ASSESSMENT OF HPAC URBAN MODELLING CAPABILITIES USING JOINT URBAN 2003 FIELD TRIAL DATA

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INTRODUCTION

The potential effects of the atmospheric release of hazardous materials continue to be of concern, particularly in urban areas. Estimates of the effects of hazardous releases within an urban environment on the underlying population are required to aid planning, emergency response, and recovery efforts. These estimates require accurate knowledge of the concentrations of dispersed material in time and space. We are engaged in an ongoing independent evaluation of the U.S. Defense Threat Reduction Agency's (DTRA) Hazard Prediction and Assessment Capability (HPAC). Our work presently focuses on comparing HPAC predictions of hazardous materials releases to data obtained during the Joint Urban 2003 (JU03) tracer gas field experiment conducted in Oklahoma City during the summer of 2003. In particular, the results presented here summarize a comparison of the performance of the various urban prediction models within HPAC as measured by comparison to JU03 observations. This work, expanded in Warner et al., 2007, is an extension of the evaluations of transport and dispersion models we have previously conducted (Warner et al., 2004a, 2006) using data from the field trial in Salt Lake City, UT, in 2000 (Allwine et al., 2002) and the Mock Urban Setting Test (MUST) at Dugway Proving Ground (Biltoft, 2002).

BRIEF DESCRIPTION OF JOINT URBAN 2003

Under the joint sponsorship of the U. S. Department of Defense (Defense Threat Reduction Agency – DTRA) and the U. S. Department of Homeland Security, a series of tracer gas releases were carried out in Oklahoma City starting on 28 June and ending on 31 July 2003 (Allwine et al., 2004). This field experiment, referred to as "Joint Urban 2003", included ten intensive operating periods (IOPs), in which the tracer gas sulfur hexafluoride (SF_6) was released in downtown Oklahoma City. In total, twenty-nine 30-minute continuous SF_6 releases were conducted with 2 hours of sampler monitoring following the start of each release. The results presented here compare HPAC predictions with the measurements from samplers located at 3 meters above ground level (AGL) in the Central Business District (CBD) and in the sampler arcs at 1 km, 2 km, and 4 km from the release points. Additional information about the JU03 experiment as applied to our studies can be found in Warner et al., 2007.

BRIEF DESCRIPTION OF URBAN HPAC

DTRA's HPAC (v4.04 SP3) is composed of a suite of software modules that can generate source terms for hazardous releases, retrieve and prepare meteorological information for use in a prediction, model the transport and dispersion of the hazardous release over time, and plot and report the results of these calculations (DTRA, 2001). For hazardous material transport and dispersion, HPAC uses the SCIPUFF model and an associated mean wind field model (Sykes et al., 1996). SCIPUFF is a Lagrangian model for atmospheric dispersion that uses the Gaussian puff numerical method and bases its turbulent diffusion parameterization on second-order closure theories. If HPAC is given observations or predictions generated by a mesoscale meteorological model, it can create mass-consistent wind fields that can be used to transport the hazardous material. Within HPAC two weather modules can be used to prepare these mass-consistent wind fields – SWIFT (ARIA Technologies, 2001) and MC-SCIPUFF. In this study, the creation of HPAC predictions was completed using SWIFT when possible.

For this study, we examined five modes of operation for urban HPAC predictions. The baseline urban capability is referred to as Urban Canopy ("UC") mode, activated by setting the HPAC surface type to "urban." UC mode employs a modification of the vertical wind and turbulence profiles appropriate for an urban canopy. The Urban Dispersion Model (UDM) (denoted "DM") computes the transport and dispersion of an instantaneous discharge of pollutant based on ensemble mean Gaussian puff dispersion methodology, but allows surface obstacles to modify the dispersion patterns according to an empirical parameterization based on extensive wind tunnel experiments (Hall et al., 2002). The Urban Windfield Module (UWM), intended to represent an improvement over simply using SWIFT for urban applications, uses computational fluid dynamics (CFD) techniques in conjunction with an urban canopy parameterization of obstacle effects to predict the steady-state wind field inside the urban boundary layer (Lim et al., 2003). UWM-generated average winds can then be used by Urban HPAC to drive material transport and dispersion. Urban HPAC using UWM with UDM toggled on is denoted "DW," and Urban HPAC using UWM alone is denoted "WM." Additionally, we examined the newest HPAC urban model, Micro SWIFT-SPRAY (MSS) (denoted "MS"), which consists of the sub-models Micro SWIFT and Micro SPRAY (Moussafir et al., 2004). Micro SWIFT, like the SWIFT module mentioned above, creates mass consistent gridded wind fields, but also creates zones of modified wind flow around urban obstacles. Micro SPRAY is a Lagrangian particle dispersion model (derived from SPRAY) that can account for urban obstacles.

METEOROLOGICAL INPUT OPTIONS THAT WERE EXAMINED

A large variety of meteorological measurements were collected during JU203, and we created HPAC predictions using measurements from several instruments in and around the city. Five representative meteorological ("MET") input options were examined for this comparative study of Urban HPAC modes. The "BAS" MET input included surface and upper air wind velocity measurements from measuring stations at airfields surrounding Oklahoma City; this input was intended to correspond to a baseline situation where the meteorological information is consistent with what could have been received from the DTRA meteorological server at some point (~2 hours or more) after the release. The "GCT" MET input corresponded to a Global Climatological Analysis Tool (GCAT) prediction of wind velocity profiles at many grid locations; this input was intended to correspond to a surrogate for "gridded" numerical weather assimilations that could be available on the DTRA meteorological server several hours after an event. SWIFT was used to create gridded wind fields from both the BAS and GCT input meteorological information. The "PNA" MET input corresponded to using both the SODAR and vertical profiler observations that were available from the Pacific Northwest National Laboratory (PNNL) meteorological instruments ~1.6 km upwind from the releases; this input was intended to be representative of an upwind vertical wind profile that could be used as input into HPAC. The "ACA" MET input corresponded to using both the SODAR and vertical profiler observations that were available from the Argonne National Laboratory (ANL) meteorological instruments located at the Christian Church site ~4 km downwind from the releases; this input was intended to be representative of a downwind vertical wind profile that could be used as input into HPAC. The "PO7" MET option corresponded to a set of observations from a single location 40 meters AGL on the roof of the Oklahoma City Post Office building (just upwind of downtown); this input was intended to be representative of a single downtown observation that could be used as input for the Urban HPAC predictions.

PROTOCOL FOR PAIRED IN SPACE AND TIME COMPARISONS

For this analysis we compared predictions and observations paired in space and time, referred to "point-to-point" comparisons. For each release, predictions and observations were compared using the four 30-minute average concentrations obtained during the two hour observation period following each release. We computed twelve statistical measures for each comparison, including the fractional bias (FB) and scatter metrics such as the normalized mean square error (NMSE), and normalized absolute difference (NAD). We also used a user-oriented measure of effectiveness (MOE) (Warner et al., 2004b) that measures both scatter and bias and allows for assessments of the ability of the model to predict either the "hazardous" region (i.e., the region above a concentration threshold of interest) or total average concentrations.

BRIEF SUMMARY OF RESULTS

Day vs. Night Releases and Predictions

There was a substantial difference in the performance of Urban HPAC predictions of the daytime releases versus the releases at night. Figure 1 compares day and night FB values for the CBD samplers for 20 sets of predictions (5 MET options × 4 urban modes, WM mode not shown). For all five MET options, the daytime releases tended to be under-predicted (30-minute average concentrations at the surface samplers in the CBD and on the arcs) and the releases at night tended to be over-predicted. With regard to the scatter-based metrics (not shown) such as NAD, the Urban HPAC predictions using SWIFT-associated MET inputs (BAS, GCT, and PO7) resulted in substantially more scatter at night than during the day, with the exception of MS. For the MC-SCIPUFF-associated MET input options (PNA and ACA), the scatter results were much more similar for the day and night Urban HPAC predictions, with perhaps some evidence of improved performance during the day for PNA and ACA. For both the bias and scatter-based metrics, examinations of arc-based results showed similar behaviour to that described above for the CBD.

MSS Model Performance Differs From That of Other Urban HPAC Modes

With respect to the under- and over-predictions described above, the MS mode typically led to less under-prediction during the day and less over-prediction at night than the other Urban HPAC modes (there were some minor exceptions where DM and DW modes were similar to MS). Typically, the MS mode resulted in the least biased predictions of the 30-minute average concentrations at the surface samplers (CBD and arcs). Furthermore, the overall performance of MSS predictions during the day was similar to the performance at night.

Relative Urban HPAC Mode Performance for Nighttime Releases: MS, DM, and DW Represented Improvements

An additional important result is that for the nighttime releases, the MS, DM, and DW modes offer improvement over the UC and WM modes for the three MET input options that invoked SWIFT. This finding was true for the samplers in the CBD and for the samplers along the arcs. This result can be considered especially important because the use of SWIFT corresponds to a recommended and default mode of Urban HPAC. In addition, these MET options, particularly BAS and GCT, appear to correspond to reasonably realistic and potential operational applications of Urban HPAC. We also found that adding UWM to UDM to create the DW mode did not lead to substantial or consistent significant improvements relative to using UDM alone, i.e., DM. This result is entirely consistent with past studies of the Urban 2000 and MUST field trials. For the releases at night that used MC-SCIPUFF-associated MET input options (PNA and ACA) results were mixed with no Urban HPAC mode consistently offering improvement, although the MS mode did so for the ACA MET option (at least relative to UC, WM, and DM).

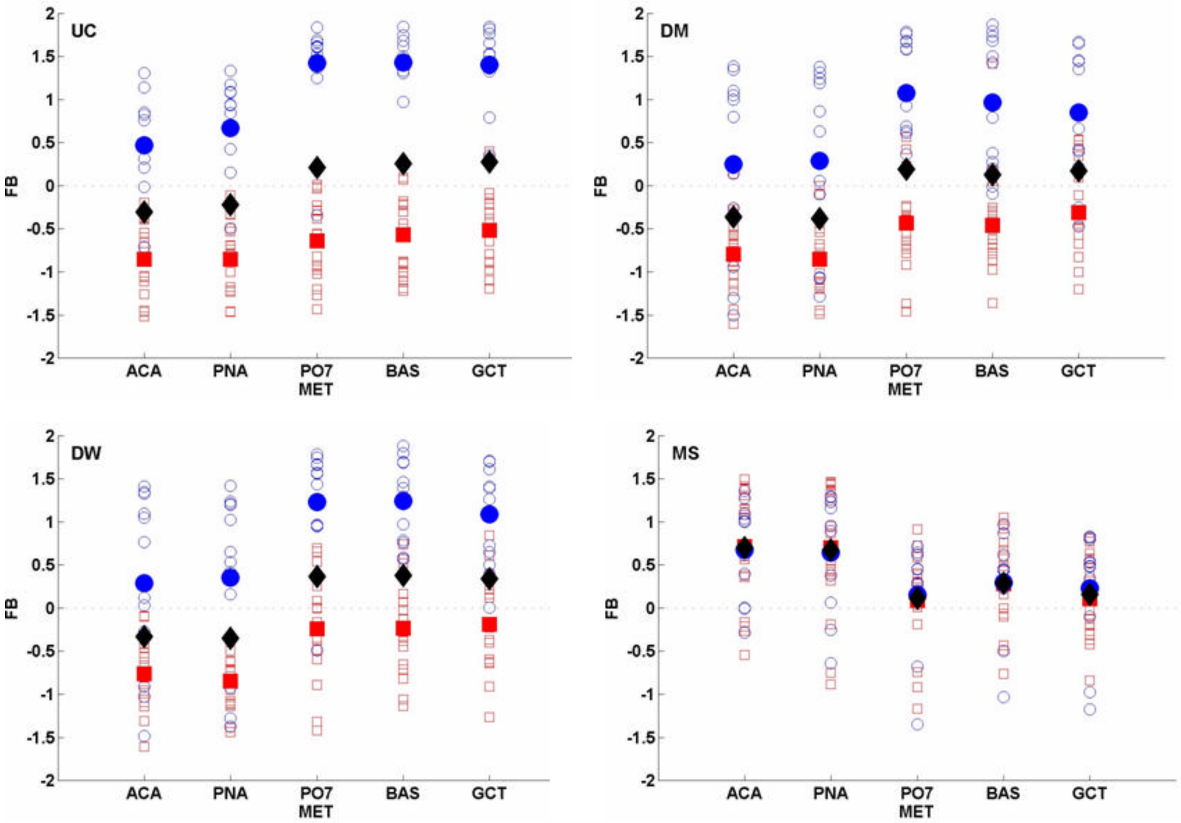

Figure 1. Comparisons of Fractional Bias Values for Urban HPAC Predictions of the Day (squares) and Night (circles) Releases of JU03 Within the CBD Using the Five MET Input Options (labelled along the x-axes of each chart as ACA, PNA, PO7, BAS, and GCT). [The open-faced points correspond to FB values for each of the individual releases (17 day, 12 night). The filled squares and circles correspond to average FB values for daytime and nighttime releases (respectively), with the filled diamonds representing the overall average for all 29 releases. Positive FB represents over-prediction and negative FB represents under-prediction.]

Relative Urban HPAC Mode Performance for Daytime Releases Was Mixed and Inconsistent

For the daytime releases, no consistent trend was found. For example, for the BAS-associated predictions on the arcs, the MS, DM, and DW modes offer improvement (e.g., less scatter) over the UC and WM modes, but for the PNA-associated predictions in the CBD, the UC, WM, and DW resulted in improved scatter relative to the MS and DM modes. However, in the latter PNA-based case, the observed improvements in scatter for the UC, WM, and DW predictions come at the cost of a large under-prediction relative to MS.

CONCLUSIONS

Several robust conclusions can be drawn from our evaluation of Urban HPAC in the JU03 experiment. The releases at night tended to be over-predicted by all of the HPAC urban modes, and the daytime releases tended to be under-predicted with the exception of MSS. The MS, DM, and DW modes offer improvement over the UC and WM modes at night for the SWIFT-related MET options. Results were mixed for the daytime releases and for the MC-SCIPUFF-related MET options at night. As indicated by our previous studies, UWM does not appear to improve performance significantly over UDM alone. MSS performance was comparable during the day and at night, as opposed to the other urban models, and MSS also tended to generate predictions with the least bias. The MSS result is considered particularly positive and warrants additional analysis.

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