A modelling system for predicting urban PM$_{2.5}$ concentrations. Numerical results and evaluation against the data in Helsinki

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1. Aims

2. The measurements

3. The modelling system
   • Emission modelling
   • Dispersion modelling
   • Background modelling

4. Results and Conclusions
   • spatial concentration distributions
   • comparison with measurements
   • problems & further work
Aims

Development and validation of a modelling system for predicting urban PM$_{2.5}$ concentrations
Measurements

- YTV – monitoring network (continuous)
- EMEP stations (continuous)
- Measurement campaigns
# PM MONITORING SITES in HELSINKI METROPOLITAN AREA

<table>
<thead>
<tr>
<th>Site</th>
<th>Site type</th>
<th>Vehicles / day</th>
<th>Distance from street</th>
<th>Measured average hourly quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Töölö</td>
<td>Urban traffic</td>
<td>12 000 - 25 000</td>
<td>5 m</td>
<td>PM$_{10}$</td>
</tr>
<tr>
<td>Vallila</td>
<td>Urban traffic</td>
<td>14 000</td>
<td>14 m</td>
<td>PM$<em>{2.5}$ &amp; PM$</em>{10}$</td>
</tr>
<tr>
<td>Leppävaara</td>
<td>Suburban traffic</td>
<td>15 000 - 61 000</td>
<td>25 m</td>
<td>PM$_{10}$</td>
</tr>
<tr>
<td>Kallio</td>
<td>Urban background</td>
<td>8000</td>
<td>80 m</td>
<td>PM$<em>{2.5}$ &amp; PM$</em>{10}$ since ‘99</td>
</tr>
<tr>
<td>Luukki</td>
<td>Regional background</td>
<td>4000</td>
<td>800 m</td>
<td>PM$_{10}$</td>
</tr>
</tbody>
</table>
Modelling systems (FMI)

NWP models
- ECMWF
- HIRLAM
  - Atlantic
  - North-Europe
  - LINUX

UAP models - LRT, regional
- MATCH (SMHI)
  - LRT, meso
- HILATAR
  - LRT, meso
- SILAM
  - LRT, meso, radioactivity
- BUOYANT
  - meso, micro, fires

UAP models - urban, local
- CAR-FMI, roadside
- UDM-FMI, urban
- OSPM (NERI), street canyon
- EXPAND (FMI, YTV)
  - population exposure
- ESCAPE, chemical accidents
- MONO32 (U Helsinki)
  - aerosol processes

Geographical information
- MapInfo

Emission characteristics
- Measurements
- Meteorology, traffic, pollution

Traffic simulation
- Macro-EMME/2 (YTV)
- Micro-HUTSIM (TKK)

Emission inventories
- VTT, LIISA
- Cornair

Weather prediction, met. pre-processing
- HIRLAM, MPP-FMI

Dispersion of pollutants
- stationary sources: UDM-FMI
- roadside: CAR-FMI
- street canyon: OSPM (NERI)
- forecasting air quality: API-FMI

Activity Model

Exposure model

Statistical Analysis

GIS
- MapInfo

Visualisation

MM5 ?

9th Harmonisation Conference
Garmisch-Partenkirchen
02/06/2004

Harmo 9, Ari Karppinen
Model for urban fine particles

\[ \text{PM}_{2.5}(r,t) = \text{PM}_{2.5}^{tr}(r,t) + \text{PM}_{2.5}^{st}(r,t) + \text{PM}_{2.5}^{bg}(t) \]

- \( \text{PM}_{2.5}(r,t) \): total measured concentration at time \( t \), at spatial coordinate \( r \)
- \( \text{PM}_{2.5}^{tr}(r,t) \): vehicular traffic (exh+non-exh)
- \( \text{PM}_{2.5}^{st}(r,t) \): stationary sources
- \( \text{PM}_{2.5}^{bg}(t) \): background (LRT)
Assumptions:

- Exhaust traffic emissions purely PM$_{2.5}$
- Other traffic related emissions are directly proportional to exhaust emissions
- Regional and long-range transported background purely PM$_{2.5}$
- Ion-sum is a good proxy for LRT
Most important model components

1. Emission model for PM$_{2.5}$
   - **coldstarts** taken into account
2. Roadside dispersion model CAR-FMI
3. Statistical model for regional and long-range transported PM$_{2.5}$
Daily averaged PM$_{2.5}$ line source emissions (kg/d/km) in the Helsinki Metropolitan Area in 2002
Daily averaged PM$_{2.5}$ line source emissions (kg/d/km) in the Helsinki Metropolitan Area in 2002

Saturday
Daily averaged PM$_{2.5}$ line source emissions (kg/d/km) in the Helsinki Metropolitan Area in 2002

Sunday

- 3 to 7.9
- 1 to 3
- 0.5 to 1
- 0.1 to 0.5
- 0 to 0.1

Kilometres
Daily averaged cold start emissions of PM$_{2.5}$ (kg/d/km$^2$) in the Helsinki Metropolitan Area in 2002

T > 0°C
Weekday

T < 0°C, 41% preheating
Weekday
Daily averaged cold start emissions of PM$_{2.5}$ (kg/d/km$^2$) in the Helsinki Metropolitan Area in 2002

- T > 0°C
- Saturday

- T < 0°C, 41% preheating
- Saturday

Daily averaged cold start emissions of PM$_{2.5}$ (kg/d/km$^2$) in the Helsinki Metropolitan Area in 2002
Daily averaged cold start emissions of PM$_{2.5}$ (kg/d/km$^2$) in the Helsinki Metropolitan Area in 2002

T > 0°C
- Sunday

T < 0°C, 41% preheating
- Sunday

Daily averaged cold start emissions of PM$_{2.5}$ (kg/d/km$^2$) in the Helsinki Metropolitan Area in 2002.
Annual average PM$_{2.5}$ concentrations (µg/m$^3$) in the Helsinki Metropolitan Area in 2002

- Solely exhaust emissions from local traffic
- All emissions from local traffic
Annual average PM$_{2.5}$ concentrations (µg/m³) in the Helsinki Metropolitan Area in 2002

All local emissions and regional background

- > 10
- 9 to 10
- 8 to 9
- 7 to 8
- < 7

Kilometres
Maximum hourly PM$_{2.5}$ concentrations (µg/m$^3$) in the Helsinki Metropolitan Area in 2002

Solely exhaust emissions from local traffic

All emissions from local traffic

Maximum hourly PM$_{2.5}$ concentrations (µg/m$^3$) in the Helsinki Metropolitan Area in 2002

Harmo 9, Ari Karppinen 02/06/2004
Maximum hourly PM$_{2.5}$ concentrations (µg/m$^3$) in the Helsinki Metropolitan Area in 2002

All local emissions and regional background

- > 100
- 80 to 100
- 60 to 80
- 40 to 60
- < 40

Kilometres
Predicted vs. observed daily mean PM$_{2.5}$ concentrations in Helsinki in 2002

- Computations by mainframe version of CAR-FMI line source model
- Observations from YTV monitoring stations at Vallila and Kallio
Location of YTV monitoring stations
Predicted vs. observed daily mean PM$_{2.5}$ concentrations – scatter plot & IA

**VALLILA**
- \( y = 0.97x - 0.75 \)
- \( R^2 = 0.57 \)

**KALLIO**
- \( y = 0.95x + 1.02 \)
- \( R^2 = 0.60 \)

**VALLILA**: \( R^2 = 0.57 \), IA = 0.84

**KALLIO**: \( R^2 = 0.60 \), IA = 0.86
Predicted vs. observed daily mean PM$_{2.5}$ concentration in **Vallila** – scatter plot in terms of wind direction

Downwind < 180 deg

Upwind > 180 deg

\[ y = 1.07x - 0.69 \quad R^2 = 0.63 \]

\[ y = 0.94x - 1.19 \quad R^2 = 0.57 \]
Predicted and observed daily mean PM$_{2.5}$ concentrations in Vallila – seasonal variation

**Winter (January, February, December)**

- **PM$_{2.5}$ (µg/m$^3$)**
  - Predicted: [Data points]
  - Observed: [Data points]

**Spring (March, April, May)**

- **PM$_{2.5}$ (µg/m$^3$)**
  - Predicted: [Data points]
  - Observed: [Data points]

**Summer (June, July, August)**

- **PM$_{2.5}$ (µg/m$^3$)**
  - Predicted: [Data points]
  - Observed: [Data points]

**Autumn (September, October, November)**

- **PM$_{2.5}$ (µg/m$^3$)**
  - Predicted: [Data points]
  - Observed: [Data points]
Predicted and observed daily mean PM$_{2.5}$ concentrations in Kallio – seasonal variation
Conclusions

- Modelling system has been developed for urban PM$_{2.5}$
  - Applicable also for other European cities (emission coefficients country-specific)
  - Includes also the evaluation of regional background PM$_{2.5}$

- Spatial concentration distributions of PM$_{2.5}$
  - The influence of traffic and LRT on total concentrations
  - The annual average, maximum hourly and guideline concentrations

- Evaluation of the model performance against the results of the urban monitoring network
  - Good statistical agreement of the predicted and measured daily concentrations
Challenges for future research

• PM emission modelling – especially non-combustion and cold start emissions, and suspension (studied in SAPHIRE, OSCAR)
• The contribution of LRT is important – Direct regional PM$_{2.5}$ measurements would be welcome; continental scale PM modelling
• Modelling of the aerosol processes, including size distributions and chemical composition (studied in SAPHIRE)
References


This is the end …

CREDITS

Academy of Finland
FMI Dispersion Modelling Group
YTV Environmental Office