Exposure to Ultrafine Particles in California

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Outline

• UFP metrics
• Source Profiles
• Source Apportionment
• Exposure Assessment Using Regional Models
• Epidemiology
• Conclusions and Future Research Needs
Ultrafine Particle Metrics

- Number, surface area, mass
- Original health hypothesis by Seton and many subsequent studies are based on particle surface area
UFP number is most widely used

- UFP number is easy to measure with commercial instruments but may not be the “best” UFP metric for health effects.

Source: 2013 T. Kuwayama, C.R. Ruehl, and M.J. Kleeman. Daily Trends and Source Apportionment of Ultrafine Particulate Mass (PM0.1) over and Annual Cycle in a Typical California City. Environmental Science and Technology, dx.doi.org/10.1021/es403235c..
Decrease in Concentration of PM with Distance from Freeway higher for smaller particles due to dilution + volatilization

Zhu et al, Atmos Environ, 2002

Haagen Smit Award, Atmospheric Environment, 2012

Data Used by Legislation in State of California, Senate Bill 25 (placement of schools with respect to roadways)
PM0.1 is a much more stable metric.
Dynamometer FTP PM0.1 Emissions Over Time

Light Duty Vehicle Particle Distributions

LEV = Low Emissions Vehicle
TWC = Three Way Catalyst
OCAT = Oxidation Catalyst
NCAT = Non Catalyst
SMOKER = smoking vehicle

FTP = Federal Test Procedure
UC = Unified Cycle
CC = Correction Cycle

Size-Resolved Source Apportionment Near Roadways

Typical Evolution of UFP Source Contributions

A) Roadside
- Diesel, 46 ± 5%
- Gasoline, 44 ± 5%
- Motor Oil, 20 ± 15%
- Meatcook, 67 ± 39%
- Other, 11%

B) Community
- Diesel, 15 ± 10%
- Road Dust, 4 ± 4%
- Motor Oil, 4 ± 1%
- Gasoline, 4 ± 1%
- Wood Burning, 8 ± 5%
- Meatcook, 67 ± 39%
- Unknown, 53 ± 22%

C) Downwind
- Diesel, 8 ± 2%
- Gasoline, 1 ± 0%
- Wood Burning, 12 ± 6%
- Meatcook, 26 ± 14%
- Unknown, 53 ± 22%

Additional Sources
- Diesel, 46 ± 5%
- Gasoline, 44 ± 5%

Additional Aging


Exposure Estimates For Epidemiology

• HEI Perspectives 3 “Understanding the Health Effects of Ambient Ultrafine Particles” surveyed the epidemiology literature
  – No consistent set of studies that link UFP to human health effects
  – Some studies found effects but they were potentially confounded with other pollutants

• Most studies surveyed used UFP number based on monitoring data
  – Similar to strategy that worked for PM2.5, but may not work for UFP

• Would a different UFP metric bring associations into focus?
UFP Gradients are sharper than PM2.5 Gradients

The central site monitor strategy employed for PM2.5 will be difficult to use for UFP

Exposure Estimates Using Regional Chemical Transport Models

\[
\frac{\partial C_i}{\partial t} + \nabla \cdot u C_i = \nabla K \nabla C_i + E_i - S_i + R_i^{\text{gas}}(C) + R_i^{\text{part}}(C) + R_i^{\text{phase}}(C)
\]
Wind Speed Bias Drives PM Bias

Obs 1/u, %

PM Mean Fraction Bias

Obs PM, %
Model Evaluation
PM2.5 EC
Time Series

• 24-h average concentrations

• Dots – measurements
  blue lines – predictions
  red lines – best-fit predictions
  within 12km of monitor

• Major seasonal trends are captured at most sites

• Sharp gradient found at certain locations for certain days

• Missed some winter high concentrations

Reference: (2014) Hu et al., Predicting Primary PM2.5 and PM0.1 Trace Composition for Epidemiological Studies in California. Environmental Science & Technology, 8 (9), pp 4971–4979, doi 10.1021/es404809j
Model Evaluation
PM2.5 OC
Time Series

- Monthly average concentrations
- Dots – measurements, colors - predictions
- Major seasonal trends are captured at most sites
Model Evaluation
PM2.5 EC vs. Obs.
at Diff. Ave. Times

$R^2$: Daily < Biweekly < Monthly < Seasonal < Annual

Model results agree better with measurements at longer averaging times

Reference: (2014) Hu et al., Predicting Primary PM2.5 and PM0.1 Trace Composition for Epidemiological Studies in California. Environmental Science & Technology, 8 (9), pp 4971–4979, doi 10.1021/es404809j
Model Evaluation
PM2.5 Trace Elements

Reference: (2014) Hu et al., Predicting Primary PM2.5 and PM0.1 Trace Composition for Epidemiological Studies in California. Environmental Science & Technology, 8 (9), pp 4971–4979, doi 10.1021/es404809j
## Model Evaluation: MFB(numbers) and R (colors) of Monthly Average EC and Trace Elements at Individual Sites

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PM0.1 EC Source Apportionment

Example Exposure Estimates For PM0.1 EC


Download data from faculty.engineering.ucdavis.edu/kleeman/
Regional Source Apportionment of PM0.1 Mass

Regional Source Apportionment of PM0.1 EC
Download from faculty.engineering.ucdavis.edu/kleeman

PM2.5 Mass
Diesel Engines
Gasoline Engines
Dust
Wood Burning
Meat Cooking
High Sulfur Fuel
Shipping

5 Published Epidemiology Results to Date


Epidemiological Analysis – California Teachers Study

• Cox Proportional Hazards Model with time-varying exposure, similar to Ostro et al. (2015)
• Residential location known through annual follow-ups
• At month $m$ of each death, the average cumulative exposure $x(m)$ for the deceased will be compared to the average pollution exposure for the surviving risk set
• Control for other mortality risk factors including age, race, marital status, smoking, BMI, etc.
• Previous analysis period: 2000 - 2007
<table>
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<th>Cohort</th>
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<td>Amer Cancer Society (National)</td>
<td>Pope (2002)</td>
<td>1.18 (1.14, 1.23)</td>
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<td>Amer Cancer Society (California)</td>
<td>Jerrett (2013)</td>
<td>1.11 (1.05, 1.18)</td>
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<td>Harvard Six Cities</td>
<td>Laden (2006)</td>
<td>1.26 (1.08, 1.47)</td>
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<td>Women’s Health Initiative (Between cities)</td>
<td>Miller (2007)</td>
<td>F: 1.67 (0.98, 2.85)</td>
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<td>Nurses Health Study</td>
<td>Puett (2009)</td>
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<td>Abbey (1999)</td>
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<td>All Canada</td>
<td>Crouse (2012)</td>
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<tr>
<td>CTS (PM &amp; cohort:2000-05)</td>
<td>Orig study</td>
<td>F: 1.20 (1.02, 1.41)</td>
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</table>

CTS Hazard ratios (HR) and 95% CI for IQRs of association of PM0.1 with Ischemic Heart Disease Mortality

Analysis also indicates that PM0.1 mass and each constituent and source provides better fit of the data than does corresponding PM2.5

Epidemiological Analysis – California Preterm Birth Study

- California birth certificate records 2000-2008: 4,370,371 pregnancies
- Infants with unknown gestational age, implausible gestational age, implausible combinations of gestational age & birth weight, or birth defects, were excluded
- 3,870,696 births tracked in study
- Maternal residence from birth certificate assigned as exposure location: average pregnancy exposure for mother
- Nested case-control approach used to analyze associations between air pollution and PTB (infants born at ≤35 weeks)
- For each PTB case, two controls (infants born at ≥37 weeks) with same birth date were randomly selected from the population without replacement
- Control for other PTB risk factors including education, race, BMI, smoking status
Odds Ratio and 95% CI for IQRs of Association of PM0.1 with Preterm Birth

Epidemiological Analysis – California Low Birth Weight Study

• California birth certificate records 2000-2008: 4,370,371 pregnancies
• Infants with normal gestational age (≥37 weeks) included
• 72,632 LBW (infants born ≤2500 grams) births tracked in study
• Maternal residence from birth certificate assigned as exposure location: average pregnancy exposure for mother
• Case cohort approach used to analyze associations between air pollution and LBW For each LBW case, five controls (infants born ≥2500 grams) with same birth date were randomly selected from the population without covariate matching or stratification
• Control for other PTB risk factors including education, race, maternal age, household income
Odds Ratio and 95% CI for IQRs of Association of PM0.1 with Low Birth Weight

9 year average SOA concentrations
9 year average
SOA source contributions
Potential Effect of NOx and Wall Losses

![Bar chart showing the potential effect of NOx and wall losses with different conditions and locations. The chart compares high yield, low yield, high wall loss, and low wall loss scenarios for San Diego, Santa Barbara, Los Angeles, Riverside, San Bernardino, and Orange.](chart.png)
Conclusions

• UFP mass, surface area, and number are different metrics that each have strengths and weaknesses
• Which UFP metric(s) can be measured and best explains unique health effects?
  – Toxicology and Epidemiology evidence needed
• UFP epidemiology is difficult because of sharp spatial gradients
• Epidemiology on UFP mass (PM0.1) shows positive associations with Ischemic Heart Disease, Preterm Birth, and Low Birth Weight
  – Exposure estimated using regional grid models
Future Work

• Unique health effects associated with UFP metrics. Is there an effect distinct from PM2.5?
  – Toxicology and Epidemiology

• Continued improvements for exposure assessments
Acknowledgements

• Funding: CARB, US EPA, NIH, CRC