THE DEVELOPMENT AND EVALUATION OF A DISPERSION MODEL FOR URBAN AREAS

Akula Venkatram[1], Jeetendra K. Upadhyay[1], Jing Yuan[1], James Heumann[1] and Joseph Klewicki[2]
[1]University of California, Riverside, CA
[2]University of Utah, Salt Lake City, UT

INTRODUCTION

There is a need for air quality models that can be used to estimate the impact of small sources of toxics within the urban canopy at scales of meters to kilometers from the source. This has motivated several tracer experiments in real and model urban canopies (McDonald *et al*., 1998; Hanna *et al*., 2000; Mavroidis and Griffiths, 2001). This paper describes preliminary analysis of results from two such tracer experiments. Results from these studies will eventually result in parameterizations that can be incorporated into models such as ISC or AERMOD.

The first experiment was conducted in a model urban canopy constructed with 1-meter high drums. The experiment was designed to provide information in controlled conditions that would allow us to examine the effects of source configurations on dispersion. This information will be incorporated into a model that will be tested in real urban situations. We have also conducted several experiments in urban areas to examine dispersion at scales ranging from 100 meters to 2 kilometers. In this paper, we describe the analysis of data from one of the experiments, conducted in Barrio Logan, California. We will compare the results from the model urban area to those from the real urban area to evaluate the applicability of results from scaled experiments to real situations.

DUGWAY EXPERIMENT

The model experiment was conducted at Dugway Proving Ground, Utah from 12th July 2001 to 26th July 2001. The urban canopy was simulated with a 5 × 9 rectangular array of 45 barrels with height, H=0.91m and diameter, d=0.57m, and a center-to-center spacing of S=1.8m. The experiment corresponds roughly to a model length scale ratio of 1:10 and plan area density of 16%, which is typical of an urban canopy.

Propylene (C_2H_6), a tracer, was released through a 25.4mm diameter pipe, both upstream and within the barrel array. The release rate was 15 standard liters/minute. The tracer was sampled on receptor arcs at 1.5S, 2.5S, and 4.5S from the source. Each arc contained 11 photo-ionization detectors (PIDs), 5^o apart at 0.23H above the ground. The furthest distance of 4.5S scales up to approximately 100 meters in a real urban area. One PID was placed at 0.5S to sample the cavity region of the obstacle where the source is located. At 4.5S, two PIDs were placed at 0.5H and 1.5H. The vertical array of three PIDs at 4.5S provided information to construct the vertical profile of concentrations.

Turbulence, velocity, and temperature measurements were made with sonic anemometers at three locations. Three sonics at 0.5H, 1.5H, and 3.5H on an upwind tower provided information on the approach flow. One sonic at 0.5H, behind the source obstacle, provided flow and turbulence information in the cavity region of the source. Two sonics at 0.5H and 1.5H located at 4.5S from the source provided information on the fully developed flow in the urban canopy.

The tracer source was located at either ground-level or at 1H. For each source location, four different barrel configurations were arranged near the source. In the first and second configurations, the source was placed directly upwind of a single barrel and two barrels placed side by side, respectively. In the third configuration, four barrels surrounded the source. In the final configuration, the source was located directly upwind of a three barrel pyramid.

RESULTS AND ANALYSIS

As the first step in the data analysis, we evaluated a parameterization developed earlier (Du and Venkatram, 1997; Venkatram, 1992) to explain results from the Prairie Grass experiment. The expression for concentrations associated with ground-level releases is:

$$C(x,y,z) = \frac{Q}{\sqrt{2\pi}\sigma_y u_e \bar{z}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left[-b\left(\frac{z}{\bar{z}}\right)^s\right] \tag{1}$$

where $\bar{z}$ is the mean height of the plume, u_e is the effective wind speed, and s and b are parameters that depend on the Monin-Obukhov length. The mean plume height depends on the roughness length. For the 2 cm roughness length of the Dugway site, the expression for $\bar{z}$ is

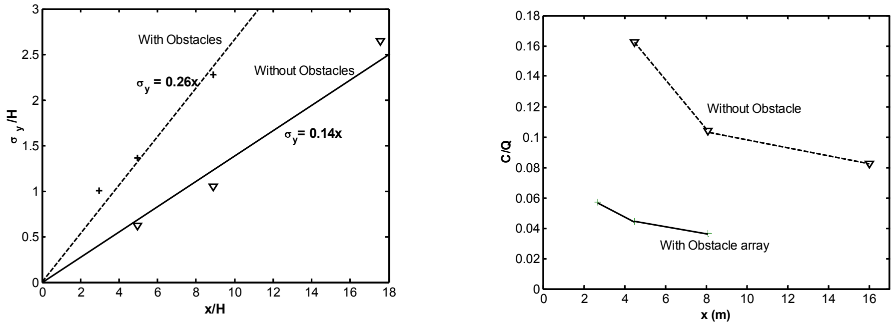
$$\bar{z} = 0.083x^{0.8} g(x/|L|) \tag{2}$$

The function g, u_e, and the parameters s and b were taken from Du and Venkatram (1997). It turns out that the product of the mean plume height and effective velocity is where m is an increasing function of x/L.

$$u_e \bar{z} = u_* x . m(x/|L|) \tag{3}$$

Most of the experiments on July 17th were conducted without obstacles in flat terrain. In these experiments, the micrometeorological variables, such as u_* and L, were derived from measurements with a sonic anemometer on an upwind tower. In the experiments with obstacles, u_* varied substantially with height within the canopy, which is consistent with results from other studies (Rotach, 2001). On the other hand, σ_w was more uniform with height in the model canopy. Thus, when Equation (3) was used to evaluate data from these experiments, we tentatively replaced u_* by an "equivalent" surface friction velocity, $\sigma_w/1.3$, which is correct in the neutral limit.

In applying Equation (1), we used values of the horizontal plume spread, σ_y, estimated by fitting a Gaussian profile to the observed concentrations at each arc. Figure 1 shows the typical variation of plume spread as a function of x/H averaged over all the experiments. We see that σ_y grows more or less linearly with distance even when the release is behind obstacles. In some of experiments, the effect of source configuration on horizontal plume spread is apparent in the first arc (not shown in the figure). It is clear that the plume growth rate is substantially larger in the obstacle array than that in flat terrain. This corresponds to the increase in σ_v/U from about 0.14 in the absence of the array to about 0.5 within the array measured just behind the source at a height of 0.5H. The value of σ_v/U just downwind of the source is about 0.26, which is more consistent with the σ_y growth rate. It appears that σ_y is governed more by the average turbulent intensity within the canopy rather than that in the cavity of the source. The behavior of σ_y, when the release is at 1H is very similar to that for the ground release, again suggesting the dependence of σ_y on average urban canopy intensities.



Figures 1& 2. Variation of plume spread and C/Q with distance with source at ground level.

Figure 2 compares the variation of the normalized concentration, C/Q in the obstacle array with that without the obstacles. We see that the concentrations are 3 to 5 times lower than those over flat terrain. We expect the concentration in the wake of the obstacle to be higher for an elevated release than that in the absence of the obstacle. A more detailed analysis of the data might provide evidence of this.

The effects of the obstacle canopy on vertical plume spread were examined by comparing model estimates of concentrations with corresponding observations. We initially analyzed experiments in which the release was at ground level. Figure 3a compares model estimates with observations at z=0.23H, the height of the PID, for the experiments in the absence of obstacles. The comparisons only include the top three observed concentrations on each arc. The concentrations corresponded to five-minute averages. We see that the estimated concentrations at arcs 1 and 2 compare well with the observed data. However, the model underpredicts the concentrations in arc 3. At this point we do not have a good explanation for this discrepancy. Figure 3b compares model estimates with observations from all the experiments with obstacles. While most of the model estimates are within a factor of two of the observations, there is considerable underprediction of the concentrations observed at arc 3. Note that concentrations with obstacles are generally lower than those without obstacles.

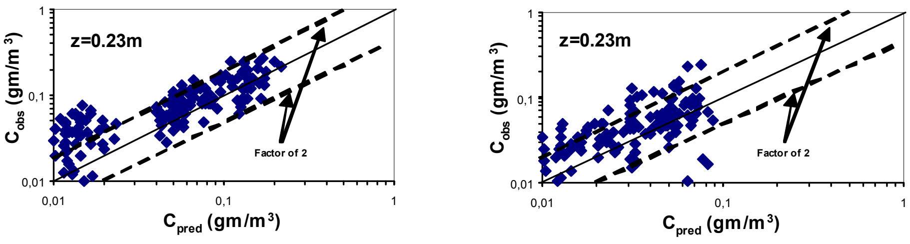


Figure 3. Comparison of observed with predicted concentrations for ground level release: (a) in the absence of obstacles and (b) with obstacles.

THE BARRIO LOGAN EXPERIMENT

This tracer experiment was conducted in the Barrio Logan area in San Diego during the period August 21-31, 2001. Barrio Logan consists primarily of single storey residences, which are located downwind of an industrial belt along the southern edge of the area. The experiment was designed to examine the impact of industrial sources on receptors at distances ranging from 200 meters up to 2 kilometers from the industrial area.

The SF_6 was released at a rate of 16 kg/hr from a single point, 5m above the ground, in the NASSCO ship building facility located in the industrial area. Fifty sampling sites were located along arcs at 100, 500, 1000 and 2000m from the release point. The samplers in arcs 3 and 4 were placed 5^0 apart, subtending an angle of 100^0 over the northeast quadrant. The samplers were programmed to collect hour-long bag samples over a period of ten hours during each day of sampling. Mean flow velocities and turbulence measurements were acquired with a three-component propeller, sonic anemometers and a minisodar. One sonic was collocated with the source and a conventional anemometer was located on the roof of a building at boundary of the NAASCO property. A vertical array of three sonics was placed on a 5-meter tower at Barrio Logan Memorial High (1000 m from source) to provide information on surface heat and momentum fluxes. A minisodar was also deployed at the High school to provide information required to estimate vertical dispersion of the plume. The range of the minisodar is 15m to 200m in 5m increments.

The data from the experiments were analyzed using the same equations as those used for the Dugway data. For this initial comparison, the meteorological data were obtained from the 5m level of the tower located at Barrio Logan Memorial High. Figure 4 shows the relationship between the "measured" horizontal plume spreads and the horizontal turbulent intensity averaged over one hour periods. Although there is considerable scatter, plume growth is consistent with linear spread, with the growth rate proportional to the turbulent intensity measured within the urban canopy.

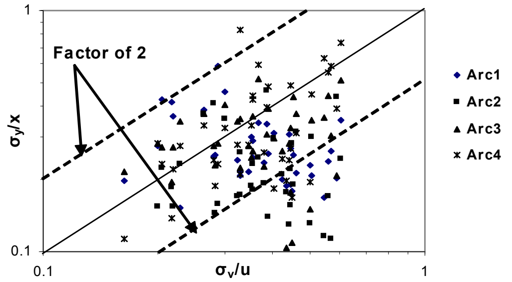


Figure 4. Relationship between measured plume spread (σ_y /x) and turbulent intensity (σ_v /u)

Figure 5 shows the comparison model estimates and corresponding observations made during the daytime experiments. The model underestimates concentrations along the 2000m arc suggesting that the coastal internal boundary layer might be limiting vertical spread at this distance.

CONCLUSIONS

There is preliminary indication that models developed for flat rural areas can be used in urban areas as long as we use meteorological variables measured within the urban canopy. Also, methods used to estimate concentrations in the field appear to be applicable to model urban canopies. This suggests that information obtained from the controlled conditions of the model canopy is likely to be useful for interpreting data from real urban areas.

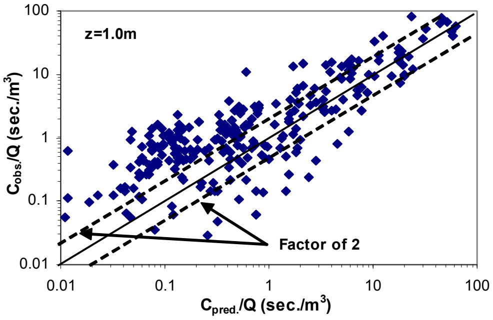


Figure 5. Comparison of observed with predicted concentrations for Barrio Logan Experiment

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