EVALUATION AND INTER-COMPARISON OF OPEN ROAD LINE SOURCE MODELS CURRENTLY BEING USED IN THE NORDIC COUNTRIES: A NORPAC PROJECT

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INTRODUCTION

In order to evaluate and develop dispersion models, inter-comparison between different models and different datasets is crucial. This paper presents model results from three open road line source models applied to three different datasets from measurement campaigns in Denmark, Norway and Finland. Evaluation of the models against measurements and inter-comparison between the models have been performed. The Finnish model applied in this study has been involved in a number of inter-comparison studies, e.g. Levitin et al. (2005) and Oettl et al. (2005). This study was initiated as part of the NORPAC project, which is a Nordic project on PM measurements and modelling. A description of the models involved follows in section 2 and the results are presented in section 3.

METHODOLOGY

A number of datasets are available from the Nordic countries from various measurement campaigns. The datasets used in this study consist of air quality and meteorological measurements carried out near major roads or highways. Most of the campaigns include a number of stations placed at different distances from the road. For the inter-comparison, stations placed at around 50 m from the road are used. NO_x is the pollutant used in the inter-comparison since its emissions are the best known and it can be treated as a tracer for the short time scales involved.

The datasets from the different measurement campaigns were distributed to all the Nordic countries involved, in order to apply the different models to all the datasets. When analyzing the data, three different selections of the data were performed; (1) all data, (2) all data with wind speeds > 2 ms^{-1}, and (3) all data with u > 2 ms^{-1} and the wind direction within 30° of the perpendicular to the road. The analysis presented here looks at principally two statistical quantities, these being the correlation coefficient and the relative bias (bias normalized by the mean observed concentration).

RESULTS AND DISCUSSION

Modelling results for OML and WORM – all data

Figure 1 shows scatter plots of modelled and observed concentrations of NO_x for OML, WORM and CAR-FMI applied to both the Danish, Norwegian and Finnish data. The background is excluded in order to capture the emission contribution from the road only. For the WORM model only wind speeds above 0.5 ms^{-1} at 10 m height are included, making the Gaussian plume formulation valid. Otherwise all wind directions and wind speeds are included. OML and WORM perform well on the Danish data, except for a slight overestimation for WORM. Both models underestimate the Norwegian data significantly. The WORM model performs poorly on the Finnish dataset, giving both too high concentrations and relatively poor correlation. The CAR-FMI model performs better on these data, although the correlation is poorer than for OML and WORM applied to the Danish and Norwegian datasets.

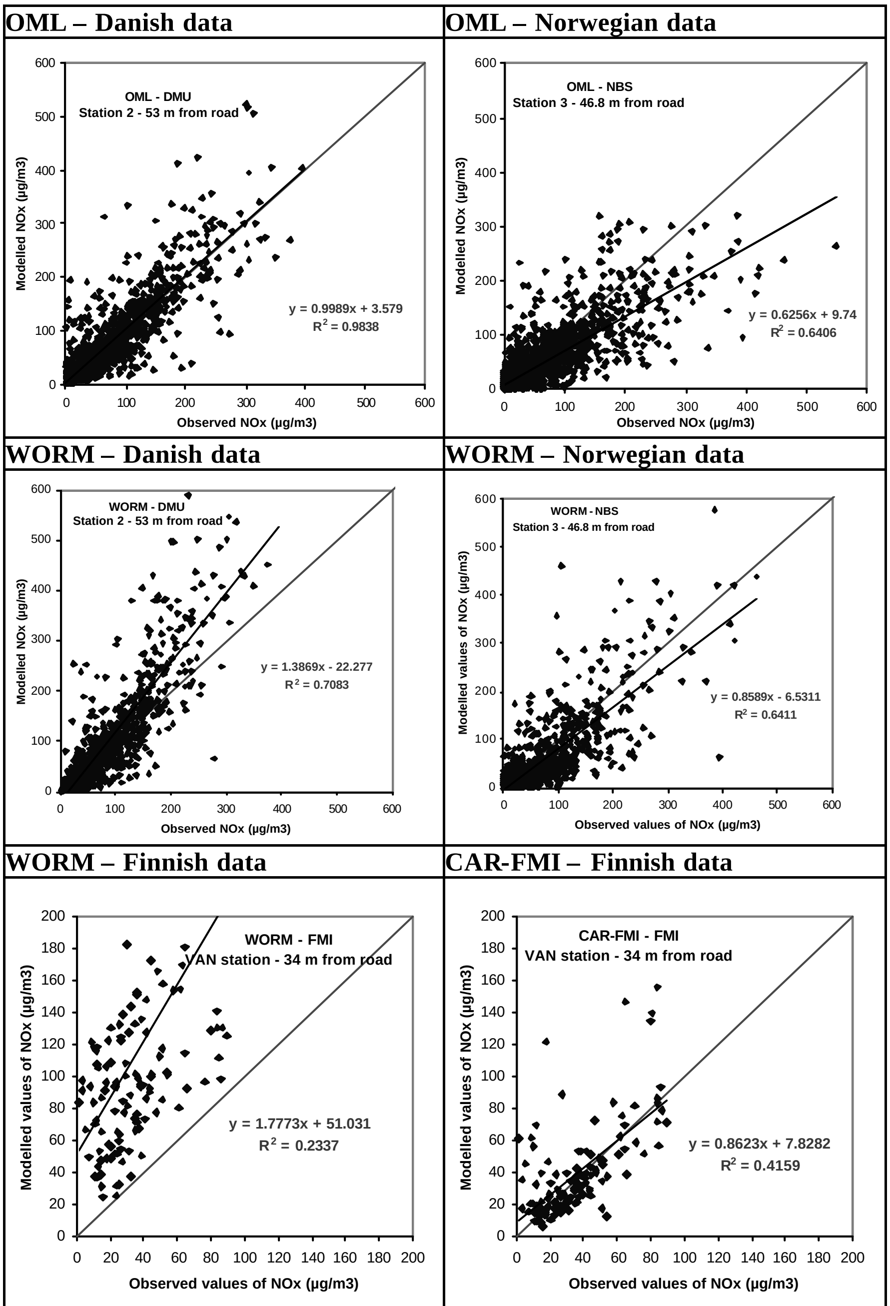

Figure 1. *Comparison between modelled and measured NO_X concentrations. For the OML and CAR-FMI models all wind directions and all wind speeds are included. For the WORM model all wind directions and wind speeds above 0.5 ms^{-1} are included.*

Modelling results for OML and WORM u > 2 ms^{-1}

Based on the knowledge that the model performance for low wind speeds is poorer than for higher wind speeds we only included data for which the wind speeds were above 2 ms^{-1}. These results are not shown here. The conditions are the same as in figure 1, except for the inclusion of higher wind speeds. The effect of this filtering is not as visible for OML as it is for WORM where there is a significant under-prediction for these higher wind speed cases, especially for the Norwegian data. This tendency is not as evident for WORM and CAR-FMI when applied to the Finnish dataset. Although the overestimation by WORM is reduced, the correlations are poorer.

Modelling results for OML and WORM u > 2 ms^{-1} and q ⊥ **road ± 30°**

Line source models are often inaccurate for winds that are directed parallel to the road, due to both numerical and physical considerations. This aspect has been tested by filtering the data so as to only allow data where the wind blows perpendicular to the road ±30°. Also, only data for which the wind speeds are above 2 ms^{-1} are included. These are highly idealised conditions for slender plume Gaussian models and the expectation is that the models should perform best under these circumstances. Making this selection significantly reduces the number of data points from the Norwegian and the Finnish site but the results are similar to those obtained for all wind directions, and are not shown here (see table 1 for a summary). There seems to be no significant improvement resulting from the exclusion of wind directions outside of this 30° sector, indicating that the models perform well for all wind directions.

The results are further summarised below in table 1 where the relative bias and regression coefficients are shown for the 3 selection criteria and the four combinations of model and datasets.

Table 1*. Relative bias (top) and correlation (bottom) for OML, WORM and CAR-FMI applied to Danish, Norwegian and Finnish datasets for all the three selections of data.*

Relative bias (RB)

Model Dataset	OML Danish data	OML Norwegian data	WORM Danish data	WORM Norwegian data	CAR-FMI Finnish data	WORM Finnish data
All data	0.05	-0.21	0.12	-0.26	0.08	2.22
u > 2 ms^{-1}	0.04	-0.24	0.05	-0.60	-0.07	2.68
u > 2 ms^{-1}, θ ⊥ road ± 30°	0.01	-0.10	0.09	-0.52	-0.20	2.22

Correlation coefficient R^2

Model Dataset	OML Danish data	OML Norwegian data	WORM Danish data	WORM Norwegian data	CAR-FMI Finnish data	WORM Finnish data
All data	0.98	0.64	0.71*	0.64*	0.42	0.23
u > 2 ms^{-1}	0.99	0.78	0.83	0.75	0.60	0.19
u > 2 ms^{-1}, θ ⊥ road ± 30°	0.87	0.81	0.85	0.85	0.84	0.42

* For the WORM model all wind directions and wind speeds above 0.5 ms^{-1} are included.

Modelling results for normalized concentrations

We also normalized the concentrations with emissions, and emissions and wind speed. Normalization by these two input parameters should aid in understanding the influence of the dispersion parameterization in the model. If a level of correlation after normalization still exists, the dispersion parameterization has an effect on the model results. Results are shown for WORM applied to the Danish data. As expected the correlation becomes worse when normalizing (0.37 when normalizing with emissions, and 0.30 when normalizing with emissions and wind speed), indicating that a significant part of the correlation in figure 1 is due to emissions and wind speed.

CONCLUSION

Three open road line source models, OML, WORM and CAR-FMI, have been compared and evaluated based on their application to datasets from measurement campaigns in Denmark, Norway and Finland. In general it can be seen that OML and WORM perform quite well on the Danish data set with the WORM model overestimating the concentrations the most. Both models, on the other hand, underestimate concentrations for the Norwegian dataset. This underestimation is most pronounced for the WORM model, especially when only data for which $u > 2\ ms^{-1}$ are selected. The results when applying WORM and CAR-FMI to the Finnish dataset are poorer, giving too high concentrations and poor correlations. All the tendencies mentioned above occur for both the filtered and unfiltered datasets, and is most evident for OML and WORM applied to the Danish and the Norwegian data. There does not seem to be a significant degradation in the results when all wind directions are included in the analysis indicating that the models perform well for all wind directions. The correlations between the models and the observations are quite similar on similar datasets. Correlation for both models generally improves when wind speeds $< 2\ ms^{-1}$ are excluded, except for WORM applied to the Finnish dataset.

All models are based on the same theoretical basis, i.e. Gaussian slender plume approximation, and use similar turbulence parameterizations. The major difference that should separate the models is the inclusion of traffic produced turbulence in the OML model. It is interesting to note that the relative bias of WORM, in regard to OML, is positive for the Danish dataset and negative for the Norwegian dataset, table 1. The conclusion is that there must be a difference between the two sites that is not accounted for in the WORM model and this difference is expected to be the TPT. The Danish measurements were carried out on a much more trafficked road than the Norwegian measurements, approximately 100 000 VEH/day compared to approximately 36 000 VEH/day, and the average traffic speed at the Danish site was also higher, 109 km/hr compared to 90 km/hr at the Norwegian site. As a result the TPT should be significantly higher at the Danish site. Since the WORM model does not take into account the TPT, as OML does, we would expect the WORM model to produce higher concentrations at the Danish site relative to those at the Norwegian site, since dilution by TPT is largest at that site. Independent runs carried out using the OML model without TPT indicate a significant increase in model concentrations, by a factor of 2 or more, when TPT is not included. This demonstrates the significance of this process. This, however, does not explain the significant negative bias of the WORM model, nor the great overestimation of WORM applied to the Finnish data. As the traffic volume on the Finnish road is approximately 7200 VEH/day, i.e. less than at Danish and Norwegian sites, one would expect lower overestimation due to the aspects mentioned above. More attention will be given to this in the future.

When normalizing the concentrations, it is evident that the correlations reduce significantly. However, there is some correlation after normalizing (~ 0.3), indicating that the dispersion parameterization has an effect on the model results. This is because of the turbulent parameters that are left in the diffusion equation when normalizing with emission and wind speed.

The inter-comparison demonstrates the usefulness of comparing models on differing datasets and will lead to improved and more robust models in the future. As this study still needs a lot of attention, further work will be carried out in this study to include results of CAR-FMI applied to the Norwegian and Danish datasets, and OML applied to the Finnish dataset. This will hopefully give more decisive conclusions.

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