16th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
8-11 September 2014, Varna, Bulgaria

DISPERSION MODELLING APPROACHES FOR NEAR ROAD APPLICATIONS INVOLVING NOISE BARRIERS

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Abstract: Roadway design and roadside barriers can have significant effects on the dispersion of traffic-generated pollutants, especially in the near-road environment. Dispersion models that can accurately simulate these effects are needed to fully assess these impacts for a variety of applications. For example, such models can be useful for evaluating the mitigation potential of roadside barriers in reducing near-road exposures and their associated adverse health effects. Two databases, a tracer field study and a wind tunnel study, provide measurements used in the development and/or validation of algorithms to simulate dispersion in the presence of noise barriers in level terrain.

The tracer field study was performed in Idaho Falls, ID, USA with a 6-m noise barrier and a finite line source in a variety of atmospheric conditions. The second study was performed in the meteorological wind tunnel at the US EPA and simulated line sources at different distances from a model noise barrier to capture the effect on emissions from individual lanes of traffic. In both cases, velocity and concentration measurements characterized the effect of the barrier on dispersion.

This paper presents comparisons with the two datasets of the barrier algorithms implemented in two different dispersion models: US EPA's R-LINE (a research dispersion modelling tool under development by the US EPA's Office of Research and Development) and CERC's ADMS model (ADMS-Urban). In R-LINE the physical features revealed in the experiments have been used to enhance the effective surface roughness and friction velocity of the flow downwind of the barrier. The pollutant field is well-mixed below the height of the barrier and decreases exponentially above. The initial dispersion of the plume coming from the roadway is enhanced by the presence of the barrier. The ADMS algorithm considers the barrier as a one-sided street canyon; it allows for the channeling of the flow along the barrier and represents the road source as a combination of ground level and elevated sources with the weighting of the sources dependent on the wind direction and the barrier properties.

Key words: *Dispersion, Roadways, Barriers, Street Canyons, Traffic***.**

INTRODUCTION

Roadside barriers, commonly used for roadway noise abatement, have been found to have significant effects on the concentrations of traffic pollutants in the areas they are designed to obscure from the road (Baldauf *et al.*, 2008). Two studies were conducted to better understand the effects of barriers on local pollutant dispersion and to provide data for development and evaluation of dispersion model algorithms. The studies included a tracer field study involving a range of meteorological conditions and a wind tunnel study. Two barrier algorithms have been developed (one each in the R-LINE (Snyder *et al.*, 2013) and ADMS-Urban (CERC, 2012) dispersion models). This paper includes a brief description of the model algorithms, the barrier studies and a comparison of the models' performance against the data bases.

EXPERIMENTS

A tracer field study of dispersion from a near ground-level line source was carried out in 2008 near Idaho Falls, ID on an open-field test site designed for transport and dispersion tracer studies (Finn *et al.*, 2010). Tracer releases were performed simultaneously at two parallel sites, one with a noise barrier and one without. Sulfur hexafluoride (SF_6) was released uniformly along a 54 m long source, positioned 1 m above ground level, throughout a 3 hour experiment consisting of 12 consecutive 15-min sampling periods. Experimental data are available from four separate days, capturing a wide range of atmospheric stabilities and wind speeds. The four days were characterized as: Day 1, neutral (average wind speed, U_{ave} = 5.5 ms^{-1} and average z/L of -0.016, where z is the height of the wind speed measurement, 3 m, and L is the Monin-Obukhov length); Day 2, convective (U_{ave} = 1.4 ms^{-1}, $[z/L]_{ave}$ = -0.312); Day 3, weakly stable (U_{ave} = 3.6 ms^{-1}, $[z/L]_{ave}$ = 0.048); and Day 5, strongly stable (U_{ave} = 1.6 ms^{-1}, $[z/L]_{ave}$ = 0.379).

A grid of 56 samplers mounted 1.5 m above ground level was deployed downwind of the source. The noise barrier, erected on-site using straw bales, was 90 m long and 6 m high and was positioned 6 m downwind of the source. Data from meteorological instruments located in the experiment area were used to derive model inputs, including an estimated roughness length of 0.053 m.

A wind tunnel study was also performed to examine the effect of a noise barrier on dispersion using the EPA's meteorological wind tunnel (Snyder, 1979), whose test section is 370 cm wide, 210 cm high, and 1830 cm long. The air speed in the test section was fixed at 2.98 ms^{-1} at a full-scale equivalent height of 30 m (using a 1:150 model scale). Emissions from the roadway were modelled using a line source that spanned 273 cm of the wind tunnel (equivalent to 410 m, full-scale). The source was constructed from hollow 0.6 cm square brass tubing, with 0.074-cm holes drilled through the bottom of the tube spaced 1 cm apart. It was positioned vertically for a full-scale equivalent release height of 1.5 m. Concentration measurements of the tracer gas (ethane) were performed using flame ionization detectors with the source positioned at seven distinct distances upwind of a 6 m high (full-scale) barrier. For the results shown here, concentrations measured using the three farthest upwind and three farthest downwind sources were averaged together to produce the effect of a six-lane highway with a central unused lane (median). Vertical profiles of concentration were measured at 10 downwind distances along the centreline of the source.

ALGORITHMS

Barrier algorithms developed for use in two different dispersion models (R-LINE and ADMS-Urban) are examined in this paper.

R-LINE is a Research LINE-source Gaussian dispersion model for near-surface releases developed by the US EPA Office of Research and Development and is designed to simulate primary, chemically inert pollutants with emphasis on near-surface releases and near-source dispersion (Snyder *et al.*, 2013). The vertical dispersion formulations were developed in part based on the open terrain (no-barrier) portion of the Idaho Falls study described in Finn *et al.* (2010) and used in this paper. The barrier algorithm is based on the observation that there is increased mixing downwind of the barrier due to the change in flow patterns induced by the barrier. The R-LINE barrier algorithm was developed using the wind tunnel database presented in this paper.

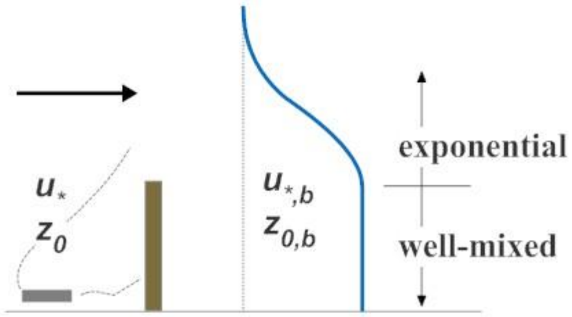

Figure 1. The R-LINE barrier algorithm features a well-mixed region below barrier height with concentration decreasing exponential above.

This change in flow downwind of the barrier is modelled as an increase in the surface roughness with a resulting roughness equal to $z_{0,b}$ = 0.11 H, where H is the height of the barrier (Figure 1). A new surface friction velocity is then calculated using $u_{*b} = u_* (z_{0,b}/z_0)^{0.17}$, where u_* and z_0 are the upwind friction velocity and surface roughness, respectively. Concentrations downwind of the barrier are assumed to be well-mixed below barrier height and to fall off exponentially above, as if released at barrier height, as $C = C_H \exp(-0.5\,(z_r-H)^2/\sigma_z^2)$, where C_H is the concentration at barrier height, z_r is the receptor height, and σ_z is the vertical plume spread. C_H is determined by balancing the mass flux upwind of the barrier with that downwind.

In the R-LINE barrier algorithm, vertical spread is calculated in two steps. The growth of the plume upwind of the barrier is determined using the upwind friction velocity (u_*) and is enhanced by an initial dispersion equal to H/2. For receptors downwind of the barrier, the plume spread is calculated at the barrier location using the upwind u_*, then allowed to continue to grow using the barrier-affected friction velocity ($u_{*,b}$). The plume spread formulation for R-LINE is a function of friction velocity (Venkatram *et al.*, 2013).

ADMS-Urban is a widely used Gaussian-type air dispersion model that is able to model the emissions from all source types found in urban areas, including roads and industrial sources. Technical information about ADMS-Urban can be found in the ADMS Technical Specification documents (CERC 2012). A new 'advanced street canyon' module has recently been added to ADMS-Urban, a general description of which is given in Hood *et al.* (2014). This module includes the effects of canyon asymmetries and so is applicable to the 'line source with noise barrier' configurations found in the experiments discussed in this paper.

The three dominant components of the advanced canyon module for a canyon with no upstream wall and wind direction perpendicular to the canyon axis, illustrated in Figure 2, are:

A) an elevated volume source above the 'canyon', located upstream of the noise barrier and across the source, influenced by the upstream wind, to model pollutant dispersion over the barrier;

B) a simplified road source subject to flow with direction opposite to that of the upstream wind, to model direct dispersion by recirculating flow; and

C) a standard road source dispersed by the upstream wind, to model direct dispersion within the canyon and pollutant downwash in the immediate wake of the barrier.

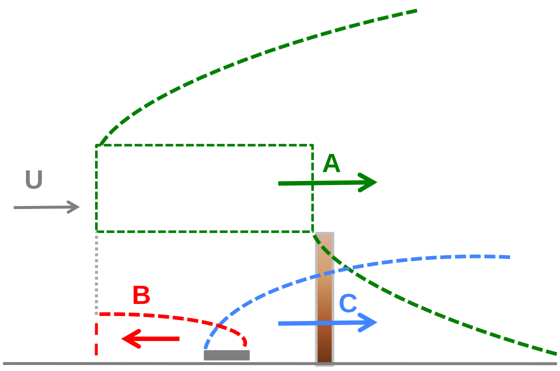

Figure 2. Illustration of the main component sources used in the ADMS-Urban advanced street canyon module for a noise barrier configuration.

The elevated volume source (A) only affects concentrations outside the canyon while the across-canyon source (B) only affects concentrations within the canyon. The weighting for the standard road source (C) is around 30% of the total emission rate, while those for both the elevated volume source (A) and the across-canyon source (B) are around 70% of the total. The different regions of influence of these sources avoid double-counting the true source emissions.

The standard ADMS-Urban initial mixing height for road sources of 1 m, which is used to account for some of the effects of exhaust gas buoyancy and vehicle-induced turbulence, was modified for both of the studies presented in this paper, as neither is a true road source. For Idaho Falls, where the source consisted of small point releases, the initial mixing height is set to zero, while for the wind tunnel study, where the source included some features to promote mixing, an initial mixing height of 0.375 m was used. For the wind tunnel study a local roughness length of 1 m was used to represent the increased turbulence due to the presence of the barrier.

RESULTS

Both the Idaho Falls and wind tunnel experiments (in addition to others – see for example, Baldauf, 2008), generally show that the presence of noise barriers leads to reductions in pollutant concentrations downwind of barriers during conditions when winds are from the roadway.

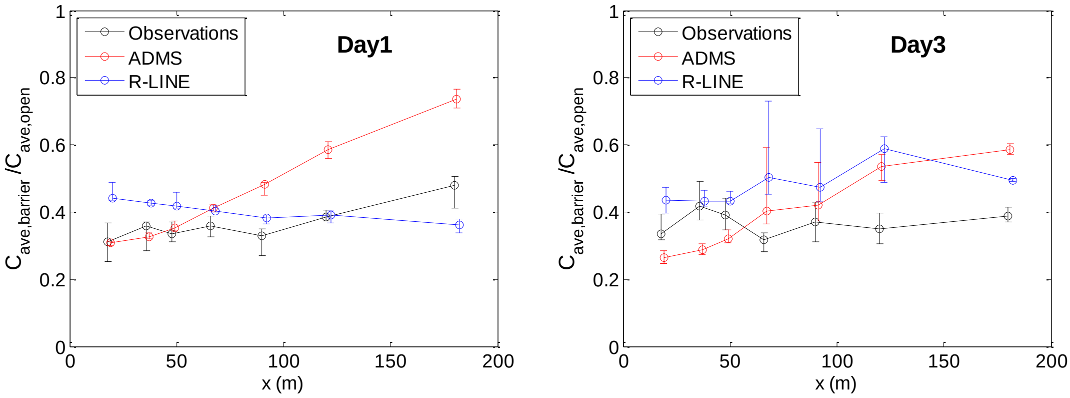

Figure 3. Results for the neutral (Day 1) and weakly stable (Day 3) test periods. Plots show the ratio of average concentrations with the barrier to those measured in open terrain. The “error bars” correspond to 25th and 75th percentile and circle is at the median.

Figure 3 shows the ratios between average concentrations measured with a barrier present to those measured in open terrain in the Idaho Falls study on two of the four days of the campaign. The averages used to compute the ratios were calculated for each 15-minute period at each downwind location by using the peak concentration and one point on either side of the peak laterally (if a point was missing in the experimental data, a neighbouring point was included instead). This averaging was employed because of the relatively coarse lateral spacing of the receptors during the study of 27 m. As seen in Figure 3, a reduction in concentration relative to the open terrain measurements was observed at each downwind distance and in each time period considered. The ratios of observed concentration ranged from roughly 0.25 to 0.50. R-LINE estimates a ratio of barrier to open terrain concentration beginning at approximately 0.45 for locations nearest the barrier and decreasing slightly to ~0.35 farther downwind on Day 1 (neutral). ADMS-Urban shows ratios beginning very near those of the observations close to the barrier and increasing with downwind distance. On Day 3 (weakly stable) both models show a similar reduction of concentration due to the presence of the barrier that is also in accord with the observed decrease.

Figure 4 shows the ability of the two algorithms employed in this study to reproduce the results for the same two test days of the Idaho Falls study. Both models performed well in simulating the open terrain conditions and the reduction in concentration caused by the barrier, generally remaining within a factor of two of the observations.

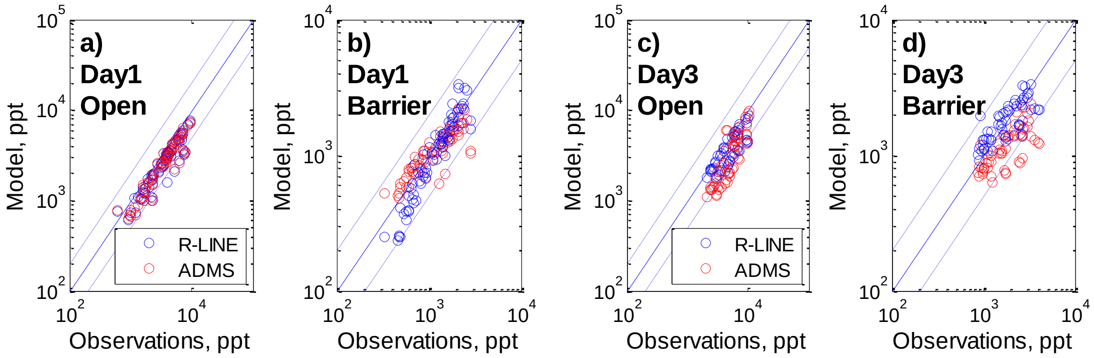

Figure 4. Idaho Falls results showing scatter plots of the average of the lateral peak concentrations with the neighbouring concentrations at each downwind distance for each 15 minutes period considered. Plots a & b show results for the day with neutral atmospheric conditions (open terrain and with barrier, respectively); similarly c & d for the weakly stable day. The solid and dashed lines are the 1:1 and factor of two lines, respectively.

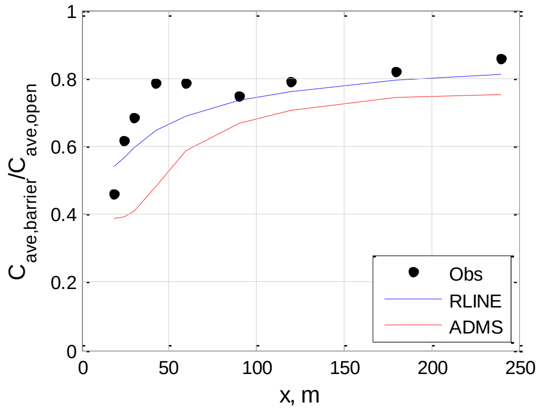

Figure 5. Observed and modelled ratios of the average concentrations with a barrier to those in open terrain for the wind tunnel experiment at z = 1.2 m.

In the wind tunnel experiments, the reduction in concentration due to the presence of the barrier was less pronounced than in Idaho Falls, with an approximate ratio of 0.80 (beyond x = 40 m) as seen in Figure 5. This smaller decrease in concentration is reproduced by both modelling approaches, though both have a more gradual increase in the ratio with downwind distance than shown by the observations. Figure 6 shows vertical profiles of concentration at two downwind distances, x = 24 and 120 m downwind of the middle of the roadway (6 and 102 m downwind of the barrier). The wind tunnel measurements demonstrate the well-mixed nature of the concentrations below barrier height and an elevated maximum consistent with an apparent elevated emission due to the barrier. The figures also exhibit the enhanced vertical spread of the plumes. Aspects of these features are incorporated into both model algorithms.

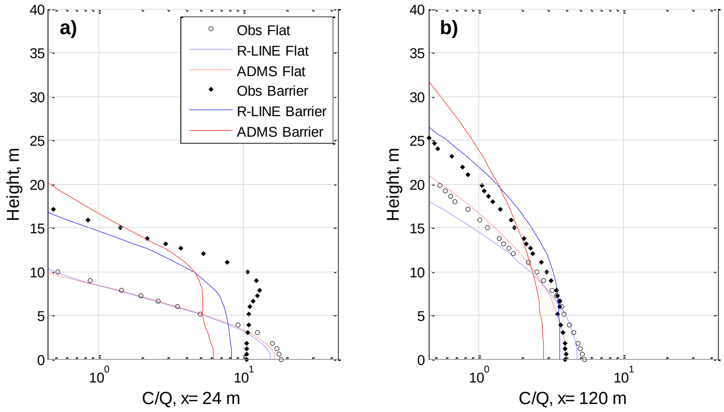

Figure 6. Vertical profiles of concentration measured in the wind tunnel and simulated with two models at full scale downwind distances of a) x = 24 m, and b) x = 120 m.

CONCLUSIONS

Two different approaches (one in R-LINE and one in ADMS-Urban) to simulating the effects of noise barriers on the dispersion of pollution from roadways have been implemented and tested. These approaches have been examined against data collected from a tracer field study in Idaho Falls under various atmospheric stabilities and a wind tunnel study where a fuller range of measurements is possible, including detailed vertical profiles of concentration, although in only one meteorological condition. Both algorithms show encouraging results, producing estimates that fall primarily within a factor of two of the observations and showing reductions in concentration of approximately the same amount as observed. The modelled vertical profiles follow the general trends of the measured profiles.

DISCLAIMER

This paper has been reviewed in accordance with the United States Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

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