

Optimizing the Design of Air Pollution Control Measures to Improve Human Health

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Impacts of Air Pollution

- Human Health
 - Acute and Chronic impacts
- Human Welfare
 - Visibility
 - Material damage
- Ecosystem Impacts
 - Nutrients
 - Toxics
- Climate Change



Table 1: Ranking of selected risk factors: 10 leading risk factor causes of death by income group, 2004

Risk factor	Deaths (millions)	Percentage of total	Risk factor	Deaths (millions)	Percentage of total
World			Low-income countries^a		
1 High blood pressure ★	7.5	12.8	1 Childhood underweight	2.0	7.8
2 Tobacco use	5.1	8.7	2 High blood pressure ★	2.0	7.5
3 High blood glucose	3.4	5.8	3 Unsafe sex	1.7	6.6
4 Physical inactivity	3.2	5.5	4 Unsafe water, sanitation, hygiene	1.6	6.1
5 Overweight and obesity ★	2.8	4.8	5 High blood glucose ★	1.3	4.9
6 High cholesterol ★	2.6	4.5	6 Indoor smoke from solid fuels	1.3	4.8
7 Unsafe sex	2.4	4.0	7 Tobacco use	1.0	3.9
8 Alcohol use	2.3	3.8	8 Physical inactivity	1.0	3.8
9 Childhood underweight	2.2	3.8	9 Suboptimal breastfeeding	1.0	3.7
10 Indoor smoke from solid fuels	2.0	3.3	10 High cholesterol ★	0.9	3.4
Middle-income countries^a			High-income countries^a		
1 High blood pressure ★	4.2	17.2	1 Tobacco use	1.5	17.9
2 Tobacco use	2.6	10.8	2 High blood pressure ★	1.4	16.8
3 Overweight and obesity ★	1.6	6.7	3 Overweight and obesity ★	0.7	8.4
4 Physical inactivity	1.6	6.6	4 Physical inactivity	0.6	7.7
5 Alcohol use	1.6	6.4	5 High blood glucose ★	0.6	7.0
6 High blood glucose ★	1.5	6.3	6 High cholesterol ★	0.5	5.8
7 High cholesterol ★	1.3	5.2	7 Low fruit and vegetable intake	0.2	2.5
8 Low fruit and vegetable intake	0.9	3.9	8 Urban outdoor air pollution	0.2	2.5
9 Indoor smoke from solid fuels	0.7	2.8	9 Alcohol use	0.1	1.6
10 Urban outdoor air pollution	0.7	2.8	10 Occupational risks	0.1	1.1

GLOBAL HEALTH RISKS

Mortality and burden of disease attributable to selected major risks

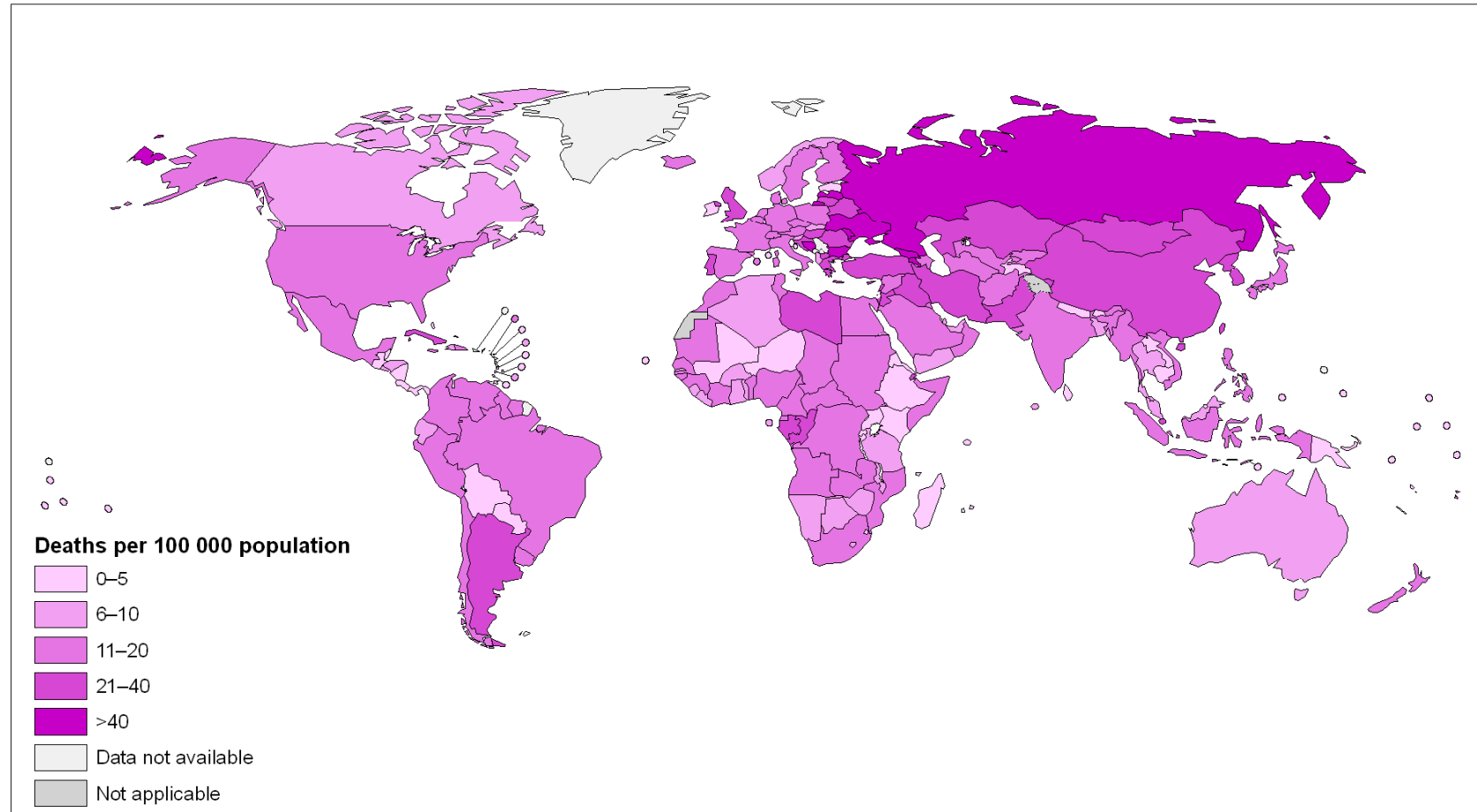


World Health Organization

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Deaths attributable to outdoor air pollution, 2008



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Public Health Information
and Geographic Information Systems (GIS)
World Health Organization



**World Health
Organization**

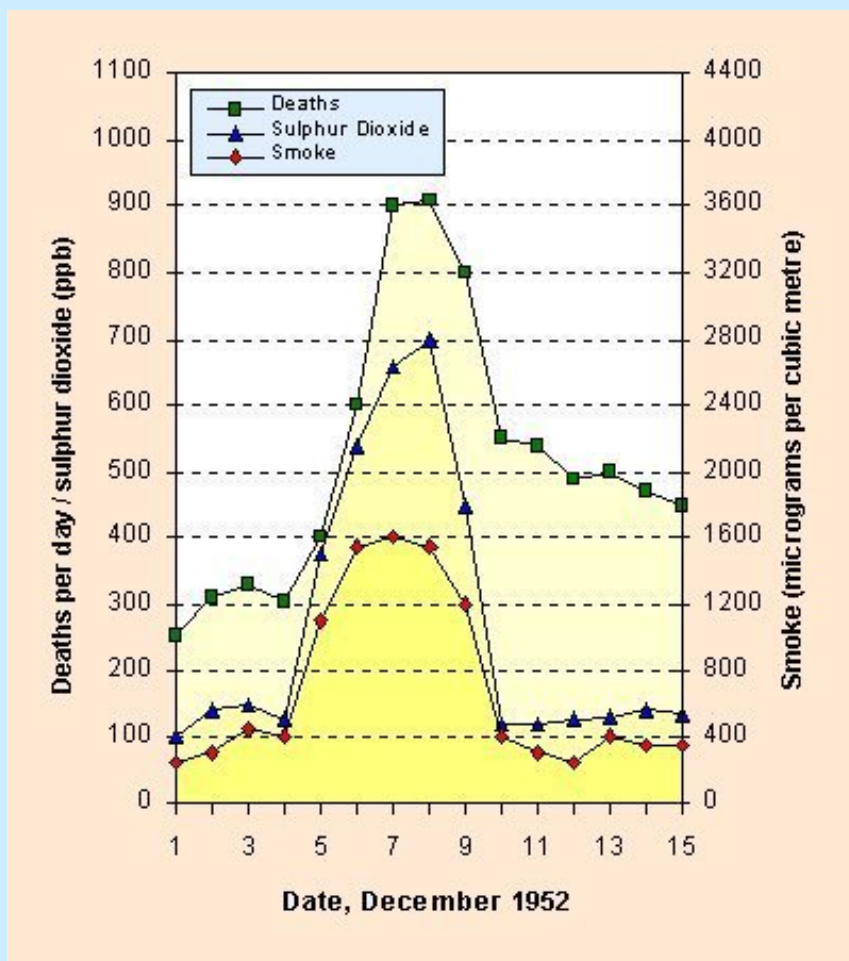
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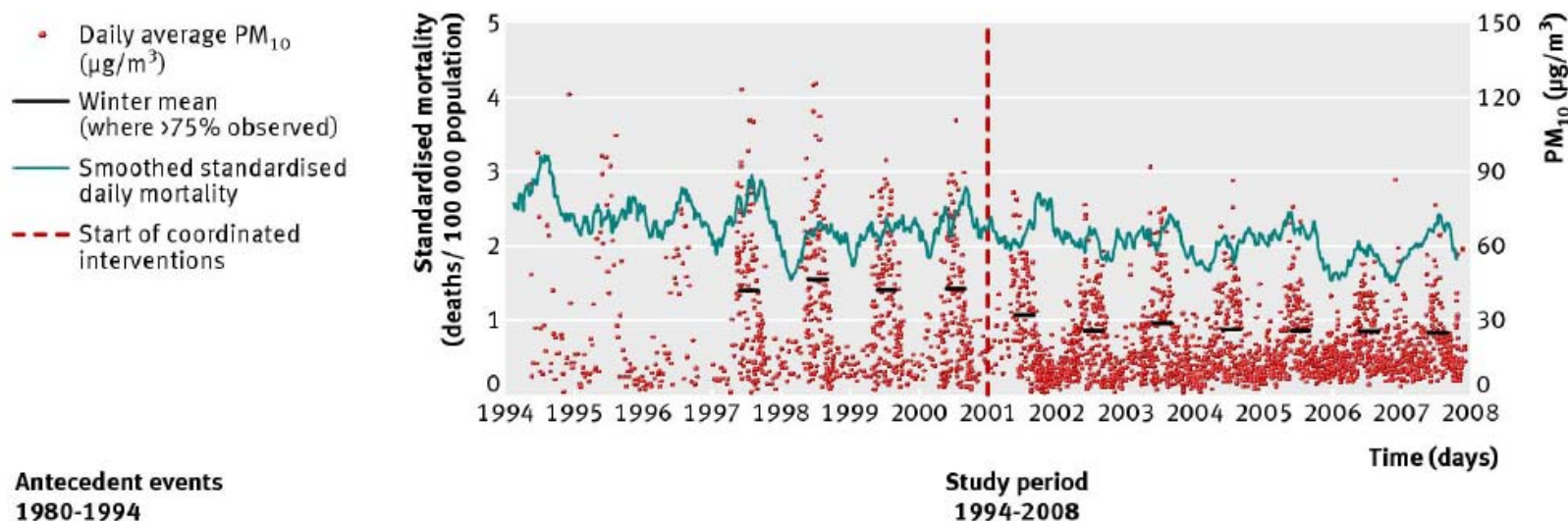
The London Smog Disaster of 1952



Evaluation of interventions to reduce air pollution from biomass smoke on mortality in Launceston, Australia: retrospective analysis of daily mortality, 1994-2007

 OPEN ACCESS

Fay H Johnston *research fellow*¹, Ivan C Hanigan *research associate*^{2,3}, Sarah B Henderson *epidemiologist*⁴, Geoffrey G Morgan *associate professor*^{5,6}



Antecedent events 1980-1994

80's: Increasing popularity of domestic wood heaters and increasing community perception of worsening air quality

91-94: An Expert Working Party was formed to provide the first detailed assessments of air quality and health, establishing the basis for subsequent monitoring and public education campaigns

Study period 1994-2008

1994-2001: Period of poor air quality

Initial responses:
 94-01: Detailed research projects on particular air pollution in the area
 94-08: Tasmania wide marketing campaign to promote electric heating
 97-08: Winter air quality forecasts issued by the Bureau of Meteorology
 00-01: Distribution of educational leaflets

2001-2008: Period of improved air quality

Coordinated interventions:
 01-04: Wood heater replacement programme
 01-03: The Airwatch education programme in schools, universities, and mass media
 02-05: Smoke patrols, targeted education, and issuance of infringement notices to households with excessively smoking chimneys

Fig 3 Air quality interventions, air quality data, and directly aged standardised mortality in Launceston, Tasmania 1991-2007

Health Impacts of Air Pollution

- Observed associations with, and impacts of, exposure to atmospheric PM continue to increase
 - Respiratory Disease
 - Cardiovascular Disease
 - Cancer
 - Auto-Immune Disorders
 - Metabolic Syndrome
 - Reproductive Impacts
- Unlikely that same components and sources impact all pathways of injury
 - Oxidative stress is an important pathway for many impacts

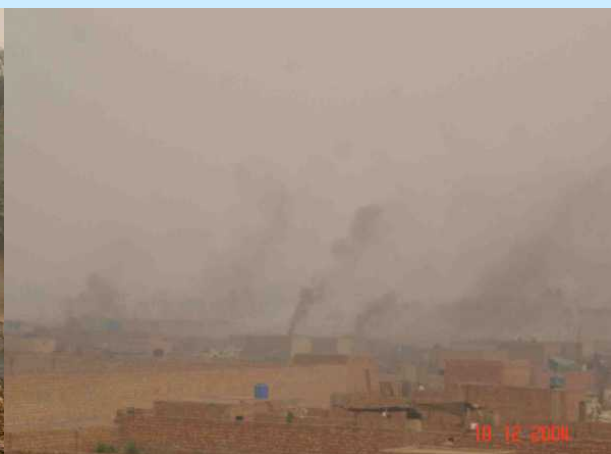


Challenges to Understand Impacts

- Complex mixture of sources with very complex chemistry
 - Large spatial variability - Sources
 - Large temporal variability – Meteorology
- Human activity patterns impact exposure
- Human susceptibility differs as a function of age, health and genetics
- Concerned with short-term and long-term exposures



Sources of Air Pollution



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Exposure Assessment

- Most people spend considerable time indoors that impact exposure
 - Indoor sources
 - Infiltration of outdoor pollution indoors
- Some micro-environments have very high exposure
 - Commuting on roadways
- Impossible to measure for large cohorts
- Some progress in models based on time-activity data



Regulating Air Concentrations

- Ambient Air Pollution
 - Regulatory authority lies with EPA
 - Outdoor concentrations away from sources
- Indoor Air Pollution
 - Regulated indirectly by building codes and consumer product regulations
- Occupational Air Pollution
 - Regulated by OSHA and NIOSH
- Personal Exposure
 - Not Regulated
 - Most important for human health



EPA (NAAQS)

- Sulfur Dioxide
 - Annual Average: 30 ppb
 - 24-Hour Average: 80 ppb
- Ozone
 - 8-Hour Average: 80 ppb
- Nitrogen Dioxide
 - Annual Average: 53 ppb
- Carbon Monoxide
 - 8-Hour Average: 9 ppm
 - 1-Hour Average: 35 ppm
- Particulate Matter
 - PM10 and PM2.5
- Lead
 - Quarterly Average: $1.5 \mu\text{g m}^{-3}$

NIOSH (PEL)

- Sulfur Dioxide
 - 8-Hour Average: 9 ppm
- Ozone
 - 8-Hour Average: 100 ppb
- Nitrogen Dioxide
 - 8-Hour Average: 3 ppm
- Carbon Monoxide
 - 8-Hour Average: 25 ppm
- Particulate Matter
 - Regulated by component
- Lead
 - 8-Hour Average: $50 \mu\text{g m}^{-3}$



Approaches to Health Studies

- Epidemiological studies
 - Usually use central monitoring sites to assess associations with outdoor air pollution
 - Increase use of panel studies to examine sub-clinical outcomes
- Toxicological Studies
 - In-Vivo Studies
 - In-Vitro Studies



Epidemiological Studies

- Epidemiological evidence that adverse health effects are associated with increased particulate matter concentrations is very strong
- Epidemiological studies are beginning to elucidate
 - Biological pathways of adverse health effects associated with exposure to PM
 - Source categories that are most biologically relevant
- Still exists a very large disconnect between potential changes in emissions of air pollution and expected health benefits
 - Requires Integrations of very complex systems
 - Sources, Atmospheric Transport, and Biological Effects



Epidemiological Results US EPA ISA for PM, 2009

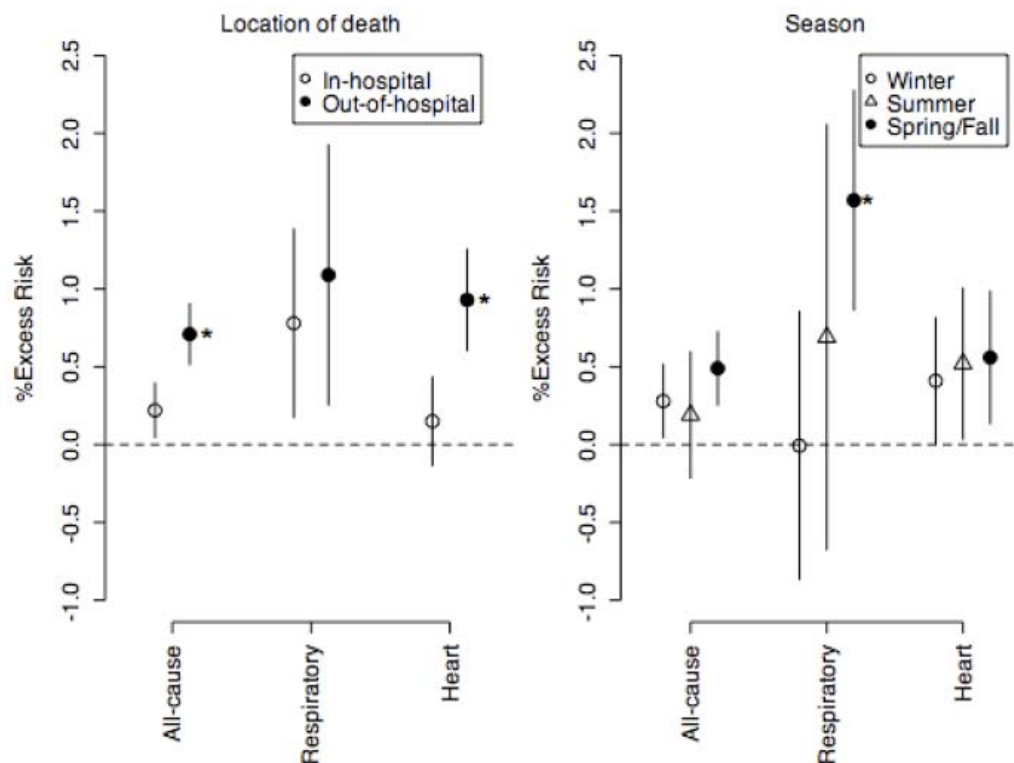


Figure 6-20. Percent excess risk in mortality (all-cause [nonaccidental] and cause-specific) per $10 \mu\text{g}/\text{m}^3$ increase in PM_{10} by location of death and by season. The risk estimates and 95% confidence intervals were plotted using numerical results from tables in Zeka et al. (2006, [088749](#)). The estimates with * next to them are significantly higher than the lowest estimate in the group.



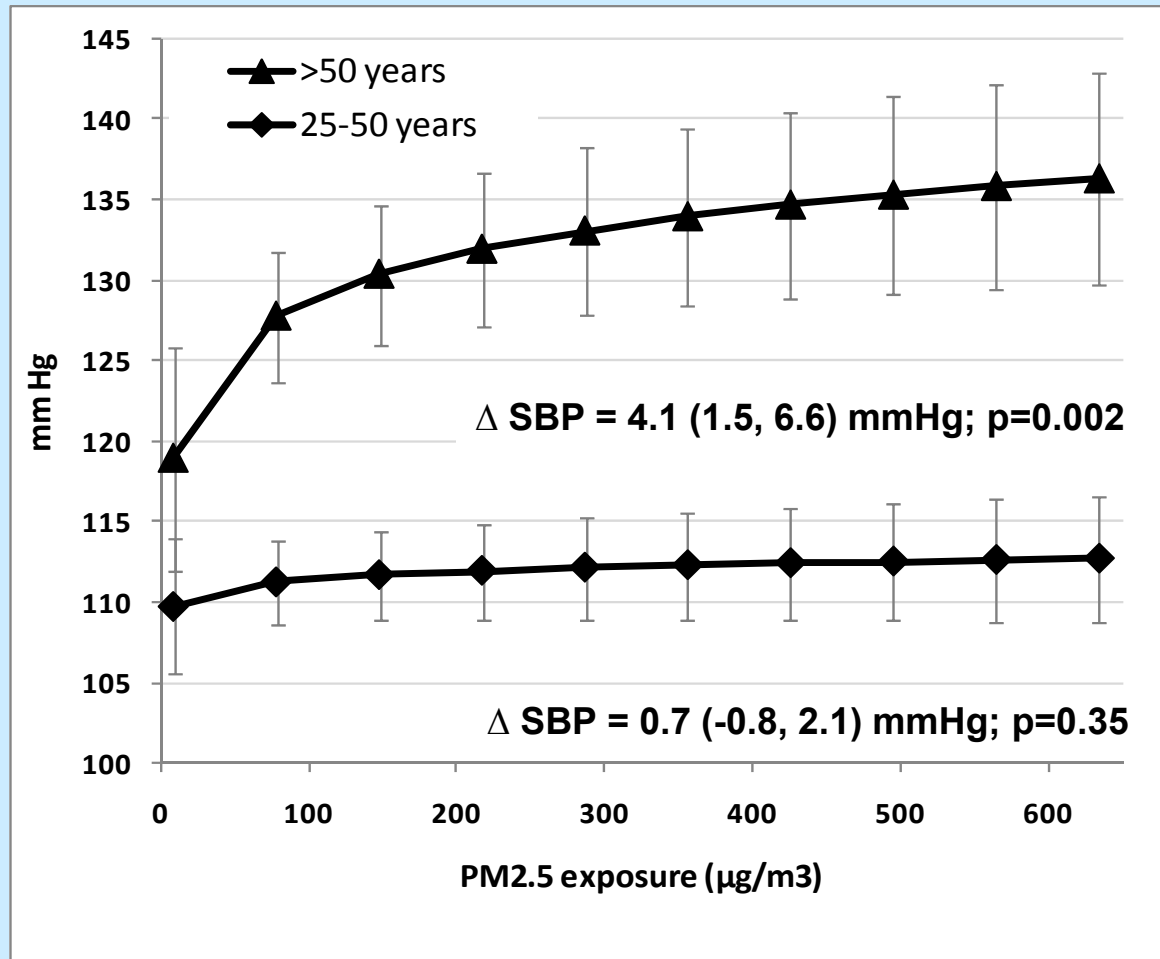
Exposure measurement design & methods

Baumgartner et al. (EHP, 2011)

- Women: Integrated gravimetric $PM_{2.5}$ for 24-hr (n=280)
 - 196 women completed summer and winter phases; 66 in winter only; 18 in summer only



Average SBP by age and exposure level



Adjusted association between PM_{2.5} exposure and SBP for women by age (exposure-by-age interaction p=0.03)

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Example: Lung Transplantation

The impact of traffic air pollution on bronchiolitis obliterans syndrome and mortality after lung transplantation

Tim S Nawrot,^{1,2} Robin Vos,^{3,4} Lotte Jacobs,² Stijn E Verleden,^{3,4} Shana Wauters,⁴ Veerle Mertens,⁴ Christophe Doods,³ Peter H Hoet,² Dirk E Van Raemdonck,^{4,5} Christel Faes,⁶ Lieven J Dupont,^{3,4} Benoit Nemery,² Geert M Verleden,^{3,4} Bart M Vanaudenaerde^{3,4}

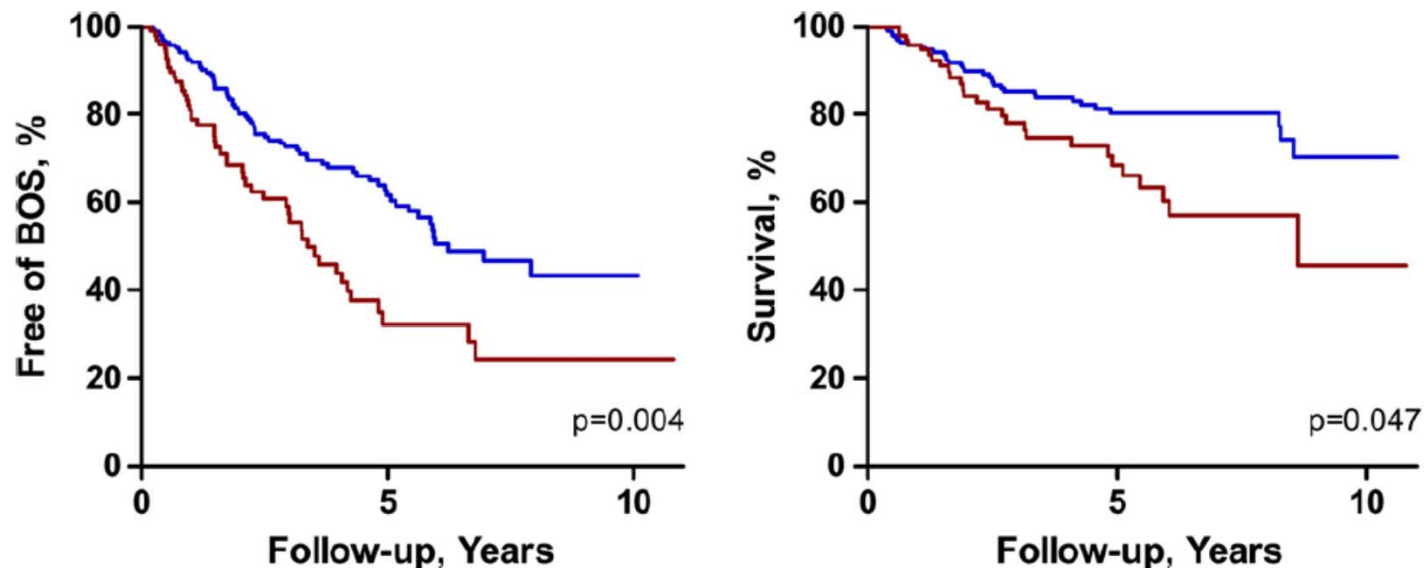


Figure 1 Unadjusted Cox regression in patients after lung transplantation classified according to whether they lived within 171 m of a major road (n=96, lowest tertile, red line) or more than 171 m from a major road (n=192, blue line). BOS, bronchiolitis obliterans syndrome.

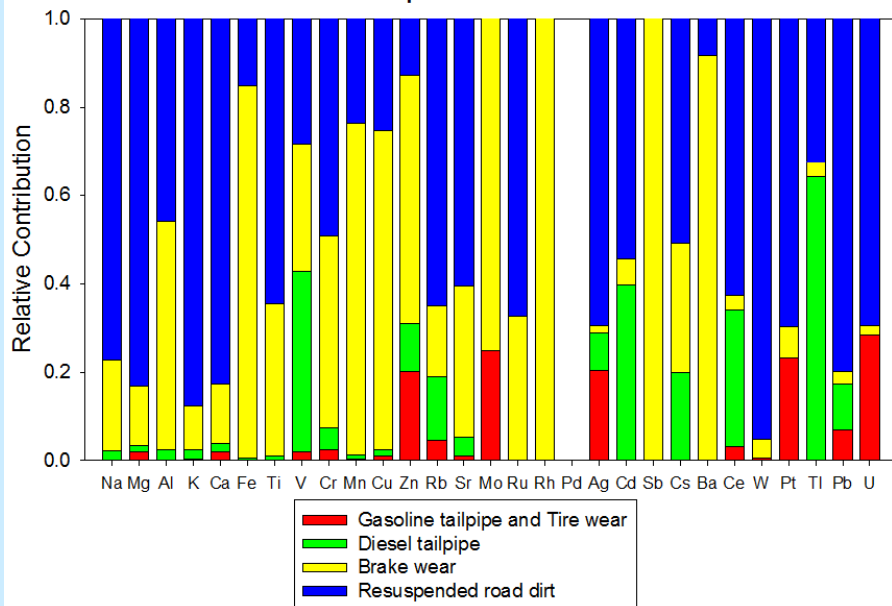


Policy Implications

- Need a basis to prioritize the control of sources or PM mass will be reduced without optimizing for the public health benefit
 - Important in the context of climate mitigation
- We are likely to draw wrong conclusions about biological importance of sources and controls
 - Example: Health Effects on Distance to Roadways
 - Does an association with roadway emissions and health really mean that tailpipe emissions are causing adverse health effects
 - Brake Dust, Tire Wear, Resuspended Road Dust
 - Are all engine operating conditions equally important
- Huge implications for co-benefits (climate mitigation and ecosystem), interventions, and unintended consequences



Relative source contributions to emissions of individual metals in PM10 Winter Airport Tunnel Test



HEALTH EFFECTS INSTITUTE

Number 133
March 2006

Characterization of Metals Emitted from Motor Vehicles

James J Schauer, Glynis C Lough, Martin M Shafer, William F Christensen, Michael F Arndt, Jeffrey T DeMinter, and June-Soo Park



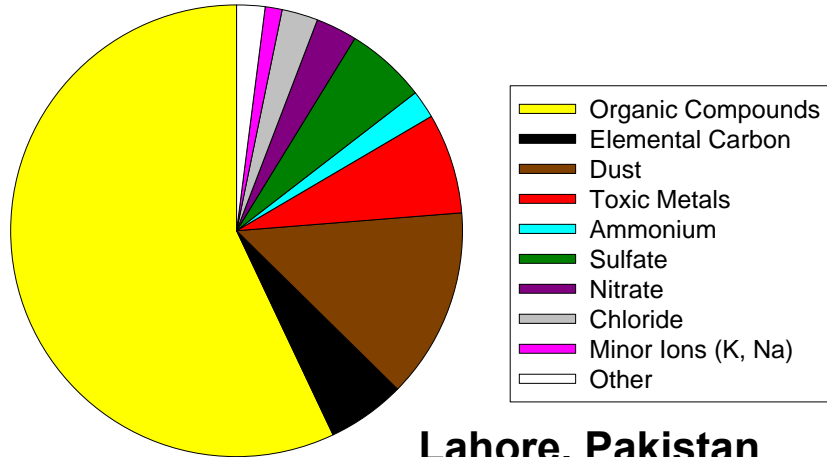
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Toxicological Results

- Toxicological results have made important contributions to understanding the biological pathways associated with adverse impact of PM exposures
- Toxicological studies often use fresh source emissions or a “typical” PM sample
 - Do not represent the diversity of PM exposures
 - Source samples do not include secondary aerosol or atmospheric processing
 - “Typical” samples do not address spatial and temporal variability in composition or sources

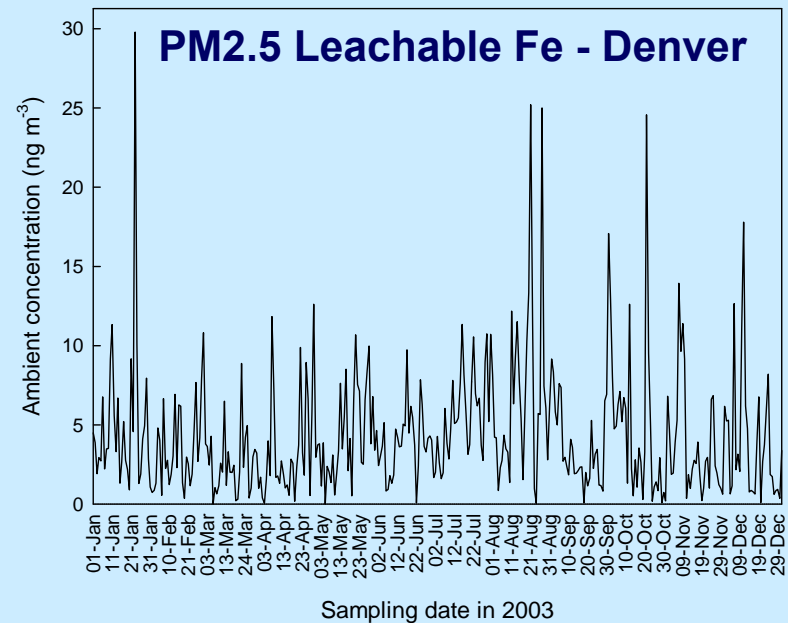
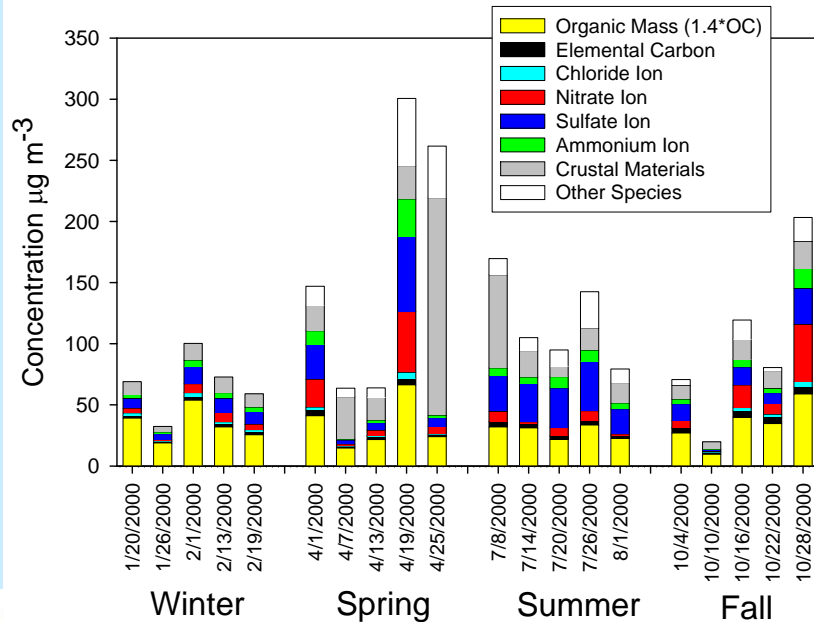


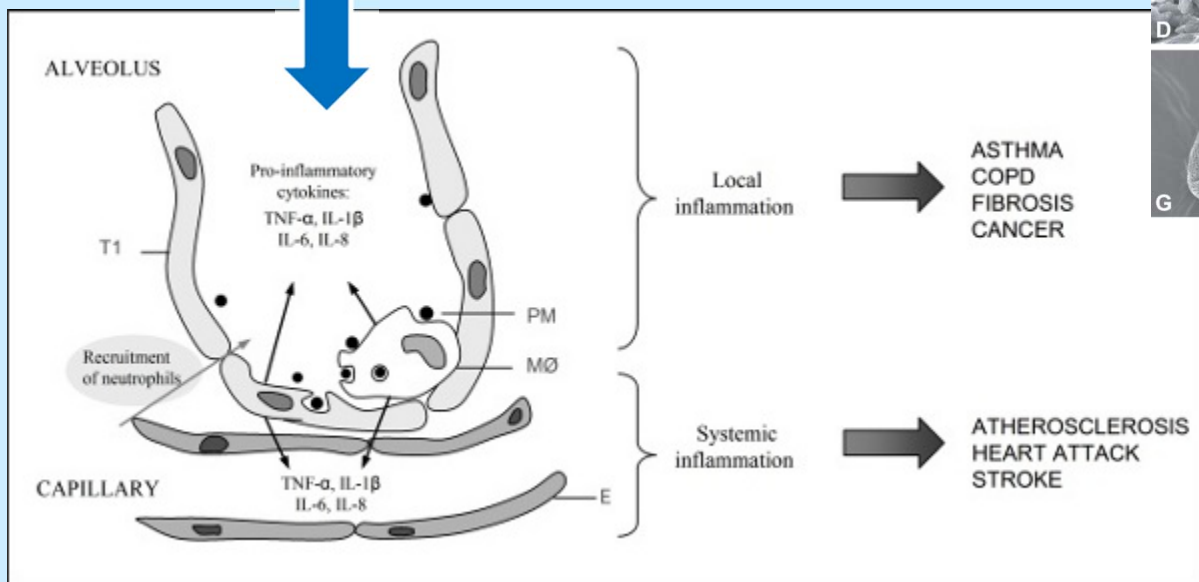
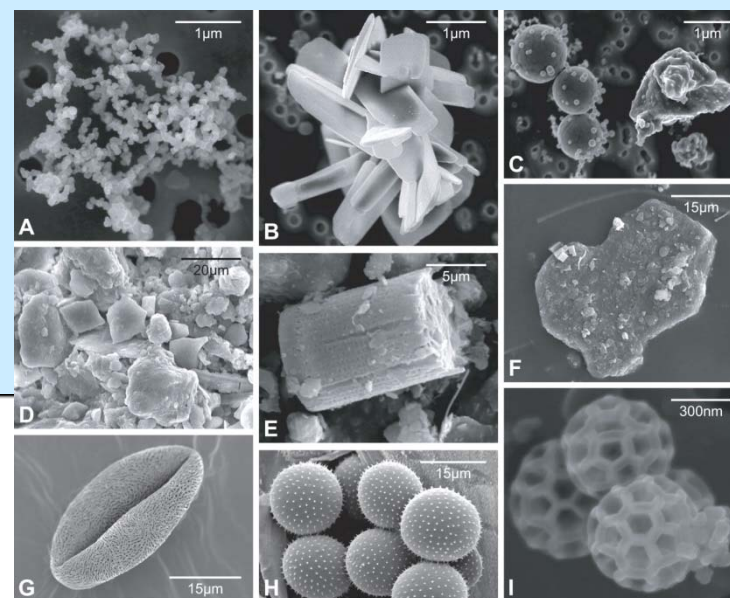


Lahore, Pakistan
2006
PM2.5

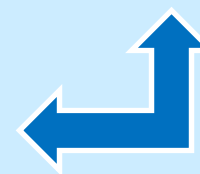


Beijing (Peking University) PM2.5 Bulk Composition - 2000





elements.geoscienceworld.org



P. E. Schwarze et al., "Air Pollution." 2010

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Integrated Approach to PM Impacts

- Integrate **tools** and not just integrate **knowledge**
 - Source Emissions
 - Atmospheric Processing
 - Toxicology
 - Epidemiology
- Examples
 - Epidemiology based on in-vitro assay measurements
 - Direct comparison of in-vitro assays with sub-clinical end points
 - Source apportionment of in-vitro biological activity



Example: Lung Transplantation

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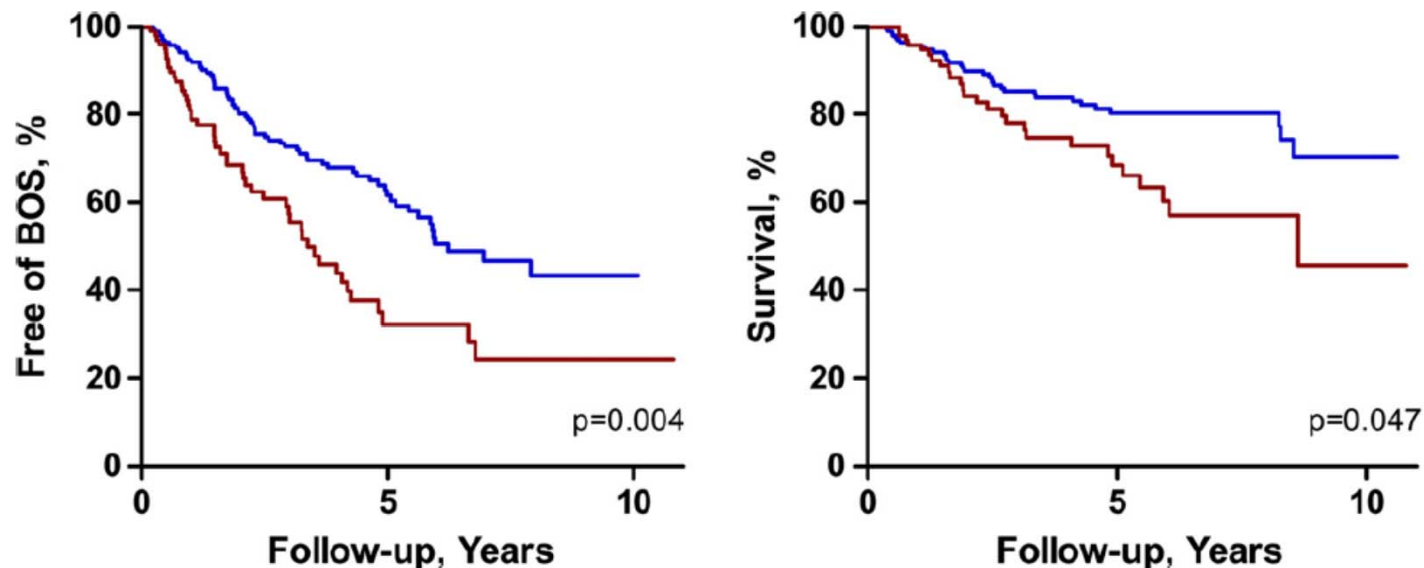
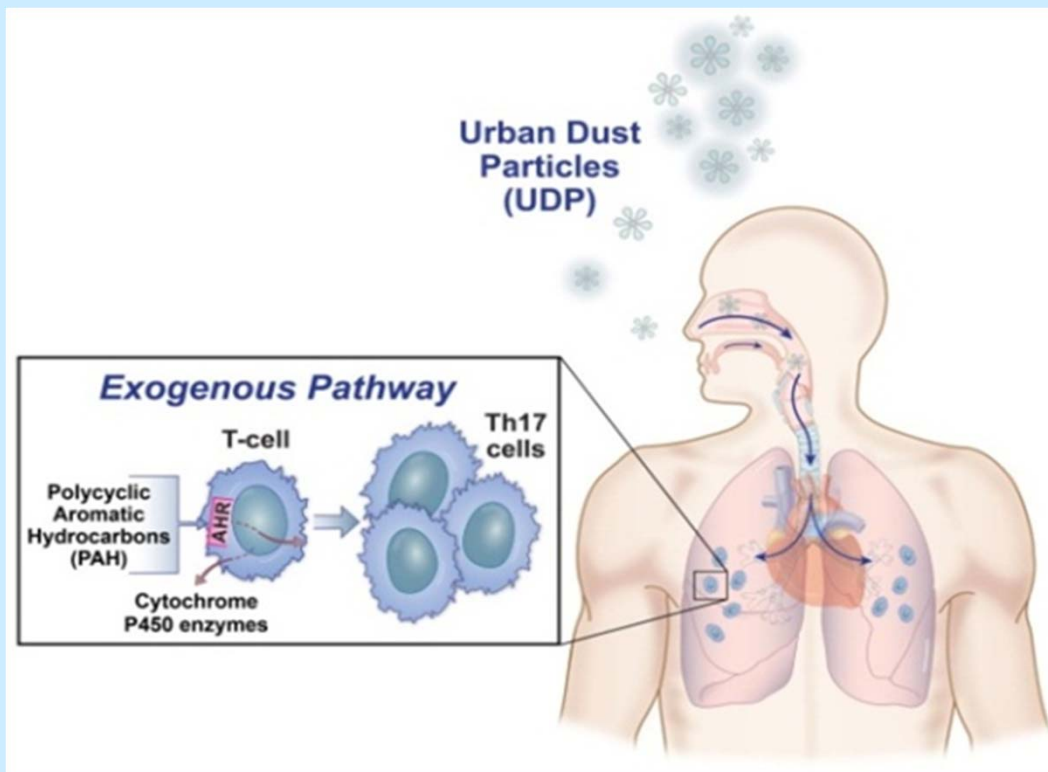


Figure 1 Unadjusted Cox regression in patients after lung transplantation classified according to whether they lived within 171 m of a major road (n=96, lowest tertile, red line) or more than 171 m from a major road (n=192, blue line). BOS, bronchiolitis obliterans syndrome.



Voorhis et al., 2014. Exposure to atmospheric particulate matter enhances Th17 differentiation through the aryl hydrocarbon receptor, Plos One.



Examined the Fraction PM samples and examining what components drive T-Cell Differentiation in a murine model

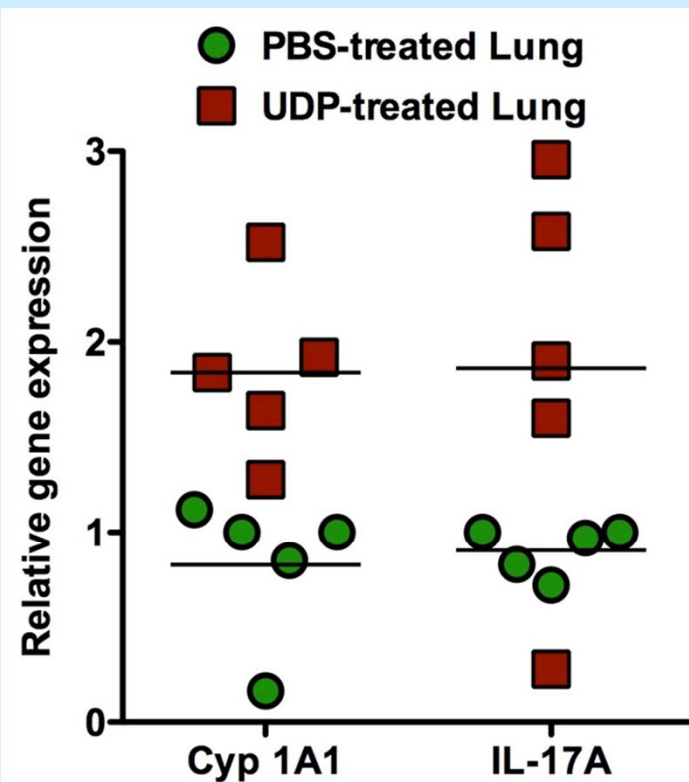


Figure 7. B6 mice were treated 3 times every 3 days by PBS (n=5) or UDP (n=5) by intranasal administration. 24 hours after the last treatment mice were sacrificed and right lungs were harvested and analyzed for gene expression by RT-PCR.



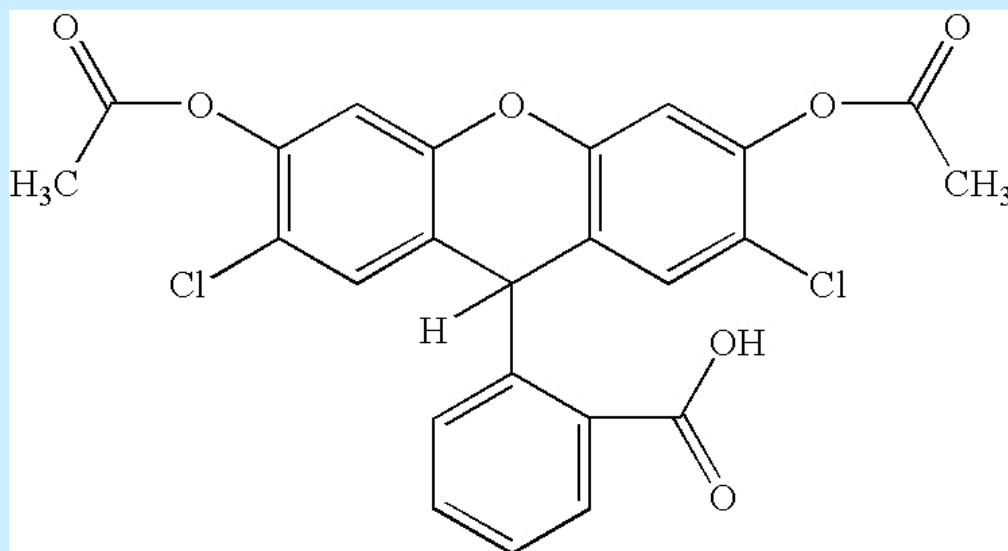
Bioassay Example: Micro-Macrophage Assay

- 24-hour low volume PM_{2.5} samples collected on 47mm Teflon Filters
- Half of the filter extracted in 900 μL
- Filtered through 0.2 μm filter to remove bacteria and/or particulates
- Extracts were combined with 10X salts/glucose media and used for exposure
- Rat Alveolar Macrophage (NR8383)
Bioassays:
 - Formation of Reactive Oxygen Species (ROS)
 - Cell Viability-(LDH release)
 - Cytokine Release

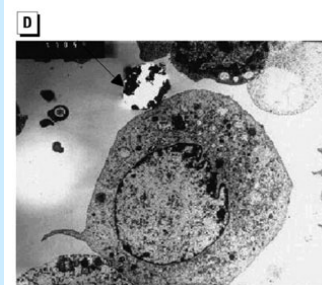
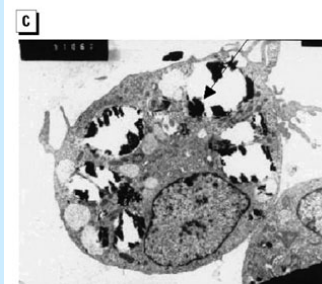
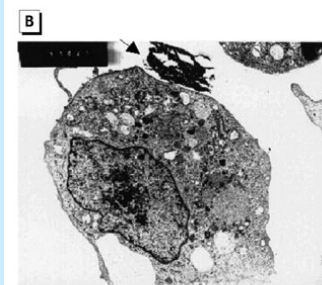
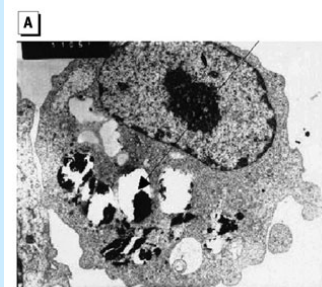


A Macrophage-Based Method for the Assessment of the Reactive Oxygen Species (ROS) Activity of Atmospheric Particulate Matter (PM) and Application to Routine (Daily-24 hr) Aerosol Monitoring Studies

Amy Prasch Landreman, Martin Shafer, Jocelyn Hemming, Michael Hannigan, and James Schauer



2',7'-dichlorodihydrofluorescein diacetate (DCFH-DA, Sigma)



Associations of Primary and Secondary Organic Aerosols With Airway and Systemic Inflammation in an Elderly Panel Cohort

Ralph J. Delfino,^a Norbert Staimer,^a Thomas Tjoa,^a Mohammad Arhami,^{b,c} Andrea Polidori,^b Daniel L. Gillen,^d Steven C. George,^e Martin M. Shafer,^f James J. Schauer,^f and Constantinos Sioutas^b

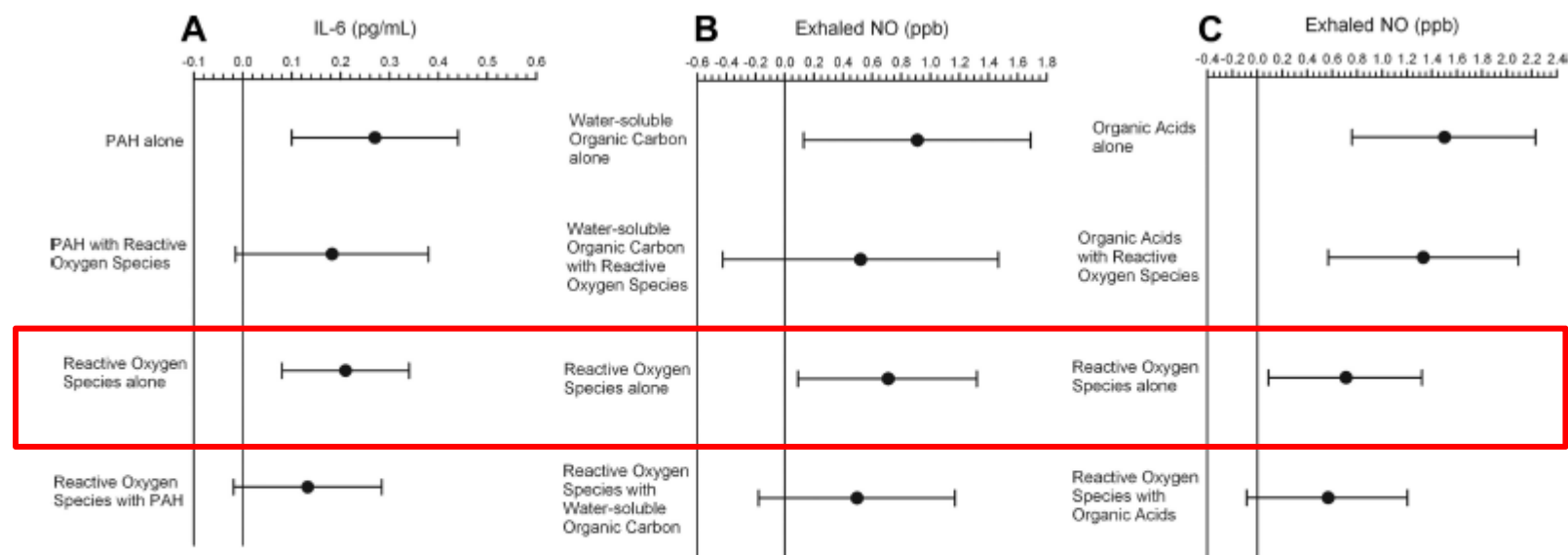


FIGURE 3. Associations of IL-6 and fractional concentrations of exhaled NO with $PM_{0.25}$ chemical components coregressed with macrophage production of reactive oxygen species from $PM_{0.25}$ aqueous extracts. A, IL-6 with polycyclic aromatics hydrocarbons (PAH) and reactive oxygen species. B, Exhaled NO with water-soluble organic carbon and reactive oxygen species. C, Exhaled NO with organic acids and reactive oxygen species. Expected change in the biomarker (adjusted coefficient and 95% CI) corresponds to an interquartile-range increase in the air-pollutant concentration (Table 2), adjusted for temperature.

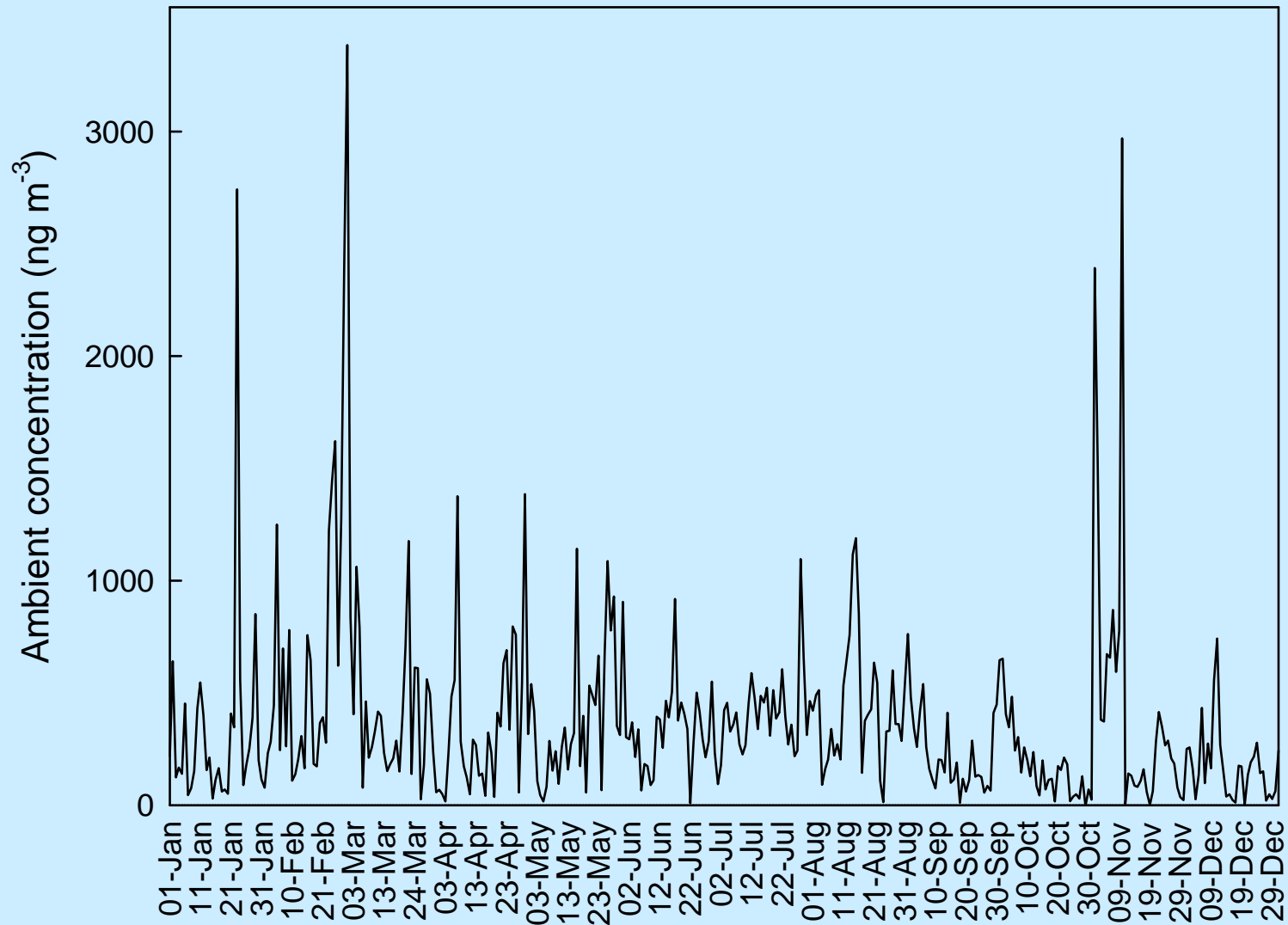


Denver, Colorado ROS Study 2003

- **Sample Collection**
 - Daily PM_{2.5} samplings in Denver for 2003
 - Bulk Chemical Analysis – Not used in this analysis
- **Water Soluble Elements Analysis**
Method: ICP-MS
52 elements: Li, B, Na, ..., Pb, Th, U
- 50 Randomly selected samples analyzed for ROS activity using a micro-macrophage assay



Leachable Sulfur

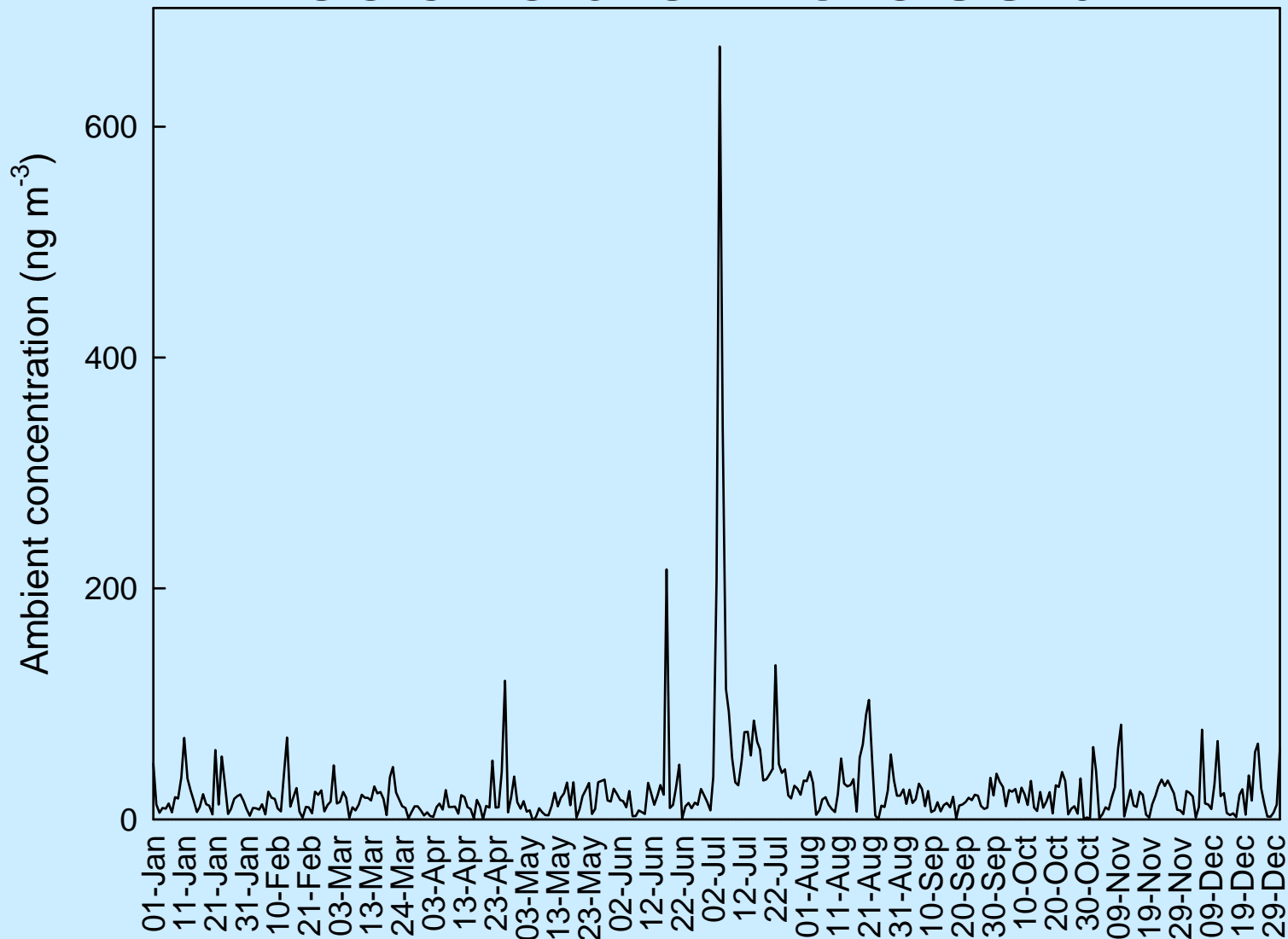


Sampling date in 2003

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Leachable Potassium

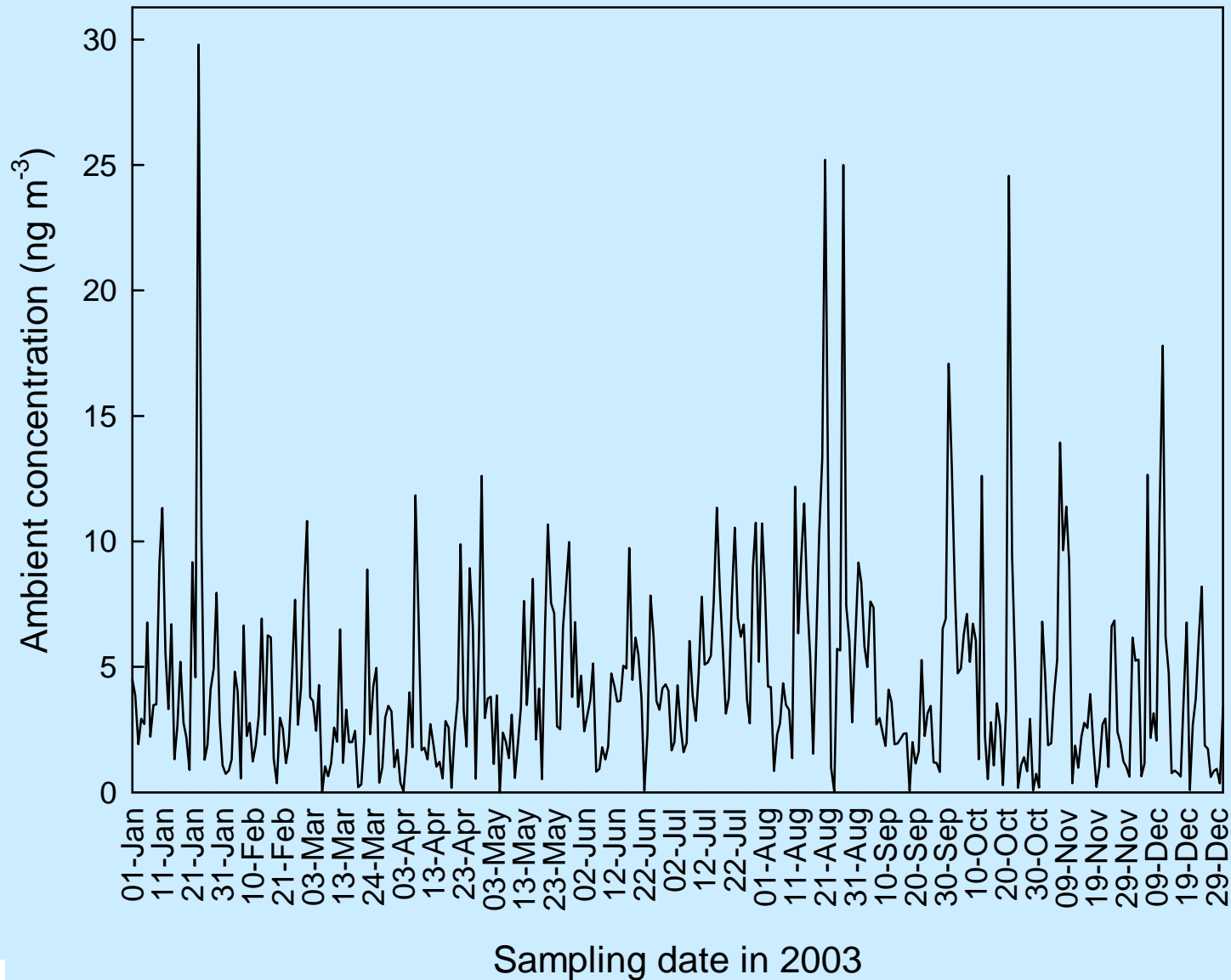


Sampling date in 2003

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Leachable Fe - Denver



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Statistical Method

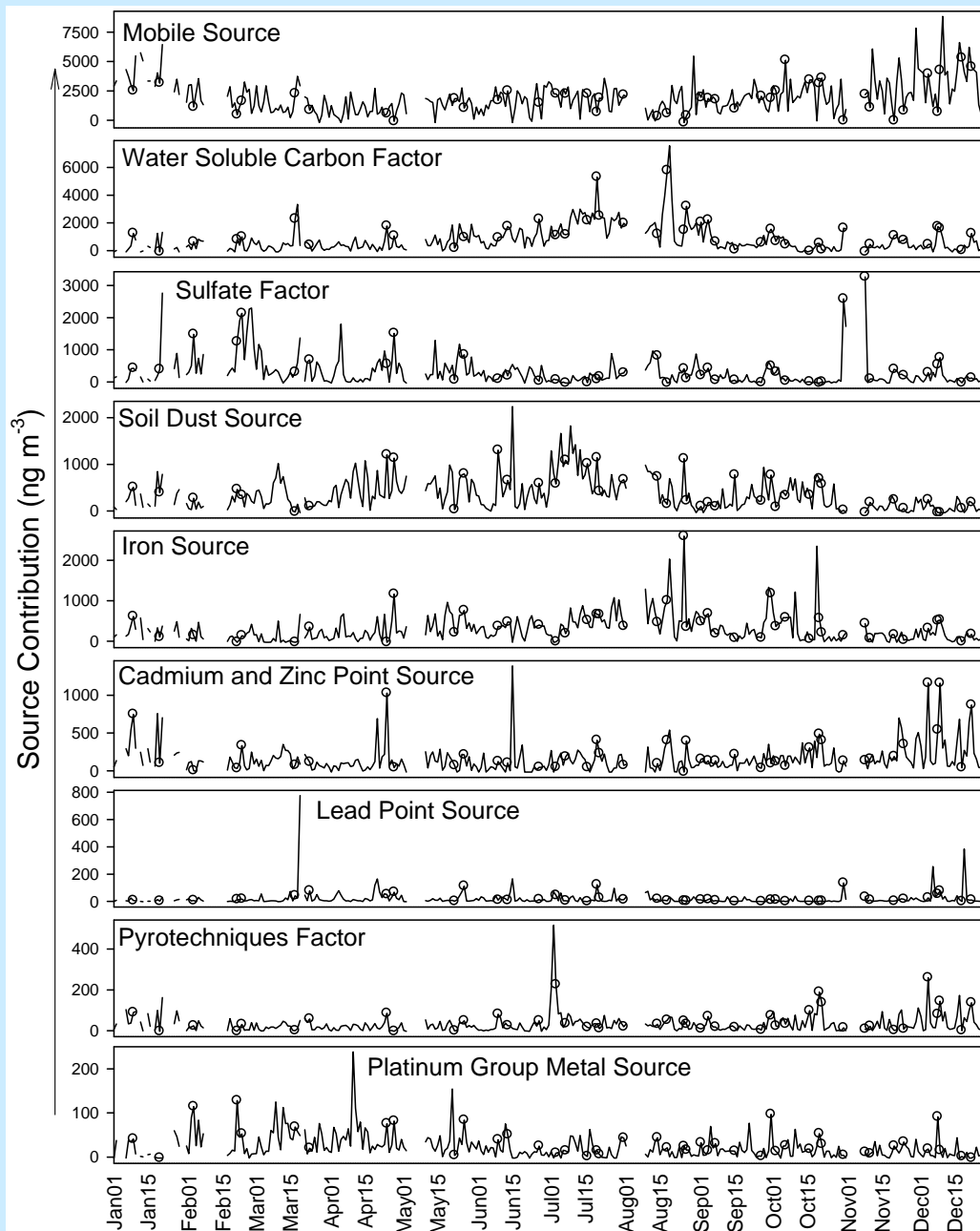
- PMF model

Source apportionment of metals measurements

- Multivariant Regression

Explore ability of metal sources to explain ROS activity



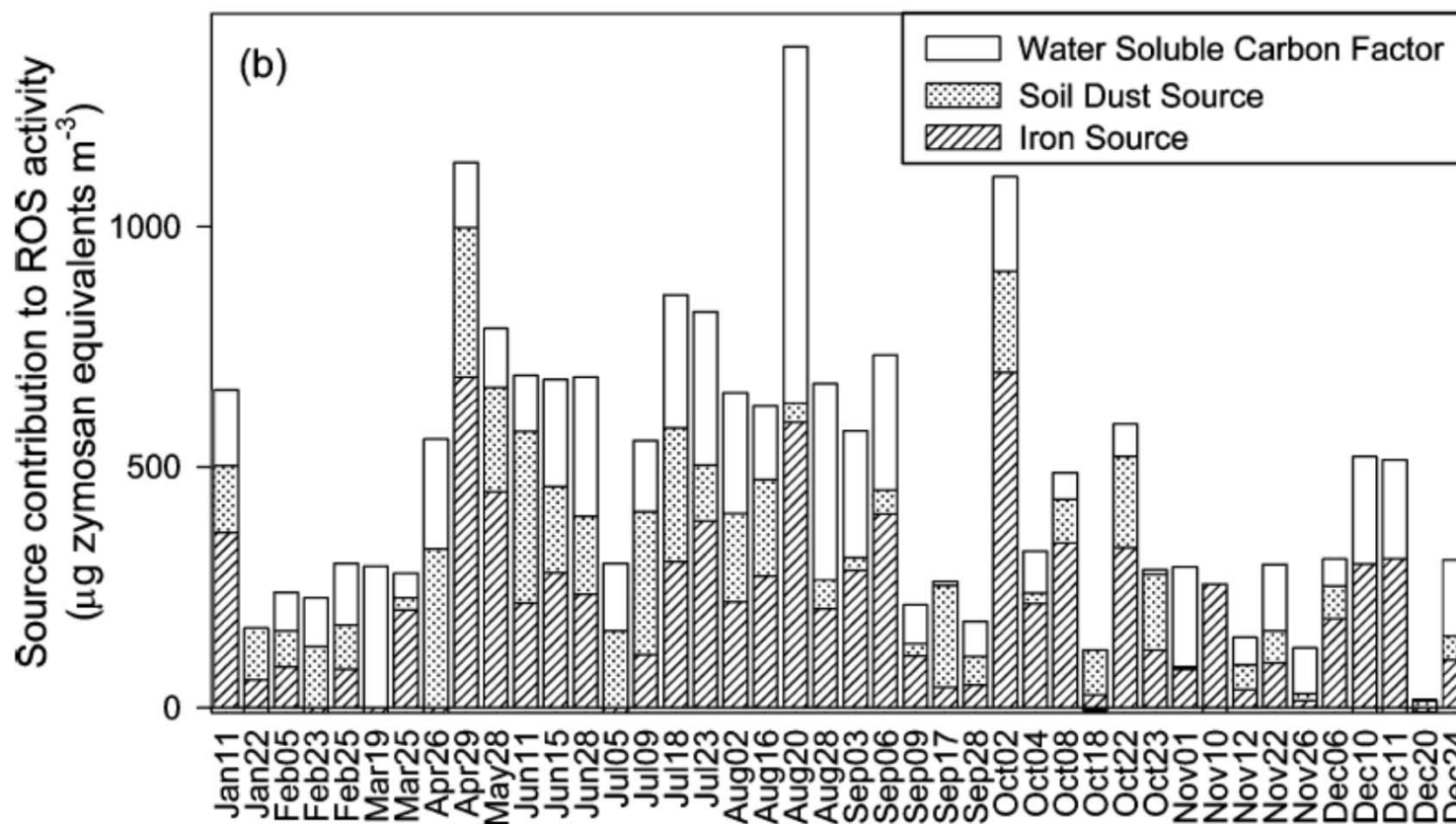


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Source Apportionment of in Vitro Reactive Oxygen Species Bioassay Activity from Atmospheric Particulate Matter

YUANXUN ZHANG,[†]
 JAMES J. SCHAUER,^{*,*,†,‡}
 MARTIN M. SHAFER,^{†,‡}
 MICHAEL P. HANNIGAN,[†] AND
 STEVEN J. DUTTON^{||}





Lahore, Pakistan

- The second biggest city of Pakistan
- Location: 31°34' N, 74°20' E
- Sub-tropical and semi-arid region
- Population: 10,000,000
- Annual temperature: 17.8-30.8 C
- Precipitation: 628.7 mm

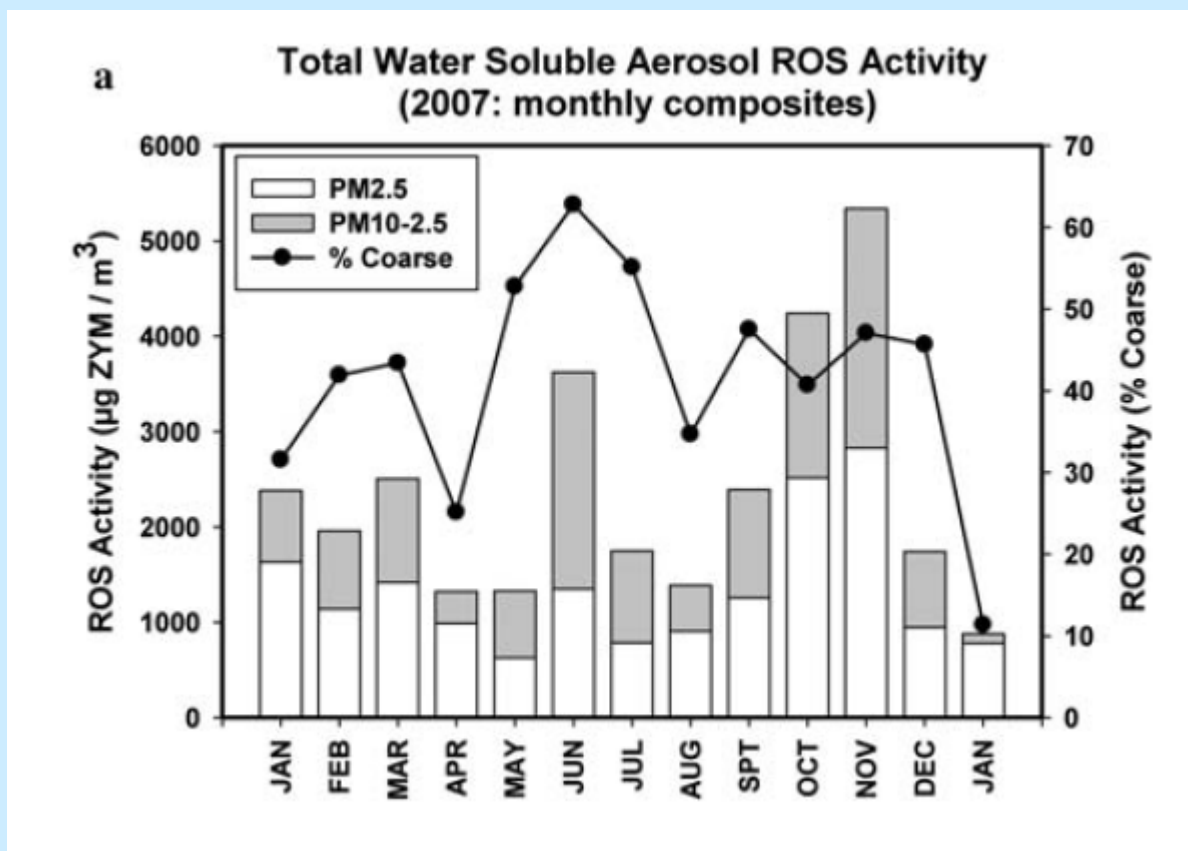


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Reactive oxygen species activity and chemical speciation of size-fractionated atmospheric particulate matter from Lahore, Pakistan: an important role for transition metals†

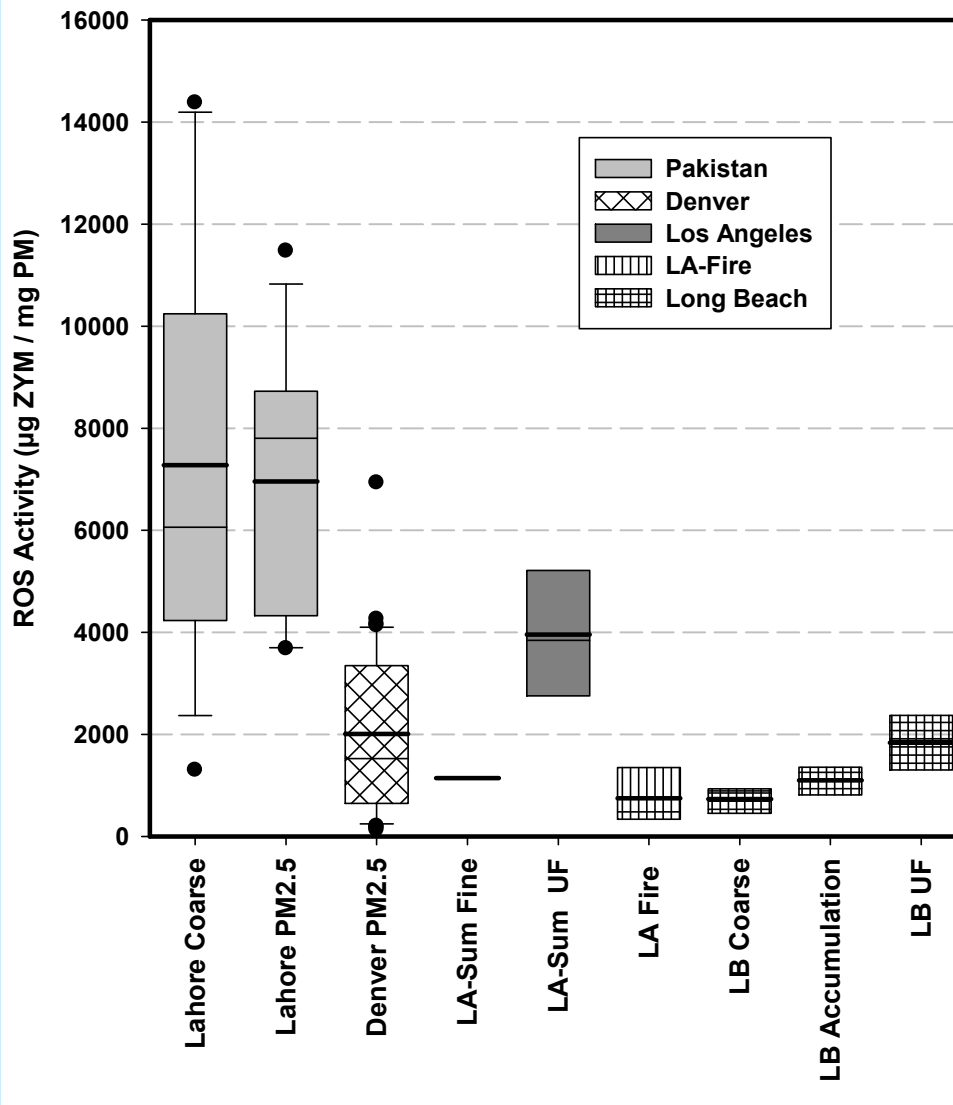
Martin M. Shafer,^{*a} Dawn A. Perkins,^b Dagmara S. Antkiewicz,^b Elizabeth A. Stone,^a Tauseef A. Quraishi^c and James J. Schauer^a



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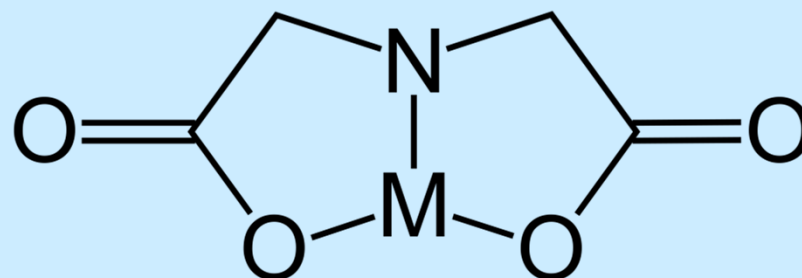


Water Soluble Aerosol ROS Activity Comparison of Aerosol Populations and Size Fractions

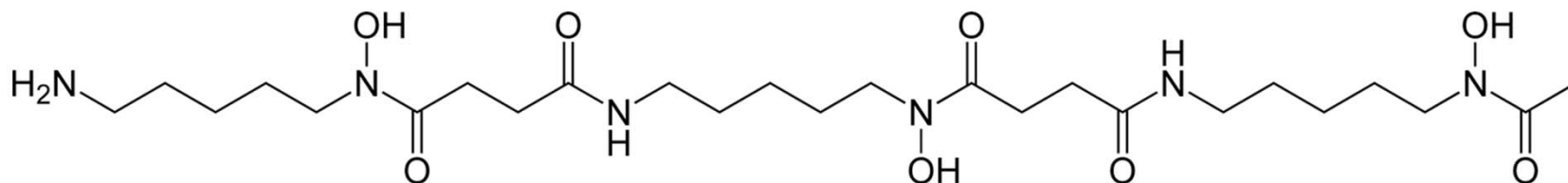


Metal Chelators

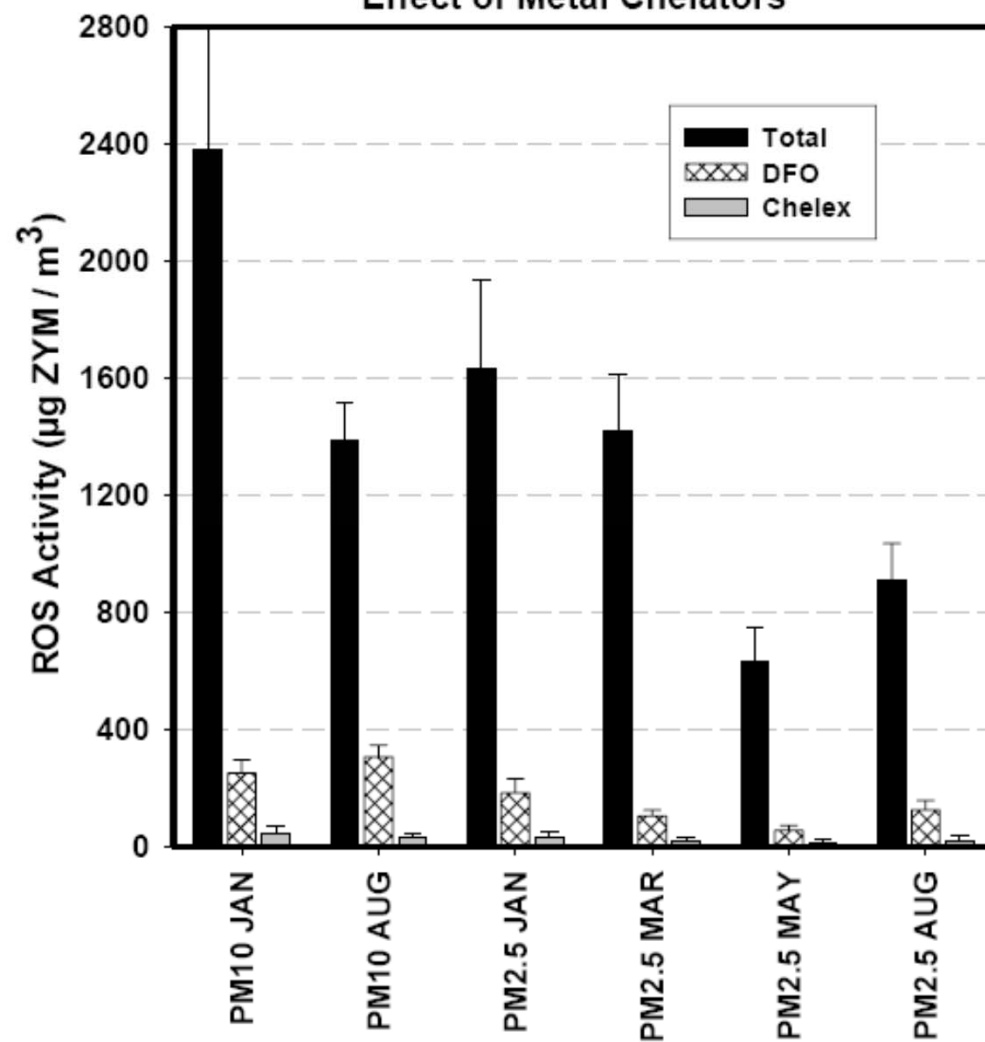
- **Chelex**® - iminodiacetate ligand immobilized on a styrene-divinylbenzene backbone. Removes a large suite of cationic metals, with preference for transition and divalent metals.



- **Desferrioximine (DFO)** – natural siderophore ligand with high specificity for iron.



Water Soluble Aerosol ROS Activity Effect of Metal Chelators



Size-Segregated Inorganic and Organic Components of PM in the Communities of the Los Angeles Harbor

Mohammad Arhami,¹ Markus Sillanpää,¹ Shaohua Hu,¹ Michael R. Olson,² James J. Schauer,² and Constantinos Sioutas¹



FIG. 1. Sampling sites locations.

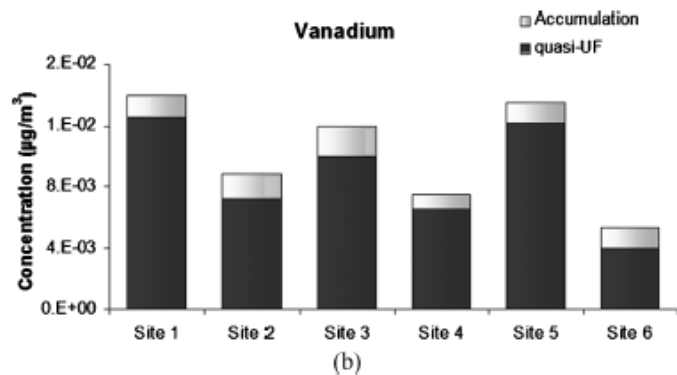
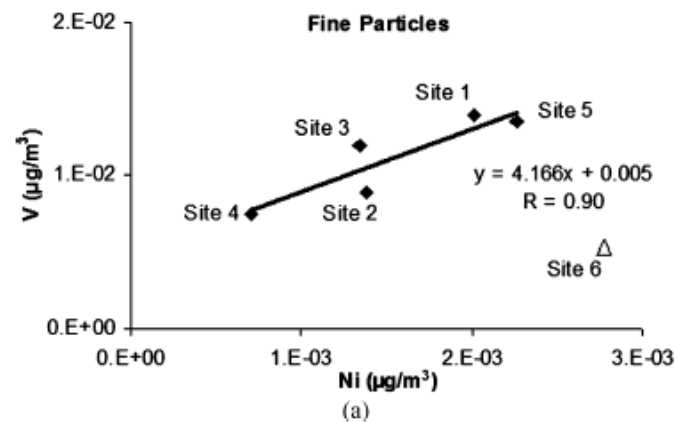


FIG. 8. Vanadium concentrations (a) plotted versus nickel concentrations and (b) measured in quasi-ultrafine and accumulation mode at all the sites.



Conclusions

- Reasonable well established that air pollution exposure is an important contributor to the burden of disease
- Protection of public health relies on the ability to control the air pollution sources that are the biggest contributors to adverse health effects
- The integration of tools for atmospheric sciences, epidemiology, and toxicology are needed to better determine the sources and components of air pollution that are most important to health

