Development of a new Plume-in-Grid model for roadways combining an Eulerian Model with a Gaussian line-source model.

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Introduction

- Gaussian plume model for line source
- Modeling platform Polyphemus
  (http://cerea.enpc.fr/polyphemus/)
- Comparisons to measurements
- Plume-In-Grid model using line sources
Hypotheses

- Emission rate (Q in g s\(^{-1}\)) and meteorological parameters are constant.
- The plume is at steady state.
- The wind (u in m s\(^{-1}\)) is strong enough so that the turbulent diffusion in the wind direction is not significant (slender plume approximation).

Point source Gaussian formula

\[
c(x, y, z, t) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp \left( -\frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2} \right)
\]

- \(\sigma_y, \sigma_z\) : standard deviation coefficients along \(y\) and \(z\) axes computed with Briggs parameterization.
Integration of the point source equation

⇒ Horst-Venkatram approximation (HV approximation)


Line source Gaussian formula

\[ C(x, y, z) = \frac{Q}{2\sqrt{2\pi}ucos\theta\sigma_z} \exp \left( \frac{-z^2}{2\sigma_z^2} \right) \times \]
\[
\left[ \text{erf} \left( \frac{(y - y_1)cos\theta - xsin\theta}{\sqrt{2}\sigma_{y_1}} \right) - \text{erf} \left( \frac{(y - y_2)cos\theta - xsin\theta}{\sqrt{2}\sigma_{y_2}} \right) \right]
\]

- \( \cos\theta \) makes the solution diverges when the wind is parallel to the road
Parameterization of the error induced by the HV approximation detailed in:

- If $\theta \in [0, 80]$, concentration = $c_{line}$
- If $\theta \in [80, 90]$, concentration = $\alpha c_{line} + (1 - \alpha) c_{discretized}$

$\Rightarrow \alpha$ varies between 0 and 1
Introduction

Gaussian Plume Model
Evaluation of the Gaussian model
Plume-In-Grid Model
Conclusion

Line source / discretized source combination


Additional features

- Romberg integration to model the line source width
- Simple NO$_2$ chemistry
Simulation set up

**Paris region**

- 1371 road sections divided in 5425 segments (831 km).
- \( \text{NO}_x \) emissions from the European model COPERT3.
- \( \text{NO}_2 \) concentrations measurement at 242 locations with passive diffusion tubes.
- \( \text{NO}_2, \text{NO} \) and \( \text{O}_3 \) background concentrations from on air quality model (Polair3D).
- Meteorological data simulated with the Weather Research and Forecasting model (WRF).

Data provided by the Centre d’Étude technique de l’Équipement (CETE) Nord Picardie, France
Scatter plot of measure versus both Polyphemus using the rural option in $\mu g m^{-3}$ (summer campaign on the left and winter campaign on the right).
Polyphemus performance indicators (Root Mean Square Error and averaged concentrations in $\mu g m^{-3}$)

<table>
<thead>
<tr>
<th></th>
<th>Measurement</th>
<th>Polyphemus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation</td>
<td>1.</td>
<td>0.74</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>0.</td>
<td>11.93</td>
</tr>
<tr>
<td>Averaged concentrations</td>
<td>26.0</td>
<td>20.7</td>
</tr>
<tr>
<td>Mean Normalized Error</td>
<td>0.</td>
<td>0.31</td>
</tr>
<tr>
<td>Mean Normalized Bias</td>
<td>0.</td>
<td>$-0.2$</td>
</tr>
<tr>
<td><strong>Winter campaign</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation</td>
<td>1.</td>
<td>0.79</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.</td>
<td>21.59</td>
</tr>
<tr>
<td>Averaged concentrations</td>
<td>40.5</td>
<td>21.6</td>
</tr>
<tr>
<td>Mean Normalized Error</td>
<td>0.</td>
<td>0.47</td>
</tr>
<tr>
<td>Mean Normalized Bias</td>
<td>0.</td>
<td>$-0.47$</td>
</tr>
</tbody>
</table>
Performance indicators of Polyphemus and ADMS for the winter campaign only (62 passive tubes only)

<table>
<thead>
<tr>
<th></th>
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<th>Polyphemus</th>
<th>ADMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>1.</td>
<td>0.81</td>
<td>0.79</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.</td>
<td>18.47</td>
<td>19.12</td>
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<tr>
<td>Averaged concentrations</td>
<td>35.15</td>
<td>19.87</td>
<td>19.4</td>
</tr>
<tr>
<td>Mean Normalized Error</td>
<td>0.</td>
<td>0.38</td>
<td>0.4</td>
</tr>
<tr>
<td>Mean Normalized Bias</td>
<td>0.</td>
<td>−0.38</td>
<td>0.39</td>
</tr>
</tbody>
</table>

- Underestimation of emission by the traffic model in winter.
- Uncertainty of measurement
Plume-In-Grid model

- Better representation of sources in an Eulerian model
- Coupling between:
  - Gaussian model using line sources ⇒ constant with time
  - Eulerian model (Polair 3d) ⇒ time dependent model
- No discretization of the plume with puffs
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Gaussian model / Eulerian model coupling

Results

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Development of a new Plume-in-Grid model for roadways

Input Data

- Meteorological data
- Emissions data
- Background concentrations

Eulerian Model
(Polair3D)

Plume In Grid Model

- Meteorological data for time t
- Gaussian transfer
- Background concentrations

Grid-averaged concentrations at t+1 with the Eulerian model

Gaussian Plume Model
using line sources

- Meteorological data for time t
- Emissions data at time t

Dispersed concentrations from line sources at t+1

Eulerian + Gaussian concentrations

Saved concentrations
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Results

(a) Polair3D results in $\mu g m^{-3}$
(b) PinG results in $\mu g m^{-3}$
(c) (Polair3D - Plume-In-Grid) in $\mu g m^{-3}$
Conclusion

- Improved line source model, already implemented and available online (http://cerea.enpc.fr/polyphemus/).
- New Plume-In-Grid model fully implemented and tested on simple cases

Ongoing work

- Use this new model for a longer period
- Compare results with Polair 3d model results
Thank you for your attention.