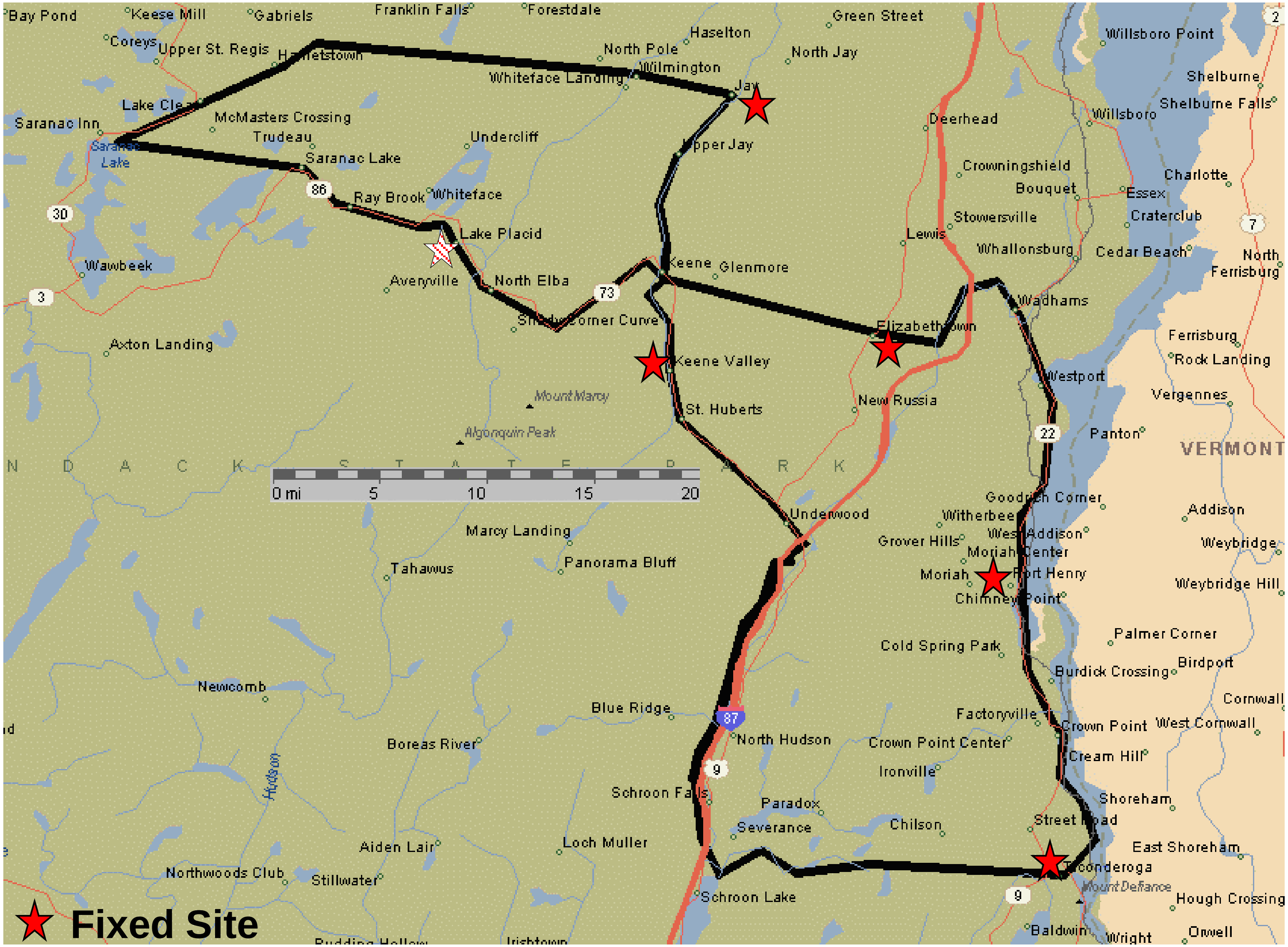


Mobile Monitoring

↓

Spatial Modeling

North loop mobile monitoring route



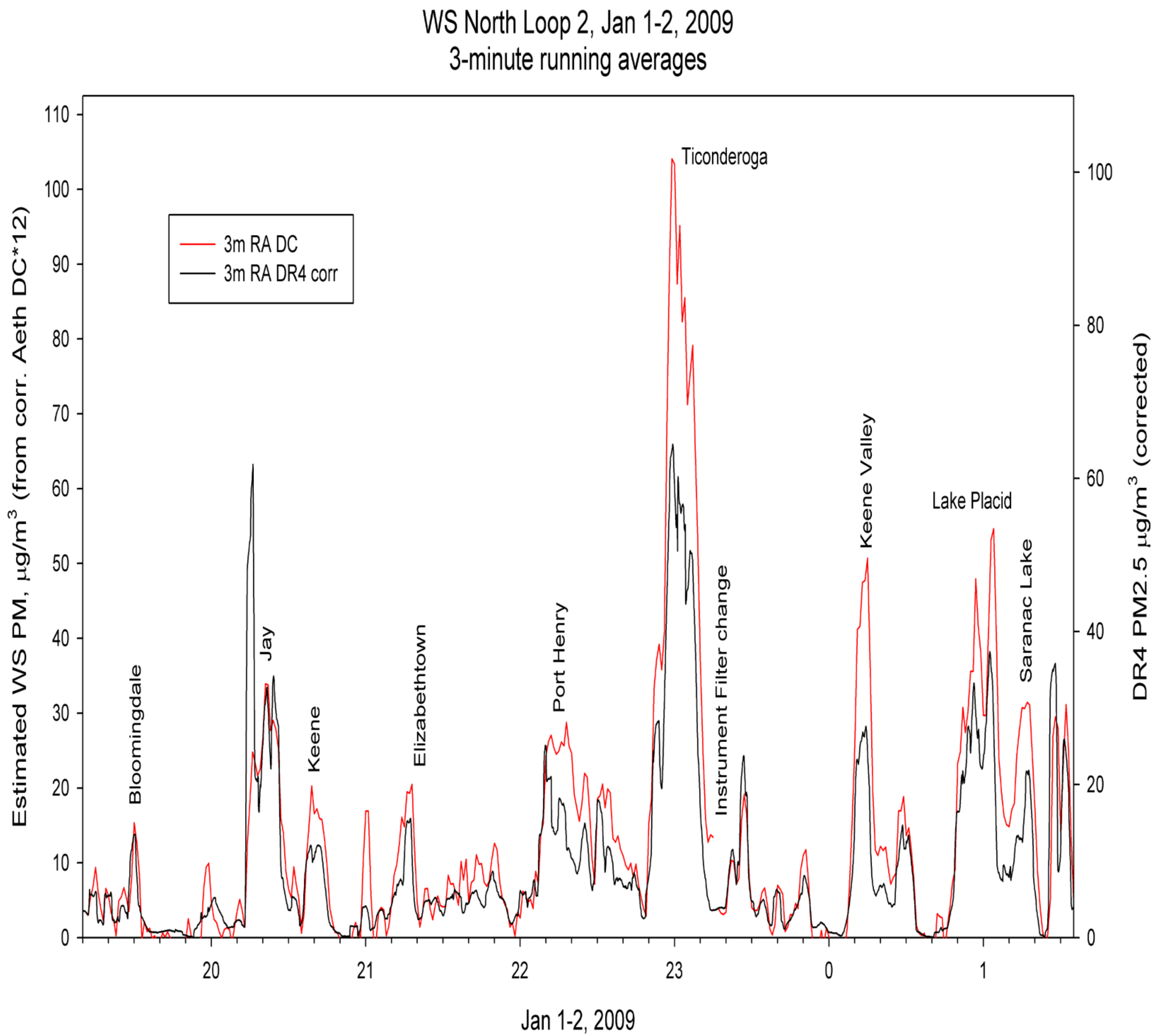
Mobile monitoring

- North Domain: 10 inversion nights
- South Domain: 4 “inversion” nights
  - Work with DEC forecasters to identify sampling nights
- Two-wavelength Aethalometer™ (Magee Scientific AE42) as WS indicator:
  - Difference btwn optical absorption of PM_1 at 880 nm (BC) and 370 nm (UV-C). (“Delta-C”). 1 min avg.
  - Delta-C factor to convert to WS concentration*
- Supplement with nephelometer (Thermo DR-4) as $PM_{2.5}$ surrogate. 1 sec avg.
- Driving speed $\leq$20 mph in towns, as-posted elsewhere

*Allen et al. 2004. Evaluation of a New Approach for Real Time Assessment of Woodsmoke PM, in Proceedings of the Regional and Global Perspectives on Haze: Causes, Consequences and Controversies, Paper #16, Air and Waste Management Association Visibility Specialty Conference, Asheville, NC, http://tinyurl.com/allen-realtime-woodsmoke.

Fixed-site monitoring

- North Domain: 6 fixed sites - for entire winter (Dec-Mar)
- South Domain: 2 fixed sites - Jan 15-Mar. 31
- Two-wavelength Aethalometer™
  - 5 mins processed to 1 hour averages
- Supplement with nephelometer at 1 fixed site in north and 1 fixed site in south domain
  - 10 minute averages


WS North Loop 2, Jan 1-2, 2009
3-minute running averages
3m RA DC
3m RA DR4 corr
Estimated WS PM, μg/m3 (from corr. Aeth DC*12)
DR4 PM2.5 μg/m3 (corrected)
Jan 1-2, 2009
Bloomingdale
Jay
Keene
Elizabethtown
Port Henry
Ticonderoga
Instrument Filter change
Keene Valley
Lake Placid
Saranac Lake
0
10
20
30
40
50
60
70
80
90
100
110
20
21
22
23
0
1

Emissions surface

↓

Fixed Site Sampler Location

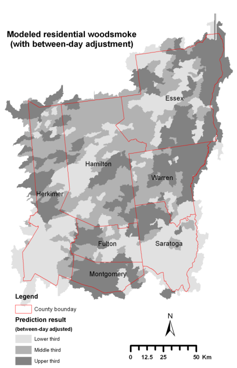
Design of Mobile Monitoring Routes

↓

Mobile Monitoring

↓

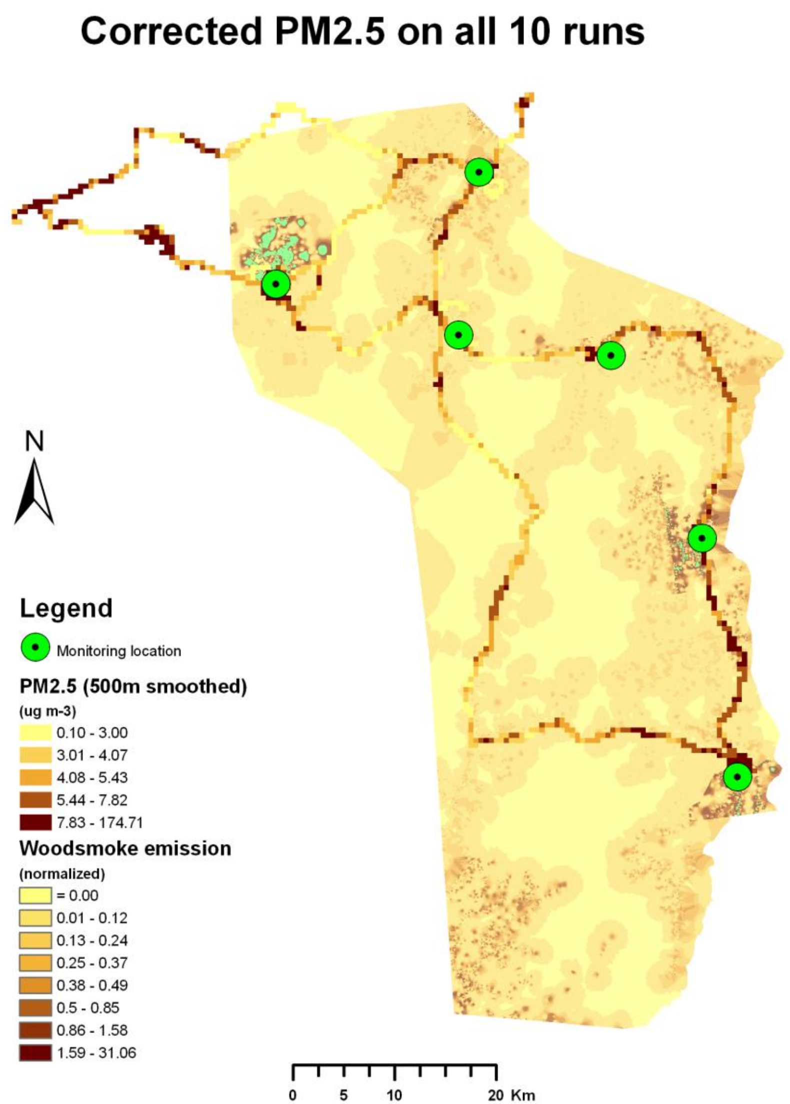
Spatial Modeling



Spatial modeling

- Mobile monitoring measurements
  - temporally-corrected for between-day differences
  - averaged within hydrological catchment areas.
- Model catchment-areas average woodsmoke with **upslope** catchment area predictors
  - Assumes that under conditions of elevated woodsmoke concentrations/monitoring periods, drainage flow dominates smoke transport
- Use model predictor variables to estimate woodsmoke PM concentrations throughout study area

Comparing woodsmoke emissions surface and between-day adjusted measurements



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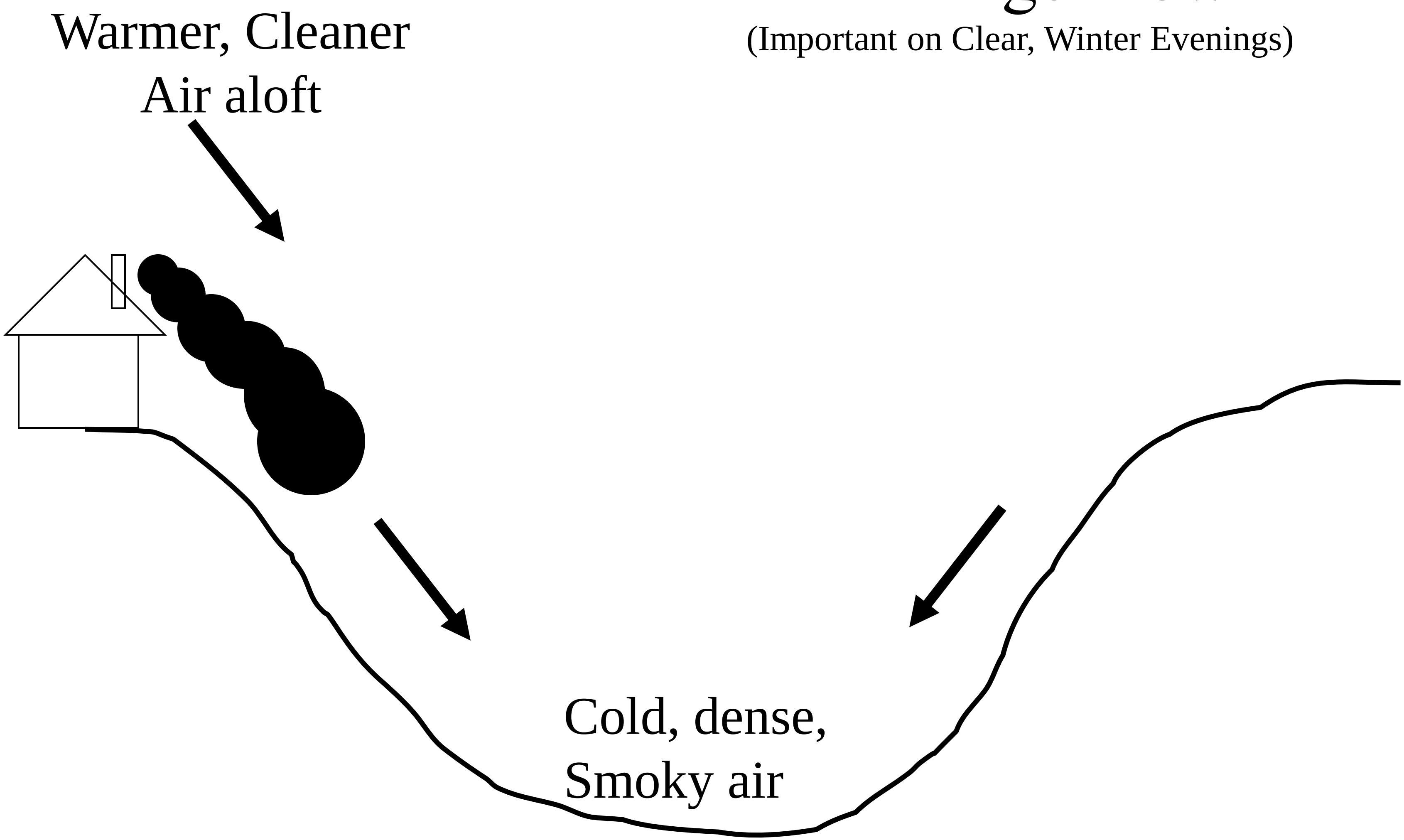
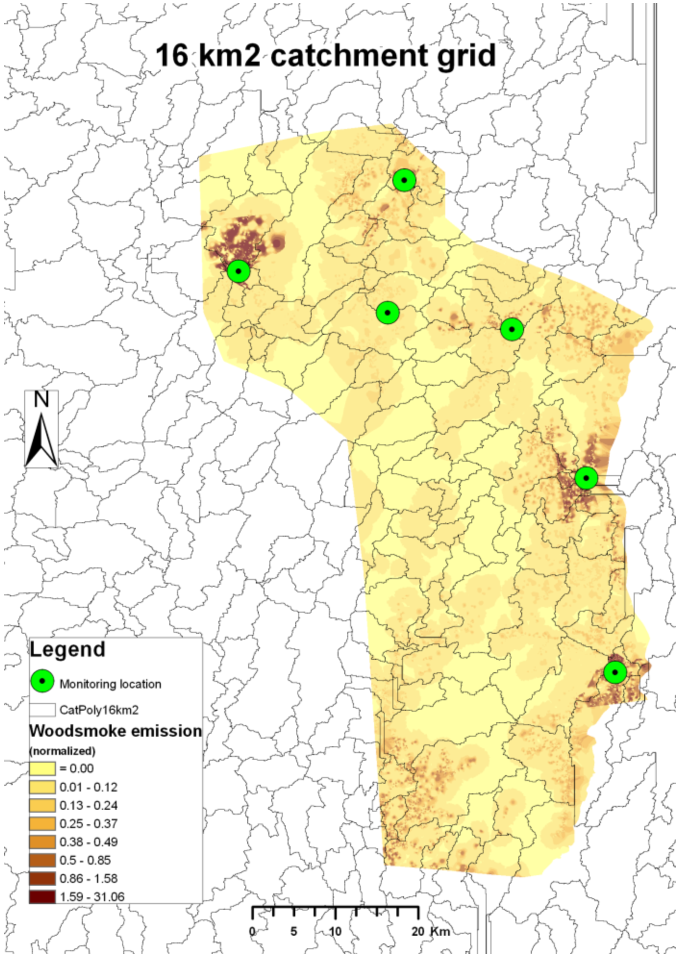
‘Drainage Flow’

(Important on Clear, Winter Evenings)



Catchment areas

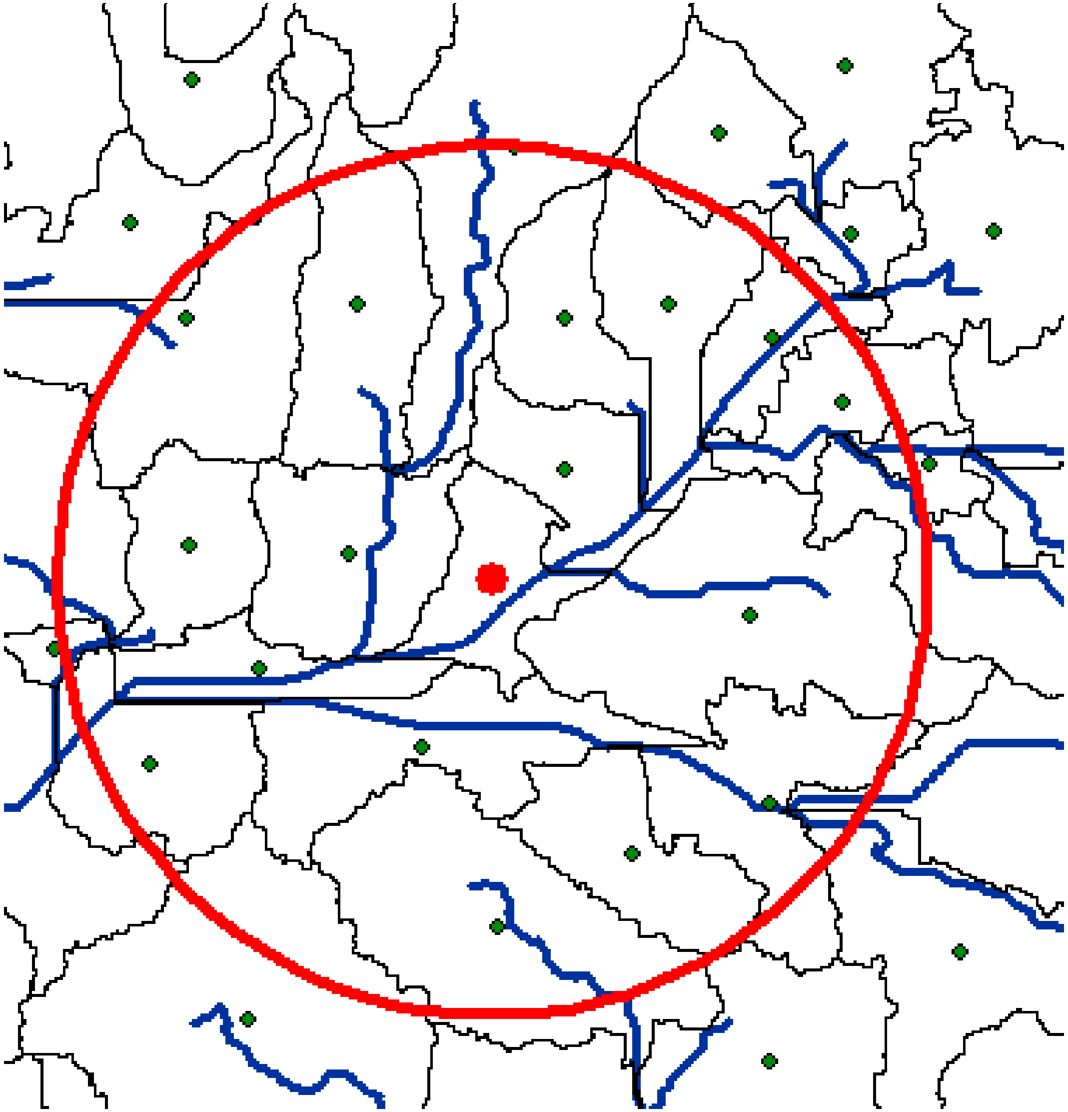


For a typical drainage wind speed of 1 m/s maintained over a 3 hour period, expect upstream influence ~ 10 km

North loop 16 km^2 threshold catchments

Catchment Buffer

(solid color area)



Compute catchment centroids

Compute distances to uphill centroids

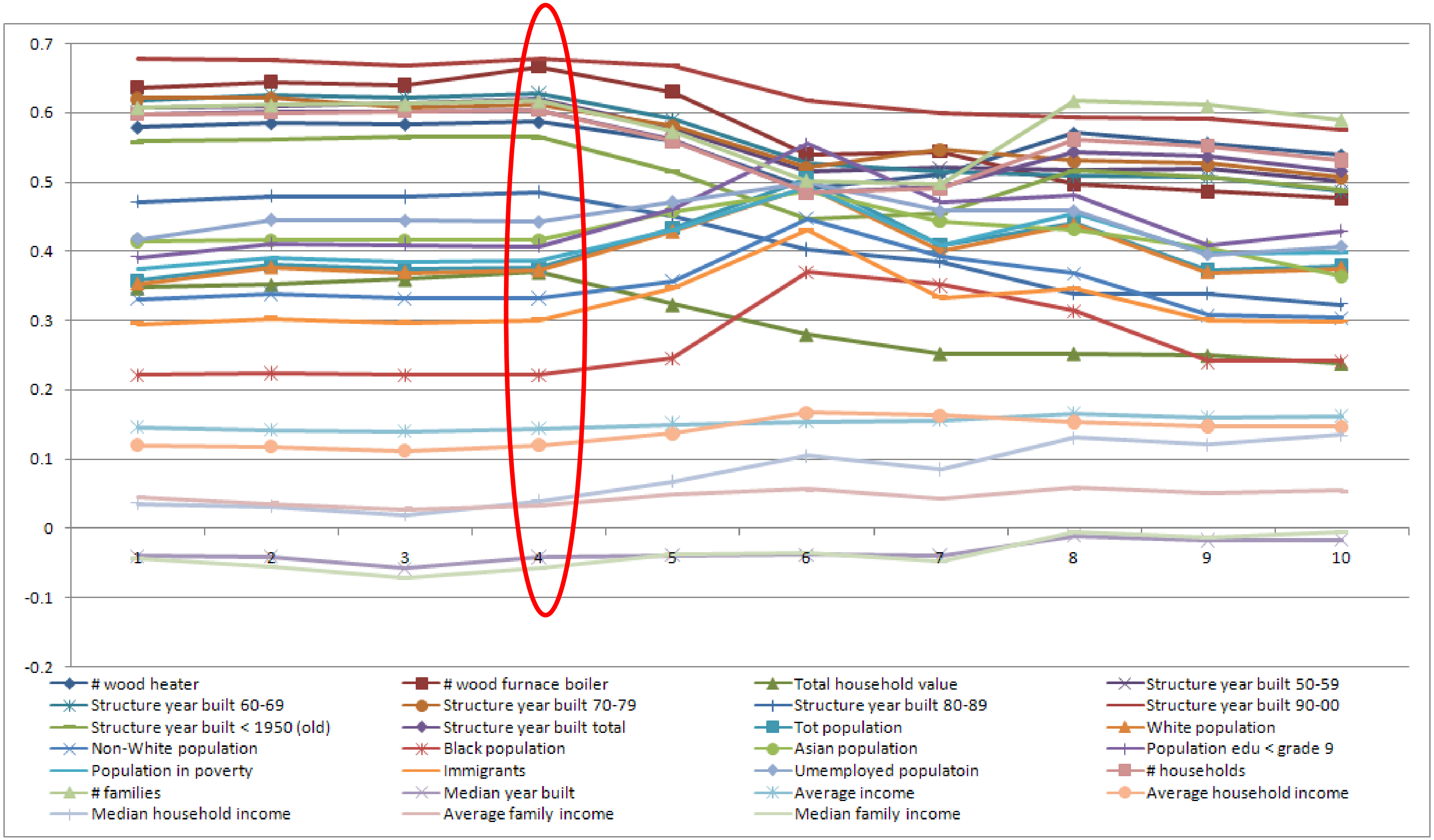
Ignore catchments > 10 km away

Search catchments 1 – 10 km away

Predictor variables

Population	Building age	Economic	Physical property
Total	<1950	Average dwelling value	Elevation
White	1951-60	Average household income	Green vegetation index
Non-White	1961-70	Median household income	Soil brightness
Black	1971-80	Median family income	**Emissions**
Asian	1981-90	Average family income	Wood heating appliance density
Immigrants	1991-00	Average income	Centralized wood heater density
Households	Total buildings	Education less than grade nine (pop)	Woodsmoke emissions
Families	Median year built	Population in poverty	
		Unemployment population (age over 25)	

Determine optimum upslope search distance (correlation between corrected residential woodsmoke and chosen spatial covariates)



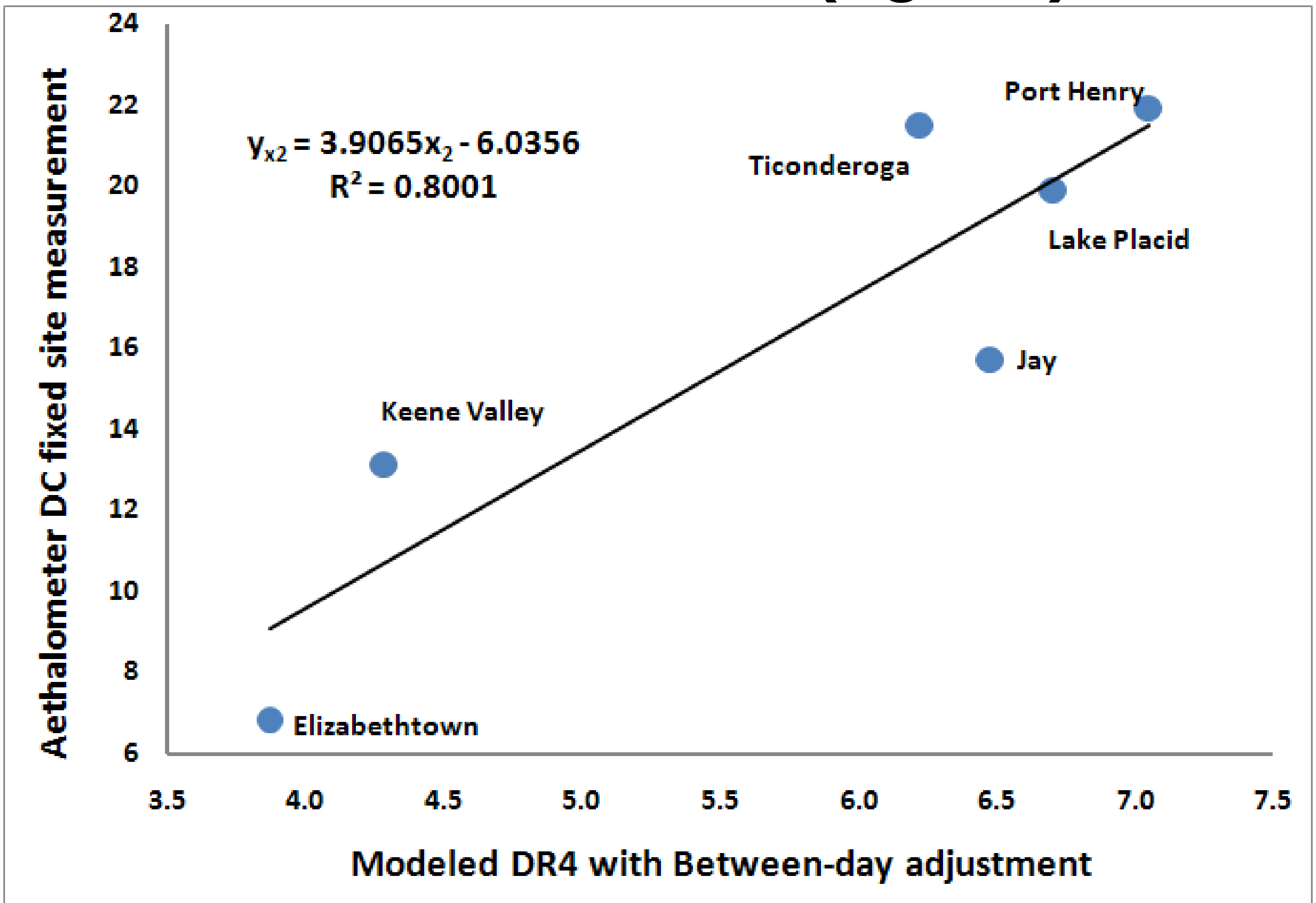
Spatial Models

Modeling type	Variable Groups	R^2	Variable(s)[2]	β	p-value
Between-day adjusted[1]	A	0.44	Centralized wood heater density	2380.843	<0.001
		0.41	Wood heating appliance density	105.193	<0.001
		0.23	Emissions surface	3.347	<0.001
	B	0.53	Dwelling value	0.0005	0.001
			Non-White population	0.04	0.006
			White population	-0.006	0.021
			# families	19.864	0.001
			Total structure built	0.01	0.019
			Elevation	-0.005	0.006
	C	0.58	Centralized wood heater density	2596.175	<0.001
			Non-White population	0.049	0.001
			White population	-0.009	0.001
			Total structure built	0.012	0.004
			Median household income	-8.90E-09	0.091
			Elevation	-0.005	0.006
	D	0.49	Centralized wood heater density	2231.464	<0.001
			Non-White population	0.024	0.023
			Median household income	-1.14E-008	<0.039

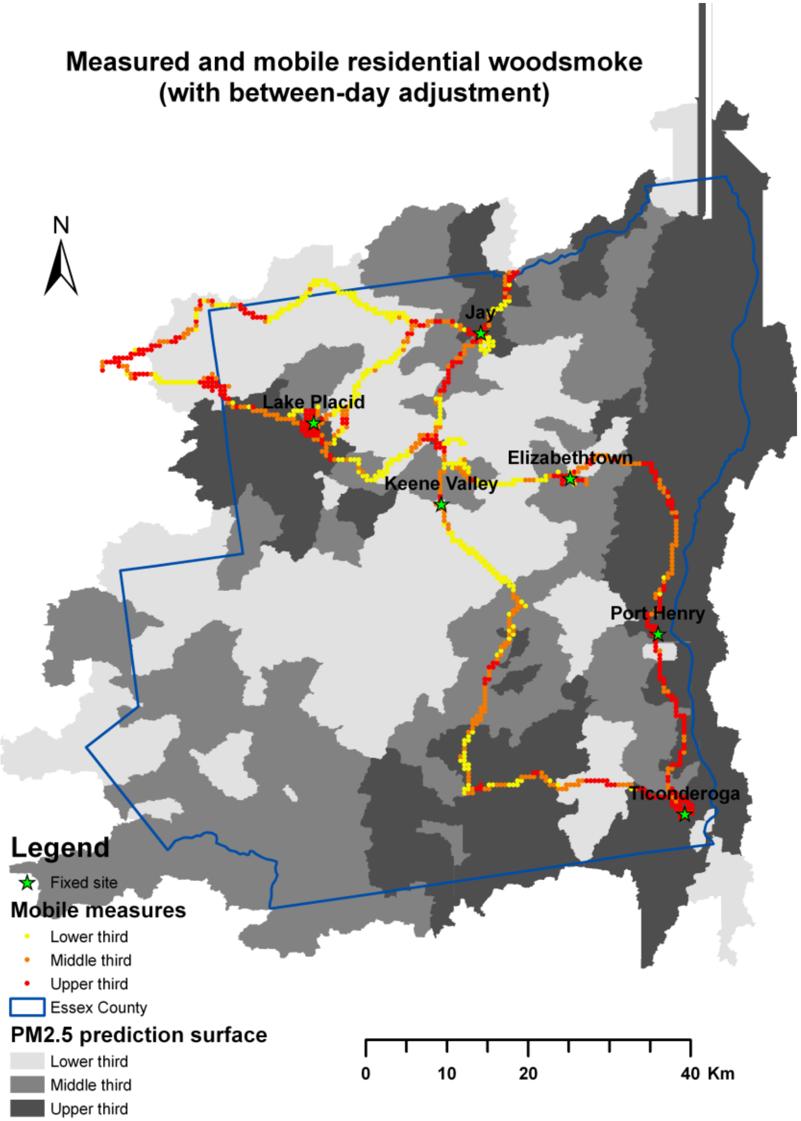
A = Emissions variables only; B = socioeconomic status and physical properties variables only: C = best fit model. D = parsimonious model

[1]Adjusted based on E-town Aethalometer data; [2]All the covariates had 4 km uphill search distance km except median household income (3 km), elevation and total structure built (on uphill distance).

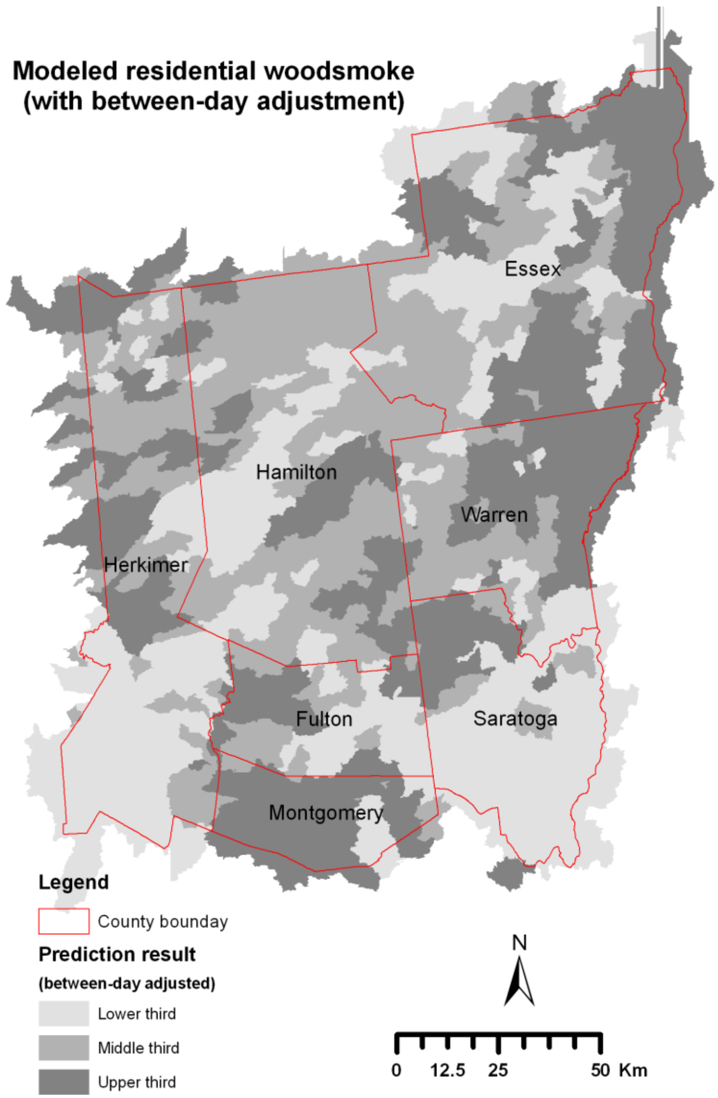
Comparing fixed-site Aethalometer DC concentrations with modeled DR4 concentrations (ug m^{-3})



Modeled residential woodsmoke (Essex County)



Modeled residential woodsmoke (all counties)



Estimated population exposure

(*Based on upper tertile)

North loop			
	Population	Exposed*	%
Total population	57,000	28,800	51
Non-White population	2,830	1,800	64
All (7 Counties)			
Total population	610,960	127,670	21
Non-White population	22,790	6,810	30

Conclusions

- Census information combined with survey and property assessment data provides a broadly applicable estimate of spatial patterns of woodsmoke $PM_{2.5}$ **emissions**.
- Catchment area-based regression model of woodsmoke $PM_{2.5}$ **concentrations** explained
  - ~50-60% of variability in measured nighttime woodsmoke $PM_{2.5}$ (mobile monitoring)
    - Up to 40% of variability explained by emissions variables
  - ~80% of variability in seasonal average woodsmoke PM (fixed–site monitors)
- Based on model, roughly 20% of the population is exposed to the highest tertile of woodsmoke $PM_{2.5}$.