COMPARISON OF PREDICTIONS FROM THE ASUDM (ANOTHER SIMPLE URBAN DISPERSION MODEL) WITH RESULTS FROM THE DAPPLE TRACER FIELD EXPERIMENT

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1. Introduction

In this note the measurements from the first DAPPLE tracer field experiment are compared with predictions from *Another Simple Urban Dispersion Model (ASUDM)* developed in [4].

2. Another Simple Urban Dispersion Model (ASUDM)

ASUDM is a Gaussian-plume based model (such as the Baseline Urban Dispersion Model [1]) for simulating the concentration field resulting from near-surface releases in urban and above canopies. It focuses on the specification of the wind profile, the friction velocity, the turbulent standard deviations and the turbulence integral time scales within and above the urban canopy.

For the ground-level concentration on the plume centre-line, the model prediction is of the form

$$C_{max}/Q = 1/(u_e \pi \sigma_y \sigma_z)$$

where C_{max} (kg/m^3) is the near field maximum concentration that would be measured at a ground-level receptor located on an arc a distance x (m) resulting from a continuous source releasing at a rate Q (kg/s) at, or near ground level; u_e (m/s) is the effective wind speed for the plume advection and dilution in and above the urban canopy, and σ_y and σ_z are the standard deviations of the cross-wind concentration distributions at that distance, x.

The wind velocity u_e can be represented by the characteristic wind velocity in the urban canopy u_c which is estimated to equal [7]:

$$u_e \sim u_c = u_* (\lambda_f/2)^{-1/2} \quad \text{for } z < H_r,$$

where u_* is the friction velocity that represents the urban surface shear stress. The friction velocity u_* can be estimated using a wind speed observation u, at a height above the average building height H_r, and the equation:

$$u_* = \kappa u/(ln((z-d)/z_0) - \psi(z/L));$$

where κ is von Karman's constant, taken to be 0.40.

The friction velocity can also be estimated by using estimates for the Monin-Obukhov length L, defined as [8]

$$L = - u_*^{\ 3}/(\kappa\, g\, H_f /T),$$

where $H_f = Q_f /\rho c_p$ and Q_f is the surface sensible heat flux, ρ, c_p and T are the density, the specific heat capacity and the temperature of air, and g is the acceleration due to gravity. For the calculation of the friction velocity, estimates of the roughness length, z_0, and displacement height, d, can be obtained in terms of the building morphology parameters using formulas derived in [7].

Estimates for σ_y and σ_z when the plume is below the urban canopy can be obtained from[4] :

$$\sigma_z = \sigma_{zo} + f_z(\lambda_f)\, x, \text{ for } z<H_r$$
$$\sigma_y = \sigma_{yo} + f_y(\lambda_f)\, x, \text{ for } z<H_r$$

where $\sigma_{zo} = \sigma_{yo} = H_r /2$, and when the plume is above the urban canopy, from:

$$\sigma_z = \sigma_{zo} + f_z(\lambda_f)\, x_H + (\sigma_w(x-x_H)/u_e)(1+(x-x_H)/2T_{lz}u_e), \quad \text{for } z>H_r$$

$$\sigma_y = \sigma_{yo} + f_y(\lambda_f)\, x_H + (\sigma_v(x-x_H)/u_e)(1+(x-x_H)/2T_{lz}u_e), \quad \text{for } z>H_r.$$

These hold for a distance x in the range $x_H < x < 10km$, where x_H is the distance at which the transition from below-to-above the urban canopy is assumed to occur (i.e where $\sigma_z=H_r$ [4]), or at:

$$x_H = (H_r - \sigma_{zo})/ f_z(\lambda_f),$$

and for the DAPPLE field site, x_H was calculated to be approximately 77m, equivalent to ~3.5H_r. Though ASUDM is presented here in terms of the maximum concentration downwind of the source, the result could be restated that the concentrations at any receptor a distance R from the source in any direction should be smaller than that provided by the model, with R replacing x.

3. The field site and collected data

Predictions from ASUDM require more input information about the urban morphology and the urban meteorology than other simple models (eg. BUDM), and it can thereby make predictions for specific sites. ASUDM requires an estimate of the effective wind speed for the plume advection and diffusion through the urban canopy, which depends both on the urban morphology and urban meteorology.

3.1 The field site: urban morphology and meteorology

An appropriate building morphology parameter, important to the drag force, is the dimensionless frontal area λ_f (also called packing density). The corresponding value for the DAPPLE field site was deduced from a 1:200 scale model used for the wind tunnel experiments [9]. The value for the λ_f parameter was calculated to be 0.093, which is rather surprising as this would be the expected value for areas with rather moderate density of buildings [10].
According to Hanna and Britter [7], in this regime of λ_f values ($\lambda_f \leq 0.15$) suitable estimates of the surface roughness length, z_0, and the displacement height, d, are given by:

$$z_0=\lambda_f H_r, \qquad \text{and} \qquad d=(0.15+5.5\,(\lambda_f-0.05))H_r,$$

which lead to

$z_0=2.04m$ and $d=8.48m$, for the DAPPLE field experiment.

The average building height (H_r) was estimated to be 22*m* [2]. The mean wind speed (u) and direction (θ) were taken from the meteorological measurements (at the reference station atop the Westminster City Council building - of a height of 30*m* [12]) to be 3 *m/s* and 200°.The source release rate (Q) was taken from the tracer experiment data set and was $1.27\text{x}10^{-7}$*kg/s*. The mean temperature recorded in the meteorological measurements was 17°*C* (290*K*). Essentially we are using meteorological data near the top of the “urban canopy”.

Estimates of the friction velocity for the DAPPLE tracer field experiment can be obtained in two ways: (a) through available estimates of the Monin-Obukhov length and the sensible surface heat flux, and (b) through available estimates of the surface roughness length, the displacement thickness and a wind velocity measurement at the site.

(a) Monin-Obukhov length (L) and surface sensible heat flux Q_f

Estimates of L are tabulated according to the weather conditions in [4]. For the wind speed range of the DAPPLE experiment, the tabulated range of values for L is between –50*m* for a sunny day and –200*m* for a cloudy day. An average value of –125*m* can be regarded as appropriate as it also respects the condition of $|L| \geq 3H_r$[4].

Estimates of the sensible heat flux ($Q_f = \rho c_p H_f$) are obtained from relevant atlas maps for Britain[11]; the values range from $40\ W/m^2$ during winter to 80 W/m^2 during summer, leading to an average estimate of 60 W/m^2. The mean recorded temperature from the DAPPLE experiments was 17°*C* [12]and with standard values for the density and specific heat capacity of air[1], the friction velocity is calculated as 0.429 *m/s.*

(b) Wind velocity measurement

The single measurement of the wind velocity (3 *m/s*) atop of the Westminster City Council (30*m*-high) leads to an estimate of the friction velocity of 0.505 *m/s.*

[1] The values for air used here: $\rho = 1.225\ kg/m^3$ and $c_p=1.046\text{x}10^3\ J\ kg^{-1}C^{-1}$.

The two estimates above lead to an average estimate for the friction velocity u*as 0.467 *m/s*, and thereby to an estimate of 2.168 *m/s* for the characteristic wind velocity u_c to use for predictions from the ASUDM model. This velocity is used as the effective wind speed for advection and dilution of the plume for all the DAPPLE predictions. At the farther distances from the source an effective wind speed of 3m/s (the measured reference wind speed at the top of the urban canopy might be more appropriate).

3.2 The concentration measurements

The experiment provided a time series of sequential 3-minute averaged data over a 30-minute time period at 9 receptor sites (one of the 10 receptors failed, and one was at elevation and the remaining 8 were close to ground level). The release was for 15 minutes and at the short distances between source and receptor in the experiments it was anticipated that the release would appear as a continuous one. However, a clear "constant" concentration was never apparent in the concentration records.

We have chosen the maximum of the 3-minute averaged data from each receptor for comparison. The receptor positions, along with the concentration data, are tabulated below and are also shown on the area map in Figure 1. These values were used for both the model predictions and for the normalization and non-dimensionalisation of the field experiment results.

Box Number #	**Distance from the source -** ***Direct, R (m)***	**Distance from the source** ***By road (m)***	**Normalised direct distance from the source, R/H_r**	**Angle from wind direction, φ (°)**	**Concentration** ***C(kg/m^3)***	**Non-dimensional concentration** ***CUH_r^2/Q***
1	200	200	9.09	67 (to the right)	1.14E-12	0.0131
2	200	250	9.09	38 (to the right)	-----	-----
3	120	160	5.45	28 (to the right)	9.58E-12	0.109
4	115	150	5.22	2 (to the left)	1.38E-11	0.158
5	115	150	5.22	2 (to the left)	1.20E-11	0.138
6	200	280	9.09	14 (to the right)	6.38E-12	0.0731
7	275	350	12.5	26 (to the right)	2.03E-12	0.0233
8	430	540	19.55	36 (to the right)	3.81E-13	0.00437
9	200	250	9.09	13 (to the left)	5.41E-12	0.0620
10	75	90	3.40	21 (to the left)	2.13E-11	0.244

4. Comparison and Discussion

A comparison between model predictions and experimental measurements are shown in Figures 2 and 3 in dimensional and non-dimensional forms. The model appears to be a good predictor of the DAPPLE experiments except for the two sensors most removed from the downwind centerline (Boxes 1 and 8).

To consider this further, and assuming a Gaussian plume structure for the measured plume, estimates of the maximum concentrations on an hypothesised plume center-line (given the recorded mean wind direction and a model estimate for σ_y and σ_z) can be made and be compared with the corresponding predictions by ASUDM[4]. These calculations produced results in somewhat better agreement with the correlation particularly closer to the source. However further from the source the estimated concentrations turn out to be much larger than the model predictions. This suggests that (a) the width of the measured plume may be larger than that assumed from [3] and/or (b) there is a preferred flow direction along the Marylebone Road with part of the plume not diffusing/dispersing but rather being advected along long, large roads and thereby establishing a preferred direction so that the center-line of the plume does not correspond to the reference mean wind direction.

It also has to be noted that the DAPPLE measurements are 3-minute averages. In ASUDM there is no particular mention about what the averaging time of the predictions corresponds to. Nonetheless the expressions for σ_z and σ_y of the model which are based on those given by the curves in [3] represent an averaging time of 10 minutes.

5. Conclusions

In this note, the DAPPLE field measurements were interpreted in the context of a comparison with predictions from ASUDM [1] – a model that includes more information about the specific urban site. The model can be interpreted as providing an upper bound for any measured concentration downwind the source. The DAPPLE measurements fell below the upper bound, supporting the arguments of the model.

References:

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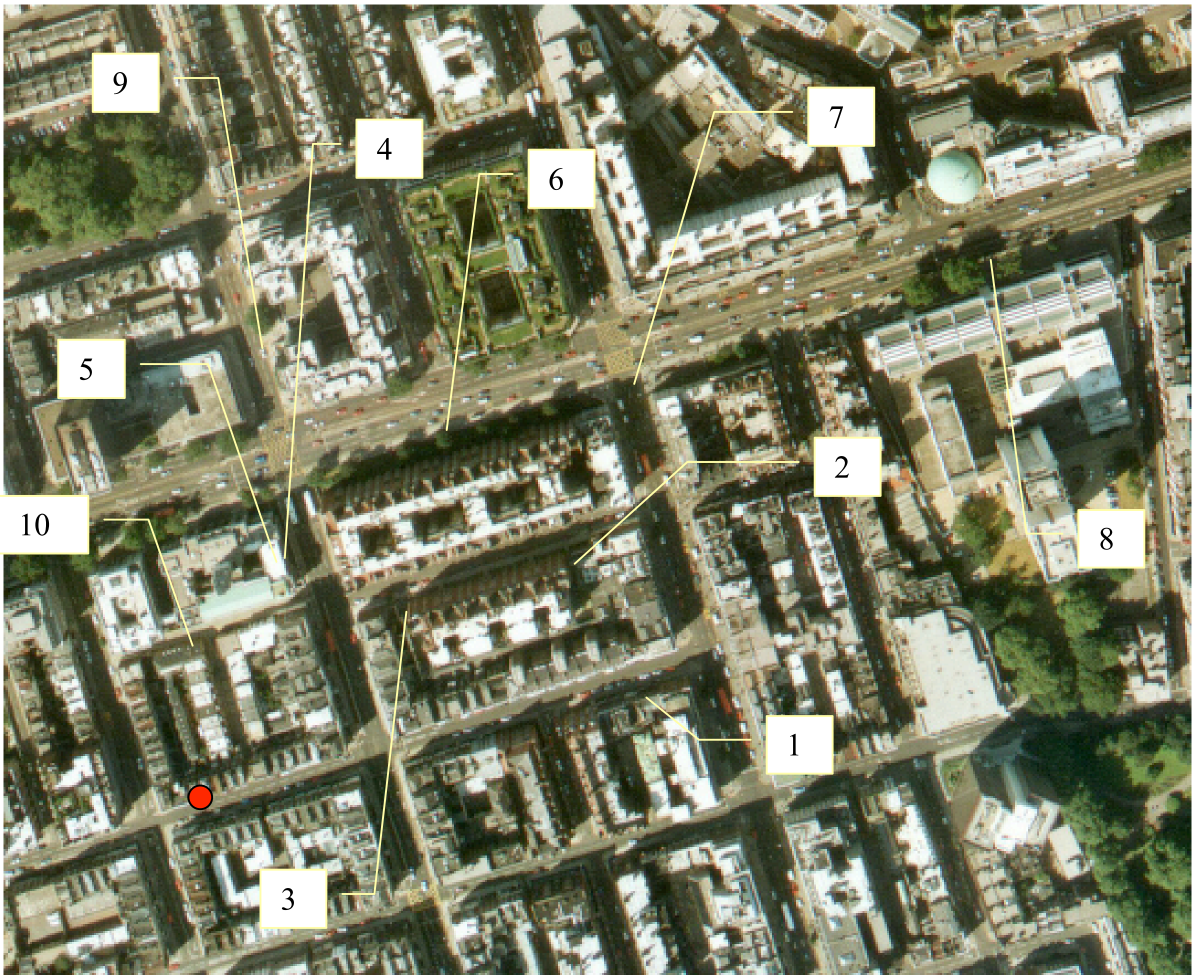

Figure 1: Area map of the tracer field study (Marylebone area) depicting source-receptor positions; source indicated by the red spot, and receptors are numbered and indicated by the yellow lines.

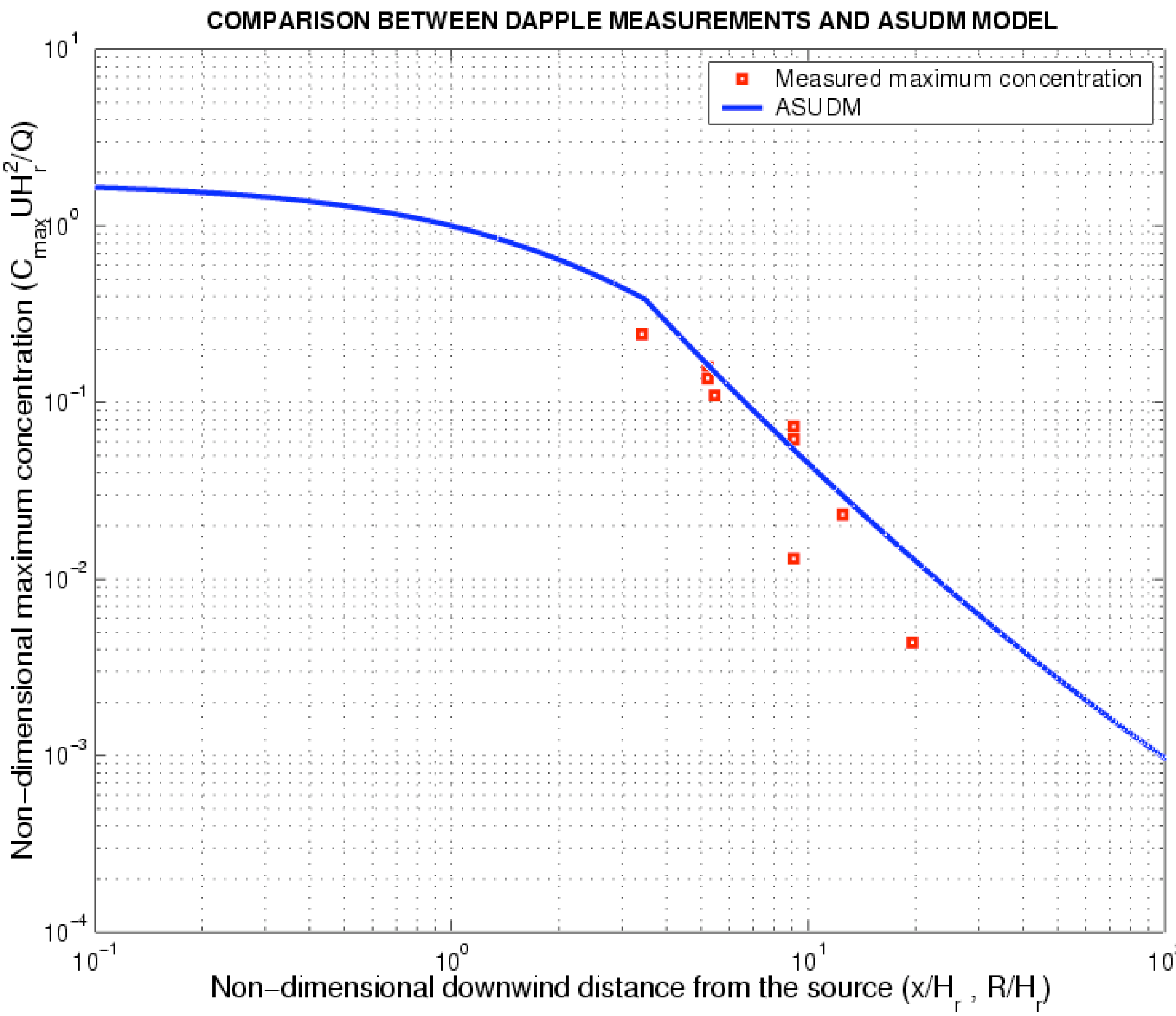

Figure 2: Comparison between DAPPLE field measurements and predictions from ASUDM developed in [4].

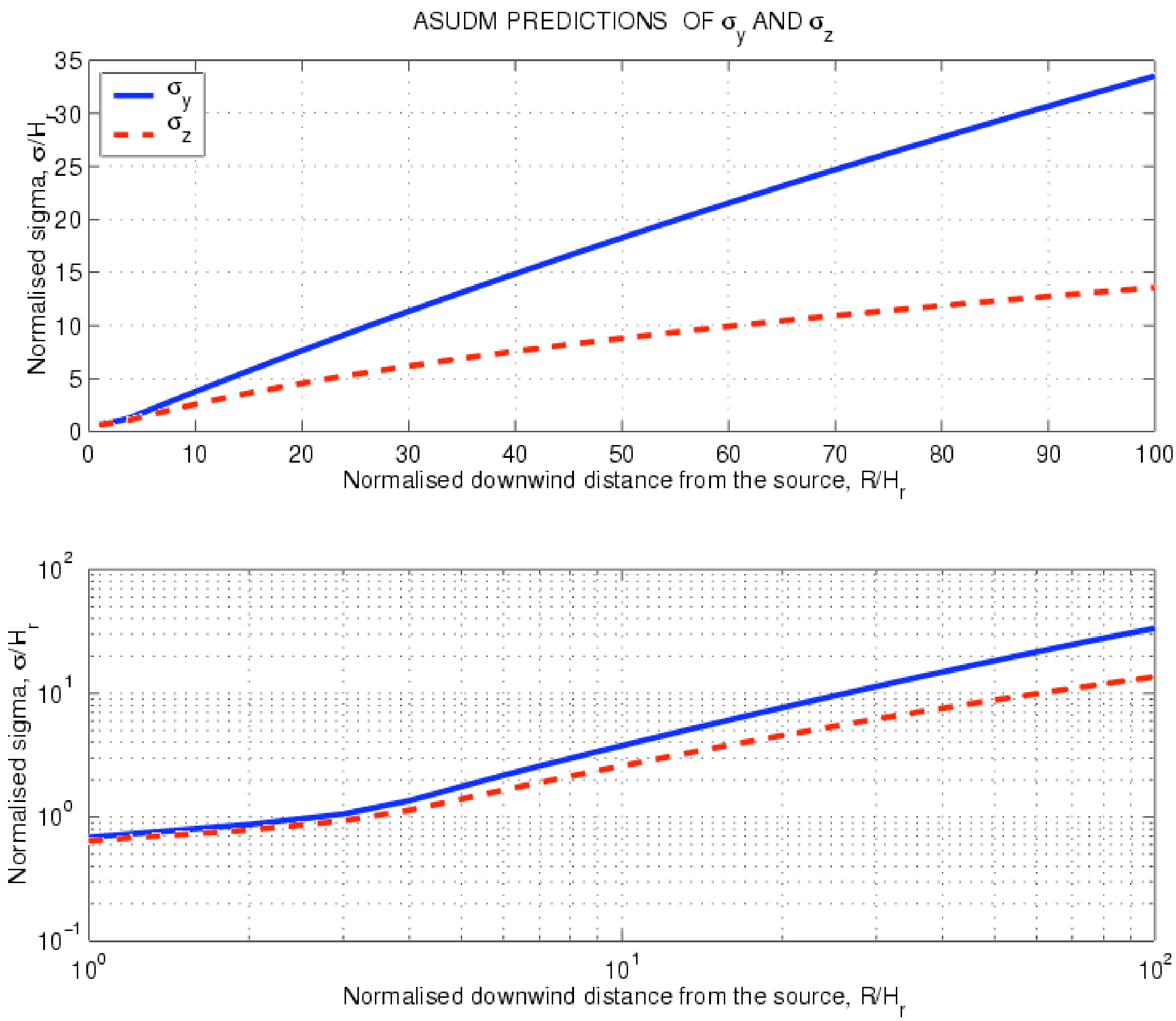

Figure 3: Predicted standard deviations of cross-wind concentration profiles (σ_y and σ_z) by ASUDM [4].