The Potential of Mobile Monitoring Campaigns to Assess Long-Term Exposure to Ultrafine Particles

Gerard Hoek
Institute for Risk Assessment Sciences
University Utrecht
Overview

- Role of mobile monitoring in assessing long-term average UFP exposure e.g. for epidemiological studies (spatial variation)
- Not other purposes

- Background (UFP, land use regression (LUR))
- Mobile monitoring campaigns
- Merits and limitations
Background UFP

- HEI, 2013 UFP report
- Toxicology: potential health effect
- Epidemiology: somewhat inconsistent results
- No studies on long-term exposure effects
- Exposure assessment main reason
- Challenges of exposure assessment
  - Large small-scale spatial variation
  - Variety of (combustion) sources
  - Monitoring methods
- Only outdoor concentrations, no indoor sources
Assessment UFP spatial variation

- Limited routine monitoring
- Monitoring alone insufficient (large spatial variation versus resolution monitoring)
- Interpolation of measurements (kriging)
- Dispersion modelling (emission factors for UFP)
- Land use regression modelling
Land use regression

- Monitored concentrations at limited number of sites
- Predictor variables near the site (GIS), typically time-invariant
- Development of a (linear) regression model to predict the measured spatial variation
LUR Monitoring campaigns

• Monitoring campaigns for LUR modeling are typically based upon 1-3 repeats of 1-2 weeks duration at 40-100 sites
• All sites simultaneous for NO$_2$ (passive samplers)
• For PM groups of sites simultaneous (temporal issue)
LUR monitoring and UFP

• Typical approach not practical for UFP
  o Equipment cost
  o Equipment supervision
• -> Mobile campaigns with short supervised monitoring at many sites
• Other reasons for mobile monitoring:
  • Cost-effectiveness
  • Large number of sites improves robustness of models
More sites lead to more robust LUR models. Wang, EST2012
Mobile Monitoring of Particle Light Absorption Coefficient in an Urban Area as a Basis for Land Use Regression

TIMOTHY LARSON, SARAH B. HENDERSON, AND MICHAEL BRAUER


- 39 intersections
- 8 days, peak afternoon
- Conventional car
- Model $R^2$ 54-72%
• 50 sites in Amsterdam
• 1-week measurements façade
• CPC3022a
• 1 home per week
• Reference site
TABLE 2. Land Use Regression Model for Particle Number Concentration (cm\(^{-3}\))

<table>
<thead>
<tr>
<th>Feature</th>
<th>Regression Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>intercept</td>
<td>14491</td>
<td>(3165)</td>
</tr>
<tr>
<td>product T.I. and inverse distance squared</td>
<td>29523</td>
<td>(3795)</td>
</tr>
<tr>
<td>address density, 300 m</td>
<td>10266</td>
<td>(3839)</td>
</tr>
<tr>
<td>port, 3000 m</td>
<td>6059</td>
<td>(3421)</td>
</tr>
</tbody>
</table>

\(^a\) regression slopes multiplied by the difference between the 10th and 90th percentile for each of the three predictors (1102, 2653, and 4149780), intercept directly from model. The \(R^2\) of the model was 0.67 (adjusted \(R^2 = 0.65\)). T.I. is traffic intensity.
Estimation of ultrafine particle concentrations at near-highway residences using data from local and central monitors

Christina H. Fuller\textsuperscript{a,b,*}, Doug Brugge\textsuperscript{c}, Paige L. Williams\textsuperscript{d}, Murray A. Mittleman\textsuperscript{e,f}, John L. Durant\textsuperscript{g}, John D. Spengler\textsuperscript{a}

Atmospheric Environment 57 (2012) 257–265

- Boston area
- 18 homes
- 1-3 weeks monitoring
- WCPC 3781
- Reference sites

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Model 4: SPH and MAC sites</th>
<th>% Change</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log(\text{UFP}_{\text{SPH}})$\textsuperscript{a}</td>
<td></td>
<td>0.4</td>
<td>0.1, 0.8</td>
</tr>
<tr>
<td>$\log(\text{UFP}_{\text{MAC}})$\textsuperscript{a}</td>
<td></td>
<td>6</td>
<td>6, 7</td>
</tr>
<tr>
<td>Distance to highway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1000 m (ref)</td>
<td></td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>100–400 m</td>
<td></td>
<td>34</td>
<td>–0.7, 81</td>
</tr>
<tr>
<td>&lt;100 m</td>
<td></td>
<td>77</td>
<td>25, 149</td>
</tr>
<tr>
<td>Wind speed (m s$^{-1}$)</td>
<td></td>
<td>–6</td>
<td>–7, –4</td>
</tr>
<tr>
<td>Wind direction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southeast (ref)</td>
<td></td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>West</td>
<td></td>
<td>8</td>
<td>1, 14</td>
</tr>
<tr>
<td>Northwest</td>
<td></td>
<td>–6</td>
<td>–12, –0.4</td>
</tr>
<tr>
<td>East</td>
<td></td>
<td>–27</td>
<td>–31, –23</td>
</tr>
<tr>
<td>Traffic volume (veh h$^{-1}$)</td>
<td></td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>&lt;5340 (ref)</td>
<td></td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5340–8630</td>
<td></td>
<td>12</td>
<td>7, 18</td>
</tr>
<tr>
<td>&gt;8630</td>
<td></td>
<td>6</td>
<td>–0.5, 13</td>
</tr>
<tr>
<td>Precipitation (yes/no)</td>
<td></td>
<td>–8</td>
<td>–12, –4</td>
</tr>
<tr>
<td>Hour (sine)</td>
<td></td>
<td>–14</td>
<td>–16, –12</td>
</tr>
<tr>
<td>Hour (cosine)</td>
<td></td>
<td>–8</td>
<td>–11, –4</td>
</tr>
<tr>
<td>AIC</td>
<td></td>
<td>3886</td>
<td></td>
</tr>
</tbody>
</table>
Spatial distribution of ultrafine particles in urban settings: 
A land use regression model

Marcela Rivera a,b,c,*, Xavier Basagaña a,b, Inmaculada Aguilera a,b,d, David Agis a,b, Laura Bouso e, Maria Foraster a,b,c,d, Mercedes Medina-Ramón a, Jorge Pey e, Nino Künzli f,g, Gerard Hoek h

Atmospheric Environment 54 (2012) 657–666

- 644 sites sidewalk
- 15 minutes monitoring
- Daytime, no rush hour
- Single measurement
- PTRAK
- NOX routine site for temporal variation

Fig. 1. Monitoring locations. Points represent monitoring locations.

<table>
<thead>
<tr>
<th>Core model</th>
<th>Coef.</th>
<th>P &gt; t</th>
<th>[95% CI]</th>
<th>$R^2_A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy, light and motorcy. veh in 24 h (veh/9726)</td>
<td>0.433</td>
<td>&lt;0.001</td>
<td>0.35</td>
<td>0.52</td>
</tr>
<tr>
<td>Area of high density residential land within 1000 m (m²/1930508)</td>
<td>0.355</td>
<td>&lt;0.001</td>
<td>0.20</td>
<td>0.51</td>
</tr>
<tr>
<td>Distance to intersection of two major roads (m/904)</td>
<td>−0.21</td>
<td>&lt;0.001</td>
<td>−0.28</td>
<td>−0.13</td>
</tr>
<tr>
<td>Household density within 100 m (number/184)</td>
<td>0.144</td>
<td>0.008</td>
<td>0.04</td>
<td>0.25</td>
</tr>
<tr>
<td>Constant</td>
<td>8.679</td>
<td>&lt;0.001</td>
<td>8.56</td>
<td>8.79</td>
</tr>
</tbody>
</table>

$R^2_A = 0.36$
Repeated measurements at 25 sites

Model for these 25 sites:
- Single 47%
- Average two 72%
A Land Use Regression Model for Ultrafine Particles in Vancouver, Canada

Rebecca C. Abernethy,† Ryan W. Allen,‡ Ian G. McKendry,§ and Michael Brauer∗,†


• 80 sites
• Single measurement
• 60 minutes per site
• Median and 90th percentile
• Four reference sites to correct for temporal variation
Table 2. LUR Models Developed for PNC in Greater Vancouver

<table>
<thead>
<tr>
<th>model</th>
<th>concentration metric</th>
<th>traffic variable type</th>
<th>buffer type</th>
<th>variables</th>
<th>coefficients (SE) (pt/cm³ or ln-pt/cm³)</th>
<th>partial R² model R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PNC₅₀</td>
<td>road length</td>
<td>circular</td>
<td>truck route length (50 m buffer)</td>
<td>150800 (25200)</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>distance to port (ln km)</td>
<td>-3000 (900)</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fast food site density (200 m buffer)</td>
<td>3700 (1700)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>intercept</td>
<td>17700 (2500)</td>
<td>model 0.48</td>
</tr>
</tbody>
</table>

Legend

- Water
- pnc_50 (pt/cm³)

<VALUE>

- 5000 - 10,000
- 10,000 - 15,000
- 15,000 - 25,000
- 25,000 - 35,000
- 35,000 - 60,000
- 60,000 - 85,000

Port
Klompmaker STOTEN 2015: MUSIC study.

- Amsterdam and Rotterdam
- 160 sites, 30 minutes per site
- Three repeats per site (season)
- Traffic and background sites each route
- Single UFP reference site + routine NO$_2$ + weather
- On-road mobile monitoring -> electric car
Walking routes (3 hr)
- 3 weeks
- CPC3781
- model $R^2$ 0.24-0.32
- Meteo + distance to main roads
## LUR models from UFP mobile and short-term sampling campaigns

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location</th>
<th>Design</th>
<th>Model type</th>
<th>Model $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zwack, 2011</td>
<td>Brooklyn, NY</td>
<td>Mobile monitoring along fixed walking routes (~3 hour per route)</td>
<td>Spatiotemporal</td>
<td>0.22–0.32</td>
</tr>
<tr>
<td>Rivera, 2012</td>
<td>Girona, Spain</td>
<td>Single 15-minute measurement at 644 sites.</td>
<td>Spatial</td>
<td>0.36</td>
</tr>
<tr>
<td>Abernethy, 2013</td>
<td>Vancouver, Canada</td>
<td>Single 60-minute measurement at 80 sites.</td>
<td>Spatial</td>
<td>0.29–0.53</td>
</tr>
<tr>
<td>Saraswat, 2013</td>
<td>New Delhi, India</td>
<td>Single 1-3 hour measurement at 39 sites.</td>
<td>Spatiotemporal</td>
<td>0.23–0.28</td>
</tr>
<tr>
<td>Patton, 2014</td>
<td>Somerville, MA</td>
<td>Mobile monitoring car driving on 43 days (3-6 hr per day)</td>
<td>Spatiotemporal</td>
<td>0.41–0.43</td>
</tr>
<tr>
<td>Ragettli, 2014</td>
<td>Basel, Switzerland</td>
<td>Three 20-minute measurements at 60 sites.</td>
<td>Spatiotemporal</td>
<td>0.58–0.68*</td>
</tr>
<tr>
<td>Sabaliauskas, 2015</td>
<td>Toronto, Canada</td>
<td>Mobile monitoring walking, 112 road segments. Three days summer 2008</td>
<td>Spatial</td>
<td>0.72</td>
</tr>
<tr>
<td>Weichental, 2015</td>
<td>Toronto, Canada</td>
<td>Mobile monitoring three cars, 405 road segments, three weeks</td>
<td>Spatial</td>
<td>0.67</td>
</tr>
<tr>
<td>Montagnge, submitted</td>
<td>Amsterdam, Rotterdam</td>
<td>Three 30-minutes measurements at 161 sites.</td>
<td>Spatial</td>
<td>0.33–0.42</td>
</tr>
</tbody>
</table>

*Universiteit Utrecht*
Why low explained variance?

Klompmaker, STOTEN 2015:
Within to between site concentration variance ratios

<table>
<thead>
<tr>
<th>Project</th>
<th>Duration</th>
<th>Repeat</th>
<th>Time corr.</th>
<th>No time corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUSIC</td>
<td>30 minutes</td>
<td>3</td>
<td>2.17</td>
<td>2.21</td>
</tr>
<tr>
<td>RUPIOH</td>
<td>24 hour</td>
<td>3</td>
<td>0.31</td>
<td>0.50</td>
</tr>
<tr>
<td>MUSiC</td>
<td>30 minutes</td>
<td>3</td>
<td>2.44</td>
<td>3.25</td>
</tr>
<tr>
<td>VE$^3$SPA</td>
<td>96 hour</td>
<td>6</td>
<td>0.69</td>
<td>2.55</td>
</tr>
<tr>
<td>ESCAPE</td>
<td>14 days</td>
<td>3</td>
<td>0.09</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Low explained variance

- Much larger temporal variation in concentration data than in longer duration campaigns
- Not accounted for by reference site
- Consequences?
- Measurement error in dependent variable
  - Low model $R^2$ Unbiased regression coefficients -> correct and robust model
Amsterdam UFP, BC and PM$_{2.5}$ spatial patterns. EST 2011.
Merits

• Promising tool for UFP
• Large number of locations -> robustness model and diverse sources
• Cost-effective
• Not exclusively for traffic
  • Amsterdam + Vancouver model: port
  • Vancouver model: fats food restaurants
  • Toronto model: airport
• Spatiotemporal models can be developed
• Other applications (Brantley et al, 2014)
Limitations and challenges

• More validation needed with external data to test robustness
• Temporal variation
  • Reference site
  • Route design
  • Repeats
• Often daytime concentrations on weekdays...
• Mobile versus short-term campaigns (local exhaust)
• Translation of on-road mobile to residential exposures
Limitations and challenges

- LUR model development (# sites, predictors, not too empirical)
- Pollution metric (mean, median, ...)

Universiteit Utrecht