SIMPLE SCREENING MODELS FOR URBAN DISPERSION

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INTRODUCTION

A set of formulas for estimating wind flow, turbulence, and dispersion in obstacle arrays such as urban areas and industrial sites was suggested by Hanna and Britter (2002). The current paper describes two simple models based on these formulas and gives results of tests of the model with tracer data from the Salt Lake City Urban 2000 field study (Allwine et al., 2002). The models are based on the Gaussian plume and puff formulas and emphasize knowledge of the wind profile, the friction velocity $u*$, and the turbulent standard deviations within and above the urban canopy, which has an average height H_r. Alternate models are suggested for plumes released below and above the urban canopy, and smooth transitions are imposed.

MODEL ASSUMPTIONS

The first screening model is called "Another Simple Urban Dispersion Model (ASUDM)" because it follows the basic philosophy of the simple urban dispersion model developed by Hanna (1971). The ensemble mean concentration, C, is given by the standard Gaussian formulas for continuous and instantaneous releases (Hanna et al., 1982). The wind speed u is either observed or estimated at the release height, h_e. The roughness length z_o and the displacement length d can be estimated using formulas in Hanna and Britter (2002), henceforth referred to as HB. The sensible heat flux or the Monin-Obukhov length L must also be specified although neutral stability is a good default assumption for urban areas. A major assumption in the HB method is that mean wind speeds and turbulence are proportional to $u*$, which is the friction velocity based on the average drag over the urban surface.

The mean wind speed in and above the urban canopy is assumed to be the <u>maximum</u> of that given by the standard Monin-Obukhov formula (Stull, 1997) and the characteristic speed, u_c, within the urban canopy.

$$u_c = u^* (2/\lambda_f)^{1/2} \quad \text{for } z < H_r \tag{1}$$

$\lambda_f = A_f / A_t$ is the building morphology parameter, where A_f is the average frontal area of the buildings within a given average lot area A_t. u_c represents the near-constant wind speed observed in field and laboratory experiments at $0.25H_r<z<0.75H_r$. $u_c/u*$ decreases as the density of the obstacles λ_f increases.

In the application described in this paper, it is assumed that the cloud speed is constant and is equal to the wind speed at the release height, h_e. Consequently, for any release near the ground below the urban canopy, the cloud speed equals the characteristic speed, u_c. Alternatively, ASUDM could calculate the cloud speed at the mean height of the cloud, but that version is not tested in this paper. The more complex version would be more appropriate for downwind distances greater than 1 km or so.

The dispersion coefficients σ_y, σ_z, and σ_x are based on HB, with modifications to assure smooth transitions. For a cloud below the urban canopy (i.e., $h_e<H_r$ and $\sigma_z<H_r$),

$$\sigma_z = \sigma_{zo} + f_z(\lambda_f)x \quad (2)$$

$f_z(\lambda_f) = 0.47\lambda_f^{1/2}$ for $\lambda_f \leq 0.15$ and $f_z(\lambda_f) = 0.18$ for $\lambda_f > 0.15$

At a distance x_H where $\sigma_z = H_r$, the transition from "below" to "above" H_r occurs. σ_x and σ_y at $z<H_r$ are also given as functions of λ_f, H_r, and obstacle width W and face-to-face spacing S_y. The dispersion coefficients for the regime above the urban canopy are used if $h_e>H_r$ and/or if $\sigma_z>H_r$, and are given by the Taylor formulas listed in HB, who also suggest parameterizations for the Lagrangian time scales.

An even simpler urban dispersion model (ESUDM) is also proposed for screening calculations and requires less inputs than ASUDM. The solution can be quickly found with hand calculations and is based on the Gaussian plume model with the Briggs urban σ_y and σ_z curves (Hanna et al., 1982). Those curves were derived from the St. Louis field experiment in the 1970s. ESUDM assumes that stabilities in urban areas are always nearly-neutral. The only modification that is made is to the σ_y formula to agree with observations that, for hourly averages, σ_v has a minimum value of 0.5 m/s during periods with light and variable mean winds (Hanna, 1990). Thus, the lead coefficient in the Briggs σ_y equation is not allowed to drop below (0.5 m/s)/u.

SALT LAKE CITY URBAN 2000 DATA AND EVALUATIONS

Allwine et al. (2002) describe the Urban 2000 experiment carried out in the Salt Lake City urban area in October 2000. The data have not been fully released but three of the SF_6 tracer data tests from the night of 26 October 2000 have been made available for preliminary studies. The tracer gas was released at a rate of about 1 g/s for one hour periods, beginning at 00, 02, and 04 am, from a location upwind of a large building in the downtown area. In the area of the experiment, H_r is determined to be about 15 m and z_o is estimated to be about 2 m. Very light (about 0.5 to 1.0 m/s) winds were observed at street level, but moderate speeds of about 4 to 5 m/s were observed at a height of 50 m. SF_6 sampling arcs were set up along semicircles at eight arc distances, R, ranging from about 0.15 to about 6 km downwind. *Figure 1* presents an example of the observed concentrations, C, (in ppt for a 30 minute average ending at 01 am) on the eight sampling arcs for the 00 release. Best-fit Gaussian curves are shown as dashed lines on each plot, with the corresponding σ_R (= σ_y) value listed. The figure illustrates typical variations in whether the observed concentrations conform to a Gaussian distribution. For example, at the R = 444 m, 931 m, and 5999 m arcs, the distributions were too flat to allow a reasonable Gaussian fit.

ASUDM was applied to the three releases on 26 October by assuming that a set of 30 puffs was released over one hour. *Figure 2* compares maximum 30-minute average ASUDM predicted concentrations versus observed concentrations as a function of downwind distance for the three periods. The comparisons in each figure use the 30-minute averaged maximum C anywhere on the arc during the two-hour sampling period for each test. The agreement is seen to be within a factor of two for most of the data points.

ESUDM was also tested, where the results are averaged over the three test periods, and a wind speed of 1 m/s is assumed. The results for C/Q and for σ_y averaged over the three experiments are shown in *Figure 3*, indicating little mean bias and agreement well within a factor of two.

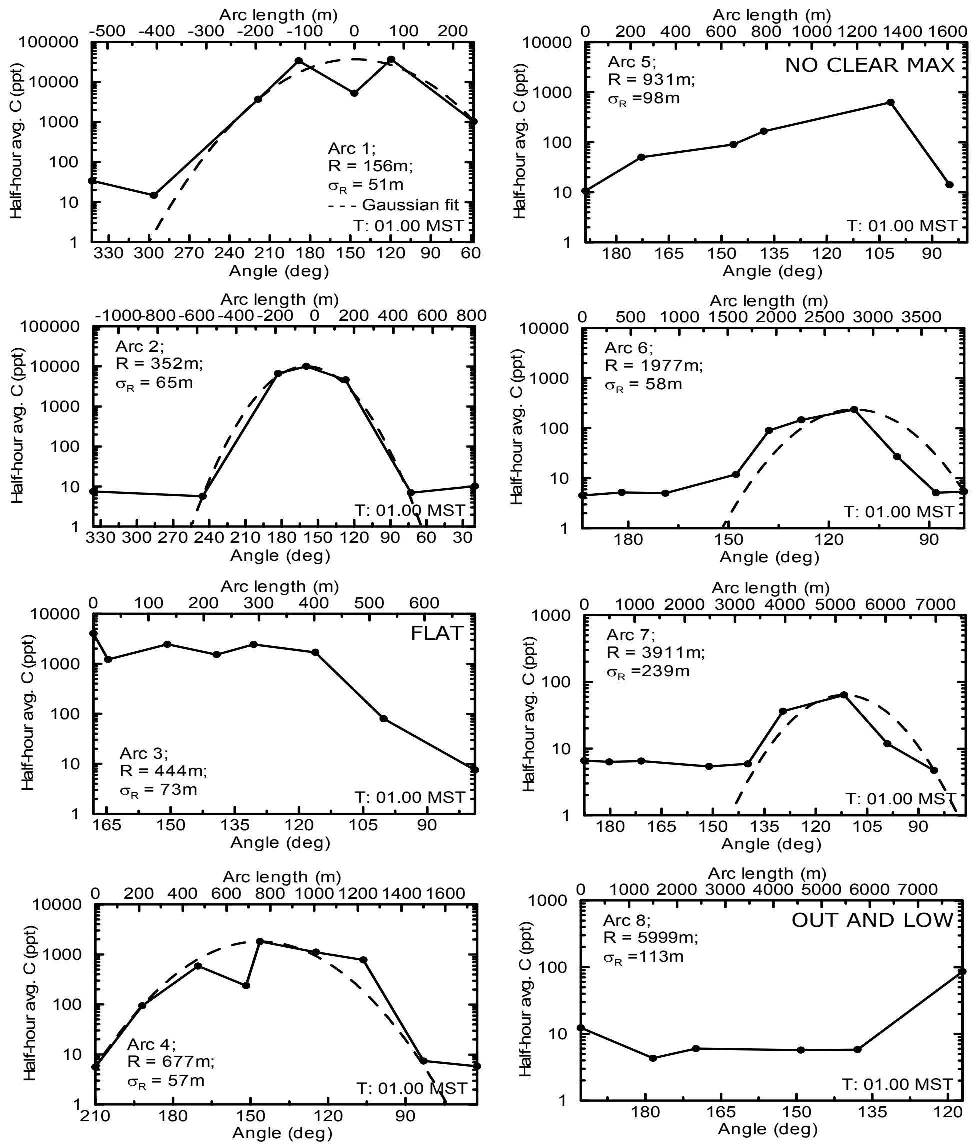

Figure 1. Observed concentrations (in ppt for 30 minute averages) on eight sampling arcs for the 26 October 00 MST SF_6 release during the Salt Lake City Urban 2000 experiment. The arc number and its distance, R, from the source are given, as well as the σ_R = σ_y value best fit using the dashed Gaussian curve.

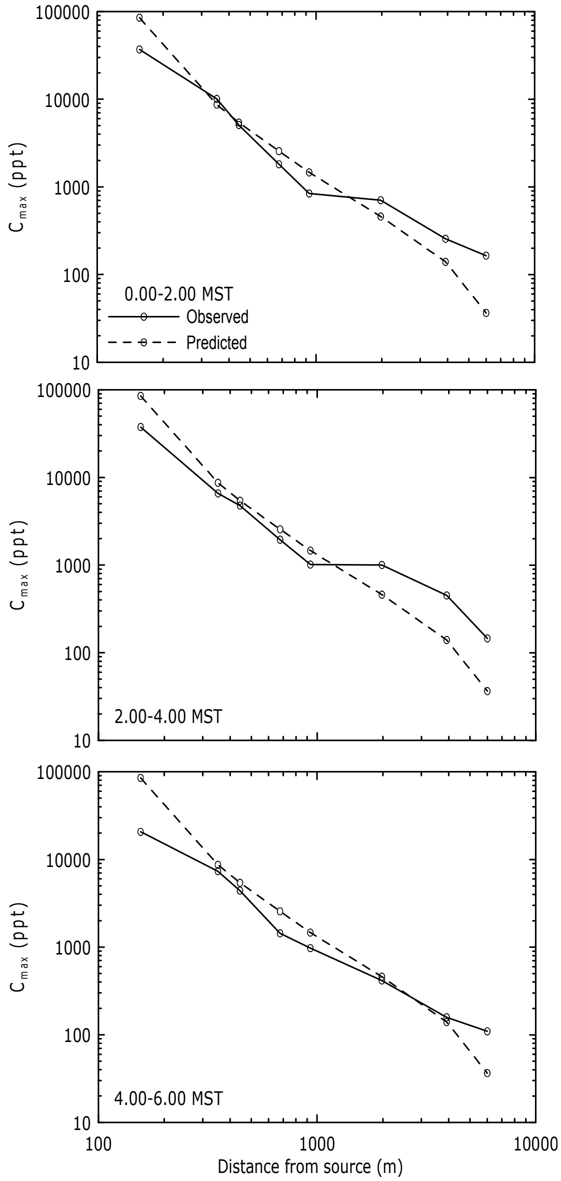

Figure 2. ASUDM predictions (dashed lines) and observations (solid lines) of maximum 30-minute average SF_6 concentration (ppt) during a two-hour experiment duration as a function of distance for three 26 October 2000 nighttime tests in SLC.

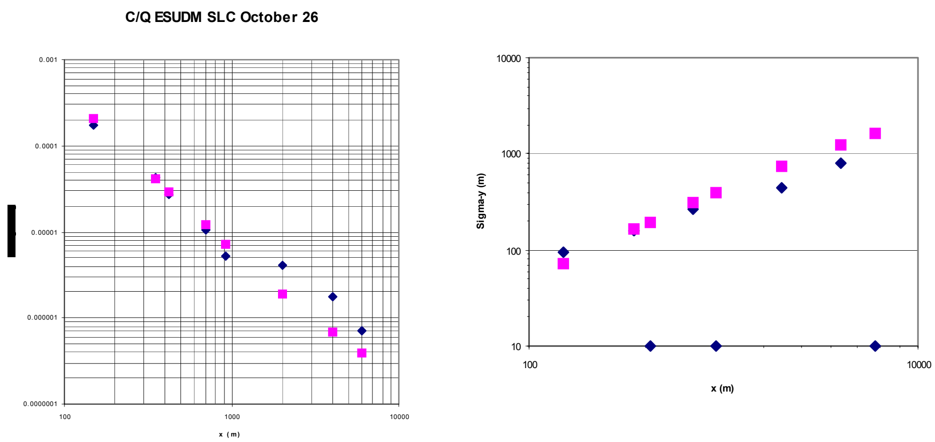

Figure 3. ESUDM predictions (squares) and observations (diamonds) of (left panel) maximum 30-minute average SF_6 C/Q and (right panel) σ_y during a two-hour experiment duration as a function of distance averaged over the three 26 October 2000 nighttime SLC tests.

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