Fine Particle Sources and Cardiorespiratory Morbidity: An Application of Chemical Mass Balance and Factor Analytical Source Apportionment Methods

Jeremy A. Sarnat

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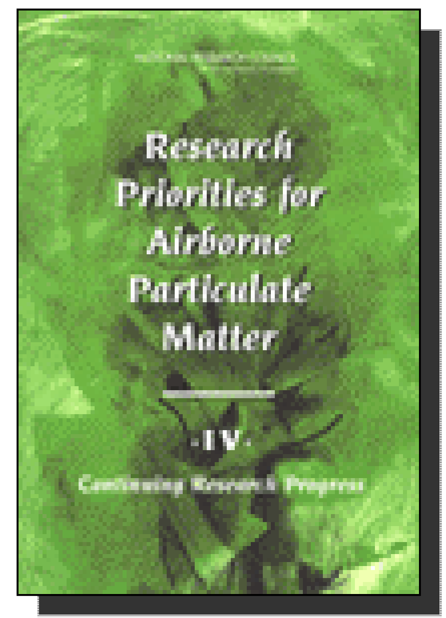
Collaborators

- Emory: Mitch Klein, Stefanie Sarnat, Paige Tolbert
- Ga Tech: Jim Mulholland, Ted Russell
- Clarkson: Phil Hopke
- CARB: Eugene Kim
- Environ Israel (formerly EPD): Amit Marmur

Background

- Numerous studies point to a link between PM mass concentrations and increased morbidity and mortality
- Focus on *components* and *sources* of PM responsible for these associations?
  - Committee on Research Priorities for Airborne Particulate Matter, NRC; EPA PM Research Centers
  - Source Apportionment (SA) of PM
- Use of SA in an epidemiologic setting
  - Ito et al. 2006; Schreuder et al. 2006; Laden et al. 2000; Mar et al. 2000, 2006; Ozkaynak and Thurston 1987



Objectives

- Present and compare results examining associations between ED visits and source-resolved $PM_{2.5}$ using PMF, modified CMB, and a single-species tracer approach
- Identify results that are robust to source attribution method in Atlanta
- What are the biggest challenges for SA-epidemiology of PM?

Not so easy….

- What SA method to use?
  - Source-based (Emission, Receptor models)
  - Model errors hard to identify
  - Different approaches have different limitations
- How sensitive are epidemiologic results to selection of source apportionment (SA) method? (robustness)
- "*Trading one set of problems for another*?" T. Russell

Approach

- Compare results examining associations between emergency department visits and source-resolved $PM_{2.5}$ using PMF, modified CMB, and a single-species tracer approach

- First time both factor analytical and mass balance approaches used together

Data Analysis

- Data used
  - Outcomes: ED visits from November ‘98 – December ’02
    - Combined CVD and combined respiratory disease groups
    - 20 county metro Atlanta area
    - ~ 4.5 millions visits
  - Exposures: Apportioned $PM_{2.5}$
    - PMF: elements, temperature-resolved C fraction, ions
    - CMB-LGO: solution constrained using gaseous co-pollutant ratios (Marmur et al. 2005)
    - Tracer: common, source-indicative species
- Analytical approach: Poisson GLM
  - RR per change in IQR
  - Zero-day lag for pollutants
  - Splines with monthly knots for time,mean temp and DP

Source categories and tracers

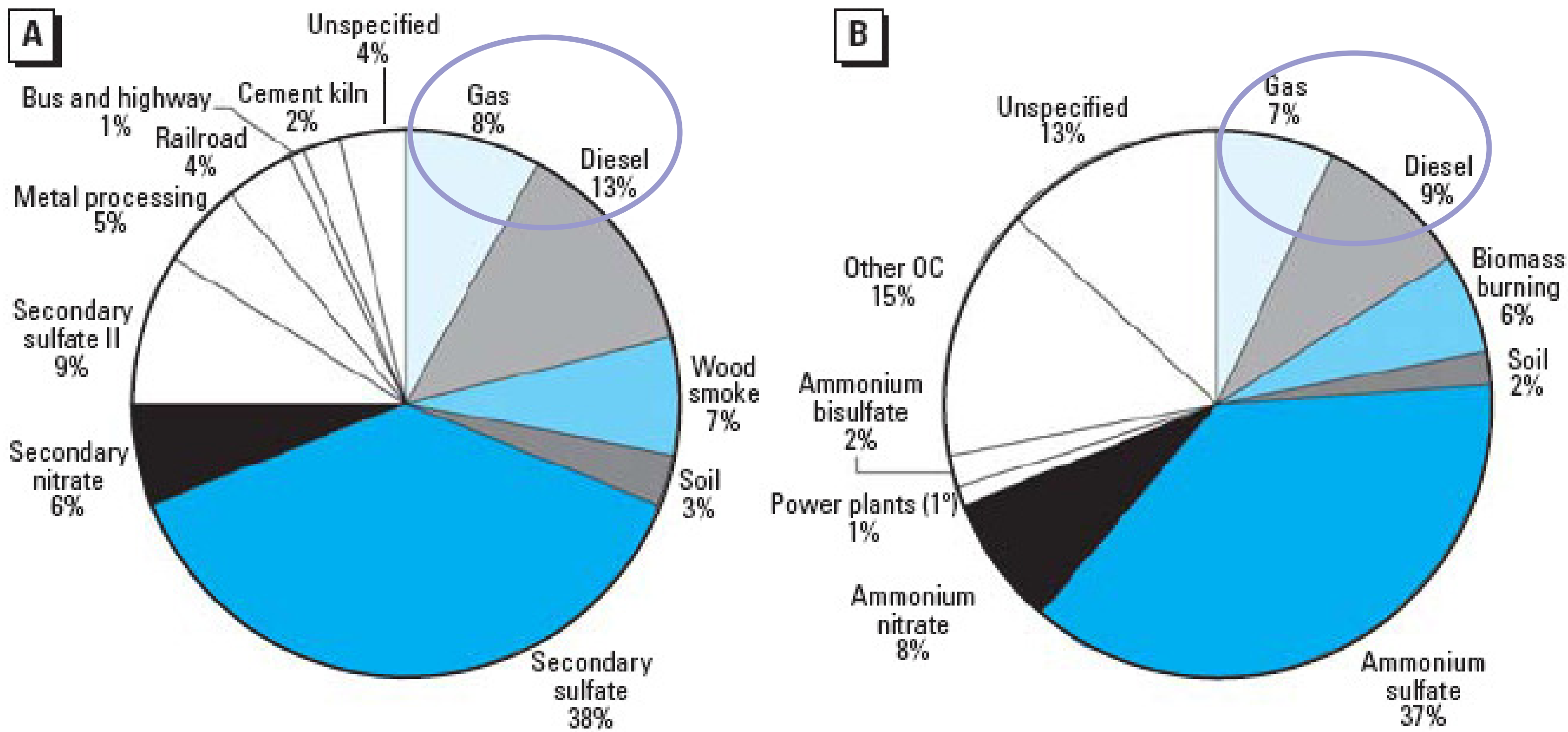
	PMF factors	CMB-LGO sources	Tracer
1	Gasoline	Gasoline	$PM_{2.5}$ Zn
2	Diesel	Diesel	$PM_{2.5}$ EC
3	Wood smoke	Biomass burning	$PM_{2.5}$ K
4	Soil	Soil	$PM_{2.5}$ Si
5	Secondary sulfate I	Ammonium sulfate	$PM_{2.5}$ sulfate
6	Secondary nitrate	Ammonium nitrate	$PM_{2.5}$ nitrate
	Secondary sulfate II	—	—
	Metal processing	—	—
	Railroad	—	—
	Bus and highway	—	—
	Cement kiln	—	—
	—	Power plants (1°)	$PM_{2.5}$ Se
	—	Other OC	$PM_{2.5}$ OC
	—	Ammonium bisulfate	

Comparable source categories are listed on the same row.

Spearman's correlations: PMF - CMB

CMB	PMF Gas	PMF Diesel	PMF Wood smoke	PMF Soil	PMF Secondary sulfate I	PMF Secondary nitrate
Cool season						
Gas	0.45	0.72	0.12	0.61	0.20	0.29
Diesel	0.57	0.88	0.16	0.45	0.20	–0.09
Biomass burning	0.23	0.33	0.89	0.28	0.25	–0.21
Soil	0.67	0.73	0.29	0.83	0.31	0.14
Ammonium sulfate	0.20	0.31	0.30	0.40	0.85	0.04
Ammonium nitrate	0.13	0.26	–0.03	0.29	0.18	0.89
Power plants (1°)	–0.08	0.01	0.38	0.04	0.00	0.01
Ammonium bisulfate	–0.13	–0.12	–0.12	–0.08	0.09	0.28
Other OC	0.80	0.76	0.11	0.45	0.16	–0.10
Warm season						
Gas	0.24	0.58	0.06	0.44	0.24	0.31
Diesel	0.28	0.81	0.15	0.30	0.34	0.22
Biomass burning	0.23	0.34	0.94	0.19	0.04	–0.09
Soil	0.60	0.62	0.49	0.69	0.29	0.16
Ammonium sulfate	0.10	0.40	0.00	0.27	0.96	0.25
Ammonium nitrate	0.15	0.44	–0.05	0.28	0.28	0.87
Power plants (1°)	0.11	0.30	0.37	0.28	0.28	0.01
Ammonium bisulfate	0.10	0.02	0.07	0.09	0.26	–0.05
Other OC	0.61	0.68	0.11	0.30	0.43	–0.04

Fractional contribution to $PM_{2.5}$ from PMF and CMB-LGO source categories



PMF

CMB-LGO

Source categories and all CVD

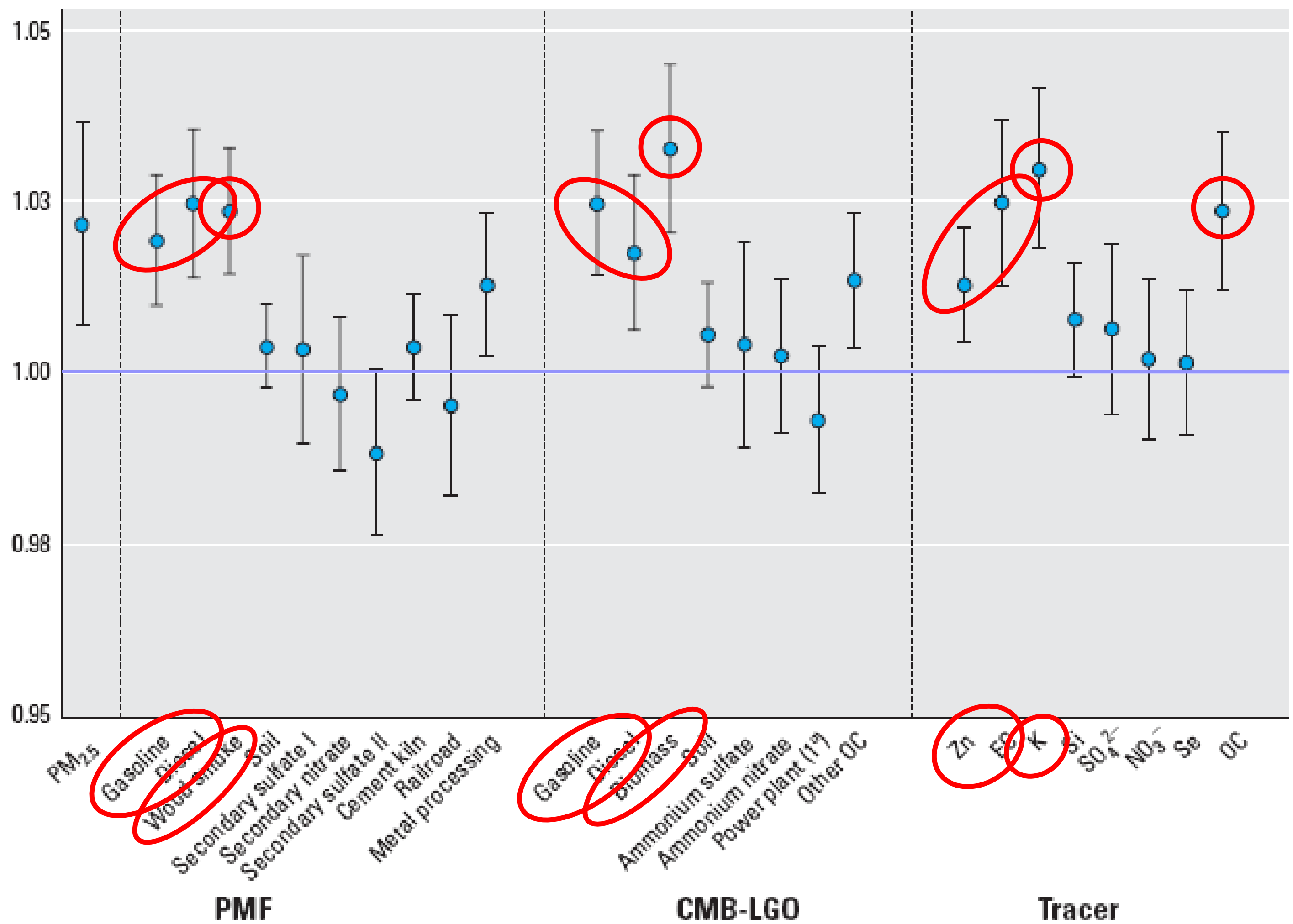


Figure 3. RRs and 95% CIs per IQR increase from same-day lag models for the association of ED visits for all CVD with daily source-apportioned ambient $PM_{2.5}$ (Atlanta, GA, November 1998–December 2002).

Source categories and all RD

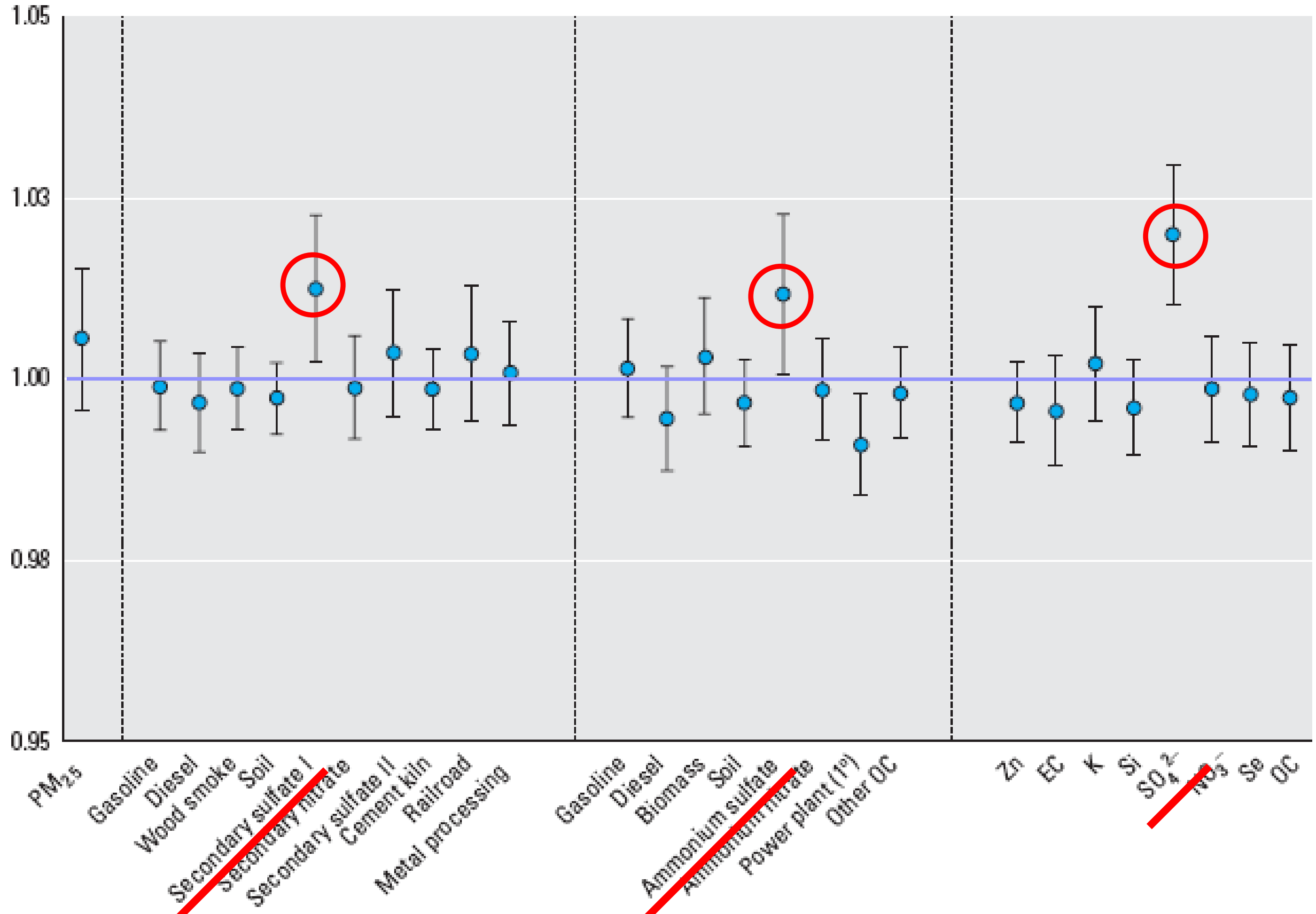
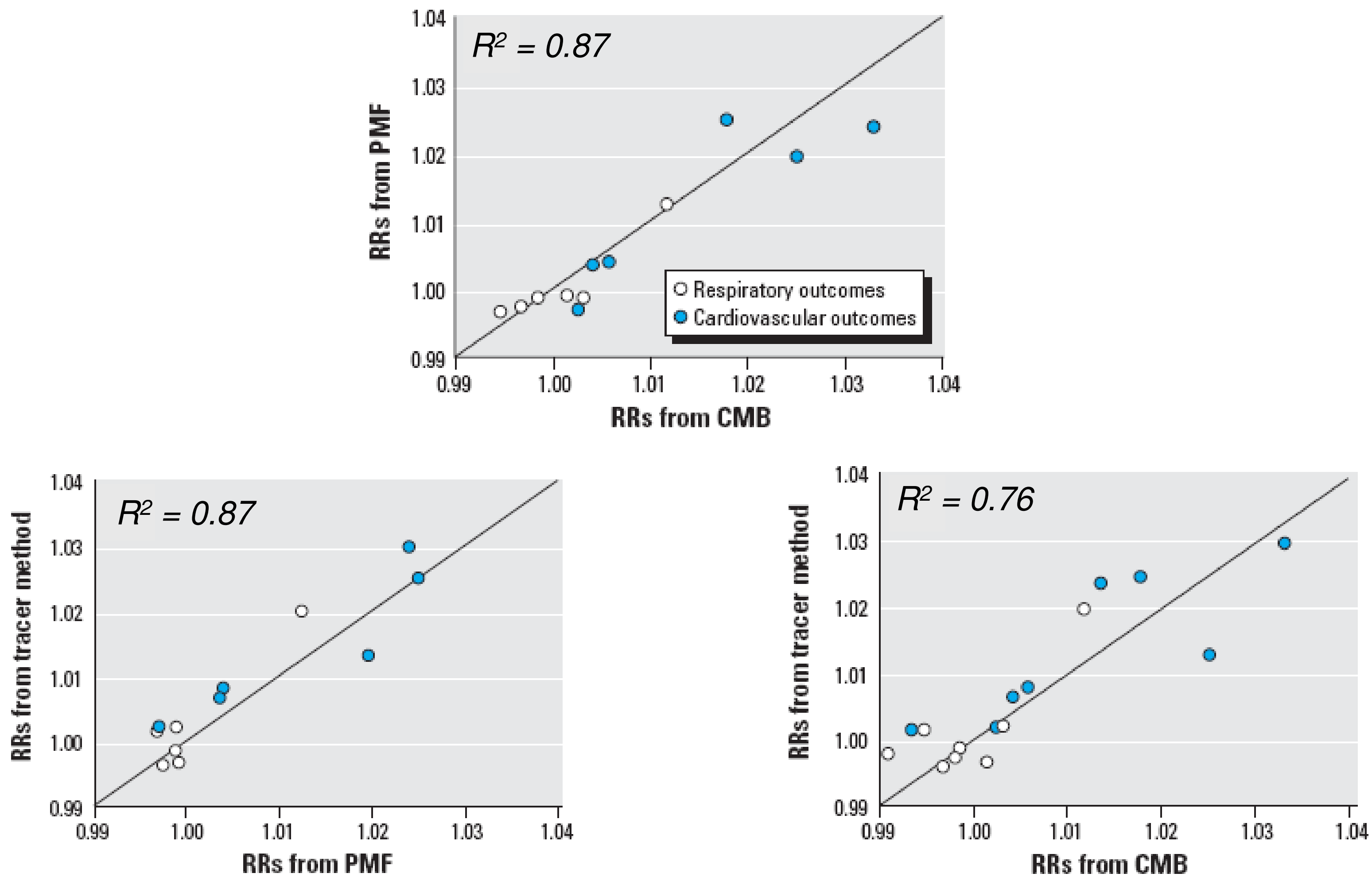


Figure 2. RRs and 95% CIs per IQR increase from same-day lag models for the association of ED visits for all respiratory disease with daily source-apportioned ambient $PM_{2.5}$ (Atlanta, GA, November 1998–December 2002).

Agreement among RRs for all RD & CVD



Lessons learned

- Use of multiple methods led to identification of results that were robust to source attribution method
  - Good agreement among results regardless of method

In Atlanta:

- CVD: Gas, diesel, woodsmoke (OC-driven sources/factors)
- RD: Secondary sulfate

- Combining multiple source-apportionment methods adds information to compensate for limitations of relying on any single method
  - PMF: Naming factors and linking with actual sources subjective
  - CMB: Assumes known and stable source profiles
  - When results agree → increased confidence that a given source is truly associated with effect

Lessons learned – Challenges

- What's driving homogeneity of results
  - In Atlanta, many of the PMF factors and CMB-LGO source impacts driven by similar species

Or, may indicate:

- Residual confounding
  - Associations with gasoline sources may represent true association or gas source may a surrogate for exposure to $PM_{2.5}$ from a co-varying source, (e.g., $PM_{2.5}$ from diesel, biomass burning, or SOA)
  - Multivariate modeling as a means of control probably not effective
- Organic speciation may offer potential to disaggregate OC-dominated source categories and achieve more accurate source characterization

Support

- Emory University: U.S. EPA (R82921301-0); NIEHS (R01ES11294); EPRI (EP-P4353/C2124)
- Georgia Tech: U.S. EPA (RD832159, RD831076, and RD830960)

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Table 2. Mean, median, and selected percentiles (10th, 90th) of daily $PM_{2.5}$ source contributions by season from the ARIES monitoring station at Jefferson Street, Atlanta, GA (November 1998–December 2002).

	Cool season (*n* = 492 days)				Warm season (*n* = 526 days)			
	Mean	10th	Median	90th	Mean	10th	Median	90th
Total $PM_{2.5}$	15.8	7.5	14.3	25.5	18.2	9.1	17.0	29.0
PMF diesel	2.6	0.5	1.8	6.3	1.9	0.3	1.5	3.9
CMB diesel	1.5	0.4	1.2	3.3	1.4	0.5	1.2	2.6
$PM_{2.5}$ EC	1.7	0.6	1.4	3.3	1.4	0.6	1.3	2.5
PMF gasoline	1.7	0.3	1.2	3.6	1.1	0.3	0.9	2.3
CMB gasoline	1.5	0.5	1.3	2.9	1.0	0.3	0.9	1.9
$PM_{2.5}$ Zn (ng/m^3)	15.7	4.6	11.7	30.2	10.9	3.3	8.5	20.2
PMF wood smoke	1.6	0.5	1.3	2.8	0.8	0.1	0.7	1.4
CMB biomass burning	1.1	0.5	1.0	2.0	0.9	0.4	0.8	1.7
$PM_{2.5}$ K (ng/m^3)	63.0	24.3	53.9	114.2	52.7	23.2	43.3	93.5
PMF soil	0.3	0.0	0.3	0.7	0.8	0.2	0.6	1.3
CMB soil	0.2	0.0	0.1	0.4	0.4	0.1	0.3	0.7
$PM_{2.5}$ Si (ng/m^3)	67.7	24.3	54.1	123.5	110.9	32.9	89.0	186.3
PMF secondary sulfate I	4.4	1.4	3.7	8.4	8.7	3.0	7.6	16.4
CMB ammonium sulfate	4.2	1.6	3.7	7.5	8.2	3.3	7.3	14.3
$PM_{2.5}$ SO_4^{2-}	3.4	1.5	0.6	5.8	6.0	2.3	5.2	10.8
PMF secondary nitrate	1.4	0.4	1.2	2.6	0.6	0.2	0.5	1.1
CMB ammonium nitrate	2.0	0.6	1.7	3.6	0.9	0.4	0.7	1.6
$PM_{2.5}$ NO_3^-	1.4	0.5	1.2	2.6	0.7	0.3	2.9	1.2
CMB power plants[a]	0.1	0.0	0.1	0.3	0.1	0.0	0.1	0.3
$PM_{2.5}$ Se (ng/m^3)	1.4	0.4	1.1	3.0	1.2	0.4	0.9	2.7
CMB other OC	2.6	0.9	2.1	4.8	2.5	1.1	2.3	4.2
$PM_{2.5}$ OC	4.6	1.9	3.9	8.0	4.0	2.1	3.7	6.4
CMB ammonium bisulfate	0.4	0.0	0.0	1.5	0.4	0.0	0.0	1.1
PMF secondary sulfate II	1.4	0.0	1.3	2.6	1.7	0.4	1.5	3.2
PMF cement kiln	0.4	0.1	0.3	0.8	0.4	0.1	0.3	0.8
PMF bus and highway	0.1	0.0	0.0	0.3	0.1	0.0	0.0	0.2
PMF railroad	0.5	0.1	0.5	0.9	0.7	0.2	0.7	1.3
PMF metal processing	0.8	0.1	0.6	1.8	0.7	0.1	0.6	1.5

Table 4. Spearman's correlation coefficients between single species tracers, CMB, and PMF by season.

Source category	Tracer	Cool season correlation with		Warm season correlation with	
		CMB	PMF	CMB	PMF
Gas	Zn	0.96	0.42	0.94	0.19
Diesel	EC	0.96	0.95	0.96	0.88
Wood smoke/biomass burning	K	0.99	0.82	0.98	0.62
Soil	Si	0.83	0.82	0.96	0.92
Secondary sulfate I/ammonium sulfate	SO_4^{2-}	0.87	0.97	0.96	0.99
Secondary nitrate/ammonium nitrate	NO_3^-	0.94	0.95	0.95	0.92
Power plant	Se	0.39	—	0.50	—
Other OC	OC	0.91	—	0.89	—

Cool season is October 15–April 14; warm season is April 15–October 14.