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Urban Dispersion Program MSG05 Field Study: Summary of Tracer and Meteorological Measurements

K. J. Allwine
J. E. Flaherty

August 2006

Prepared for the U.S. Department of Homeland Security under a Related Services Agreement with the U.S. Department of Energy under contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The Urban Dispersion Program (UDP) is a multi-year project, funded by the U.S. Department of Homeland Security, to better understand the flow and dispersion of airborne contaminants through and around the deep street canyons of New York City. 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. The study is designated MSG05 where six safe, inert, gaseous perfluorocarbon tracers (PFTs) were released simultaneously at five street-level locations (two PFTs were co-located for quality control) during two experimental days. PFT samples were collected by several tracer samplers located at street-level and on buildings around MSG. Additionally, some types of tracer samplers were located indoors, and other types (personal air samplers) were carried along prescribed paths by project staff measuring the tracer exposure along the various paths. The total study area was approximately 1-km-by-1-km centered on the MSG.

In addition to collecting tracer data, meteorological data were also collected. These included sonic anemometer data from six street-level locations around MSG. Sonic anemometers were also deployed at three building setback locations and three building rooftop locations. A sodar for measuring the vertical profile of winds was 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 were collected from several permanent stations on Manhattan as well as from nearby automated surface observing systems operated by the National Weather Service.

Brookhaven National Laboratory (BNL) conducted the bulk of the tracer and meteorological field efforts with Pacific Northwest National Laboratory and SIT assisting by measuring the vertical profile of winds at the SIT campus. The Environmental Protection Agency worked with BNL in accomplishing the personal exposure component of the study. This report is a companion to the two BNL MSG05 reports giving details of the tracer and meteorological components of the study. This report gives the coordinates of all the instruments deployed for this field study geo-referenced to a detailed building database. The coordinates were defined by positioning the instruments within a geographic information systems map using the detailed building and roads databases for the midtown Manhattan area. A quality-assured tracer dataset was developed as a subset of the complete tracer dataset for direct use in dispersion model validation studies. These data were carefully analyzed to assess internal consistency. This report presents some results from this analysis. In general, different release locations showed vastly different plume footprints for tracer materials, and the situation was made very complex with upwind and/or crosswind transport of tracer near street-level for the different release locations. Overall wind speeds and directions upwind and over the city were generally constant throughout each of the two experimental periods.

The MSG05 tracer data (release rates and concentrations) currently have limited distribution, and will only be distributed with a need-to-know. This report does not give any quantitative tracer release or concentration information, so it will be available for general distribution.

Acronyms

AMSL	above mean sea level
ASOS	automated surface observing system
AV	AeroVironment sodar
BNL	Brookhaven National Laboratory
BATS	Brookhaven atmospheric tracer sampler
CDTA	continuous dual trap analyzer
DHS	Department of Homeland Security
EST	Eastern Standard Time
GIS	geographic information system
IOP	intensive observation period
MSG	Madison Square Garden
NAD	North American Datum
NOAA	National Oceanic and Atmospheric Administration
NYC	New York City
NWS	National Weather Service
PAS	personal air sampler
PFT	perfluorocarbon tracer
PNNL	Pacific Northwest National Laboratory
SAS	sequential air sampler
SIT	Stevens Institute of Technology
UDP	Urban Dispersion Program
UTM	Universal Transverse Mercator
WDIR	wind direction
WSPD	wind speed

Acknowledgments

This research was supported in part by the U.S. Department of Homeland Security under a Related Services Agreement with the U.S. Department of Energy (DOE) under Contract DE-AC05-76RL01830. Pacific Northwest National Laboratory is operated for DOE by Battelle.

The Urban Dispersion Program's MSG05 field study would not have been possible without the support of New York City (NYC) agencies, private land owners, and the general public. Mr. Kevin Clark of the NYC Office of Emergency Management was instrumental in the success of MSG05 by spearheading many of the needed logistical arrangements and operating permissions. The support of Dr. Tony Fainberg (Department of Homeland Security program manager) and Rick Fry (Defense Threat Reduction Agency program manager) was much appreciated. The easy collaboration of Urban Dispersion Program team members, various NYC staff, private land owners, and local university students and faculty was essential for the success of the study. Further acknowledgments to successfully accomplishing MSG05 are given in the Brookhaven National Laboratory (BNL) companion tracer report (Watson et al. 2006) as well as in Berg and Allwine (2006).

A number of key individuals provided the necessary information and feedback to develop the refined instrument coordinates that are presented in this report. Mr. John Heiser and Dr. Tom Watson of BNL provided information on tracer sampler locations, and Dr. Michael Reynolds and Mr. Victor Cassella, also of BNL, assisted with meteorological instrument coordinates. Dr. Steve Hanna of the Harvard School of Public Health helped with the quality assessment of the tracer and meteorological data.

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1.0 Introduction

The Urban Dispersion Program (UDP), a multi-year program that began during early 2004, is aimed at investigating air flow and atmospheric dispersion through the heavily urbanized Manhattan borough of New York City (NYC). The UDP will collect ground-truth dispersion data that will be used to develop and validate tools to aid planners and first responders in the event of a contaminant release into the atmosphere of Manhattan. The Madison Square Garden (MSG) dispersion study, conducted during March 2005 (designated MSG05), was the first field study conducted under the UDP. A second, more extensive field study was conducted in Midtown during August 2005 (MID05). The MID05 study will not be discussed in this report.

The MSG05 tracer and meteorological field study was conducted in Midtown, Manhattan, in an approximately 1-km by 1-km domain centered on the MSG. The MSG05 comprised of two intensive observation 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 sites were sampled, 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.

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. A sodar was 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 in Hoboken, New Jersey. Additional meteorological data are available from several permanent stations on Manhattan as well as from nearby automated surface observing systems (ASOSs) operated by the National Weather Service (NWS).

This report summarizes the locations of the instruments deployed for this field study, as well as some results from the data. The coordinates have been defined by positioning the instruments within a geographic information systems (GIS) map with a Universal Transverse Mercator (UTM) coordinate system using the 1983 North American Datum (NAD). Geodetic positions are also presented. All latitude values are north of the equator, and all longitude values are west of the prime meridian. The GIS software used for the instrument location refinement was ArcView Version 9.0. In addition to the photographs that documented the instrument positions, the Windows Live Local website (http://local.live.com/) and Google Earth (http://earth.google.com/) were used to refine the coordinates.

2.0 Tracer Measurement

The MSG05 study consisted of two 6-hour-long IOPs. During each IOP, six perfluorocarbon tracers were released simultaneously from five ground-level locations. Figure 2.1 shows a map of the study area with the release locations labeled A through E. The circular MSG building is labeled in the center of the image. The buildings that had rooftop instrumentation are also labeled in this figure. Two different PFT compounds were released from location C for quality control. Table 2.1 presents the coordinates of each of the release locations. The easting and northing coordinates are for UTM grid zone 18 (NAD 1983).

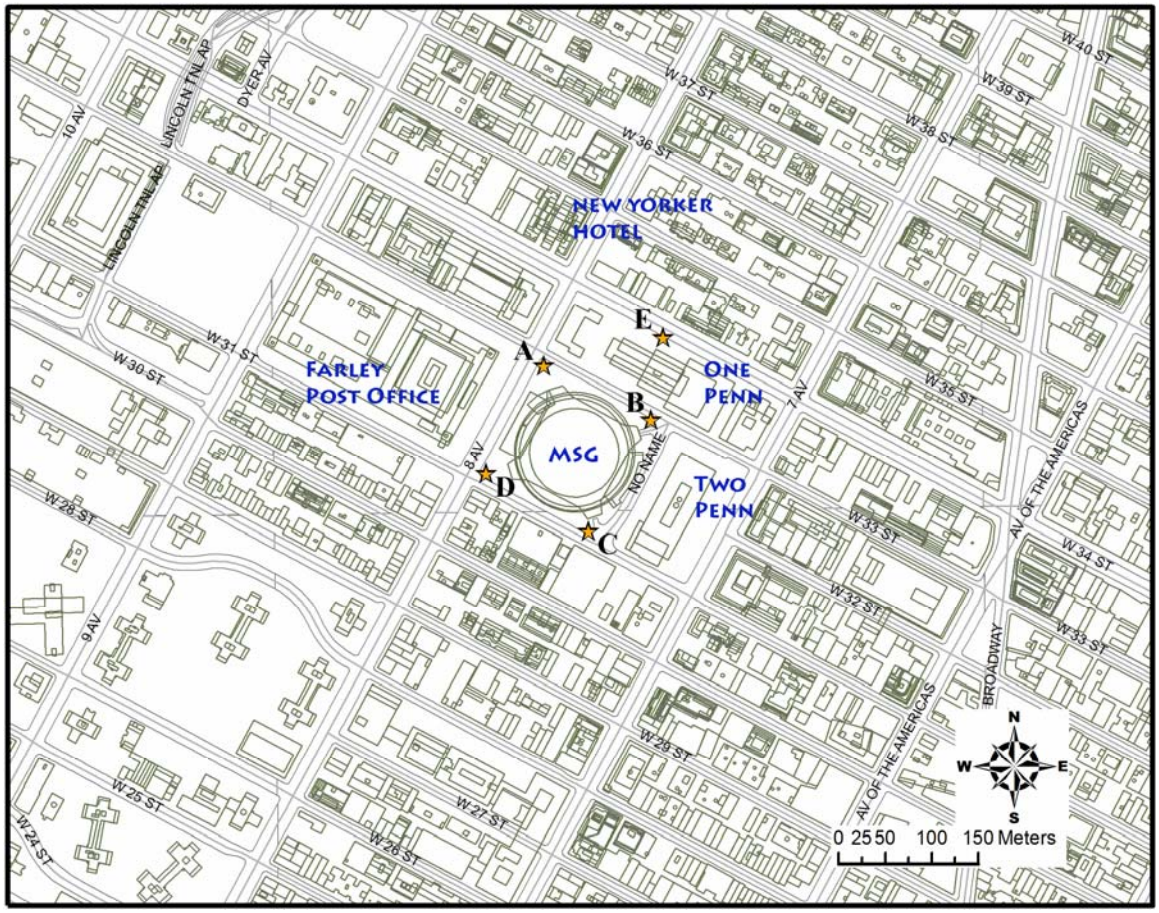

Figure 2.1. Perfluorocarbon Tracer Release Locations

Table 2.1. Release Location Coordinates

Release ID	Location Description	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)
Release A	8th and 33rd—North corner MSG	40.75136	73.99385	584937	4511643
Release B	33rd midway between 7th & 8th—East corner MSG	40.75083	73.99249	585052	4511585
Release C	31st midway between 7th & 8th—South corner MSG	40.74975	73.99330	584985	4511465
Release D	8th and 31st—West corner MSG	40.75032	73.99460	584875	4511527
Release E	34th between 7th & 8th—middle of Penn One	40.75162	73.99233	585065	4511673

The ground-level perfluorocarbon tracer samplers in this study were deployed at 19 outdoor locations in two concentric circles, approximately 200 meters and 400 meters from the center of the MSG. Seven sampler sites were also employed on the rooftops of the One Penn Plaza, Two Penn Plaza, Farley Post Office, and New Yorker Hotel. Finally, two samplers were deployed inside MSG itself and one inside the New Yorker Hotel conference room. Figure 2.2 shows the ground-level sampler locations, labeled 1 through 20, and the rooftop samplers, labeled V1 through V7. Table 2.2 shows the coordinates of each of the outdoor sampler locations.

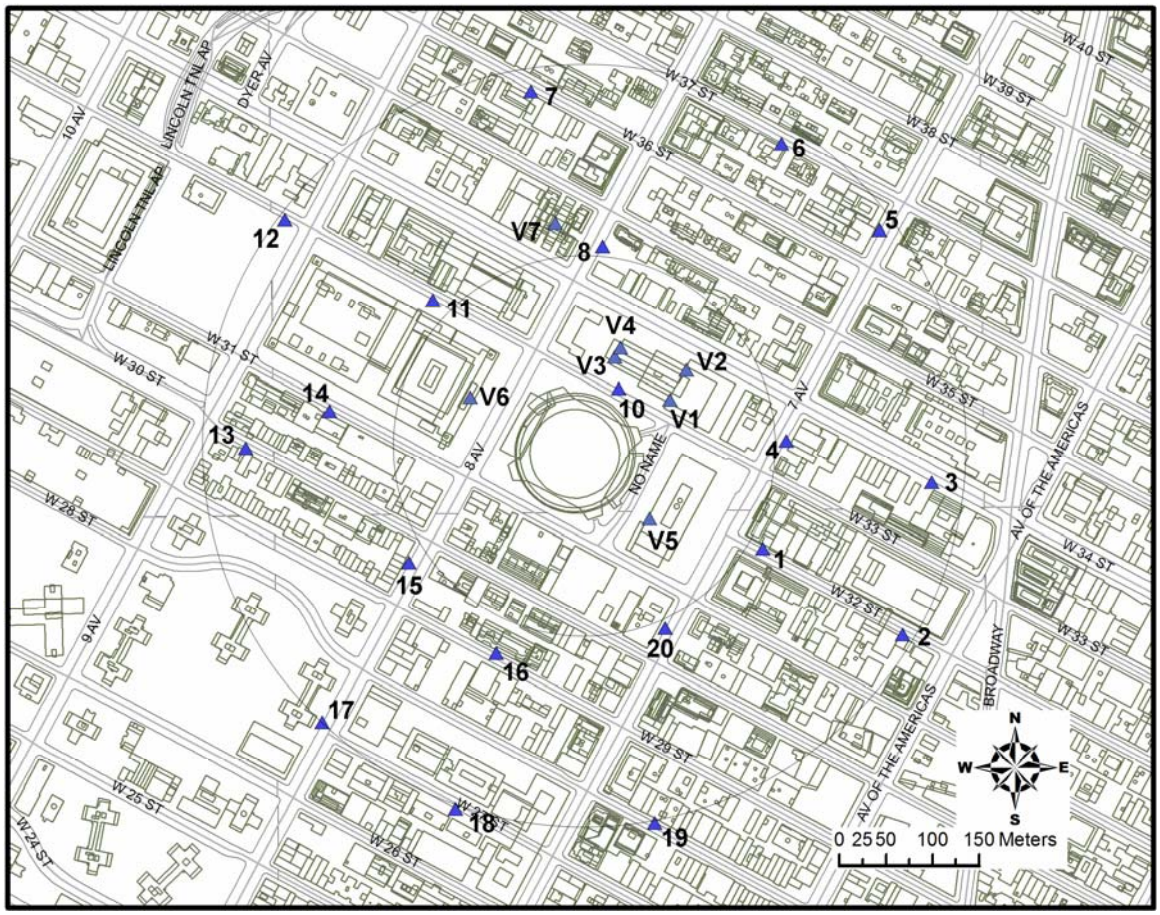

Figure 2.2. Outdoor Perfluorocarbon Tracer Sampler Locations. The two concentric circles represent distances 200 and 400 meters from the center of the MSG.

A number of different tracer-measurement instruments were deployed in support of this field study. These included Brookhaven atmospheric tracer samplers (BATSs), sequential air samplers (SASs), personal air samplers (PASs), and a continuous dual trap analyzer (CDTA). The BATSs were programmed to collect 30-minute samples, while the SASs collected 6-minute samples. The PASs were deployed at many of the ground-level locations as well as in walking paths to investigate personal exposure. Adsorption tubes in the PASs were simply replaced every half-hour by the student participants to produce 30-minute samples. The CDTA was deployed in a mobile van to capture the PFT plumes at time and spatial resolutions that could not be achieved by the stationary samplers. See Watson et al. (2006) for additional details about the tracer instrumentation deployed for this field study.

Table 2.2. Brookhaven Sampler Coordinates

Sampler #	Location Description	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)
1	7th & 32nd In front of the Hotel Pennsylvania—north side of street	40.74957	73.99109	585172	4511447
2	West of 6th & 32nd in front of the Blarney Stone Bar—south side	40.74872	73.98932	585322	4511354
3	34th & Broadway South side—in front of Footlocker	40.75019	73.98894	585353	4511518
4	Midway between 34th & 33rd East side of 7th—in front of McDonald's	40.75061	73.99078	585197	4511563
5	Between 36th & 37th in front of Bates Worldwide—west side of 7th	40.75264	73.98956	585297	4511789
6	232 W. 37th south side in front of West Tandoori Club—midway 7th & 8th	40.75349	73.99079	585192	4511882
7	Midway 8th & 9th on 36th in front of 320 Goldie Restaurant—south side	40.75402	73.99397	584923	4511938
8	In front of McDonald's Midway 34th & 35th—east side of 8th	40.75251	73.99308	585000	4511772
10	One Penn Plaza—middle of building north side of 33rd	40.75113	73.99290	585017	4511619
11	In front of the Post Office, south side of 33rd—between 8th & 9th	40.75201	73.99525	584818	4511714
12	Across from St. Michael's Church, south side of 33rd—between 9th & 10th	40.75280	73.99712	584659	4511800
13	9th and 30th 370 W. 30th—south side of 30th, close to 9th	40.75060	73.99765	584617	4511555
14	South side of 31st midway 8th & 9th—across from bay 16 of the Post Office	40.75095	73.99658	584707	4511595
15	West side of 8th #393 midway between 30th & 29th—in front of 8th Ave Garden	40.74947	73.99559	584792	4511432
16	In front of 29th St Marketplace, north side of 29th—between 7th & 8th	40.74858	73.99449	584886	4511334
17	8th & 27th, middle of T-bone intersection—west side 8th	40.74793	73.99672	584699	4511260
18	In front of Nagler Hall on the south side of 27th	40.74708	73.99504	584842	4511167
19	North side of 28th in front of Center Floral Design—between 6th & 7th	40.74692	73.99250	585056	4511152
20	In front of Seven Penn Plaza between 30th & 31st—west side of 7th	40.74881	73.99234	585067	4511361
V1	12th story Penn One 33rd Street side	40.75102	73.99225	585072	4511607
V2	12th story Penn One 34th Street side	40.75131	73.99203	585090	4511639
V3	Top of Penn One 33rd Street side	40.75144	73.99294	585013	4511653
V4	Top of Penn One 34th Street side	40.75153	73.99287	585019	4511663
V5	Top of Penn Two	40.74987	73.99253	585050	4511479
V6	Top of Post office 8th and 33rd	40.75107	73.99479	584858	4511610
V7	Top of New Yorker Hotel	40.75274	73.99368	584949	4511796

3.0 Quality-Assured Tracer Dataset

The perfluorocarbon concentration data collected from the BATS instruments have been thoroughly quality-assured for use in model validation efforts. Background concentrations have been removed to retain only those measurements that result from the PFT releases. The method for determining the background concentration involved plotting all of the BATSs and visually filtering the data to eliminate outliers and high concentrations, retaining only a band of data that appeared to be the background/noise. The average of the background/noise was then subtracted from the data to produce values that represent the portion of the ambient PFT concentration that is attributable to the tracer release.

The total set of quality-assured BATS data include 15 ground-level samplers (plus one duplicate), five rooftop samplers, and one indoor sampler for IOP 1. IOP 2 had data from 16 ground-level samplers (plus one duplicate) and seven rooftop locations. This quality-assured BATS dataset for model validation efforts is available as an Excel file. Details about the quality-assurance procedures applied to this verified dataset can be found on the "Info" tab of the Excel workbook that contains these data. For completeness, also included in this Excel file are the PFT release rates from Table 3 in Watson et al. (2006). The MSG05 tracer data currently have limited distribution, and will only be distributed with a need-to-know. The data will be available from a secure database in the future. At this time, individuals may request the data by contacting the authors at jerry.allwine@pnl.gov or julia.flaherty@pnl.gov.

4.0 Meteorological Measurements

Meteorological measurements were made by several street-level, building setback, and building rooftop wind stations. Three sodars were also deployed to measure vertical wind profiles. Many of the instruments were deployed near MSG to characterize the local flow patterns that affect plume transport. Figure 4.1 presents a map with the meteorological instruments that were deployed near MSG.

The street-level sonic anemometers, labeled s1 through s5 and s7 in Figure 4.1, were deployed on 3-m aluminum tripods. The rooftop stations, on the other hand, were mounted on 6-m tripods of similar construction. Building setback stations, such as s6, r6, and r7, were mounted on booms. The meteorological instruments in the near-field were deployed by BNL. See Reynolds (2006) for additional details concerning meteorological instruments deployed by BNL.

Winds were also measured at a location across the Hudson River, west of Manhattan. Two sodars and a meteorological tower were located at the Stevens Institute of Technology (SIT) in Hoboken, New Jersey. See Berg et al. (2006) and Berg and Allwine (2006) for a description of the sodars deployed at SIT.

In addition to the meteorological instruments that were deployed specifically to support this field study, permanent instruments continuously collected data that are available for analysis. These permanent installations include the National Oceanic and Atmospheric Administration (NOAA) and DCNet instruments and the ASOS. Figure 4.2 shows a map of the instruments deployed on and around Manhattan. Figure 4.3 shows an overview of all the NWS ASOS stations around NYC. Table 4.1 gives the coordinates of each of the meteorological instruments shown in Figure 4.1 to Figure 4.3.

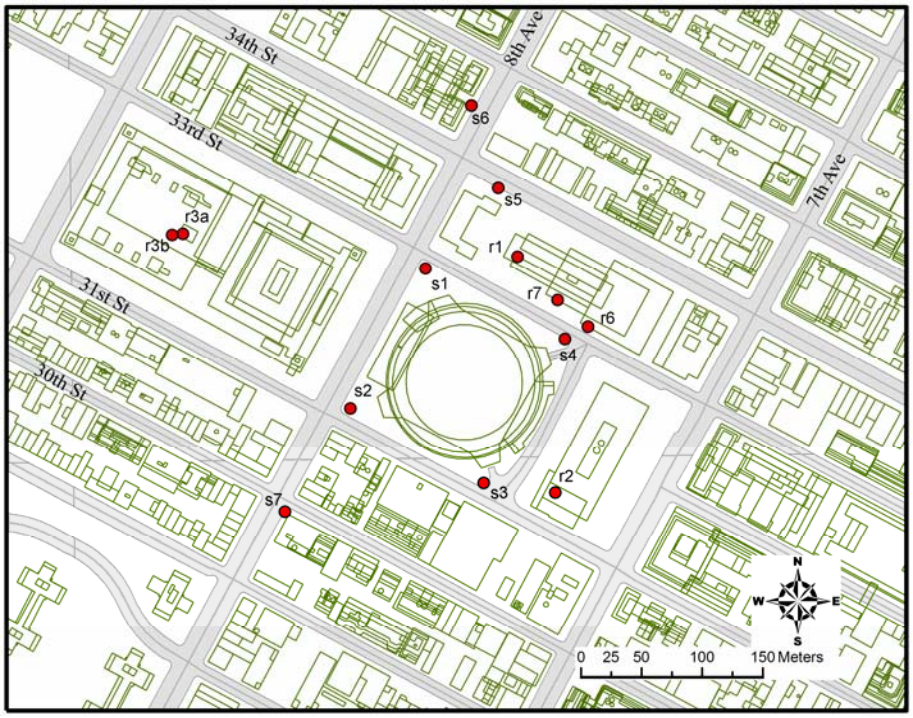

Figure 4.1. Sonic Anemometer Locations in the Vicinity of MSG

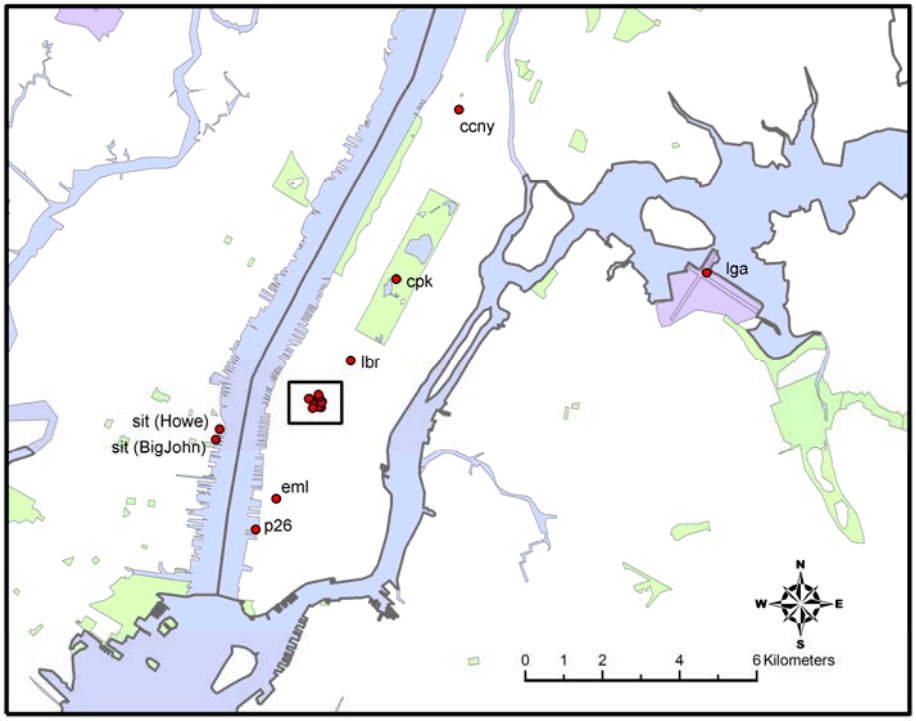

Figure 4.2. Meteorological Stations in the Vicinity of Manhattan. The small box southwest of lbr represents the area shown in Figure 4.1.

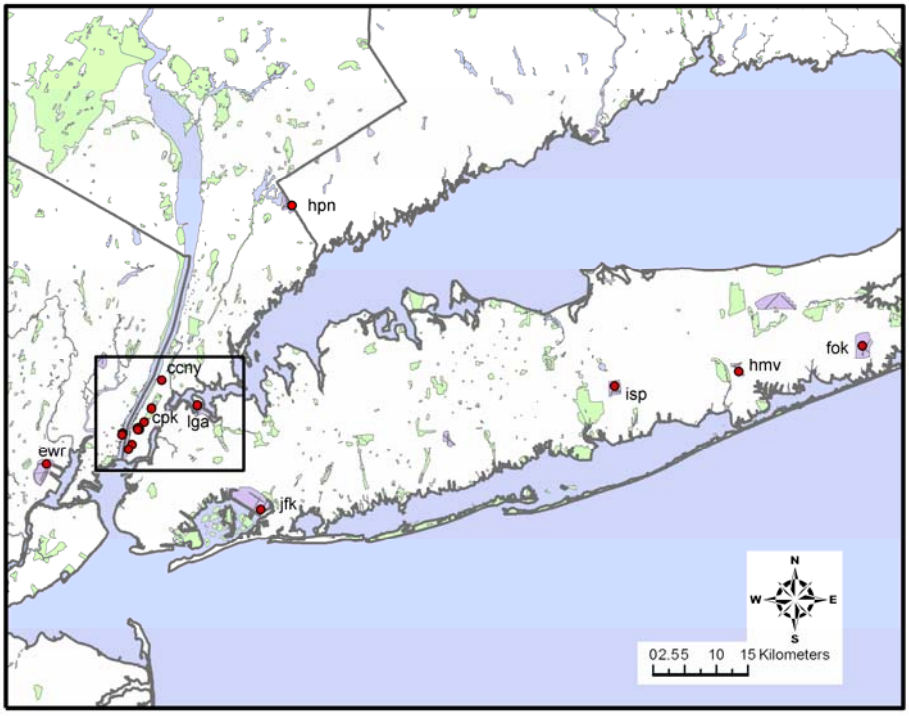

Figure 4.3. Overview of All Meteorological Stations in the Vicinity of NYC. The box in the western portion of the image, east of ewr, represents the area shown in Figure 4.2.

Table 4.1. Meteorological Instrument Coordinates

Station Name	Location Description	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)
NOAA—ccny	CCNY[a] Roof NOAA GPS station	40.81923	73.94911	588623	4519222
ASOS—cpk	Central Park NOAA ASOS	40.77944	73.96907	586992	4514785
DCNet—eml	Environ Meas Lab 15th floor roof	40.72838	74.00666	583884	4509080
ASOS—ewr	Newark Airport ASOS	40.69250	74.16868	570240	4504955
ASOS—fok	Westhampton Gabreski Airport	40.84999	72.63334	699499	4524801
ASOS—hpn	White Plains Westchester Co Airport	41.06667	73.70000	609223	4546972
ASOS—hwv	Shirley Brookhaven Airport	40.81667	72.86667	679919	4520596
ASOS—isp	Islip Long Island Macarthur Airport	40.80000	73.10000	660279	4518292
ASOS—jfk	New York JFK International Airport	40.63333	73.76667	604299	4498786
DCNet—lbr	Lehman Brothers roof	40.76049	73.98326	585819	4512667
ASOS—lga	New York LaGuardia Airport	40.78006	73.87345	595060	4514953
MESO—p26	Pier 26 Hudson River	40.72122	74.01311	583348	4508279
ROOF—r1	One Penn Plaza Roof	40.75144	73.99293	585014	4511652
ROOF—r2	Two Penn Plaza roof	40.74967	73.99259	585045	4511457
ROOF—r3a	Farley PO[b] met station	40.75164	73.99620	584738	4511672
SODAR—r3b	Farley PO sodar	40.75163	73.99631	584729	4511671
SBACK—r6	One Penn Plaza 7th floor setback	40.75091	73.99225	585072	4511595
SBACK—r7	One Penn Plaza 12th floor setback	40.75111	73.99255	585047	4511617
STREET—s1	NW corner of MSG	40.75136	73.99383	584938	4511643
STREET—s2	SW corner of MSG	40.75032	73.99458	584876	4511527
STREET—s3	SE corner of MSG	40.74975	73.99329	584986	4511465
STREET—s4	NE corner of MSG	40.75082	73.99248	585053	4511585
STREET—s5	34th St N of One Penn Plaza	40.75196	73.99311	584998	4511709
SBACK—s6	NY Hotel Overhang (8th Ave)	40.75257	73.99337	584976	4511778
STREET—s7	SE corner 8th and 30th	40.74955	73.99523	584822	4511441
MESO—sit	Stevens Institute of Tech Howe Ctr	40.74486	74.02384	582413	4510893
miniSodar—sit	Stevens Institute of Tech Howe Ctr	40.74486	74.02384	582413	4510893
SODAR—sit	Stevens Institute of Tech Big John	40.74242	74.02505	582314	4510621

(a) CCNY = City College of New York
(b) PO = Post Office

5.0 Initial Results

During each of the two study days of the MSG experiment, the overall wind conditions were generally constant through the 6-hr study period. The first study day (IOP 1) experienced winds that were nearly parallel to the streets, at about 300 degrees. Figure 5.1 shows the wind speeds and directions from four elevated measurements: 30-minute averages from the 90-meter range gate of the SIT Sodar on Howe Center, 5-minute averages from the roof of One Penn Plaza, the roof of the Farley Post Office, and the roof of Two Penn Plaza. The yellow bars on the figure represent each of the hour-long tracer release periods, and all times are presented in Eastern Standard Time. The SIT sodar was west of the MSG study area, across the Hudson River (see Figure 4.2), and this supports the fact that the rooftop measurements near MSG represent mean above-city flows. The wind directions are similar between the four measurement locations, and the wind speeds increase with the height of the measurement. The average temperature and pressure during the first release period of IOP 1 was about -3.8^{o}C, and 1003mb, respectively. Conditions were similar during the second release period, with average temperature and pressure approximately -2.2^{o}C and 1002mb.

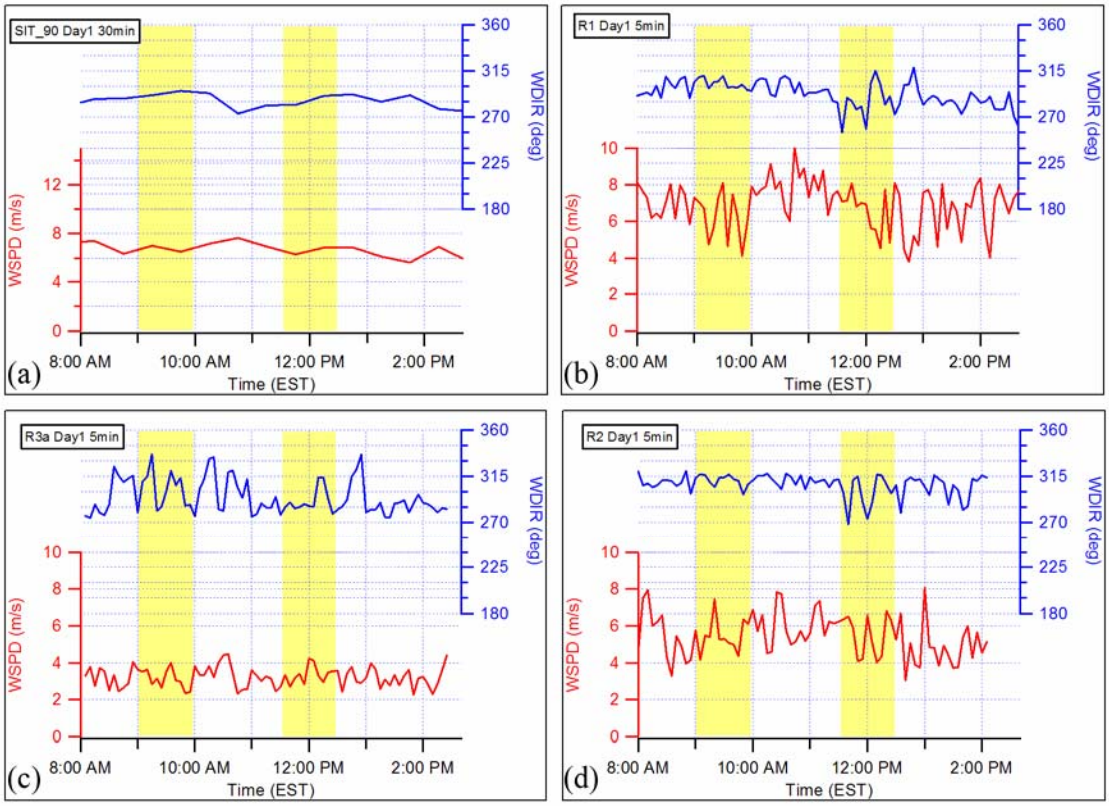

Figure 5.1. IOP 1 Winds from (a) the 90-m Level (175m above mean sea level [AMSL]) of the AeroVironment (AV) Sodar at SIT, Rooftop Meteorological Stations at (b) One Penn Plaza (240m AMSL), (c) Farley Post Office (47m AMSL), and (d) Two Penn Plaza (146m AMSL). Yellow bars represent the two 1-hour tracer release periods. WSPD means "wind speed," and WDIR means "wind direction."

Figure 5.2 presents time series plots of the four street-level sonic anemometers that were deployed on the street corners around MSG. The two sites to the west of MSG, s1 and s2, indicate that the flow is diffluent at the MSG and forces channeling in opposite directions along 8th Avenue. Location s3, which was between MSG and Two Penn Plaza, appears to be influenced by flows traveling down the windward face of Two Penn Plaza and away from the building, towards MSG near the ground surface. The winds at the final sonic anemometer location of Figure 5.2, s4, are less steady than the previous three locations. Winds at s4 tend to switch between southerly and northerly at time intervals between 5 and 30 minutes.

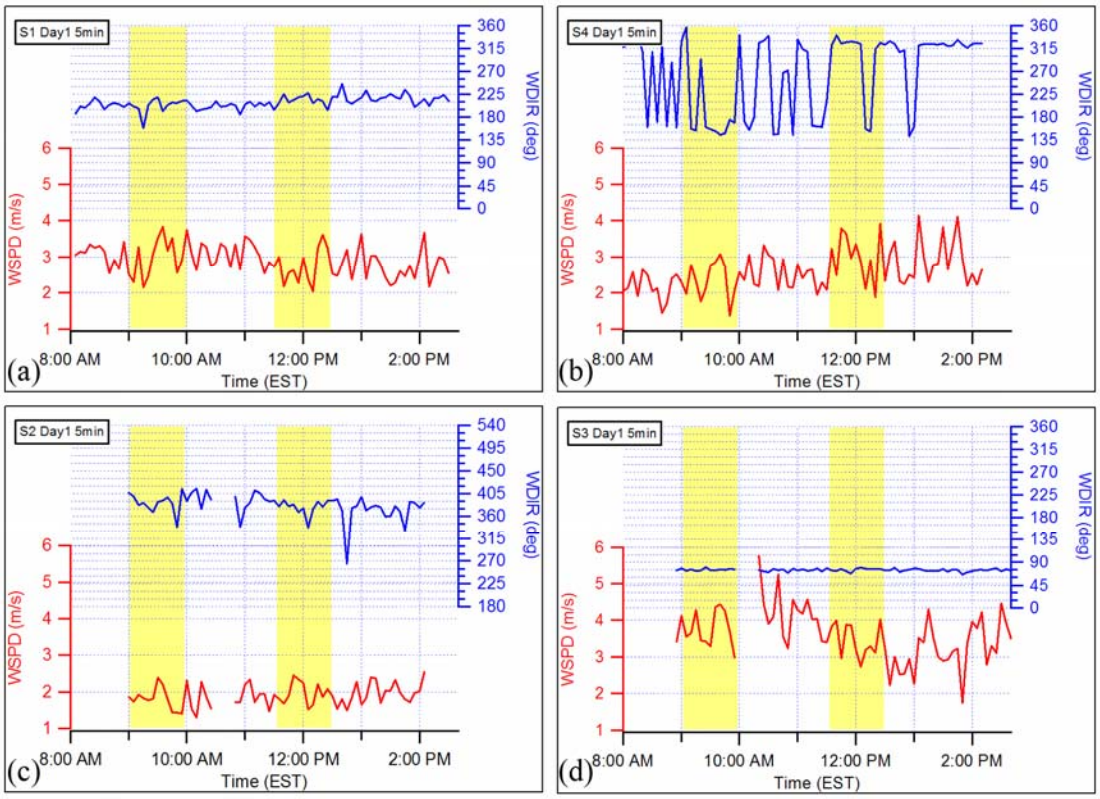

Figure 5.2. IOP 1 Winds from the Street Level Sonic Anemometers Surrounding MSG on the (a) Northwest, (b) Northeast, (c) Southwest, and (d) Southeast Corners. Yellow bars represent the two 1-hour tracer release periods. WSPD means "wind speed," and WDIR means "wind direction."

The average of four 30-minute BATS measurements for the two hour-long tracer release periods was computed. The background concentration was removed from the BATS measurements so that only the concentrations that were attributable to the tracer release were used. These average values were then plotted on a map to develop an estimate of the plume footprint for each of the five tracer release positions. Figure 5.3 presents the results of these contours. To protect the sensitive nature of these concentration results, the contour intervals have been intentionally omitted from this figure. In addition to the plume footprints, Figure 5.3 shows the vector-averaged wind speed and direction for the measurement locations near MSG during the same 2-hour period. The variability in winds during these two-hour periods are represented by wedges that are two standard deviations of the wind direction.

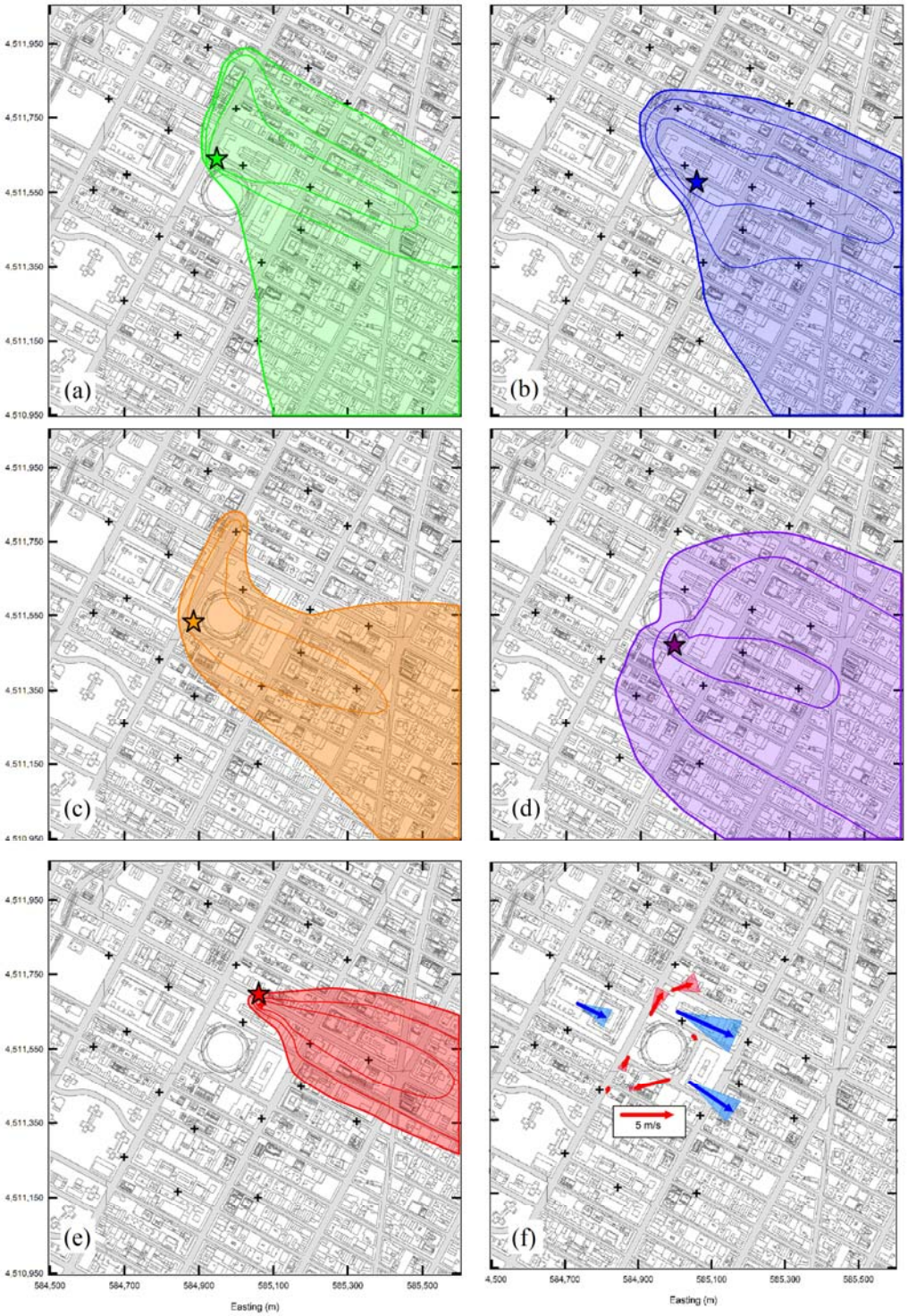

Figure 5.3. IOP 1 Plume Contours Based on the Average of Two Separate Hours of Tracer Release for Various Release Locations. (a) Release A, (b) Release B, (c) Release D, (d) Release C, (e) Release E, and (f) average wind speed and direction with wedges representing two standard deviations of wind direction. Blue arrows represent building-top winds and red arrows represent street-level winds.

Figure 5.3 shows that there are vastly different plume footprints for each of the release locations. In general, there is a fair amount of upwind and/or crosswind transport of tracer material. The exception to this is the tracer release from location E, which was on the north side of One Penn Plaza. It appears that the tracer is mostly channeled downwind along the street from this location because the winds were aligned with the streets.

The second study day (IOP 2) experienced winds that were at an angle to the streets, at about 330 degrees. Figure 5.4 shows the wind speeds and directions from four elevated measurements: the 90-meter range gate of the SIT Sodar on Howe Center, the roof of One Penn Plaza, the roof of the Farley Post Office, and the roof of Two Penn Plaza. Compared with IOP 1, the wind measurements at the SIT sodar were commensurate with the measurements made near MSG. The wind directions are similar between the three near-MSG measurement locations, and the wind speeds increase with the height of the measurement. Average temperatures during the tracer release periods of the second IOP were -0.6°C and 1.5°C for the first and second release periods, respectively. The average pressures during these periods were 1008mb and 1007mb.

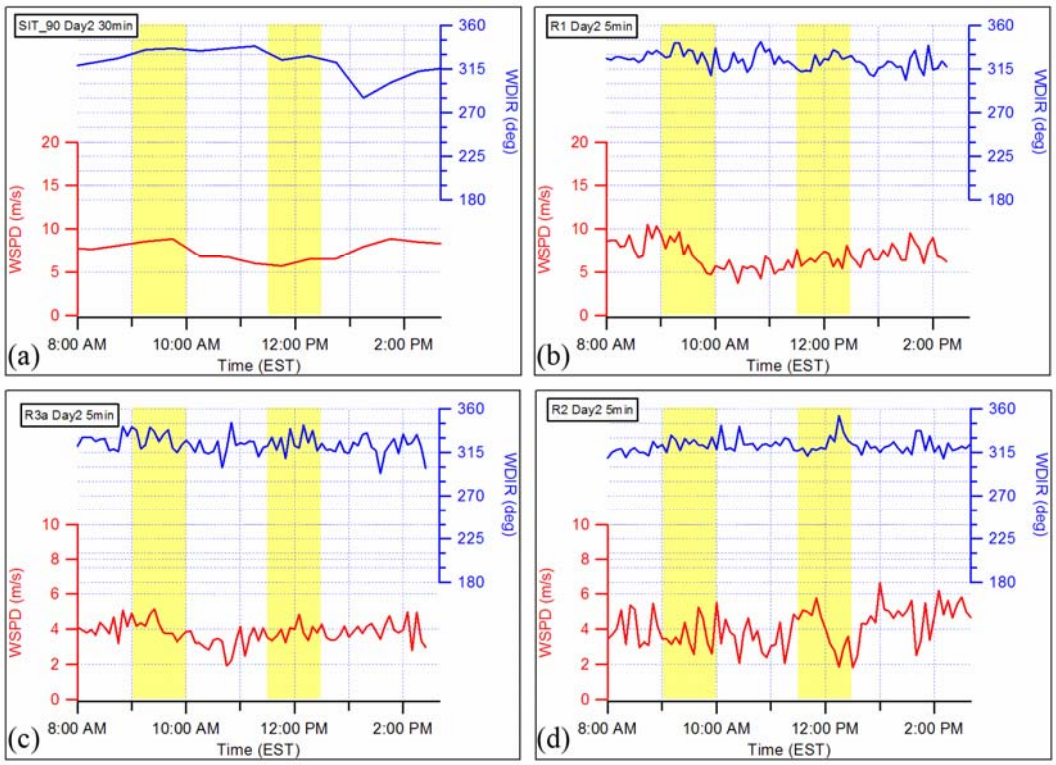

Figure 5.4. IOP 2 Winds from (a) the 90-m Level (175m AMSL) of the AV Sodar at SIT, Rooftop Meteorological Stations at (b) One Penn Plaza (240m AMSL), (c) Farley Post Office (47m AMSL), and (d) Two Penn Plaza (146m AMSL). Yellow bars represent the two 1-hour tracer release periods. WSPD means "wind speed," and WDIR means "wind direction."

Figure 5.5 presents time series plots of the four street-level sonic anemometers that were deployed on the street corners around MSG for the second study day (IOP 2). As was seen during IOP 1, the two sites to the west of the MSG (s1 and s2) indicate flow divergence at MSG with channeling in opposite directions. However, the winds at s2 were not as steady as during the first day, and winds shifted between

40 degrees and 195 degrees. Although location s3 experienced very steady winds during IOP 1, this location had highly variable wind directions during IOP 2. Winds at s3 shifted from about 90 to 270 degrees at intervals between about 30 and 60 minutes. This is a potential indicator of a recirculation zone behind the Madison Square Garden, or simply intermittency between flow channeling down 31st Street and flow away from Two Penn Plaza. Unlike the conditions during IOP 1, the sonic anemometer at s4 experienced very constant wind directions and periodicity in wind speeds during IOP 2. The winds at s4 were generally from 165 degrees, which is nearly 180-degrees from the mean above-city wind direction. In this case, s4 may have been experiencing flow that was deflected away from Two Penn Plaza.

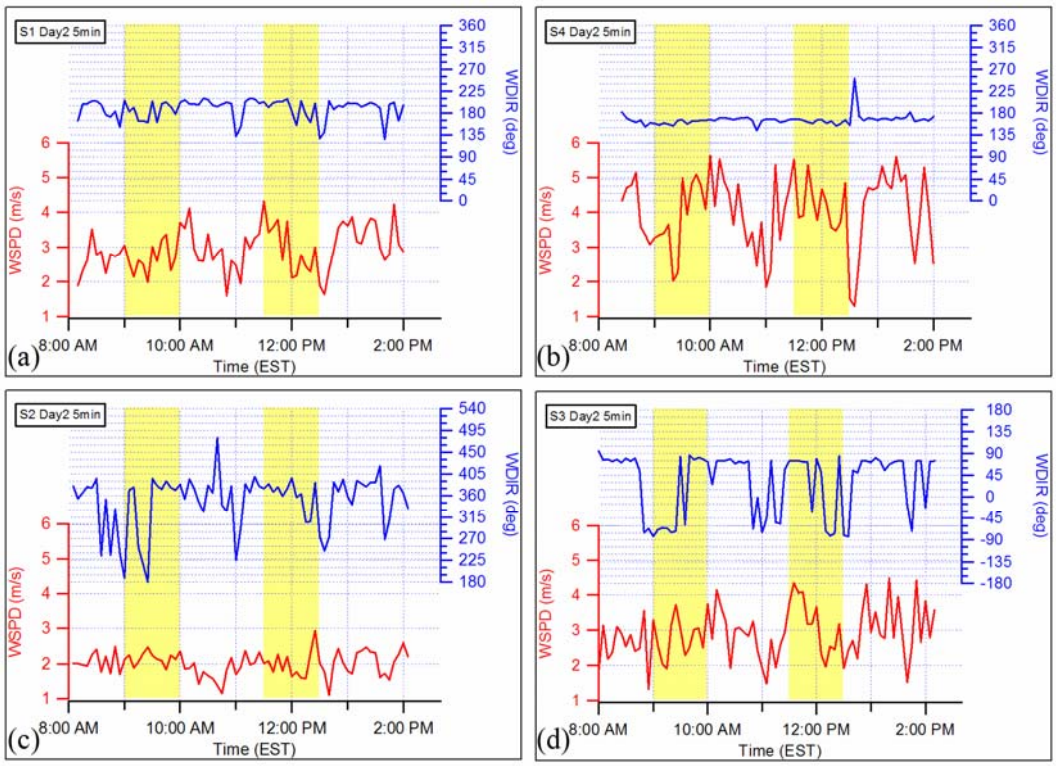

Figure 5.5. IOP 2 Winds from the Street Level Sonic Anemometers Surrounding MSG on the (a) Northwest, (b) Northeast, (c) Southwest, and (d) Southeast Corners. Yellow bars represent the two 1-hour tracer release periods. WSPD means "wind speed," and WDIR means "wind direction."

Figure 5.6 presents the average BATSs and wind measurements from the two hour-long tracer release periods for IOP 2. As was shown in Figure 5.3 for the first study day, there is a variety of different plume footprint shapes and a fair amount of upwind and/or crosswind transport of tracer for the different release locations. In general, the overall extent of the plume was similar in shape between the two IOPs. The exception to this is that the release from location D (southwest corner of MSG) did not have the crosswind transport near the source that was seen during IOP1. Also, although release E (north of One Penn) during IOP 2 exhibited a similar initial channeling down 34th Street as was observed during IOP 1, the plume became broader in the first block downwind from the source.

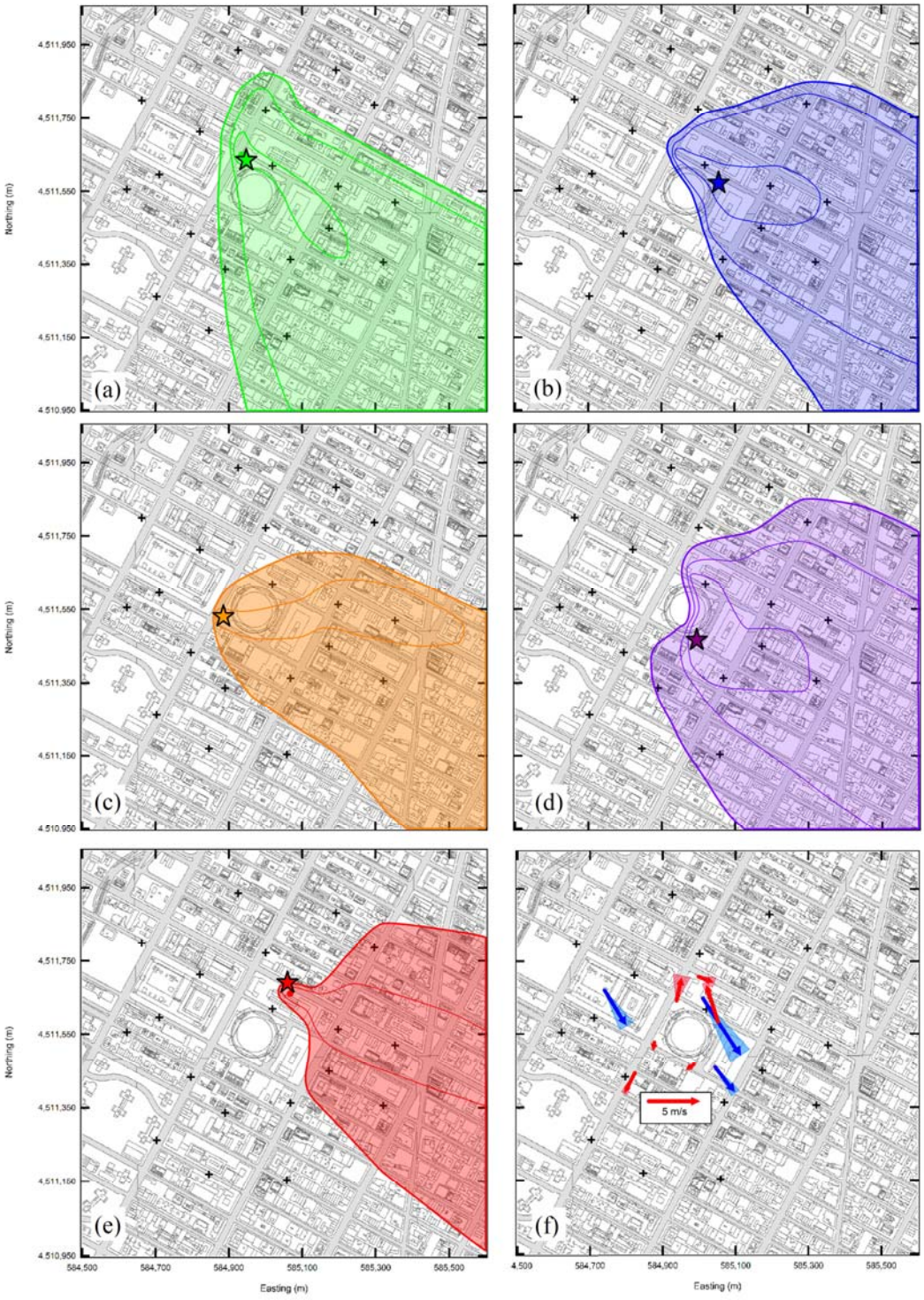

Figure 5.6. IOP 2 Plume Contours Based on the Average of Two Separate Hours of Tracer Release for Various Release Locations. (a) Release A, (b) Release B, (c) Release D, (d) Release C, (e) Release E, and (f) average wind speed and direction with wedges representing two standard deviations of wind direction. Blue arrows represent building-top winds and red arrows represent street-level winds.

6.0 References

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