WORM – A NEW OPEN ROAD LINE SOURCE MODEL FOR LOW WIND SPEED CONDITIONS

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INTRODUCTION

Emission from road traffic constitutes one of the most important sources of air pollution in urban areas. This paper describes a newly developed air pollution dispersion model for open roads and highways called WORM (Weak Wind Open Road Model), and give some results using this model during low wind speed and (strongly) stable atmospheric conditions at Nordbysletta in Norway during a 3-4 months period in the winter/spring of 2002.

THE WORM MODEL

The WORM model is an integrated Gaussian puff/plume model for calculating hourly average concentrations from open roads and highways in a set of arbitrary receptor points. In the development we have put special emphasis on attempting to model well concentrations during Nordic winter-time, strongly stable, low-wind speed conditions, within the framework of a fast Gaussian model. In addition, the WORM model has been developed specifically with the aim of producing concentration values with some calibrated quantification of uncertainties, using sensible input data perturbations and model ensemble runs, as described in (Walker, S.E., 2007).

The WORM model is coded in FORTRAN 95/2003 using modern principles of Object Oriented Programming (OOP). The current version consists of the following system components (modules):

- An emission pre-processor
- A background concentration pre-processor
- A pre-processor for meteorological data
- An integrated Gaussian puff/plume type of dispersion model
- A module containing numerical routines for integration etc.

The emission pre-processor generates hourly emission data (Q in $gm^{-1}s^{-1}$) for each lane of the roadway based on traffic data from NILUs AirQUIS system (AirQUIS, 2005). The background concentration pre-processor generates hourly average background concentrations for the road, based on using nearby (upwind) background stations, and/or urban/regional scale models, also provided by AirQUIS.

A new meteorological pre-processor (WMPP) has been constructed as part of the WORM model development, in order to calculate meteorological parameters such as:

- Friction velocity (u*)
- Temperature scale (θ*)
- Inverse Obukhov length (L^{-1})
- Mixing height (H_{mix})

and other derived meteorological quantities based on Monin-Obukhov similarity theory, and hourly data for local wind speed and stability.

The WORM model calculates hourly average concentrations in one or more receptor points by integrating a Gaussian puff or plume function along each lane of the road. The plume formulation is used whenever the wind speed is higher than a certain user specified limit. The puff formulation is used, with dispersion parameter $\sigma_x = \sigma_y$, during low wind speed conditions (typically for $U_{eff} < 1\ ms^{-1}$). In the latter case, the concentration in a receptor point $r = (x_r, y_r, z_r)$ is calculated by:

$$C_r = \iint_{s=0\,t=0}^{S\,T} \frac{Q}{(2\pi)^{3/2}\cdot\sigma_x(t)\cdot\sigma_y(t)\cdot\sigma_z(t)}\cdot\exp\left(-\frac{(x_r(s)-U_{eff}\cdot t)^2}{2\sigma_x^2(t)}\right)\cdot\exp\left(-\frac{y_r^2(s)}{2\sigma_y^2(t)}\right)\cdot \left\{\exp\left(-\frac{(z_r-H_{eff})^2}{2\sigma_z^2(t)}\right)+\exp\left(-\frac{(z_r+H_{eff})^2}{2\sigma_z^2(t)}\right)\right\}dsdt \quad (1)$$

where Q is the emission intensity ($gm^{-1}s^{-1}$), Ueff is the plume effective wind speed (ms^{-1}), Heff is the plume effective height above ground (m), and where the coordinates of the receptor point and dispersion parameters in the integrand generally depends on the position s on the road, and time t since release. The integrations (for puffs and plumes) are performed using fast approximations, employing Gaussian error-functions (erfs), except for situations when the wind is along the road where a highly accurate (nested) Gaussian quadrature scheme is employed.

New in the current release of the WORM model, is that horizontal and vertical dispersion parameters can be calculated using the same formulation as suggested in the OML Research Version model (Olesen, H.R. et al., 2007):

$$\sigma_y^2 = \sigma_{y,Atm}^2 + \sigma_{y,TPT}^2$$
$$\sigma_z^2 = \sigma_{z,Atm}^2 + \sigma_{z,TPT}^2 \quad (2)$$

where $\sigma_{y,Atm}$ and $\sigma_{z,Atm}$ defines growth of the puff or plume due to ambient atmospheric turbulence divided into mechanical and convective parts, and where the horizontal part in addition includes the effect of plume meandering. For roadway models it is also important to include traffic produced turbulence (TPT) generated by the moving vehicles, in a proper manner, especially in situations with low wind speeds (Berkowicz, R. et al., 2007). In previous beta releases of the WORM model, $\sigma_{x,TPT} = \sigma_{y,TPT}$ and $\sigma_{z,TPT}$ were calculated as constant additive terms in equation (2) (Berger, J. et al., 2008), This has been shown not to be adequate, especially for strongly stable atmospheric conditions with very low wind speeds ($U_{10m} < 0.5\ ms^{-1}$), as is the case at Nordbysletta, giving model concentrations much higher than observed. In the new version of the model we have therefore included a new formulation for TPT based on the same scheme as used in the OML Highway model (Berkowicz, R. et al., 2007). In this scheme, production of turbulent kinetic energy (TKE) is calculated based on the number and speeds of light and heavy duty vehicles on the road. Growth of puffs and plumes are then calculated based on this, and on subsequent decay (dissipation) of TKE with time and distance from the road.

RESULTS

A previous beta release of the WORM model was recently tested extensively on a number of datasets from the Nordic countries (Norway, Denmark and Finland), including data from Nordbysletta (Berger J. et al., 2008). In that study, only hours with wind speed 0.5 ms^{-1} or higher (at 10 m above ground) were used. Also, a minimum horizontal diffusivity $\sigma_v = 0.5\ ms^{-1}$ was applied in order to make the model fit the air quality observations for low wind speeds without overshooting.

For the runs with the WORM model for Nordbysletta presented here, the same setup is used except for the following differences. Now hours with wind speed (at 10 m above ground) below 0.5 ms^{-1} is also used (minimum is 0.1 ms^{-1} during the 3.5 months period). Further, plume dispersion is calculated using the same procedure as in the OML Research Version model (Olesen, H.R. et al., 2007, chapters 5.2-3), and in the OML Highway model for TPT (Berkowicz, R. et al., 2007), except that we still employ a fixed effective plume height equal to 3 m above ground. Minimum horizontal diffusivity σ_v is now effectively set to 0.2 ms^{-1}, since this is the value of σ_v used in the horizontal meandering part of the OML Research Version model. The latter minimum value is in agreement with recent observations of σ_v as wind speed approaches zero as described in (Olesen, H.R. et al., 2007).

Figure 1 shows a time series plot of observed and model calculated hourly average concentrations of NOx at station 2 (17 m from the road), calculated by the new version of WORM during the first half of January 2002. This was a period with (strongly) stable (max $\Delta T_{10\text{-}2m} = +4.0$ K) and weak wind (minimum $U_{10m} = 0.1$ ms-1) conditions. As can be seen from the figure, despite these extreme conditions, there is a reasonable good correspondence between observed and model calculated values during this period, except for some larger deviations. The latter must not come as a surprise, since clearly wind directions will be quite un-steady (and therefore uncertain) at hours with wind speed well below 1 ms^{-1}.

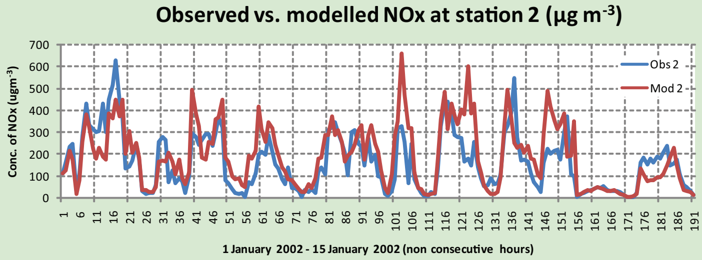

Figure 1. Time series plot of observed and model calculated concentrations of NOx at station 2 (17 m from the road) for the first half of January 2002. This was a period with (strongly) stable conditions (max $\Delta T_{10\text{-}2m} = 4.0$ K at hour 132) with low wind speed (min $U_{10m} = 0.1\ ms^{-1}$ at hour 40).

Overall, there is generally a good correspondence between observed and model calculated values, except for a certain tendency of model underestimation. Observed vs. model calculated averages were 111 vs. 95 μgm^{-3} at station 2; 147 vs. 113 μgm^{-3} at station 1 (7 m from the road); and 74 vs.71 μgm^{-3} at station 3 (47 m from the road).

A scatter plot of model calculated vs. observed values at station 2 is shown in Figure 2, showing a reasonable good agreement between observed and model calculated values. Correlations are fairly high on all stations, being 0.84 at station 1; 0.81 at station 2; and 0.78 at station 3.

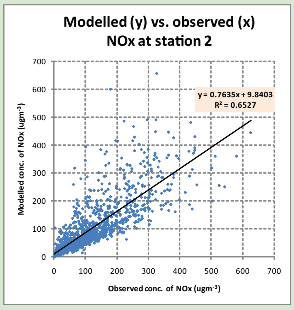

Figure 2. Scatter plot of observed (x) vs. model calculated (y) concentrations of NOx at station 2 (17 m from the road). All hourly values with wind direction towards station 2 between 1 January 2002 and 15 April 2002 plotted (N = 1345).

SUMMARY AND CONCLUSION

A new version of the WORM model is presented. It incorporates an advanced (state-of-the-art) scheme for puff/plume modelling, applying dispersion functions for ambient atmosphere and traffic produced turbulence (TPT) harmonized with the recent OML Research Version and OML Highway models (Olesen, H.R. et al., 2007; Berkowicz, R. et al., 2007). Applying the new model using data from Nordbysletta in Norway during a 3-4 months period in the winter/spring of 2002, good agreement between observed and model calculated values of NOx was obtained, even in periods of (strongly) stable (max $\Delta T_{10\text{-}2m} = +4.0$ K), and low-wind speed (min $U_{10m} = 0.1\ ms^{-1}$) conditions.

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