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URBAN DISPERSION PROGRAM: URBAN MEASUREMENTS APPLIED TO EMERGENCY RESPONSE

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1. INTRODUCTION

Air motions in and around cities are highly complex, and the increasing threat of harmful releases into urban atmospheres makes advancing the state-of-science of understanding and modeling atmospheric flows and dispersion in and around cities essential. The four-year (2004-2007) Urban Dispersion Program (UDP) funded primarily by the U.S. Department of Homeland Security and the Defense Threat Reduction Agency has recently been completed (Allwine and Flaherty 2007). The program's primary focus was to conduct tracer and meteorological field studies in Manhattan to improve our understanding of flow and dispersion of airborne contaminants through and around the deep street canyons of New York City, including outdoor-indoor-subway exchange mechanisms. Additionally, urban dispersion models are being validated and first-responder guidance is being refined using data collected during the two UDP field studies.

UDP had several accomplishments that included conducting two tracer and meteorological field studies in Midtown Manhattan. Pacific Northwest National Laboratory led several government laboratories, universities and private companies in conducting the two UDP field studies. The first field study was a small-scale study that investigated dispersion in the immediate vicinity of Madison Square Garden during March 2005 (MSG05). The second UDP tracer and meteorological field study, designated as MID05, was an extensive study conducted during August 2005 in Midtown Manhattan. The MID05 study was unique in being the first extensive tracer study in Manhattan and, more importantly, the first study to investigate atmospheric transport and diffusion through the coupled outdoor-indoor-subway pathways in NYC.

To date, 56 publications, reports, and presentations have been completed documenting the various findings and accomplishments of UDP. Key accomplishments include:

- Conducting and documenting the two Midtown field studies.
- Developing response guidance from findings of the two field studies and briefing NYC agencies as to the guidance.
- Advancing mesoscale meteorological forecasting methods through ensemble techniques and advancing urban parameterizations of the surface energy balance.
- Applying and evaluating computational fluid dynamics models and other building resolved models for application in the complex NYC urban environment.
- Installing and operating a permanent meteorological network in and around Manhattan that includes state-of-the-art instruments for continuously measuring the winds as a function of height and providing the results graphically to responders.

A brief overview of the UDP field studies will be given followed by first-responder guidance based on findings from recent urban field studies.

2. MADISON SQUARE GARDEN 2005 (MSG05)

The first UDP tracer and meteorological field study was a limited study conducted during March 2005 near the Madison Square Garden (MSG) in Midtown Manhattan (Allwine and Flaherty 2006). This study was conducted in Midtown Manhattan, in an approximately 1-km-by-1-km domain centered on the MSG as shown in Figure 1. The MSG05 comprised two intensive observation

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periods (IOPs), where each IOP was conducted from 0900 to 1400 Eastern Standard Time (EST). During an IOP, six safe, inert, gaseous perfluorocarbon tracers (PFTs) were released simultaneously at five near-surface sites around the MSG. In addition to 19 outdoor ground-level sampling locations, several indoor and rooftop samplers were placed, and personal exposure measurements were made. Two 1-hour-long continuous releases of PFTs were conducted during each IOP. These occurred from 0900 to 1000 EST and from 1130 to 1230 EST. The two IOPs were conducted on March 10 and 14, 2005.

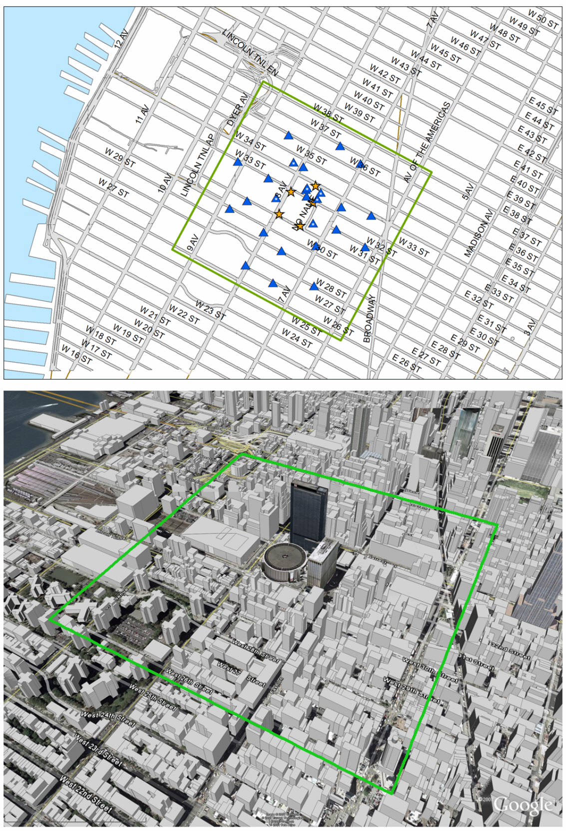

Figure 1. MSG05 Study Area. The top panel shows the 1-km-by-1-km MSG05 study domain (green square) with the release positions (stars) and sampler positions (triangles). The bottom panel shows an aerial perspective of the MSG05 study area.

Data from meteorological measurements at a number of locations are available to support this study. Sonic anemometers were deployed at six ground-level locations around MSG as well as at three building setback locations and three building rooftop locations. Sodars were positioned on the Farley Post Office, just west of MSG, as well as at two locations across the Hudson River at the Stevens Institute of Technology (SIT) in Hoboken, New Jersey. Additional meteorological data are available from several permanent stations on Manhattan as well as from nearby automated surface observing systems (ASOS) operated by the National Weather Service (NWS).

3. MIDTOWN MANHATTAN 2005 (MID05)

The MID05 study was unique in that it was the first extensive tracer and meteorological field study investigating outdoor-indoor-subway dispersion in the borough of Manhattan in NYC. The study was conducted in Midtown Manhattan during the period August 8-26, 2005 (Allwine and Flaherty 2007).

The MID05 tracer and meteorological field study was conducted in Midtown Manhattan in an approximately 2-km-by-2-km domain centered to the south of Central Park (Figure 2) from approximately 36th Street to 61st Street south to north, and from 10th Avenue to 3rd Avenue west to east.

This study was designed to examine the dispersion of airborne materials through the deep street canyons, into a modern office building and through the subways. A human exposure component of MID05 was also conducted on one day of the study by the U.S. Environmental Protection Agency. MID05 comprised six IOPs, where each IOP was conducted from 0600 to 1200 EST. During an IOP, six safe, inert, gaseous PFTs and sulfur hexafluoride (SF_6) tracer were simultaneously released from a number of locations, including outdoor street-level locations, within a building and in the subway. Each IOP consisted of three tracer release periods of 30-minutes each beginning at 6, 8 and 10 AM EST. Tracer measurements were made using a total of 158 integrating tracer samplers and 9 fast-response tracer analyzers deployed at street-level on an 8-by-8 grid covering the study domain, at 19 street-level locations within an approximate 2-block area near 49th Street and 6th Avenue, at 15 rooftop locations within the study domain, and at 8 locations in the subway.

In addition to collecting tracer data, meteorological measurements at a number of locations were accomplished to support this study. Sonic anemometers were deployed on five building rooftops, two building setbacks and 10 street-level locations in Midtown for this study. An additional three permanent rooftop anemometer locations in Manhattan and one in Hoboken, New Jersey, collected data that were available to support this field study. Furthermore, vertical

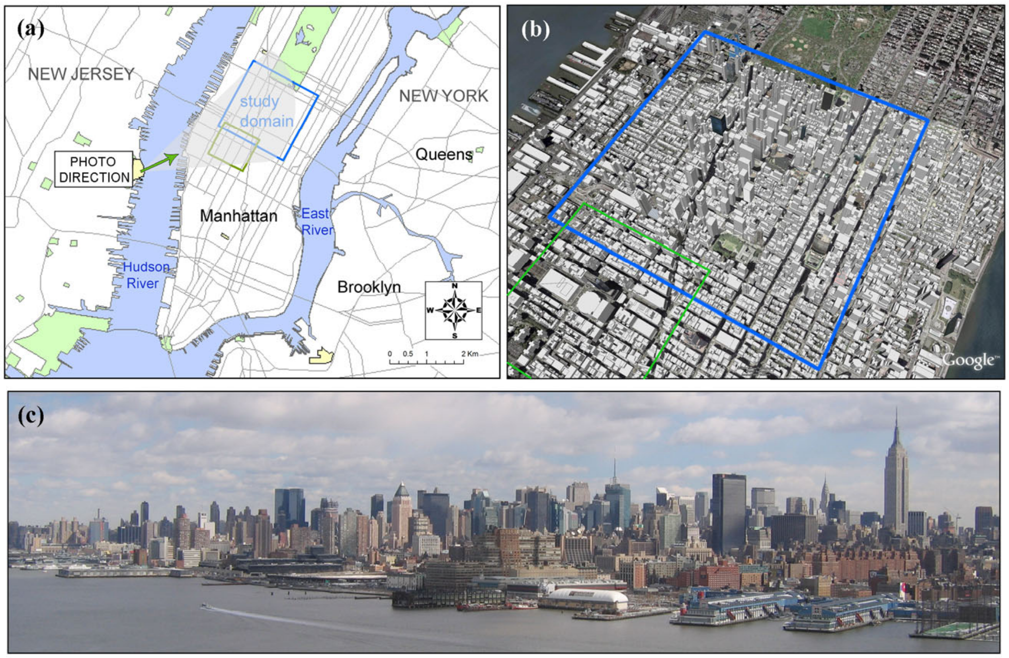

Figure 2. MID05 Study Area in Manhattan. The blue box in Panel (a) shows the 2-km-by-2-km MID05 study domain, and Panel (b) shows the domain in an aerial perspective of Midtown Manhattan extending from the Hudson River on the west to the East River on the east. The domain is just south of Central Park. The skyline of the Midtown study area is shown in Panel (c) where the photograph is taken from the Stevens Institute of Technology in New Jersey. Panel (a) shows the photograph direction. The MSG05 domain is also shown as green boxes in Panels (a) and (b).

profiles of winds were measured with two sodars deployed in Midtown Manhattan, and with a radar wind profiler and radiosonde launches that were deployed in Hoboken at SIT. Temperatures in Midtown were also measured at 17 locations distributed from the East River to the Hudson River, and from 28th Street into Central Park. Lastly, nearby ASOS stations, located at airports and in Central Park, completed the available meteorological measurements. Figure 3 shows the general coverage of the tracer releases and sampling, and the meteorological measurements for MID05 in the NY-NJ vicinity of NYC.

The MID05 tracer data (release rates and concentrations) are currently considered "For Official Use Only" and are not available for public distribution or publication. The data will be distributed on a need-to-know basis, and any results derived from analysis of the data will be subject to review and may be limited in publication and distribution. This paper does not give any quantitative tracer release or concentration information, so it is available for general distribution.

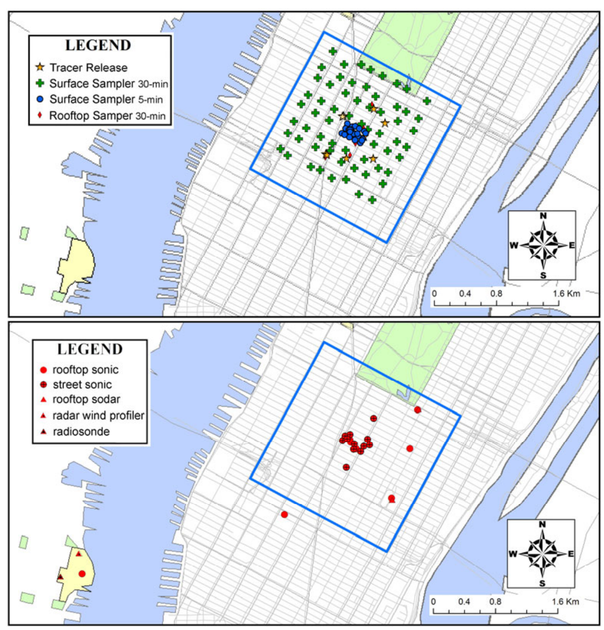

Figure 3. Coverage of Tracer Releases and Sampling (top panel) and Meteorological Measurements (bottom panel) in the Manhattan study Area. The blue box shows the 2-km-by-2-km MID05 study domain.

4. FIRST RESPONDER GUIDANCE

The first-responder guidance determined from the UDP field studies and supported by findings from other urban studies (e.g., Allwine et al. 2002, and Allwine et al. 2004) is listed below. The guidance is grouped according to the wind speed at the tops of the tallest buildings in the urban area. The wind speed categories are "moderate-to-strong winds" where winds at the top of the urban canopy are greater than 3 m s^{-1}, "light winds" where building-top winds are less than 3 m s^{-1}, and "all wind conditions" where the guidance applies to any building-top wind speeds. The guidance listed is not all inclusive, but rather highlights important guidance to date.

4.1 *All Wind Conditions*

- Always use wind direction measurements at tops of tallest nearby buildings rather than street-level winds to assess transport direction of an airborne plume in the city. Ready availability to building-top wind data is essential.
- Do not consider roof-tops of tall buildings near street-level releases to be safe-havens because of the rapid vertical dispersion around buildings.
- Do not use winds measured adjacent to chemical/biological/radiological (CBR) detectors located in street canyons to interpret direction or extent of release. Do not automatically locate wind sensors with CBR detectors.

4.2 Moderate-to-Strong Winds (> 3 m s^{-1})

- Evacuate 2-3 blocks upwind (relative to building-top winds) from the release site. Hazardous cloud may be encountered one-to-two blocks upwind from the known or suspected release site.
- Evacuation routes of the area within a one-to-two block radius of a known or suspected hazardous airborne release should, as much as possible, be perpendicular to the wind direction measured on the top of the nearest tall building. Wind directions measured at street-level should not be used.
- A 90° sector, starting ~500 m upwind of the release, will conservatively bound potential exposures to the plume. The downwind extent of a 90° sector will be at most 2-3 km, after which a narrower sector width is more appropriate. See Figure 4 for a description of the evacuation zone and the application of the exclusion guidance to two tracer releases during the MSG05 field study where the building-top wind speeds were approximately 6 m s^{-1}. The tracer plumes given in the right panel of Figure 4 are two-hour-average ground-level tracer concentrations, where the outer contour represents plume concentrations distinguishable from zero.

4.3 *Light Winds (< 3 m s^{-1})*

- Current dispersion models should not be used for making emergency response decisions for releases within the Midtown urban area. Specific guidance for response during light winds is in the process of being developed.

5. CONCLUSIONS

The completion of the Urban Dispersion Program will contribute significantly to urban dispersion research and preparation for the potential threat of harmful airborne materials released in urban areas. The tracer and meteorological data from the MSG05 and the MID05 field studies, in conjunction with field data from the Salt Lake City URBAN 2000 study and the Oklahoma City Joint Urban 2003 study, will allow for the continued improvement and validation of urban dispersion models for application in complex urban areas under various meteorological conditions.

ACKNOWLEDGEMENTS

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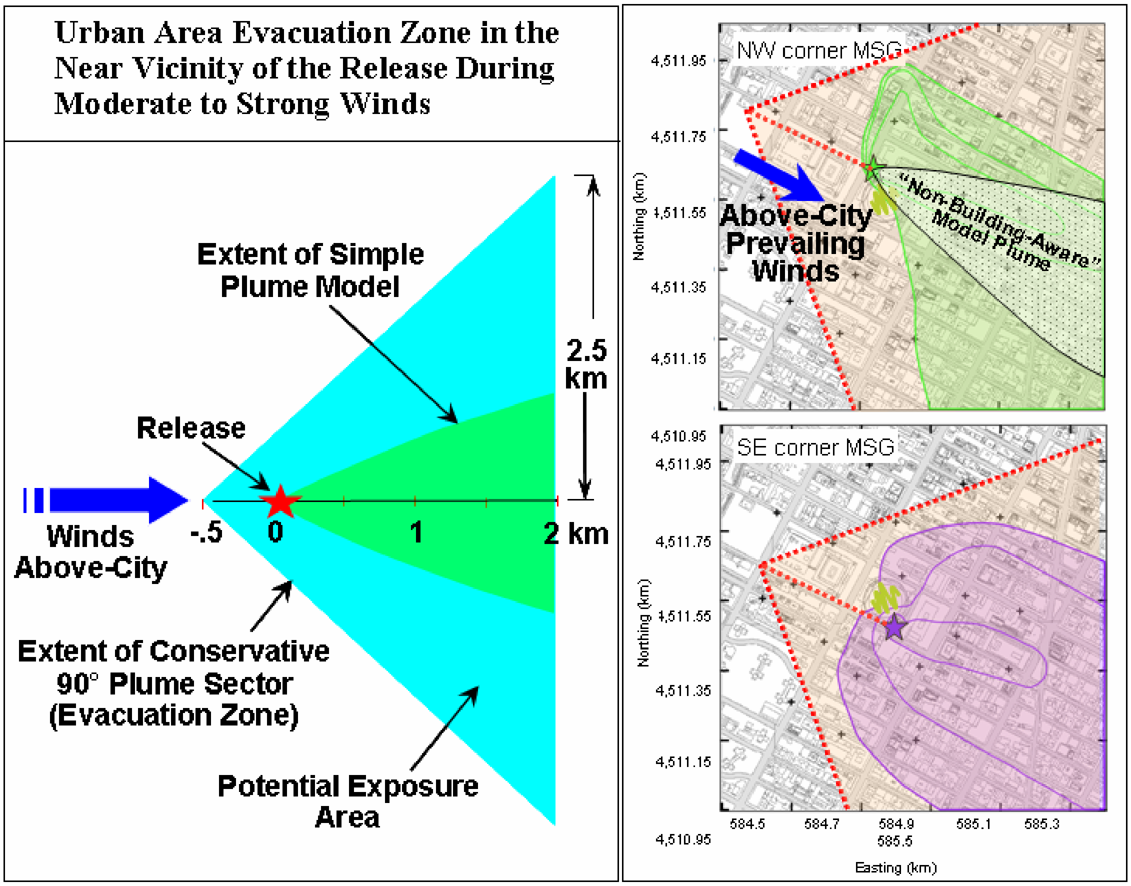

Figure 4. Description of the Urban Area Evacuation Zone. The left panel describes the urban area evacuation zone in the near vicinity of a release during moderate-to-strong building-top winds. The right panel shows the evacuation zone applied to two street-level tracer releases in the vicinity of Madison Square Garden during the MSG05 field study.

Numerous scientists, engineers and students from several organizations, national laboratories, universities and private companies contributed significantly to UDP and to the successful accomplishment of the two UDP field studies. The list of participants in UDP and the UDP field studies is given in Allwine and Flaherty (2007) and we thank all participants for the success of UDP.

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