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Skyscraper rooftop tracer concentration observations in Manhattan and comparisons with urban dispersion models

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HIGHLIGHTS

- Tracers were observed at rooftops (127 < z < 197 m) in the MID05 field study.
- Tracer releases took place near street level.
- Near-field ratios of rooftop to surface concentrations have a median of 0.02.
- Vertical spread is enhanced by large eddies around tall buildings.
- HPAC urban dispersion model underpredicts the rooftop concentrations and ratios.

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ABSTRACT

This paper focuses on the observed and model-predicted rooftop concentrations on very tall buildings at distances less than a few hundred meters downwind of near-surface releases in built-up urban centers. These results are important when public health must be protected in populated urban areas with deliberate or accidental releases of toxic chemicals, or with significant traffic emissions. Observations of tracer concentrations taken at seven samplers on skyscraper rooftops (113 m < z < 197 m) during the Manhattan Midtown 2005 (MID05) field experiment are analyzed, with emphasis on the near-field (x < 100 m). To calculate the ratio of rooftop to surface concentrations, we pair each rooftop sampler with the closest street level sampler. Six tracer gases (SF_6 and five perfluorocarbon tracers (PFTs)) were released near street level from several locations. In the near-field, the median ratio of observed rooftop to surface concentration is about 0.02, even very close to the source, although there is much scatter. The large recirculating eddies adjacent to the tall buildings may cause the relatively large vertical spread. It is noted that, at distances greater than a few hundred meters, the ratio approaches unity (although there is still significant scatter). The observed normalized rooftop and surface concentrations and rooftop to surface ratios are compared to the predicted concentrations and ratios by three urban dispersion options (Urban Dispersion Model (UDM), Urban Canopy (UC), and MicroSwiftSpray (MSS)) in the HPAC/SCIPUFF model. There is a general tendency towards an underprediction of the rooftop concentrations and a slightly smaller underprediction of the surface concentrations. The median ratio of rooftop to surface concentrations is underpredicted by most of the meteorology-urban module options, with much scatter for all options. These results underline the need to better parameterize the dispersion of plumes in the street canyons and recirculating eddies around tall buildings.

1. Objectives and background

Improving the accuracy of transport and dispersion models in urban downtown areas has been a major focus of scientists, emergency planners, and decision-makers alike. The current paper addresses a specific topic – the rooftop and surface concentrations observed and modeled for source release scenarios involving finite duration (30 min) point releases near street level in built-up areas with tall skyscrapers. Emphasis is on the near-field (distances less than about 100 m from the source). This topic has become important because of the need to advise the public whether it is “safe” to

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climb to higher levels of buildings or even the roof top after a deliberate or accidental release of toxic chemicals near street level. A similar concern arises due to releases of NOx, Volatile Organic Compounds (VOCs) and particular matter (PM) and other hazardous pollutants from traffic sources. How quickly does the pollutant mix to the rooftops?

In an earlier comparison of four urban dispersion models with observations from two surface-level SF_6 tracer releases during the Oklahoma City Joint Urban 2003 (JU2003) field experiment, it was found that, although there was much uncertainty or variability in the concentration fields, the models underpredicted the skyscraper rooftop concentrations and the ratios of rooftop to surface concentrations near the release location (Hanna et al., 2011). For example, during one tracer release, a rooftop sampler was on the Bank One building (z = 148 m) at a distance 82 m NNE of the release, and a ratio of rooftop to surface concentration of about 0.13 was observed. The four models underpredicted this ratio by factors of two to ten. During the same tracer release period, a ratio of rooftop to surface concentration of 0.26 was observed at the Kerr-McGhee building (z = 115 m) on the plume centerline about 320 m NNW of the release. The four model-simulated ratios of rooftop to surface concentrations ranged from about 0.01 to 0.1, suggesting about the same amount of underprediction as at the closer Bank One building. However, these results are likely to vary for different (but still reasonable) choices for wind and other inputs, as found by Brown et al. (2013), who report that their urban model both over and underpredicted rooftop winds for a different wind input.

Similar findings were reported by Hanna and Baja (2009) at skyscraper rooftops for the Manhattan Madison Square Garden 2005 (MSG05) field experiment. Two tall buildings had rooftop samplers: One Penn Plaza (z = 223 m) and Two Penn Plaza (z = 153 m). There were two samplers on each building's rooftop. These tall buildings were at downwind distances less than 100 m from the five PFT tracer release locations, which were on the sidewalks at the corners of Madison Square Garden. For all releases, the average observed ratio of rooftop to surface concentration at One Penn Plaza was 0.038, and at Two Penn Plaza was 0.043. Some of the tracer releases took place at street level on the sidewalk adjacent to One Penn Plaza, and, even then, observed rooftop concentration were a few percent of street-level concentrations.

A sonic anemometer network was set up at street-level during MSG05, and revealed flow perturbations that extended outward from the tall skyscrapers in all directions to distances of about one building height (100–200 m). Computational fluid dynamics (CFD) modeling showed that the flow patterns were primarily caused by the downdrafts on the windward side of the buildings and updrafts on the leeward side (Hanna et al., 2006). Thus at street level, the flow near the building was away from the windward building face and towards the leeward building face.

The JU2003 and MSG05 tracer observations and sonic anemometer data discussed above suggest that there is much turbulence and initial mixing of the tracer plume near the source due to local obstacles (e.g., vehicles, trees, building projections) and street canyon circulations. Hanna et al. (2007), Hanna and Zhou (2009), and Hanna and Baja (2009) compared observed and model predicted turbulence during JU2003 and MSG05 and found that the observed horizontal and vertical turbulence intensities were as large at street level as at rooftops. Nelson et al. (2007) report similar findings for JU2003 street canyons, and point out that heterogeneous building heights in U.S. cities contribute to enhanced street level turbulence.

The above conclusions were based on the two urban field experiments JU2003 and MSG05, and our analysis of near-field rooftop observations focused on only one or two tall buildings and on only a few tracer releases. The current paper uses the much more extensive observations from the Manhattan Midtown 2005 (MID05) urban field experiments (Allwine and Flaherty, 2007), where there were 12 samplers on near-field rooftops and roof setbacks. We investigate the observed and model-predicted rooftop normalized concentrations and ratios of the skyscraper rooftop and surface concentrations.

Comparisons are made with predictions by three optional urban dispersion algorithms in the HPAC/SCIPUFF model software (DTRA, 2008; Sykes et al., 2007). These MID05 HPAC/SCIPUFF model runs were made in 2009 and some comprehensive evaluations with several sets of urban data were reported by Hanna and Chang (2012). In addition, we also considered three input meteorology assumptions (weather forecast model products, standard airport observations, and representative rooftop observations).

We hoped to find additional available urban dispersion model simulations of MID05 that would allow predicted rooftop and surface concentrations to be compared with observations. For example, Flaherty et al. (2007) compared five CFD models' predictions with MID05 street-level observations. However, no quantitative summaries of rooftop predictions are available in the paper or the model output files.

2. Description of MID05 field experiment

The Manhattan Midtown 2005 (MID05) field experiment was the fourth in a series of major urban field experiments sponsored by the U.S. Department of Energy (DOE), Defense Threat Reduction Agency (DTRA), and Department of Homeland Security (DHS) from 2000 through 2005. The four experiments are Urban 2000 in Salt Lake City (Allwine et al., 2002), JU2003 (Allwine and Flaherty, 2006a), MSG05 (Allwine and Flaherty, 2006b), and MID05 (Allwine and Flaherty, 2007). These cities are large enough to have numerous skyscrapers of height 100 m or more above ground level (agl). Of the four urban field experiments, MID05 has the most extensive set of rooftop and surface sampler measurements, as well as the largest concentration of very tall buildings.

The MID05 tracer experiments took place on six days in August 2005. There is a wide range of building heights with many buildings with heights exceeding 100 m across the approximate 2 km by 2 km geographic domain where sampling took place. Several buildings have heights exceeding 200 m. One set of model evaluations in Section 4 uses the wind observations from a height of 247 m on the Met Life building rooftop (named RFT).

Fig. 1 shows the 1 km by 1 km inner (or central) MID05 sampler domain and indicates the locations of the rooftop and surface samplers that we analyzed in this paper. The stars show the tracer source locations that were used. A given 30-min release period usually had simultaneous releases of six tracers from 4 or 5 locations. Often two tracers were released from a single location, which allowed sampler accuracies to be investigated.

Table 1 lists the general characteristics of the six days of MID05 field experiments. On each day there were three tracer release periods of duration 30 min, beginning at 0800, 1000, and 1200 Eastern Daylight Time. The start times of the releases were 2 h apart so as to allow the tracer from one release to clear out of the MID05 domain before the next release. The table includes wind speeds and directions observed at the Met Life rooftop (designated RFT in later model runs) and LaGuardia Airport (LGA), which is the closest official National Weather Service (NWS) well-exposed observing site. The tracer release locations for each of the six tracers are indicated in the table for each day (see Fig. 1 for the locations). Note that, for two of the MID05 days, the source positions for PPCH and SF_6 were shifted to accommodate wind direction shifts during the four hour duration of the release period.