Data assimilation in open road line source modelling

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Description

The aim of this case study is to see if open road line source models can be improved by using local air quality (AQ) observations.

Data assimilation is used to improve estimates of model input parameters (meteorology), and thereby reducing the uncertainties in the model output concentrations.

WORM line source model

WORM = Weak Wind Open Road Model

- New Gaussian integrated line source model developed at NILU
- Originally similar to the CAR-FMI model
- Contains a meteorological preprocessor based on Monin-Obukhov similarity theory (MEPDIM) and COST-710 recommended equations
  - Wind, temperature and turbulence profiles
  - Lagrangian time scales
  - Mixing height

New features

- Uses an accurate numerical integration scheme based on Gauss-quadrature to calculate concentrations in receptor points
- Growth of sigma-y determined by new formula from recent article by Oettl et al., (Atm. Env. 39 (2005)) taking into account plume meandering at low wind speeds
- Meandering parameters taken from the Graz Lagrangian model (GRAL) (function of wind speed)
- Minimum setting of sigma-v = 0.5 m/s

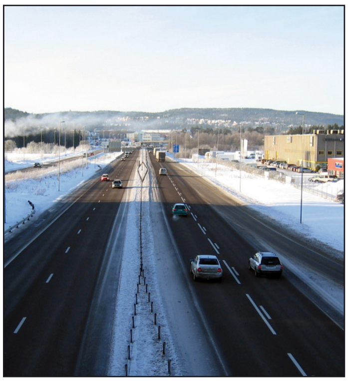
Data set used

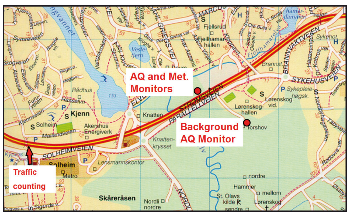
Nordbysletta in Lørenskog close to Oslo. Single 850 m long roadway with 4 separate lanes.

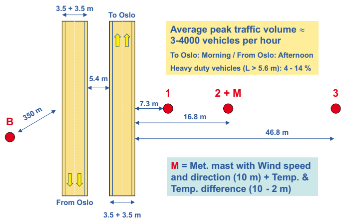
Hourly data from 1 January – 15 April 2002:

- Observations of NO_x, NO_2, O_3 and PM at three stations close to the roadway
- Observations of background concentrations of the same species
- Wind speed, wind direction and vertical temp. difference
- Traffic counting of light and heavy duty vehicles

Nordbysletta







Picture, map and figure showing the 4-lane roadway at Nordbysletta.

Data filter applied

Wind direction between 58 and 238 degrees i.e. direction of wind towards stations 1 - 3.
Wind speed above 0.5 m/s at 10 m height.
Traffic with more than 60 vehicles per hour.

Resulting data set:

- 1038 hours of data from a total of 2520 hours

WORM model setup

Surface roughness tentatively set to 0.25 m based on Davenport & Wieringa site classification

Emission height = 0.5 m (lane) + 1.0 m (dam) = 1.5 m

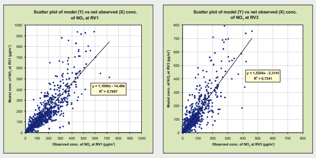
Initial horizontal and vertical dispersion parameters sigma-y0 and sigma-z0 defined as in CAR-FMI (1976 GM experiment)

- Sigma-y0 ≈ 5-7 m and sigma-z0 ≈ 2.5-3.5 m

Focus on NO_X since it is the simplest component

- No photochemical reactions
- Easier to estimate emissions than for PM

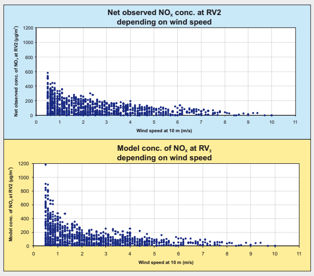
Model evaluation



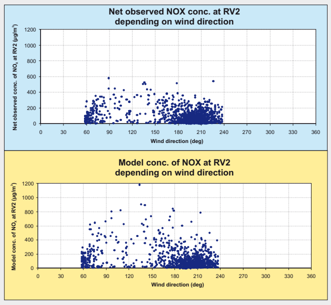
Station 1 Station 3

N = 1038	Obs 1	Mod 1	Obs 2	Mod 2	Obs 3	Mod 3
AVER	137	148	103	129	67	99
SDEV	120	162	93	144	67	119
MAX	722	1336	581	1185	463	979
RMSE		82		82		78
RMSS		25		42		48
C0RR		0.88		0.87		0.86

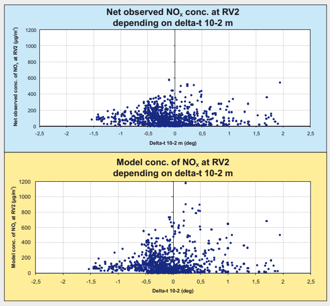
The evaluation shows that the model overpredicts on all three stations.



Net observed (top blue) and modelled (bottom yellow) NO_X concentrations at station 2 (16.8 m from the roadway) as a function of wind speed at 10 m above ground.



Dependence on wind direction.



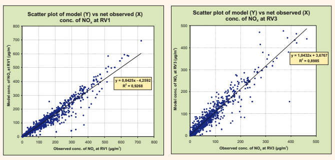
Dependence on stability.

The figures show good correspondence between observed and modelled values, except for low wind speed and stable conditions (< 1-2 m/s), where the model overpredicts.

Data assimilation setup

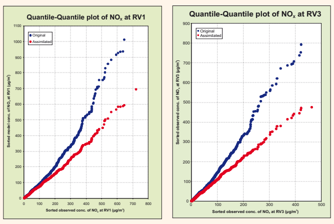
- Use observations of NO_X at station 2 to estimate sigma-v (theta-v) and sigma-z0 (sigma-y0) on an hourly basis
- Use a sequential Monte-Carlo method known as SIR (Sequential Importance Re-sampling) to estimate the parameters
  - Based on a Gaussian likelihood function for the parameters assuming that the AQ observations have 5% relative error
- Create ensembles of N = 2500 modelled NO_X conc. at each station for each hour by randomly drawing input parameters
  - sigma-v ~ Uniform(sigma-v0, 2)
    theta-v = atan(sigma-v/uh)
  - sigma-z0 ~ Normal(sigma-z0, 1.5)
    sigma-y0 = 2*sigma-z0

Data assimilation results

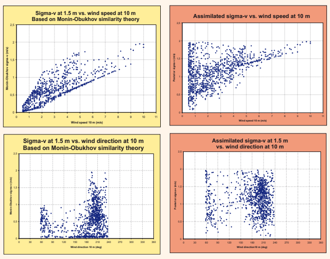


N = 1038	Obs 1	Mod 1	Obs 2	Mod 2	Obs 3	Mod 3
AVER	137	111 148	103	96 129	67	73 99
SDEV	120	105 162	93	92 144	67	74 119
MAX	722	695 1337	581	583 1185	463	475 979
RMSE		43 82		23 82		25 78
RMSS		32 25		8 42		7 48
C0RR		0.96 0.88		0.98 0.88		0.95 0.86

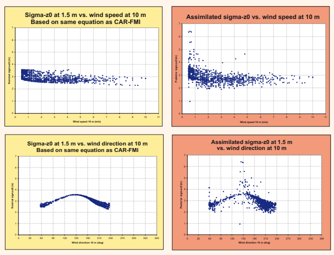
The adjusted model based on data assimilation no longer systematically overpredicts NO_X concentrations as shown at the independent stations 1 and 3.



This is also shown in these Q-Q plots of percentiles of observed and model calculated concentrations of NO_X, before use of data assimilation (blue curve) and after (red curve).



Horizontal diffusion (sigma-v) calculated according to standard Monin-Obukhov similarity theory (yellow plots) and estimated based on data assimilation (red plots). Shown in the top row as a function of wind speed (10 m), and in the bottom row as a function of wind direction.



Initial dispersion (sigma-z0) calculated according to the 1976 GM experiment semi-empiricial model (yellow plots) and estimated based on data assimilation (red plots). Shown in the top row as a function of wind speed (10 m), and in the bottom row as a function of wind direction.

Conclusions

- Gaussian integrated lines source models such as the WORM model can clearly be improved by assimilation of roadside AQ observations
- Estimation of horizontal diffusion and initial size of plume can be used to correct for systematic errors in the high percentiles of the model concentration distribution
- Other results in this case study show that
  - Using more than one station helps to improve the model further but at a slower pace
  - Vertical processes are more easy to estimate than horizontal ones
  - It is difficult to estimate Lagrangian time scales

References

Doucet A., et al. (eds) (2001) Sequential Monte Carlo methods in practice. *Springer Verlag, New York.*
Oettl, D. et al. (2005) A new hypothesis on meandering atmospheric flows in low wind speed conditions, *Atm. Env. 39, pp. 1739-1748.*
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