H14-104: Improvement of a simple dispersion model for calculations of urban background concentrations

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Outline

- Motivation
- Model description
- Improvements
- Validation against measurements
Cold weather conditions in Sweden affect the Air Quality

Mean temperature below 0°C in winter

Slippery roads and need of anti-skid treatment
⇒ road wear and resuspension of road dust

Need of heating
⇒ emissions from residential wood combustion
Cold weather conditions in Sweden affect the Air Quality

Stability plays an important role for Swedish conditions with cold winters and small towns.

Mean temperature below 0°C in winter

Difficulties for models to reproduce the highest concentration peaks
The Swedish national web based Air Quality model system SIMAIR

- Tool for evaluation of compliance with EU Air Quality Directive.
- Can be used by all Swedish municipalities to calculate air pollution levels.
- Coupled model system, with databases and dispersion models on regional, urban and local scale.
- Emission data from EMEP, SMED and ARTEMIS.
- Meteorological data from the routine objective analysis system Mesan.
- Yearly updates

References:
The Swedish national web based Air Quality model system SIMAIR


The model system is applied for more than 150 Swedish cities and towns.
The Swedish national web based Air Quality model system SIMAIR

In this study, the model calculating urban background contributions, is improved.

References:
Model description of SWE-BUM

SWE-BUM

- Model for urban background contributions.
- Contributions from ground-level emission sources are calculated by a simple trajectory model using an adjoint approach, similar to the model developed for Copenhagen (Berkowicz, 2000).
- Spatial resolution: 1 km x 1 km
- Temporal resolution: 1 h

Reference:
Model description of SWE-BUM

SWE-BUM

- Model for urban background contributions.
- Contributions from ground-level emission sources are calculated by a simple trajectory model using an adjoint approach, similar to that developed for Copenhagen (Berkowicz, 2000).
- Spatial resolution: 1 km x 1 km

However, the model seems to underestimate the concentrations in comparison with measurements in Sweden.

Reference:

Improvements:
correction of meteorology to represent urban conditions

\[
\begin{align*}
    u(z)_{urban} &= \frac{u_{*urban}}{k} \left( \ln \left( \frac{Z}{Z_{0 urban}} \right) - \Psi \left( \frac{Z}{L_{urban}} \right) + \Psi \left( \frac{Z_{0 urban}}{L_{urban}} \right) \right)
\end{align*}
\]

- The meteorology in the routine objective analysis system (Mesan) can be regarded as representing rural conditions.
- Hence, it is important to adopt a correction of the meteorology to represent urban conditions.
- This is done by means of Monin-Obukov’s similarity theory.
Improvements:
correction of meteorology to represent urban conditions

\[ u(z)_{urban} = \frac{u_{*urban}}{k} \left( \ln \left( \frac{Z}{Z_0_{urban}} \right) - \Psi_m \left( \frac{Z}{L_{urban}} \right) + \Psi_m \left( \frac{Z_0_{urban}}{L_{urban}} \right) \right) \]

- The meteorology in the routine objective analysis system (Mesan) can be regarded as representing rural conditions.
- Hence, it is important to adopt a correction of the meteorology to represent urban conditions.
- This is done by means of Monin-Obukov’s similarity theory.

The effects of implementing a correction of meteorology according to above. Example for a town in northern Sweden (Umeå), where Mesan and corrected wind speeds are compared with measurements.
Improvements: a simple stability parameterisation of $\sigma_z$

A sensitivity study has been carried out

- The vertical dispersion parameter $\sigma_z$ is the most important parameter affecting the concentrations of NO$_2$. 

Testing $\sigma_z$ with a constant value of 50 m, 20 m and 10 m.
Improvements:  

a simple stability parameterisation of $\sigma_z$

$$\sigma_z(x) = h_0 + (h_{mix} - h_0)(1 - e^{-\frac{\beta \cdot \tau_{w} \cdot x}{u(h_{mix} - h_0)}})$$

Variation of $\sigma_z$ with distance

- It is rather similar to Brigg’s formulas for open county conditions (see curves C-F).
- However, for a winter month in a town in northern Sweden, more stable conditions are expected.

A simple stability parameterisation is introduced

$$L \leq 0 \quad \beta = 1$$

$$L > 0 \quad \beta = \frac{1}{1 + \frac{20z}{L}}$$
Validation against measurements

Monitoring stations

- The model has been validated against NO$_2$ measurement data, for 13 urban background stations in different parts of Sweden.
- The measurements have been carried out by the municipalities.

<table>
<thead>
<tr>
<th>City</th>
<th>Station name</th>
<th>Location</th>
<th>Instrument type</th>
<th>Measuring period</th>
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<tbody>
<tr>
<td>Malmö</td>
<td>Rådhuset</td>
<td>Rooftop</td>
<td>Active</td>
<td>2005, calendar year</td>
</tr>
<tr>
<td>Jönköping</td>
<td>Hoppets torg</td>
<td>3 m above ground</td>
<td>Passive</td>
<td>2005, winter half-year</td>
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<td>Göteborg</td>
<td>Femman</td>
<td>Rooftop</td>
<td>Active</td>
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<tr>
<td>Norrköping</td>
<td>Rosen</td>
<td>Rooftop</td>
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<td>2005, calendar year</td>
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<td>Karlstad</td>
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<td>Folkets hus</td>
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<td>Passive</td>
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<td>Örnsköldsvik</td>
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<td>Passive</td>
<td>2005, winter half-year</td>
</tr>
<tr>
<td>Umeå</td>
<td>Stadsbiblioteket</td>
<td>Rooftop</td>
<td>Active</td>
<td>2004, 2005, 2007, calendar year</td>
</tr>
<tr>
<td>Luleå</td>
<td>Stadshuset</td>
<td>Rooftop</td>
<td>DOAS</td>
<td>2006, calendar year</td>
</tr>
</tbody>
</table>

Monitoring data available at the hosting of Air Quality in Sweden: http://www.ivl.se/tjanster/datavardskap/luftkvalitet
Validation against measurements

Example for Umeå in northern Sweden

Time variation

- The seasonal variation is much better captured in the new model version.
- The correlation increases.
- However, the highest concentration peaks are still not fully reproduced in the model.
Validation against measurements

Scatterplots

- The new model is able to reproduce better NO₂ annual average values and 98 percentiles of daily and hourly average.
- 95 % of the data points are within a factor of 2 for the improved model, in comparison with 41 % for the original model.
Validation against measurements

<table>
<thead>
<tr>
<th></th>
<th>NO₂ annual average</th>
<th>NO₂ 98 percentile daily average</th>
<th>NO₂ 98 percentile hourly average</th>
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<tbody>
<tr>
<td></td>
<td>old</td>
<td>new</td>
<td>org</td>
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<tr>
<td>RPE max</td>
<td>0.69</td>
<td>0.41</td>
<td>0.79</td>
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<tr>
<td>median</td>
<td>0.55</td>
<td>0.27</td>
<td>0.67</td>
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<tr>
<td>RDE max</td>
<td>0.33</td>
<td>0.19</td>
<td>0.81</td>
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<tr>
<td>median</td>
<td>0.19</td>
<td>0.08</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Comparison with the quality objectives in the EU Air Quality Directive

- The new model yields improved performance, both in terms of Relative Directive Error (RDE) and Relative Percentile Error (RPE).
- RDE values lower than RPE for annual average, reflecting the fact that the concentrations in general are far below the EU AQ standards for NO₂ annual average.
Thank you for your attention!