URBAN HPAC AND A SIMPLE URBAN DISPERSION MODEL COMPARED WITH THE JOINT URBAN 2003 (JU2003) FIELD DATA

Steven Hanna[1] *Ian Sykes*[2], *Joseph Chang*[3], *John White*[4], *and Emmanuel Baja*[5]

[1]Hanna Consultants, Kennebunkport, Maine, USA
[2]Sage Management, Princeton, NJ, USA
[3] Fairfax, VA, USA
[4]US Army Dugway Proving Ground, UT, USA
[5] Harvard School of Public Health, Boston, MA, USA

Abstract: The Hazard Prediction and Assessment Capability (HPAC) dispersion model is widely used by the U.S. Department of Defense and the results of previous evaluations have been presented at Harmonization conferences. The version of its diagnostic wind model that is applied to urban areas has been significantly updated to remove biases in wind speed estimates, requiring re-evaluations with urban tracer data sets such as the Joint Urban 2003 (JU2003) data base. For comparison purposes, a simple Gaussian-format urban dispersion model has been run for the same JU2003 data base. The simple urban model has previously been evaluated with the Madison Square Garden 2005 (MSG05) data. The evaluations focus on 30-minute averaged (1) arc maximum concentrations and (2) concentrations paired in space. It is shown that the revisions to the diagnostic wind model in urban HPAC have resulted in improved performance. Similar good performance is found for the simple urban dispersion model, although it has more errors for off-centerline and upwind receptors in the downtown area.

Key words: *Urban dispersion; Model evaluation; Joint Urban 2003 field experiment,; HPAC model.*

1. INTRODUCTION

The current study focuses on a widely-used model system - the Hazard Prediction and Assessment Capability (HPAC) (DTRA, 2008), which includes the SCIPUFF atmospheric transport and dispersion (T&D) model (Sykes et al., 2007). Earlier evaluations of version 4.04 of HPAC/SCIPUFF by the same authors (Hanna et al., 2007a) and by Warner et al. (2008) showed differences in model bias for the day and night tracer data from the Joint Urban 2003 (JU2003) experiments. The model underpredicted by about a factor of two during the day and overpredicted by a factor of three or four during the night. In the months since the Hanna et al. (2007a) paper was written, the model has been revised (now version 5.0 SP1) in order to improve several aspects of the code and the current paper concerns evaluations of the new version with the same JU2003 data. During the same period, a simple urban dispersion model has been evaluated with the same JU2003 data by Hanna and Baja (2008) and it is of interest to compare these results with the HPAC/SCIPUFF results.

2. DESCRIPTION OF JU2003 FIELD EXPERIMENT

The JU2003 field experiment is part of a series of urban experiments sponsored primarily by the Defense Threat Reduction Agency (DTRA) and the Department of Homeland Security (DHS) intended to address transport and dispersion from near-surface releases in highly-populated downtown areas. Each experiment consists of a few Intensive Observation Period (IOP) days, during which a number of tracer releases take place, with detailed meteorological observations. Each of the ten IOP days during JU2003 involved intense observations over a period of about eight hours (Allwine et al., 2004, Clawson et al., 2005). The current study addresses daytime IOPs 3, 4, 5, and 6 and nighttime IOPs 7, 8, 9, and 10. IOP05 was dropped from consideration after it was discovered that it was anomalous because of low mixing depths caused by a nearby thunderstorm complex (White et al., 2008). During each of the JU2003 IOPs considered here, three continuous releases of SF_6 of duration 30 minutes were made at two-hour intervals. Samplers were set out on a rectilinear grid in the downtown area at distances less than 1 km from the source, and on three concentric arcs (at 1, 2, and 4 km) to the north of the downtown area. Fig. 1 shows several types of samplers operated by different groups. The current evaluations use the concentrations averaged over 30 minutes from the samplers at triangle-shaped locations, which are the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory-Field Research Division (ARL-FRD) samplers, described by Clawson et al. (2005). JU2003 had 29 separate SF6 tracer continuous releases (30-minute in duration), and 21 are used in this paper. The releases during IOPs 3, 4, 5, 6, and 7 were from the Botanical Gardens site. The Westin Hotel site was used for IOP08 and the Park Avenue site was used for IOPs 9 and 10.

3. HPAC OPTIONS TESTED

Several changes were made to HPAC in Version 5.0 SP1 (released in January 2008). For the purposes of the urban comparisons, the revised HPAC/SCIPUFF contains modifications to the SWIFT diagnostic meteorological model to remove errors in urban canopy winds in version 4.04. Also the MicroSwift-Spray (MSS) urban diagnostic wind and Lagrangian particle model is included in version 5.0 SP1. The evaluations use the following HPAC/SCIPUFF urban options:

- UC – Urban canopy (a parameterization of the urban wind and turbulence profiles in SCIPUFF)
- UDM – Urban Dispersion Model (UDM and UC are alternate and separate urban modules in previous HPAC versions)

- MSS – MicroSWIFT/SPRAY (a new addition in version 5.0 SP1)

The current runs use the same four alternate sets of meteorological data inputs as the Hanna et al. (2007) evaluations:

- Basic Default (BDF) – Basic National Weather Service (NWS) default (airport data)
- MEDOC – Mesoscale Meteorological Model – Version 5 (MM5) MEDOC outputs using special 4 km resolution runs by NCAR (see Liu et al., 2006). MEDOC is a special format used just for inputs to HPAC.
- AVG – Average wind speed and direction from all anemometers in urban area (Hanna et al., 2007b)
- UPWND – Wind speed and direction from DPG Portable Weather Information Data System (PWIDS) #15 (Post Office) with estimated mixing heights determined from the Pacific Northwest National Laboratory radiosonde data. PWIDS#15 is about 1 km upwind of the downtown area and is at a height of 40 m agl.

Note that SWIFT (or MicroSWIFT for the case of MSS) is always triggered for all meteorological input options except for MEDOC, where no additional diagnostic analysis of winds is performed.

The evaluations are carried out for the following outputs: Group 1 - Compares predicted to observed arc maximum 30-minute averaged C_{max}/Q for each downwind distance and release trial; and Group 2 – Compares predicted to observed 30-minute averaged C/Q paired in space (i.e., for each sampler and release trial). Note that both C_o and C_p had to exceed 3 times the SF_6 background (3 x 5 ppt = 15 ppt).

4. SIMPLE URBAN GAUSSIAN MODEL DESCRIPTION

Simple urban dispersion models have been proposed and tested by several groups (e.g., Neophytou et al., 2005; Hanna et al., 2003 and Venkatram, 2005). The simple models account for enhancements of turbulence (and hence dispersion), reductions of mean wind speeds, and a tendency towards neutral stabilities in urban areas. The model used in this paper is a revised version of that described in Hanna et al. (2003), based on earlier work by the author (Hanna 1971) and incorporates suggestions by McElroy and Pooler (1968) from the St. Louis tracer study and urban dispersion coefficient parameterizations by Briggs (1973, see Hanna et al., 1982). For more details, see Hanna and Baja (2008). Assuming a continuous source near ground level in an urban canopy, the Gaussian formula can be written:

$$C/Q = (1/(\pi u \sigma_y \sigma_z)) * \exp(-y^2/2\sigma_y^2) \qquad x > 0 \qquad (1)$$

where C is concentration near ground level in gm^{-3}, Q is continuous release rate in gs^{-1}, u (ms^{-1}) is the averaged vector wind speed for the plume as it is transported in the urban canopy, σ_y (m) is the lateral cross-wind standard deviation of the concentration distribution, and σ_z (m) is the vertical cross-wind standard deviation of the concentration distribution. σ_y and σ_z are assumed to be made up of two parts, an initial σ_o due to the mixing in the street canyons at the source location, and a turbulent σ_t due to the usual ambient turbulence, which exists over all types of terrain. The turbulent part is a function of downwind distance, x (m), defined as the along-wind distance from the release point to a point on the plume axis (centerline). Earlier field experiments in urban areas (e.g., the St. Louis tracer data reported by McElroy and Pooler, 1968) suggest that the initial $\sigma_{yo} = \sigma_{zo} = 40$ m. The following formulas are assumed for σ_y for day and night conditions in urban built-up areas:

$$\sigma_y = \sigma_{yo} + \sigma_{yt} = 40\ m + 0.25\ x \qquad \text{day} \qquad (2a)$$
$$\sigma_y = \sigma_{yo} + \sigma_{yt} = 40\ m + 0.08\ x \qquad \text{night} \qquad (2b)$$

The same formulas are used for σ_z. The parameters (or "constants") 0.25 and 0.08 are based on Briggs' (1973) urban sigma formulas for neutral and slightly stable conditions. This parameter can be thought of as the turbulence intensity (turbulent standard deviation divided by wind speed). The stability is assumed nearly neutral in the day because of the strong mechanical mixing generated by the large buildings even in the presence of a large sensible heat flux. This is confirmed by observations of JU2003 and MSG05 heat fluxes and Monin length, L, reported by Hanna et al. (2007b). Similarly, at night, there is significant mechanical mixing and anthropogenic heat fluxes that prevent the boundary layer from becoming very stable.

Because of use of the initial σ_o, it is implied that the cloud of material spreads out into a hemispherical shape around the source area. Thus there is material dispersing even in the upwind direction (at x < 0). This can be accounted for by the following correction for x < 0, where the along-wind σ_{xo} is assumed to also equal 40 m.

$$C/Q = (1/(\pi u \sigma_{yo} \sigma_{zo}))*\exp(-y^2/2\sigma_{yo}^2)\exp(-z^2/2\sigma_{zo}^2)\exp(-x^2/2\sigma_{xo}^2) \qquad \text{for } x < 0 \qquad (3)$$

This formula is designed to handle the JU2003 samplers that are located in an upwind (x < 0) sector.

The model is most valid after the plume has passed around and/or over several buildings, since it assumes that there is large initial mixing due to the influence of recirculating wakes and street canyon vortices caused by several buildings. It can be hypothesized that a downwind distance equal roughly to the average building height is necessary for this initial mixing to take place. Thus in comparisons with the JU2003 data, the above model is assumed valid for downwind distances greater than about 100 m.

The simple urban dispersion model needs an estimate of the wind speed, u, and the wind direction, WD. The WD is important for the paired in space comparisons, since the performance measures could be poor if the assumed WD were significantly different (i.e., > 60°) than the observed plume direction. For JU2003, the so-called average (or AVG) wind speeds and directions are used. They are one of the meteorological input options in the HPAC runs described above. To check the choice of wind directions, a comparison was made between the assumed AVG wind direction for each release trial and the "observed" plume wind direction, as determined by drawing a straight line through the set of samplers where significant SF_6 concentrations were observed. For the 21 JU2003 release trials investigated here, the mean bias between the observed plume and AVG wind directions was only 2° and the RMSE was about 10°.

5. EVALUATION METHODOLOGY

The model evaluation exercise has looked at the maximum concentration observed for a given release by the set of samplers on a given distance arc (Group 1), and at the concentration observed at all samplers (Group 2). In addition the maximum 30-minute averaged concentration during each release trial is evaluated. The comparisons of model predictions and observations use the quantitative performance measures in the BOOT statistical model evaluation method (Chang and Hanna, 2004). Because of the relatively small number of points, scatter plots are also used to show the relation between predicted and observed C/Q. Assume that *X=C/Q* in the following definitions of quantitative performance measures:

Fractional Bias	$FB = 2\langle X_o - X_p\rangle/(\langle X_o\rangle + \langle X_p\rangle)$	(4)
Normalized Mean Square Error	$NMSE = \langle(X_o - X_p)^2\rangle/(\langle X_o\rangle\langle X_p\rangle)$	(5)
Geometric Mean	$MG = \exp(\langle \ln X_o\rangle - \langle \ln X_p\rangle)$	(6)
Geometric Variance	$VG = \exp(\langle(\ln X_o - \ln X_p)^2\rangle)$	(7)
Fraction of X_p within a factor of two of X_o	(FAC2)	(8)

Subscripts p and o refer to predicted and observed values, and the symbol < > represents an average. A perfect model would have FB=0, NMSE=0, MG=1.0, VG=1.0, and FAC2=1.0.

6. RESULTS

The results of the model evaluation are presented as quantitative performance measures in Table 1 and as scatter plots in Figures 2 through 5. To save space, the results for the arc maximum concentrations are emphasized. Also, only two combinations of the HPAC urban model and the meteorological input options are included in the tables and figures – UDM/MEDOC and UDM/UPWND. The table and the plots treat the day (IOPs 3, 4, and 6) and night (IOPs 7, 8, 9, and 10) runs separately. The observed overall maximum *C/Q*, which occurs at a sampler close to the release location, is about a factor of 8 larger in the night than in the day. The observed average *C/Q*'s are about a factor of 4 larger in the night than in the day.

Table 1. JU2003 statistical performance measures for HPAC and the simple urban model. The arc maxima (Group 1) are compared here. Note that C/Q has units of sm^{-3} times 10^6. Equations (4) through (8) define the performance measures.

Performance Measure	Day HPAC UDM/MEDOC	Day HPAC UDM/UPWND	Day Simple Urban Model	Night HPAC UDM/MEDOC	Night HPAC UDM/UPWND	Night Simple Urban Model
Max Co/Q	14.5	14.5	14.5	130	130	130
Max Cp/Q	100*	12	8.5	140	183	54.2
FB	-0.37	0.03	0.22	0.05	-0.80	0.00
NMSE	11.2	0.3	1.14	7.0	9.8	2.54
MG	0.95	0.85	0.93	1.78	0.51	0.67
VG	1.41	1.24	1.93	8.47	3.32	3.48
FAC2	0.87	0.91	0.92	0.57	0.40	0.92

*Isolated max. The second high is 14.

Comparing with the evaluations of the earlier HPAC version (4.04), an improvement is seen in the statistical performance measures for HPAC 5.0 SP1. The daytime underpredictions for 4.04, reported by Hanna et al. (2007a) and Warner et al. (2008) have been eliminated. The nighttime overpredictions remain but not to such a large extent.

For daytime IOPs (3, 4, and 6), Table 1 shows that HPAC UDM with either MEDOC or UPWND meteorological inputs performs quite well, according to criteria given by Chang and Hanna (2004). The mean bias is fairly low, and the scatter as measured by FAC2 of about 0.9 is good. However, it is seen that the simple urban model also does well. Although it is not shown here, MSS combined with all meteorological options does well with low bias and scatter except for a few high concentrations near the source, which are overpredicted by a factor of 5 to 10. A few bugs were still present in the way UDM interacts with the diagnostic wind model, SWIFT.

For night time IOPs (7, 8, 9, and 10), Table 1 shows that the large overpredictions for HPAC version 4.04 were partially eliminated with version 5.0 SP1, although a significant overprediction bias (about a factor of 2) still exists for versions using SWIFT for meteorological processing (i.e., the UPWND meteorological option). SWIFT is found to produce winds in the nighttime urban canopy layer that are a factor of 3 to 5 too small. UDM combined with the MEDOC meteorological option show the least bias, lowest scatter and highest FAC2 at night (greater than 50%). Because it is not influenced by the SWIFT diagnostic met model, MSS generally shows better statistical performance. However, the same large overpredictions for MSS at a few nearby samplers were found during the night as during the day. Table 1 shows that the simple urban model has better performance for the night IOPs for some of the performance measures, such as a fractional mean bias (FB) of 0.0 and a FAC2 of 0.92 (versus FAC2 of 0.40 and 0.57 for the HPAC models). The simple urban model seems to underpredict the absolute maximum by about a factor of 2.5, whereas the HPAC models slightly overpredict the absolute maximum.

The scatter plots confirm the quantitative results in Table 1, and more clearly show the scatter and any trends. For example, Figures 2 and 3 (for day and night for HPAC UDM/MEDOC) show that the small mean bias and the magnitude of scatter are about the same at all values of C/Q. It also suggests that a few anomalous overpredictions and underpredictions are likely the cause of the relatively large NMSE. The simple urban model scatter plots (e.g., Figure 4 for day) confirm the minimal bias and scatter. There is little difference between the "look" of the day and night plots. The simple model plots also show how there are slight underpredictions at large C/Q, but little bias over the rest of the points.

The quantitative performance measures for the paired-in-space comparisons are not shown here because of space limitations, but generally indicate poorer values than for the arc maxima. Of course this is expected. Figure 5 contains an "all-data" scatter plot for HPAC UDM/UPWND, indicating a similar "look" and magnitude of scatter. For the simple urban model, FAC2 drops from 0.92 to 0.65 when all samplers are included. However, the relative mean bias (FB) has a magnitude less than 0.05.

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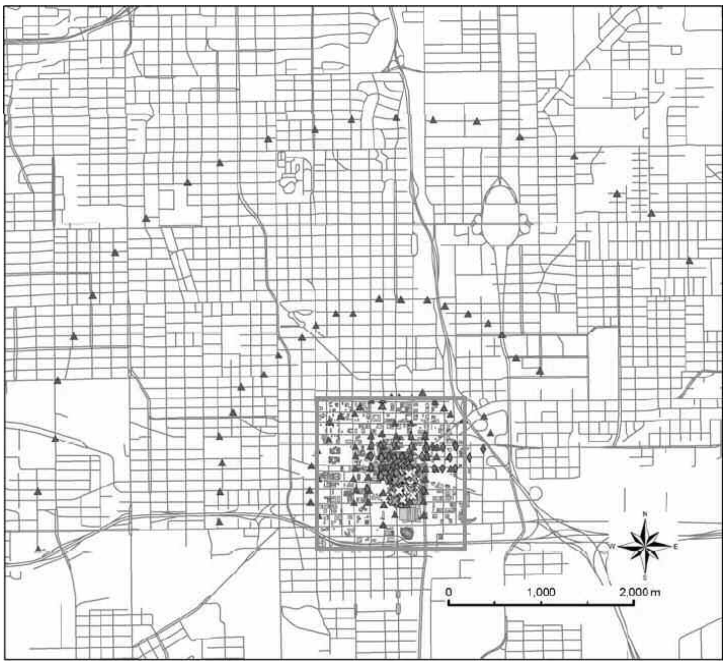

Figure 1. Map of downtown Oklahoma City, site of Joint Urban 2003 (JU2003) field experiment. Locations of åOAA Air Resources Laboratory Field Research Division (ARL/FRD) SF_6 samplers are shown as triangles.

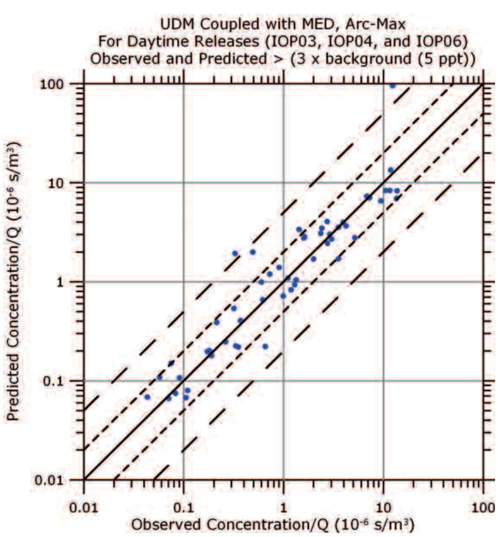

Figure 2. Scatter plot for HPAC UDM/MEDOC for day IOPs.

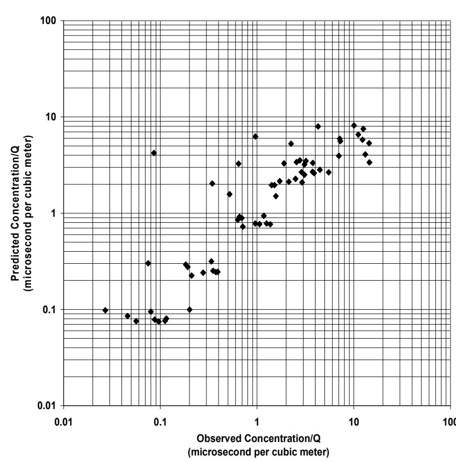

Figure 4. Scatter plot for simple urban model for day IOPs.

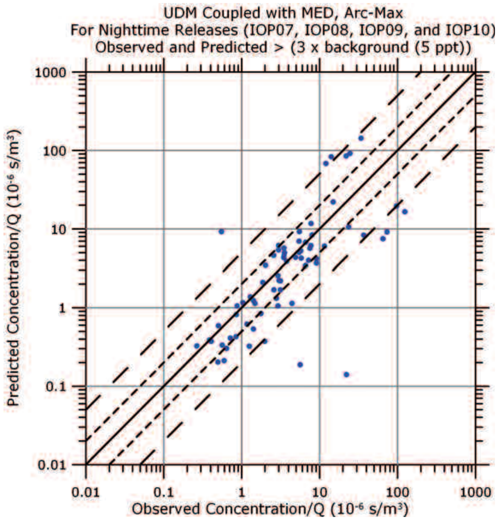

Figure 3. Scatter plot for HPAC UDM/MEDOC for night IOPs.

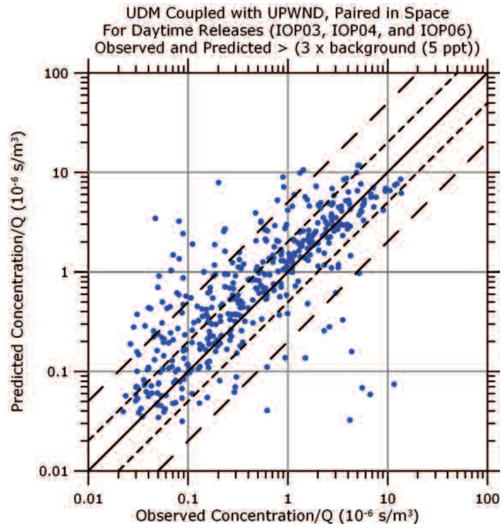

Figure 5. All data scatter plot for HPAC UDM/Upwind for day IOPs.