1.18 EVALUATION OF THE CALINE4 AND CAR-FMI MODELS AGAINST THE DATA FROM A ROADSIDE MEASUREMENT CAMPAIGN

Joseph Levitin[1], Jari Härkönen[2], Jaakko Kukkonen[2] and Juha Nikmo[2]
[1]Israel Meteorological Service (IMS), Bet Dagan, Israel
[2]Finnish Meteorological Institute (FMI), Helsinki, Finland

INTRODUCTION

The main objective of the present study was to evaluate the Gaussian finite line source models CALINE4 (California line source dispersion model, version 4) and CAR-FMI (Contaminants in the Air from a Road - Finnish Meteorological Institute, version 3) models against the results of a measurement campaign.

MEASUREMENT SITE AND EXPERIMENTAL SET-UP

The measurements were conducted in a rural area in Southern Finland from September 15 to October 30, 1995. The main features of the measurement system and its immediate environment are presented in Figure 1. The measurement site is located in flat, homogeneous terrain with no major buildings and very few obstacles. There are no local air pollution emission sources, except for traffic on the road considered.

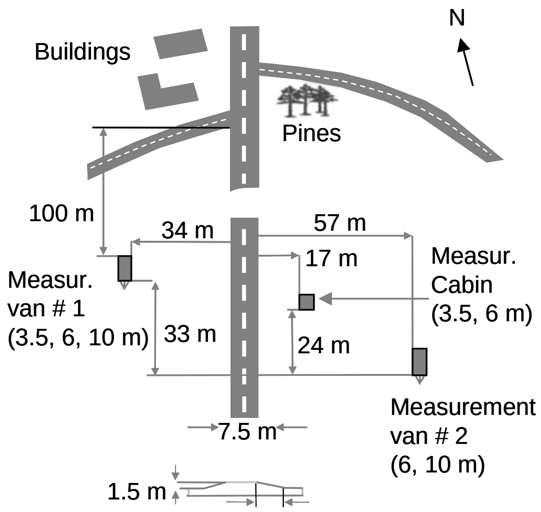


Figure 1. A schematic diagram of the measurement devices and their locations with respect to the road. The measurement heights are indicated in parentheses (Kukkonen et al., 2001).

Concentration data were obtained from van #1 at three heights, 3.5, 6 and 10 m, from the measurement cabin at two heights, 3.5 and 6 m, and from van #2 from one height, 6 m. Traffic flows were measured electronically at a distance of 300 m from the monitoring site. The meteorological parameters measured included hourly means of wind speed and direction, ambient temperature, global solar radiation intensity and relative humidity.

METHODS

For a more detailed description of the models, the reader is referred in the case of CAR-FMI to Härkönen et al. (1996) and Härkönen (2002), and in the case of CALINE4 to Benson (1984 and 1992). Atmospheric stability parameters and the mixing height were evaluated using the MPP-FMI meteorological pre-processing model (Karppinen et al., 2000). The CAR-FMI model includes an emission model, a dispersion model and statistical analysis of the computed time series of concentrations. The dispersion parameters are modelled as a function of the Monin-Obukhov length, the friction velocity and the mixing height, according to Gryning et al. (1987).

The CAR-FMI model uses the same analytical solution of the basic chemistry reaction equations of nitrogen oxides, oxygen and ozone as in CALINE4. CALINE4 uses the discrete parcel method (DPM) as a so-called source-oriented version, following Benson (1984), whereas CAR-FMI applies a so-called receptor-oriented DPM (Härkönen et al., 1996).

In the CALINE4 model, the concentrations predicted by the Gaussian line source equation for an arbitrary wind direction are solved by a numerical procedure. This procedure divides the road into a series of elements, from which incremental concentrations are then computed and summed up.

The CALINE4 model applies the Pasquill stability classes. The horizontal dispersion parameter is evaluated directly from the standard deviation of the wind direction, σ_θ, using a method developed by Draxler (1976). The relationships between the Pasquill classes and the σ_θ's are evaluated according to Hanna (1983).

RESULTS

Selection of data for the evaluations

The traffic flow on the road was fairly low, on average approximately 7200 vehicles/day (i.e., 300 vehicles/hour). We have neglected data, for which traffic volumes were lower than 60 vehicles/h, as in those cases the traffic flow cannot be considered to be continuous. We have also neglected data, for which the measured ratio of downwind NO_x concentration to background NO_x concentration is smaller than 2.0. In such conditions, the road-traffic-originated concentrations are lower than the background concentrations. The anemometers employed cannot measure wind direction at wind speeds lower than approximately 0.5 m s^{-1}. We excluded here data, for which the wind speed was lower than 1.0 m s^{-1}. We also excluded those data, for which the angle between the road and the wind vector is smaller than 10°.

Concentration data were obtained from van #1 at three heights, 3.5, 6 and 10 m, and from the measurement cabin at two heights, 3.5 and 6 m. In the previous studies (Kukkonen et al., 2001 and Oettl et al., 2001) it was found that the model evaluation results were not substantially different at a height of 10 m, compared with the corresponding results at heights of 3.5 and 6 m. In this study, therefore, we have only utilized the data at 3.5 m and 6 m.

The concentrations were computed at van #1 (at a distance of 34 m from the centre line of the road) in easterly winds, and at the measurement cabin (at a distance of 17 m from the road) in westerly winds. The background concentrations were then extracted from the corresponding data of the upwind measurement station. The measured NO_x and NO_2 concentrations at van #2 (at a distance of 57 m) were mostly fairly close to the measured upwind background concentrations; these data were therefore not used in this study.

The evaluation of the vehicular emissions

The average measured speed of vehicles was approximately the same as the speed limit, 100 km h^{-1}, with a very moderate variation. We have utilized emission factors of NO_x that correspond to the local car fleet, and a vehicle speed range of 100-120 km h^{-1}, i.e., 3.7 and 12.3 g km^{-1} for light- and heavy-duty vehicles, respectively.

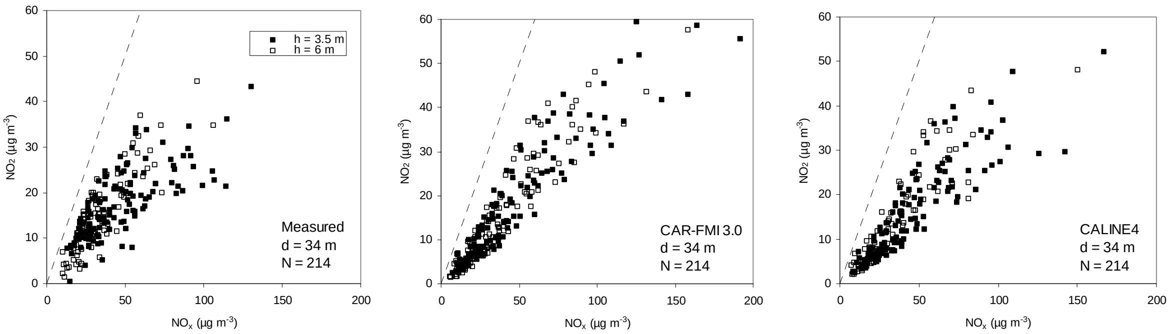
On average, the percentage of heavy-duty traffic was 9.3 %. The fraction of NO_x emitted as NO_2 was assumed to be 10 %. The initial release height of the pollutants was assumed to be 1.0 and 3.0 m for light- and heavy-duty traffic, respectively.

The variability of atmospheric conditions during the measurement campaign

The variability of atmospheric stability, ambient temperature, wind velocity and the amount of solar radiation was modest during the measurement campaign (Kukkonen et al., 2001). For instance, the average temperature and its standard deviation were + 8 ± 4.4 °C, and the average wind velocity at a height of 10 m was 2.8 ± 1.3 m s^{-1}. Atmospheric stratification varied from moderately stable to moderately unstable. In terms of the Pasquill classes, the fractions of neutral (class D), slightly stable (class E), and slightly unstable (class C) cases were 84, 15 and 1 %, respectively.

Analyses of the NO_2 data

The levels of NO_2 concentrations are mainly determined by the efficiency of NO oxidation caused by ozone. Directly emitted NO_2 constitutes only a minor fraction (approximately 10%) of the nitrogen oxides emitted by traffic. The qualitative behaviour of the predicted NO_2/NO_x ratio is similar to that of the observed ones (Figures 2a-c).



Figures 2a-c. The dependency of NO_2 concentrations on NO_x concentrations, for the measured and predicted results at a distance of 34 m. The upper limit of NO_2 concentration is shown by the 1:1 line. Left panel: measured data, middle panel: CAR-FMI model, right panel: CALINE4.

Diagnostic evaluation of measured and predicted concentrations

The ratio of predicted to measured NO_x concentrations plotted against wind direction and speed is presented in Figure 3 for the CALINE4 model. The wind direction has been normalized in terms of the road, and defined clockwise.

There are some anomalously high values (defined here as > 3.0) at normalized wind directions from approximately 280° to 300°. At wind speeds lower than approximately 2 m s^{-1}, there are excessively high predicted concentrations, compared with the measured data. Model performance therefore tends to deteriorate for situations with the lowest wind speeds. There is also a tendency to overpredict for parallel-to-road wind conditions. This can be seen as higher values in approaching the smaller wind directions, i.e., the directions of 15° or 20°, and in approaching the wind direction of 180°.

In parallel wind conditions, the background concentration measurements could be influenced by traffic-originated pollution from the road; this would tend to result in model overpredictions of the downwind concentrations. Parallel wind conditions also make Gaussian line source models much more sensitive to the assumption of steady-state, homogeneous wind flow (Benson, 1992). Wind meandering is most pronounced at low wind speeds or in calm situations, and it is then also most difficult to measure reliably. Substantial meandering can cause measured concentrations to be much lower, compared with those computed assuming a homogeneous wind flow (e.g., Benson, 1992). It is also more difficult to evaluate atmospheric stability parameters and mixing height, and to model atmospheric dispersion processes at low wind speeds or in calm conditions.

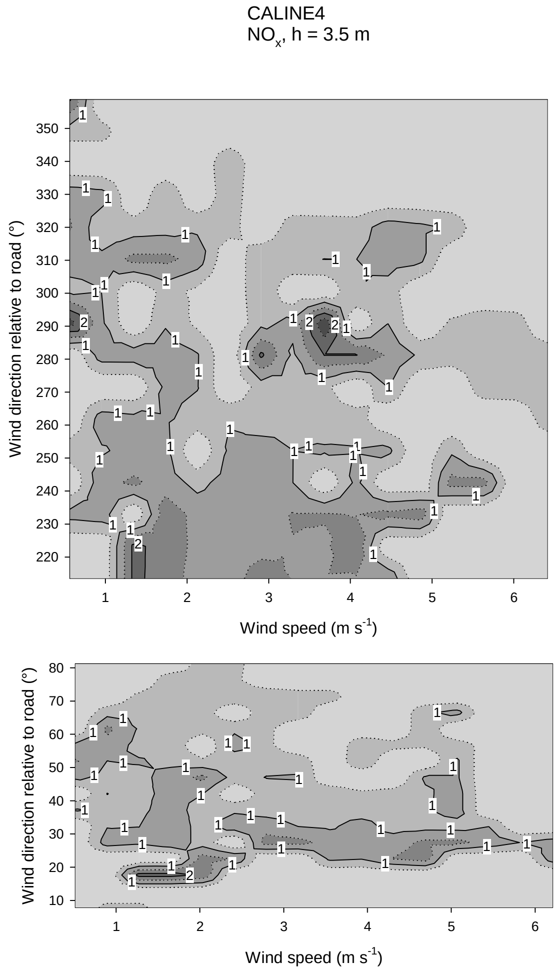


Figure 3. The ratio of predicted to observed concentrations plotted against wind speed and direction, for the CALINE4 model. We have utilized the data from both the measurement van #1 and the cabin, both of these at a height of 3.5 m.

CONCLUSIONS

We have presented an evaluation and inter-comparison of two atmospheric dispersion models against the results of a measurement campaign that was conducted near a major road in southern Finland in 1995. The agreement between measured and predicted datasets was good for both models, as measured using various statistical parameters.

In general, the performance of the two models was fairly similar, as evaluated both statistically and diagnostically, despite substantial differences, both in their mathematical treatments and their numerical procedures. In particular, the CAR-FMI model utilizes boundary-layer scaling with a meteorological pre-processing model; the CALINE4 model, on the other hand, utilizes simple Pasquill stability classifications; the limitations of the latter procedure are well-known. However, the range of variability of the atmospheric stability was modest during the measurement campaign, and so the present evaluation does not test the models in extreme stability conditions.

ACKNOWLEDGEMENTS
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