Development and Preliminary Results for a Model of Temporal Variability in Residential Wood Combustion Emissions

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Objectives

- Improve simulation of temporal variability from residential wood combustion (RWC) sources
- Explore relationships between meteorology and RWC emissions
- Develop a model to estimate temporal profiles of RWC emissions from simulated meteorology
  - Given an annual RWC inventory and hourly simulated met, calculate daily variability in emissions
- Compare the modeled profiles at different locations to current RWC temporal profiles

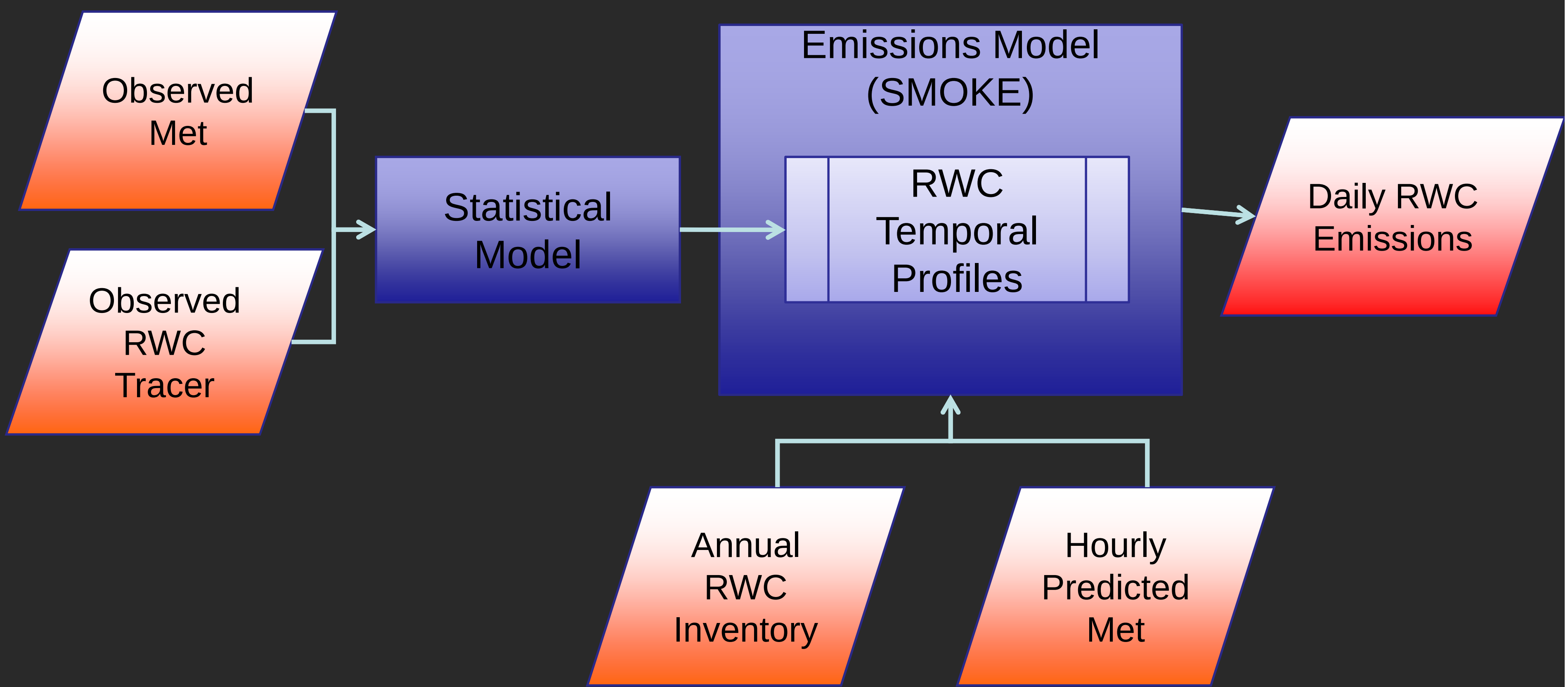
Approach

- Use ambient PM measurements at surface monitors as proxies to RWC emissions
- Develop a regression equation based on correlations between meteorology and chemical observations
- Construct temporal profiles from the predicted ambient concentrations
- Integrate the regression equation into the SMOKE processing sequence for RWC sources

Approach

- Phase I
  - Identify wood combustion tracers available from the U.S. ambient monitoring network
  - Identify monitors that are dominated by RWC sources
- Phase II
  - Develop a statistical model that relates meteorology to pollution from RWC sources
  - Construct temporal profiles from the predicted pollutant concentrations
- Phase III
  - Integrate the RWC profile generator into the emissions processing sequence
  - Conduct air quality modeling to evaluate the simulated profiles

Conceptual Model

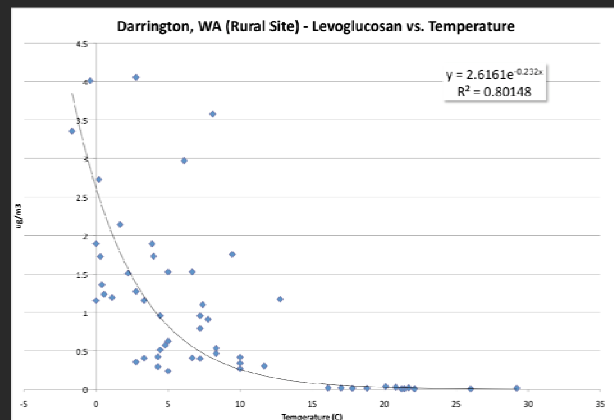


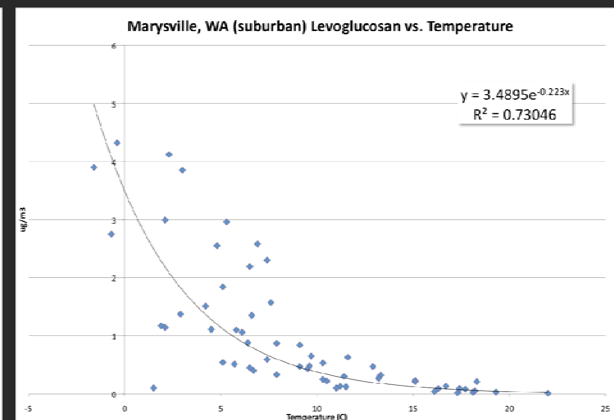
Phase I: Date Sources

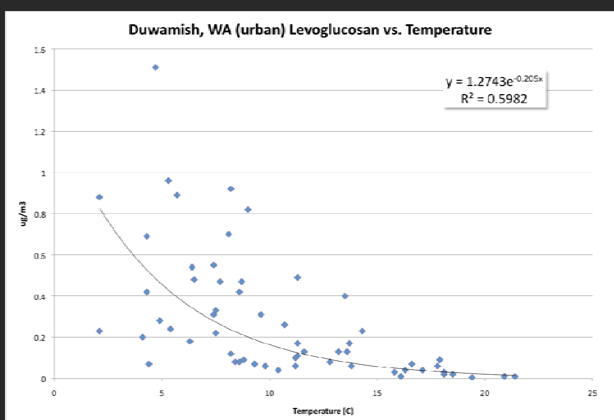
- Chemical Observations (RWC Tracer Data)
  - Levoglucosan (LG)
    - Puget Sound (PSCAA) sites for 2005-2007
    - Southeast US for 2007
  - Elemental Carbon (EC) and Organic Carbon (OC)
    - Daily from CSN
  - Nephelometer $PM_{2.5}$
    - PSCAA sites for 2004-present
- Meteorology
  - Ambient temperatures at chemical obs. sites
  - Modeled temperatures, wind speed, PBL height, and ventilation index for grid cells with monitors
    - Annual 2006 12-km Western US, 12-km East US, and 36-km CONUS

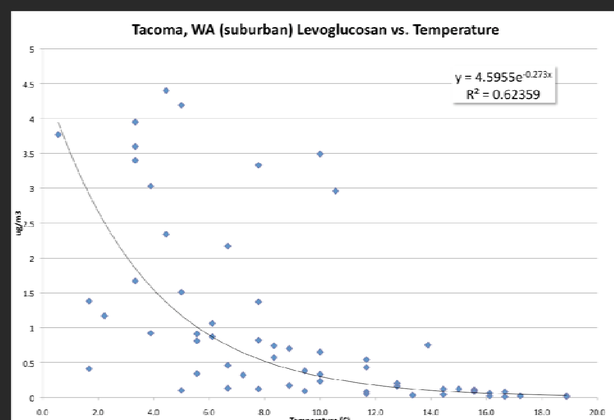
PSCAA LG vs. Temperature

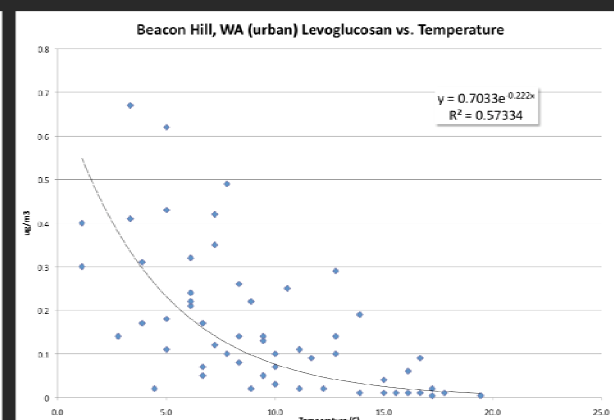
- 1 rural, 2 suburban, 2 urban sites; years 2005-2007





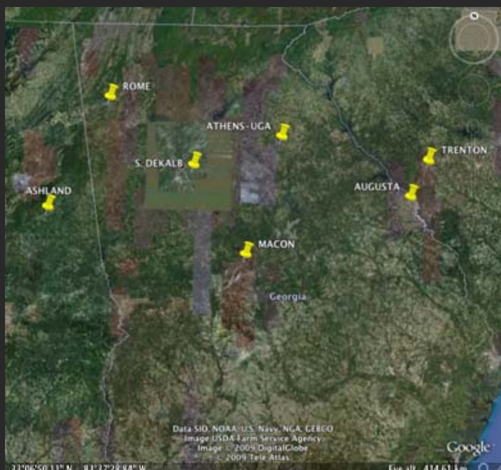


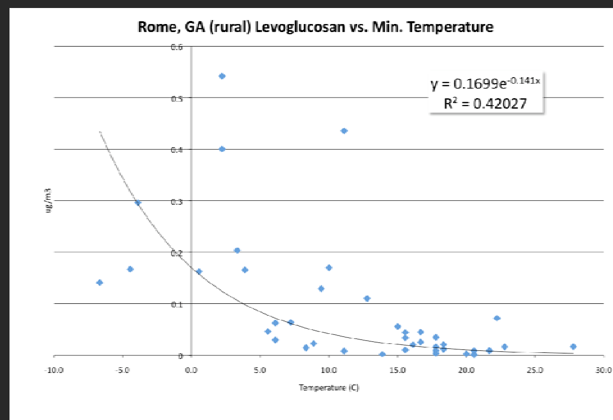


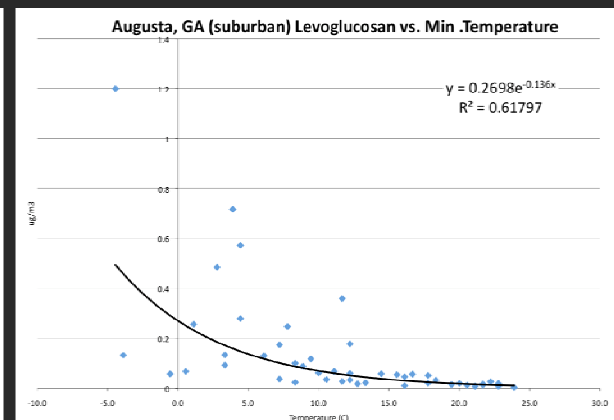


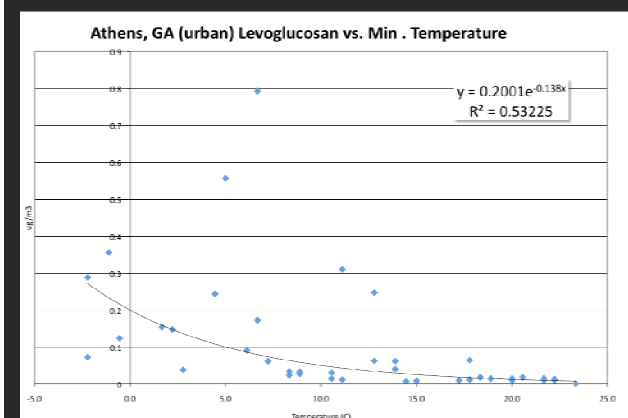
SE U.S. LG vs. Temperature

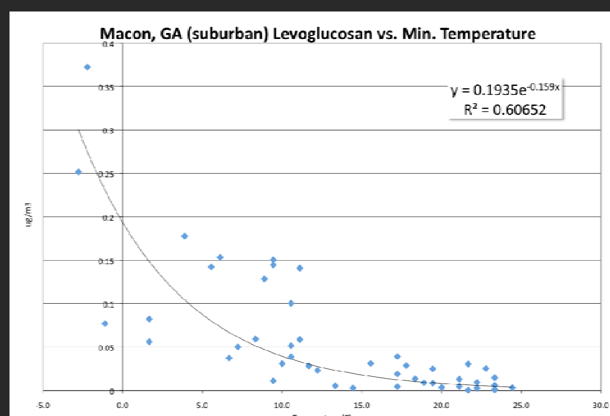
- Sites in GA, AL, SC; year 2007

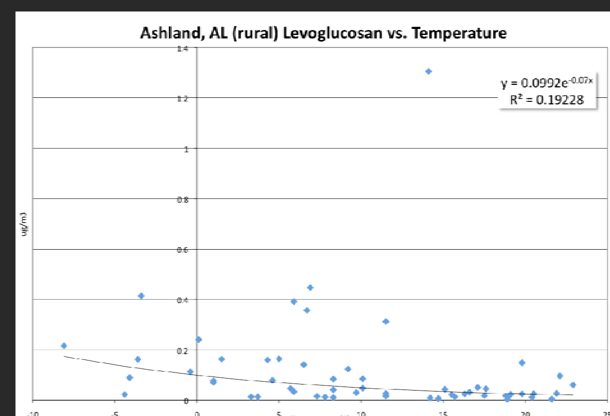












CSN Site Selection

- Applied temperature restrictions (10°C) to exclude warm days/periods; assumed to be a proxy for wildfire season as well
- Calculated average OC/EC ratios to select sites impacted by RWC
  - 80% percentile of avg. OC/EC ratio considered to be RWC sites, high OC/EC ratios shown to be an indicator of biomass combustion
  - Only used sites with negative correlation between OC and temperature
- Calculate correlation between OC and daily minimum temperature
- Some sites that passed this test are known RWC sites (e.g. Missoula, MT)

CSN "RWC" Sites

Obs	State_name	County_name	Unique_ID	Mean	Median	No. of Obs	Corr
1	California	Plumas Co	6-63-1009	16.4542	15.0000	58	-0.66155
2	Oregon	Lane Co	41-39-60	22.6467	8.4076	38	-0.65874
3	California	Butte Co	6-7-2	12.9292	10.8000	36	-0.62111
4	Oregon	Jackson Co	41-29-133	14.6109	13.0085	41	-0.61450
5	Montana	Lincoln Co	30-53-18	63.9475	12.5759	48	-0.41110
6	Idaho	Canyon Co	16-27-4	63.1415	9.9390	47	-0.39716
7	Oregon	Union Co	41-61-119	15.3529	13.4674	43	-0.37476
8	North Carolina	Buncombe Co	37-21-34	11.2095	9.4103	33	-0.27715
9	Montana	Missoula Co	30-63-31	12.1630	9.0000	81	-0.18745
10	South Carolina	Greenville Co	45-45-9	44.5487	9.4490	48	-0.18711
11	Massachusetts	Hampden Co	25-13-8	14.2456	9.2365	34	-0.15018
12	Georgia	Floyd Co	13-115-5	19.9213	9.5082	30	-0.12476
13	Virginia	Henrico Co	51-87-14	31.5479	8.7162	45	-0.08493
14	Indiana	Vanderburgh Co	18-163-12	17.6479	8.1405	34	-0.06512
15	Minnesota	Hennepin Co	27-53-963	11.5916	8.1673	66	-0.04818
16	Tennessee	Lawrence Co	47-99-2	32.6421	11.1330	31	-0.01946

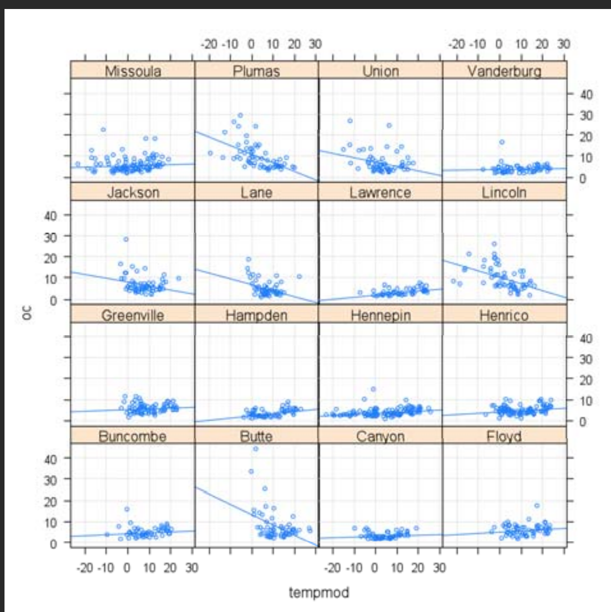
Sites in the 80^{th} percentile mean OC/EC ratio, negative correlation for OC and temperature; sorted by correlation coefficient

Phase II: Model Development

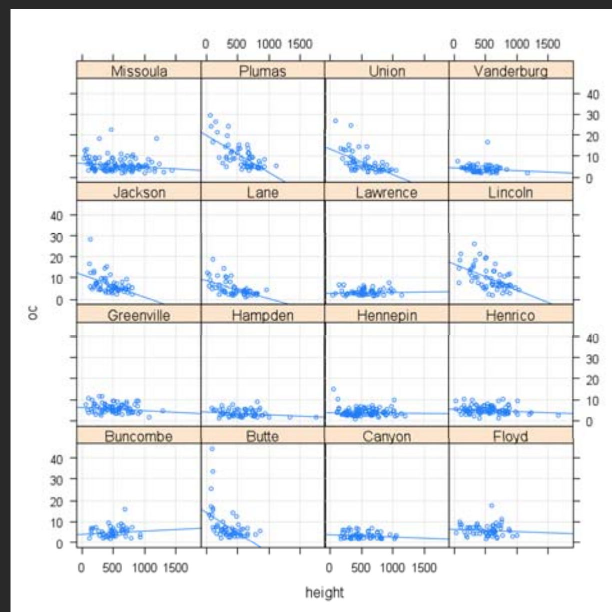
- Looking for a general model in time and space that considers met and emissions confounders
  - Met confounders related to stability/mixing
  - Emissions confounders could be weekday/weekend/holiday effects, non-RWC smoke, and activity patterns
- Initial approach focused on levoglucosan (LG)
  - Limited sites and years inhibited the statistical strength/extensibility of the model ($n < 60$)
- Next looked at EC and OC in the CSN to access larger database

OC vs. Met Parameters at RWC Sites

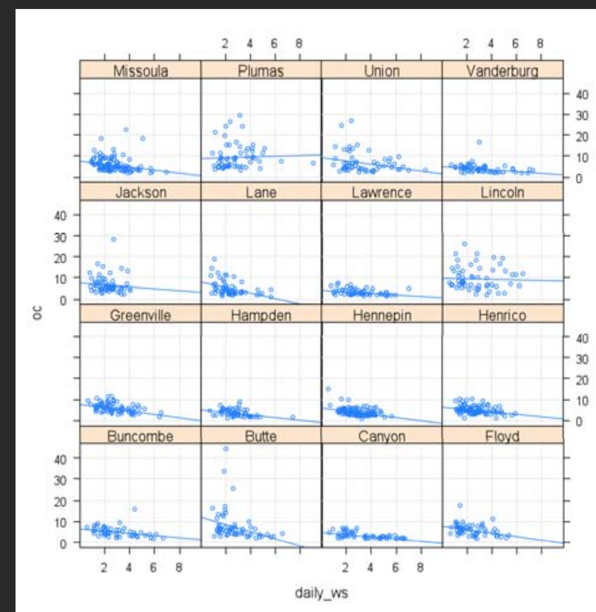
- Try to determine associations between model predictors and OC before developing regressions



Temperature



PBL Height



Wind Speed

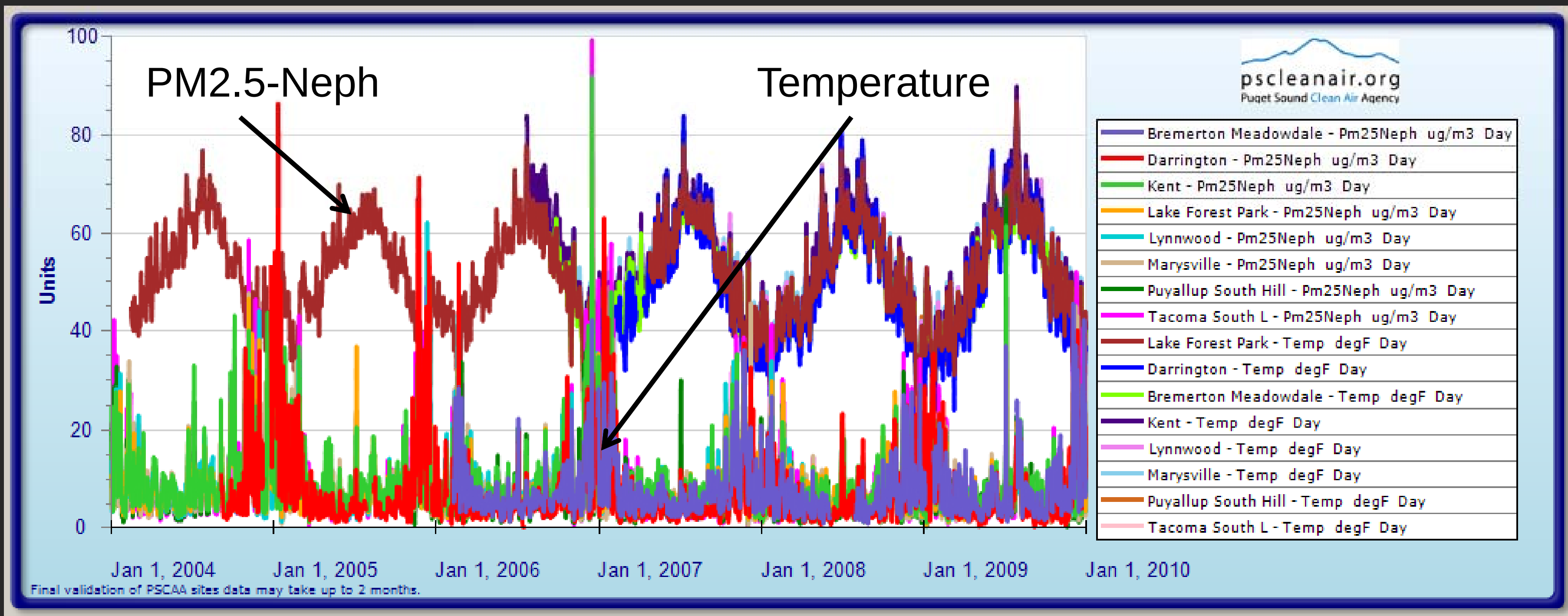
CSN Modeling Conclusions

- Model showed most significant influence from site ID and date
  - Looked at aggregating from single sites to general locations (e.g. NE, NW, SE, SW) and days to week/month season
  - Limitation because it says that statistically the models are site- and date-specific

	Variables controlled in the model	***R^2***
# 1	Date, Temp, Height, Wind speed, and all possible interaction among these variables	15%
#2	Same as #1 **+ month specific variable**	16%
#3	Same as #1 **+ site specific variable**	35%
#4	Same as #1 **+ location specific variable**	20%
	Same as #3 **+ all possible interaction of site variable with other predictors**	51%

- Tried filtering by different PBL heights and wind speeds to see if there were relationship in different categories of met. conditions

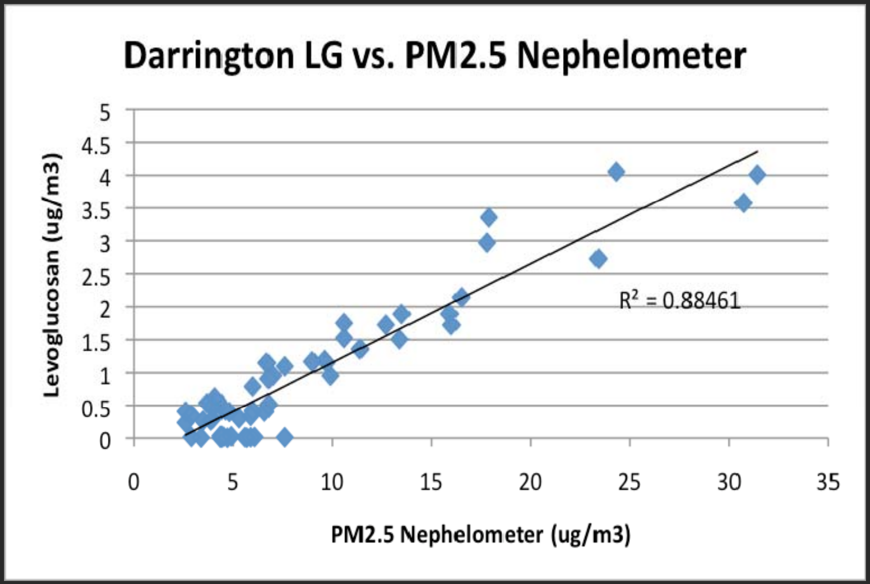
Temperature and PM2.5 Timeseries at Puget Sound "RWC" Sites

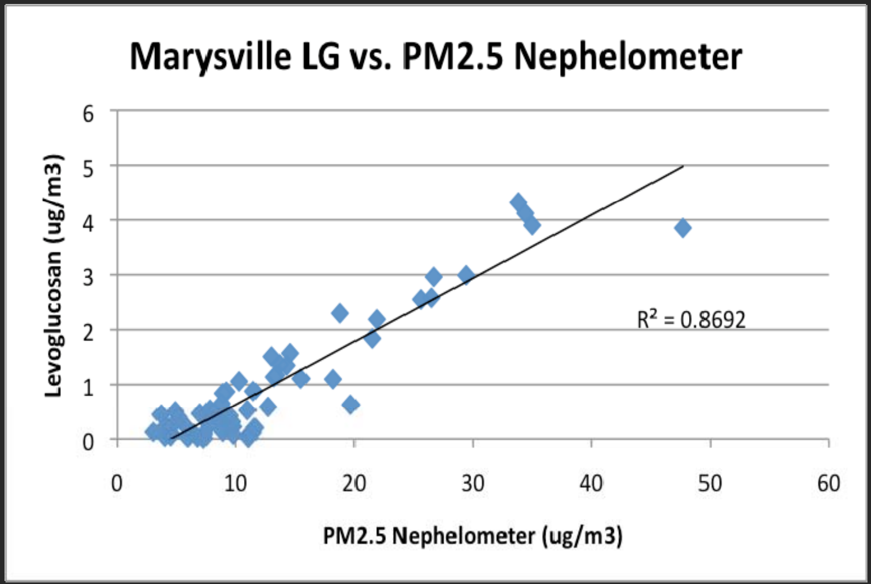


Plot generated at http://trendgraphing.pscleanair.org/

PSCCA PM2.5 Observations

- Nephelometer PM2.5 measured at Puget Sound sites for several years (2004-present).
- Light scatter instrument correlated with LG for RWC sites





Paired in Space and Time Daily Average LG vs. PM2.5 Nephelometer

PM2.5 – Temperature Regressions for PSCCA Sites

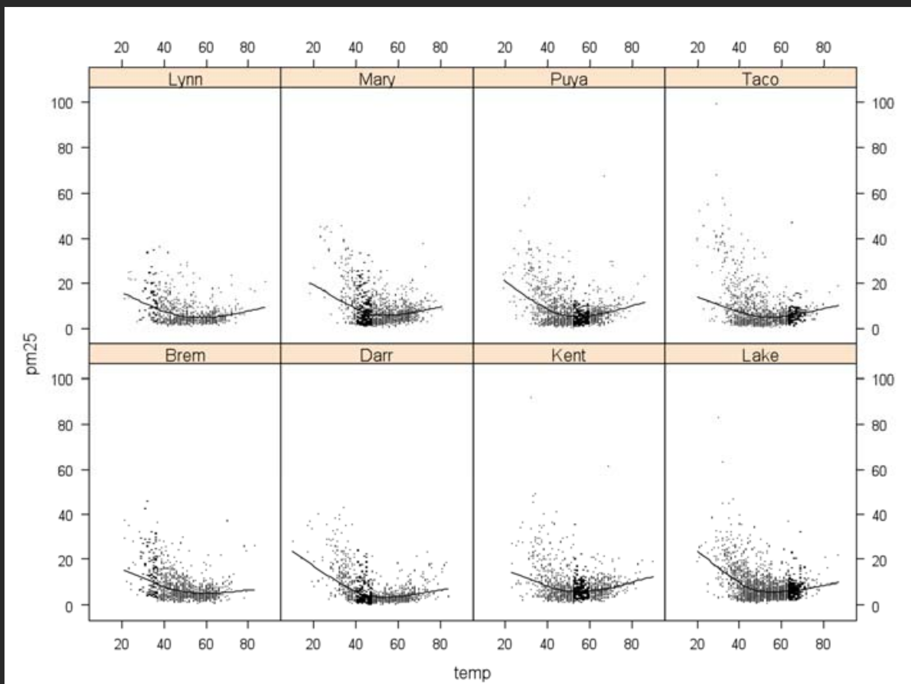


Fig. 1: No restrictions on temperature and PM25

Full dataset

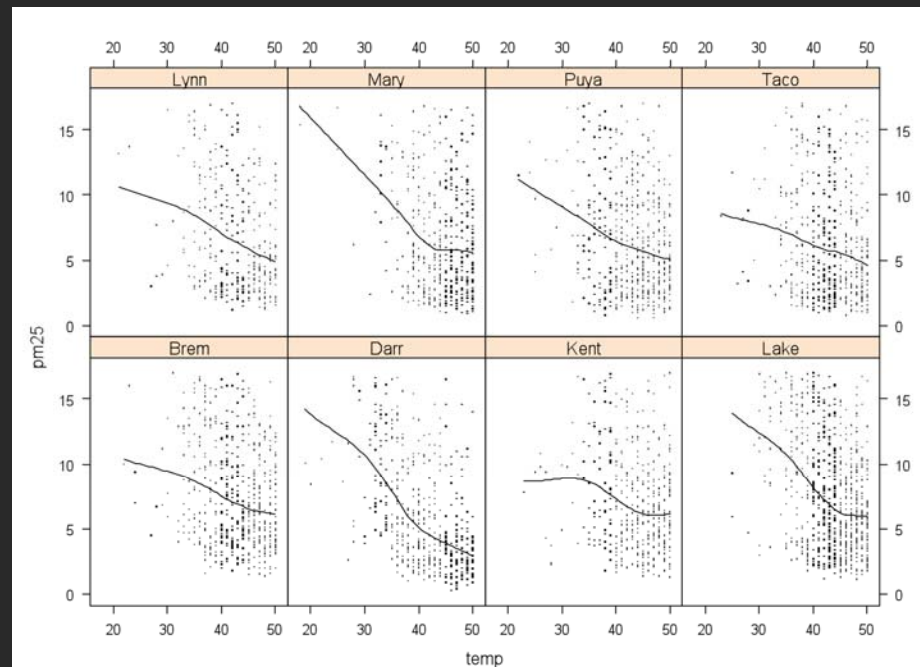


Fig. 2: After putting restrictions on temperature (removed observations above 10 deg F) and PM25 (removed upper 10% observations)

Restrictions for outliers/confounders

- Site ID was still the only significant predictor of PM2.5

RWC Regression Model

- Sources of variability in the $PM_{2.5}$ observations that are difficult to parameterize in a model, like human behavioral patterns
- Chose three PSCAA monitors that could be definitively identified as "RWC" sites through LG vs. PM2.5-neph relationship
- Simplify regression model to relate daily minimum temperatures to daily average PM2.5-neph
- Averaged from daily to weekly and monthly to try to capture correlations between temperature and PM2.5
- Monthly profiles derived from regression-based PM2.5

RWC Regression Model

Daily $PM_{2.5} = 42.12 - 0.79T_d$ ($n = 2008$, $R^2 = 0.26$)

Weekly $PM_{2.5} = 38.03 - 0.68T_w$ ($n = 305$, $R^2 = 0.26$)

Monthly $PM_{2.5} = 36.52 - 0.64T_m$ ($n = 71$, $R^2 = 0.35$)

T_d = daily minimum temperature (°C)

T_w = weekly averaged temperature (°C)

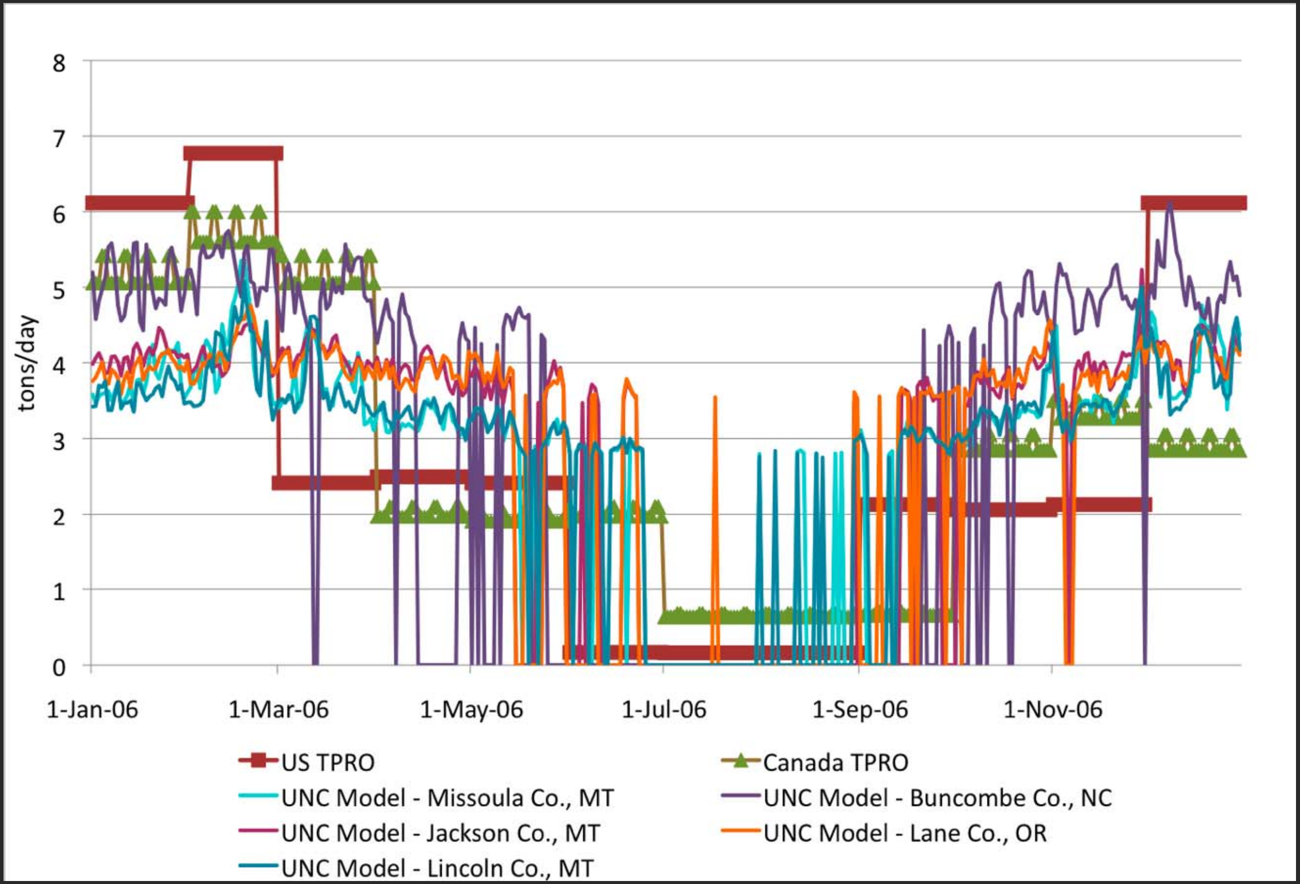
T_m = monthly averaged temperature (°C)

$$PE_{i,d} = \frac{(E_{i,d})}{\sum_{d=1}^{365}(E_{i,d})}$$

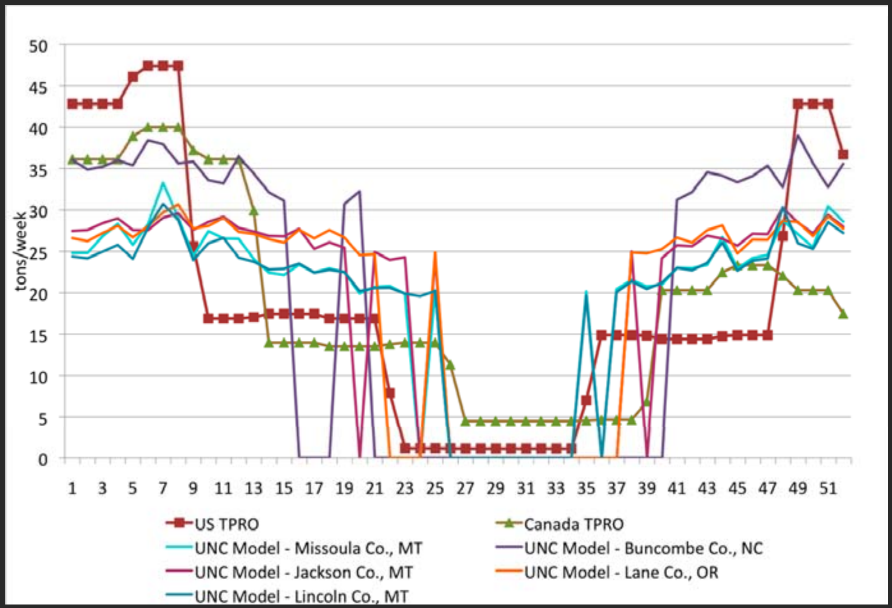
$PE_{i,d}$ = Percentage of annual emissions in county *i* on day *d*.

$E_{i,d}$ = Daily predicted RWC $PM_{2.5}$ tracer in county *i* on day *d*.

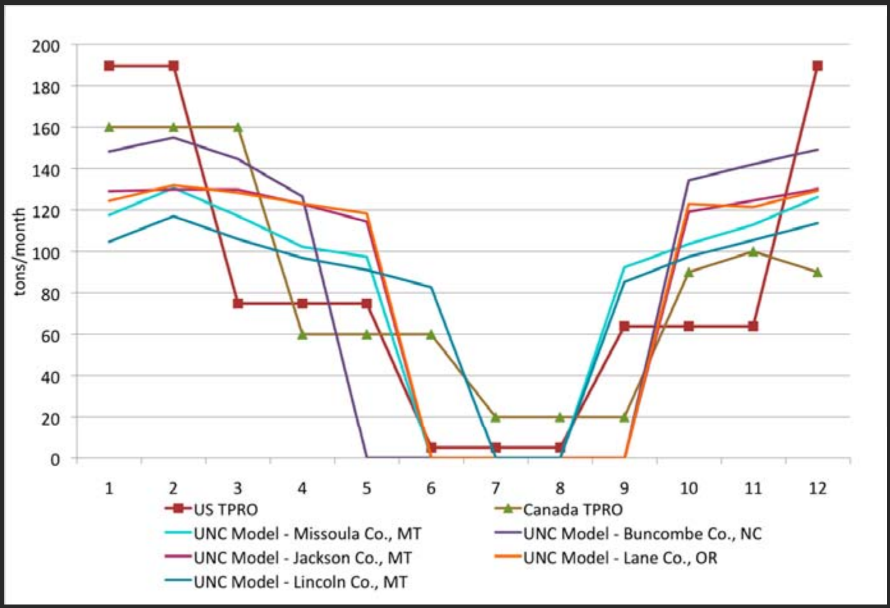
Daily Predicted Temporal Profiles



Weekly and Monthly Predicted Temporal Profiles



Weekly



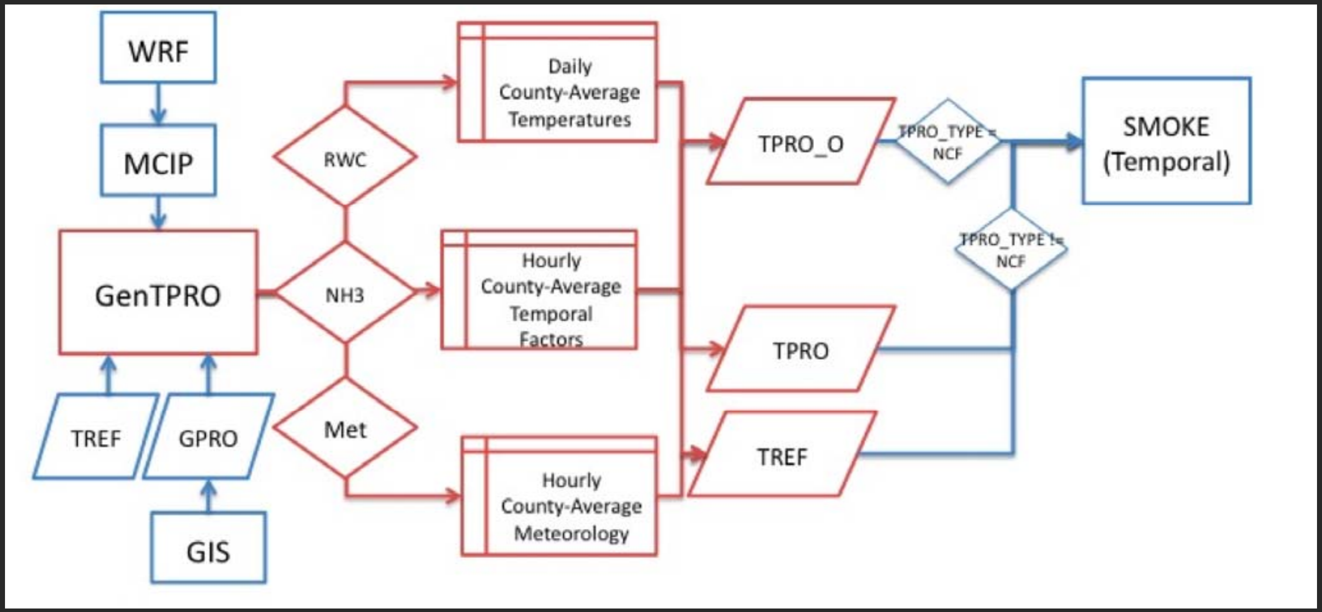
Monthly

Conclusions

- Known issues with the models and predicted temporal profiles that warrant further exploration include:
  - The assumption that a daily minimum temperature of 10°C is the point above which RWC ceases
  - The assumption that RWC emissions go to zero above the temperature threshold
  - Episodic spikes in the profiles are reflective of reality, i.e. does a single cold night in the summer initiate the use of RWC heating for one day?
  - Does systematic variability, or noise, exist in the day-to-day use of RWC during cold months or is a flat profile more representative of use patterns?
  - How well do the model predictions correlate with behavioral surveys of RWC use patterns?
  - The model only considers temporal variability driven by temperatures and does not consider behavioral patterns. Different RWC use patterns during holidays, for example, are not captured by the model

Next Steps

- Conduct and air quality modeling study to validate the predicted temporal profiles
- Tune the temporal variability model with results from future research.



GenTPRO: Temporal Profile Generator Flow Diagram