5.42 EVALUATION OF THE PERFORMANCE OF AIR QUALITY MODELS IN URBAN AREAS USING TRACER EXPERIMENTS

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INTRODUCTION

The California Air Resources Board sponsored a project to develop models that can be used to examine the air quality impact of urban sources of toxics at source-receptor distances ranging from a few meters to several kilometres. The project included several tracer studies to collect data that could be used to evaluate existing models and develop new models. This paper describes results from two tracer studies. The first, conducted at the College of Engineering, Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside, examined dispersion at scales of meters from the source. The second was conducted at Barrio Logan, San Diego, California, to understand dispersion at scales at hundreds of meters to kilometres from the release.

CE-CERT EXPERIMENT

In the tracer experiment conducted at the CE-CERT parking lot, SF_6 was released from the top of a trailer surrounded by buildings. The height of release was 3.2 m. This arrangement mimics a small source on the top of a building in an urban area. SF_6 concentrations were measured continuously along two arcs, located to the east and downwind of the emission source at 10 m and 20 m arcs. In addition, SF_6 concentrations were continuously measured at six locations surrounding the trailer at distances ranging from 2 to 5 m from the source.
Meteorological observations were made at a height of 3 m using a sonic anemometer located on the 20 m arc. The observations included mean and turbulent velocities, wind speed, direction, and temperature. SF_6 was released continuously over the three-week period between June 11th and June 28th 2001, to ensure measurements could be collected over a wide range of atmospheric conditions. For analysis, we averaged concentrations and meteorological measurements over one-hour periods. The measurements indicated that the standard deviation of wind direction fluctuations often exceeded 50^o, which suggested the need to account for wind meandering in modeling dispersion.
AERMOD (**A**merican Meteorological Society/**E**PA **R**egulatory **Mod**el, *Cimorelli et al.,* 1996) accounts for meandering by expressing the horizontal concentration distribution as a linear combination of Gaussian and uniform distributions. The weighting between the two distributions is designed to make the distribution Gaussian when the horizontal turbulent intensity is small. The distribution becomes uniform when the turbulent intensity is large. The model described here, referred to as the Air Quality Model with Meandering (AQMM), incorporates a modified version of the algorithm in AERMOD in which polar co-ordinates are used to facilitate concentration calculations at large angles relative to the wind direction. By comparing AQMM's performance with those of AERMOD and ISCST3 against observations, we can examine the relative importance of meandering. It also allows us to explore the hypothesis that onsite meteorological data automatically accounts for building effects, and that it might not be necessary to explicitly model building effects when on-site information is available.

MODEL EVALUATION

Figure 1 shows concentrations as a function of the deviation of the wind direction from the line joining the centre of the source to the receptor. Observed concentrations are shown in the upper panel of this figure. We see that the highest concentrations occurred directly downwind of emission sources, but levels close to half the maximum value are observed at angles over 100^o. The second and third panels of figure 1 show the corresponding concentrations estimated using AERMOD-PRIME and ISCST3-PRIME. The PRIME algorithm accounts for two main processes associated with buildings: enhancement of plume dispersion in the turbulent wake, and reduction in plume rise caused by streamline depression over the cavity. Both ISCST3 and AERMOD overestimate concentrations close to zero wind deviation from the source-receptor line, and underestimate concentrations at larger angles, suggesting that both models might have to account for building induced plume meandering.

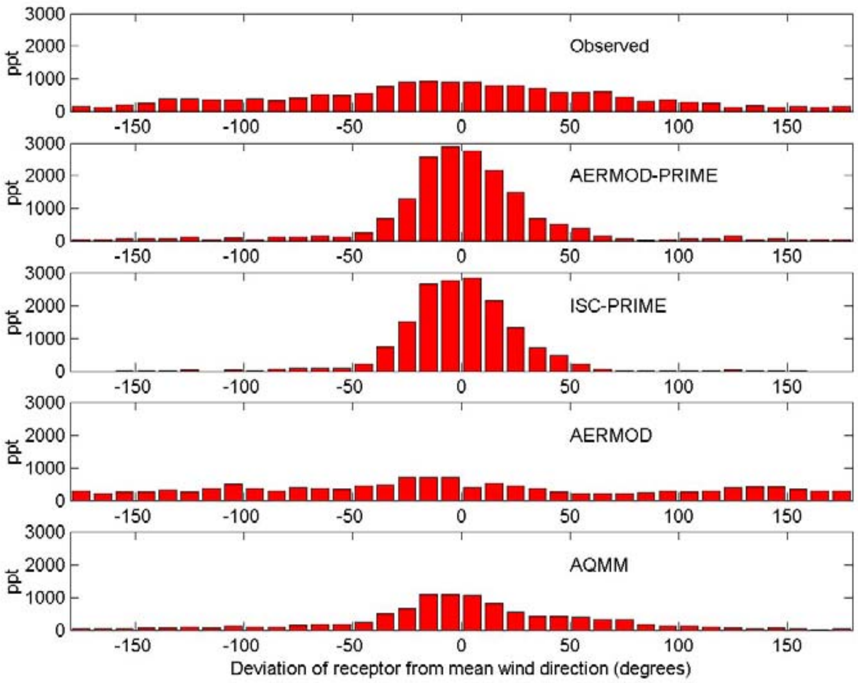

Figure 1. Concentrations as a function of the deviation of the wind direction from the line joining the centre of the source to the receptor.

The meandering algorithm in AERMOD is turned off in the wake region influenced by PRIME. This is the likely explanation for AERMOD-PRIME overestimating the concentrations at downwind receptors if we assume that these receptors are within the influence of PRIME. The similarity between AERMOD and ISCST3 at these receptors supports this assumption.

The fourth panel of figure 1 shows the performance of AERMOD when PRIME is switched off and the source treated as a volume source. The dispersion is now controlled by onsite turbulence, which is an input to AERMOD. We see that the concentration distribution is now closer to the observed distribution: concentrations are estimated over a wide range of angles, and the magnitudes are closer to the observed values. However, the distribution is much flatter than that observed. The estimates from AQMM, shown in the bottom panel of figure 1, are close to the observed values, both in terms of angular distribution as well as magnitude. This suggests the importance of the knowledge of near source turbulence in estimating observed concentrations.

BARRIO LOGAN EXPERIMENT

The Barrio Logan tracer study was conducted in Barrio Logan, San Diego, a residential community, which is surrounded by numerous small industries, large shipyards, and naval installations located to the south-west. The area consists mostly of one storey buildings about 4 m high with $\lambda_f = 0.11$ (frontal area/lot area; *Grimmond and Oke,* 1999) suggesting flow in which wake interference is small. The roughness sub-layer (RSL), associated with building induced turbulence, did not extend much beyond 10 m (2-5 times the average building height of 4 m; *Rotach,* 1999).

Five tracer release experiments were conducted from August 21st, 2001 to August 31st, 2001, with each experiment lasting 10 hours per day. SF_6 was released from a height of 5 m from the middle of a shipyard at a rate of approximately 16 kg/hr. The tracer was sampled with bag samplers at ground-level on four arcs at 200, 500, 1000, and 2000 m. Each of the outer two arcs contained 21 samplers, spaced 5 degrees apart to cover a 100 degree wedge around the south-west direction. Four samplers on the 200 m arc were spaced 10 degrees apart, and the 500 m arc contained four samplers at approximately 33 degrees apart.

The meteorological measurements were made by the University of Utah at the Logan Memorial Junior High School grounds. A SODAR measured mean and turbulent velocities from 15 meters up to 200 m at a resolution of 5 m. Measurements close to the ground were made using 5 sonic anemometers mounted on a tower at one-meter intervals, starting at 1 m from ground level.

The M-O length derived from the 5 m sonic measurements indicated that the boundary layer was convective during the 50 hours of the experiment, even during the late evening hours of August 29th, 2001. The mean value of the M-O length was close to -50 m.

MODEL EVALUATION IN BARRIO LOGAN

Model evaluation indicated that the observed arc maximum concentrations could be explained with a Gaussian dispersion model in which the plume spreads are given by:

$$\sigma_z = \frac{\sigma_w x}{U}\left(1 + \frac{x}{L_s}\right)^{1/2}$$
$$\sigma_y = \sigma_{yo} + \frac{\sigma_v x}{U} \tag{1}$$

The length scale, L_s, was taken to be 50 times the absolute value of the M-O length derived from the 5 m sonic measurements. The meteorological parameters in equation (1) correspond to medians of the SODAR measurements from 15 m to 150 m. This implies transport of the plume in the boundary layer above the urban canopy layer. Measured values of horizontal spread were consistent with estimates from equation (1).

The initial horizontal spread σ_{yo} was taken to be 50 m to account for building induced effects such as channelling. It turned out that including this spread was critical to explaining the concentrations at 200 m and 500 m. Furthermore, the concentrations at 1000 m and 2000 m were overestimated when the stability effects on σ_z were neglected. Figure 2 illustrates the performance of the model.

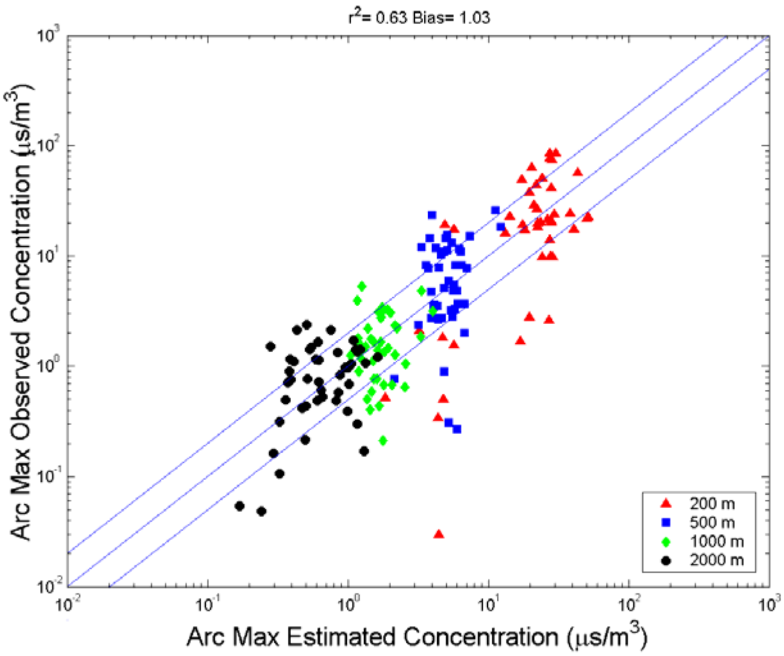

Figure 2. Comparison of arc maximum observed concentrations with estimates using Equation (1) in a Gaussian dispersion model.

We also examined the performance of the Gaussian dispersion model when the plume spreads were represented by equations proposed by Briggs (1973) to describe observations made in St. Louis (McElroy and Pooler, 1973) during unstable conditions:

$$\sigma_z = 0.24x\left(1+0.001x\right)^{1/2}$$
$$\sigma_y = \sigma_{yo} + \frac{0.32x}{\left(1+0.0004x\right)^{1/2}}, \quad (2)$$

where σ_{yo} was taken to be 50 m, and the wind speed used in the dispersion model is the 5 m sonic measurement. Equation (2) implies uniform turbulent intensities in the plume transport layer. The meteorological measurements made in the Barrio Logan study provided strong support for this assumption. The model performance using equation (2) was comparable to that from equation (1). The r^2 was 0.61 and the bias was 0.97. The model performance deteriorated substantially when the initial plume spread was set to zero.

It turns out that equation (2) is consistent with the average of the meteorological parameters used in equation (1). This is likely to be a coincidence. Note that Hanna et al. (2003) have suggested coefficients that are at least 50% smaller than those in equation (2) to explain concentrations measured during the night in a field study conducted in Salt Lake City.

CONCLUSIONS

The analysis of data collected in the urban tracer experiments at CE-CERT and Barrio Logan indicate that

The maximum concentrations at distances of tens of meters from a near surface release are strongly influenced by the horizontal meandering induced by building effects such as wake turbulence and channelling in urban canyons. These effects can be incorporated through simple models described in this paper.

Turbulent intensities in the urban boundary layer above the RSL govern ground-level concentrations at distances of hundreds of meters from a surface release.

Because the urban boundary layer is convective most of the time, the formulation for vertical plume spread at receptor distances of hundreds of meters from a surface release needs to include the $x^{3/2}$ behaviour indicated in equations (1) and (2).

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