J7.1 OVERVIEW OF JOINT URBAN 2003 –
AN ATMOSPHERIC DISPERSION STUDY IN OKLAHOMA CITY

K. J. Allwine[1] *, M. J. Leach[2], L. W. Stockham[3], J. S. Shinn[2], R. P. Hosker[4], J. F. Bowers[5], and J. C. Pace[6]
[1]Pacific Northwest National Laboratory, Richland, Washington; [2]Lawrence Livermore National Laboratory, Livermore, California; [3]Northrop Grumman Information Technology, Albuquerque, New Mexico; [4]Atmospheric Turbulence and Diffusion Division, Oak Ridge, Tennessee; [5]Dugway Proving Ground, Dugway, Utah; [6]Defense Threat Reduction Agency, Washington DC

1. INTRODUCTION

Air motions in and around cities are very complicated and the increasing threat of toxic agents being released into urban atmospheres makes advancing the state-of-science of understanding and modeling atmospheric flows in and around cities essential. Quality-assured meteorological and tracer data sets are vital for establishing confidence that indoor and outdoor dispersion models used to simulate dispersal of potential toxic agents in urban atmospheres are giving trustworthy results. To provide this critically needed high-resolution dispersion data, the U.S. Department of Defense – Defense Threat Reduction Agency (DTRA) and the U.S. Department of Homeland Security (DHS) joined in an effort to conduct the Joint Urban 2003 atmospheric dispersion study in Oklahoma City, Oklahoma (Figure 1) during July 2003. Numerous investigators from government laboratories, universities and private companies conducted the multi-million dollar Oklahoma City study. Additionally, investigators from several other U.S. federal agencies and foreign government agencies participated in the study.

This major urban study was conducted beginning June 28 and ending July 31, 2003. It included several integrated scientific components necessary to describe and understand the physical processes governing dispersion within and surrounding an urban area and into and within building environments. The components included characterizing: 1) the urban boundary layer and the development of the urban boundary layer within the atmospheric boundary layer, 2) the flows within and downwind of the tall-building core, 3) the flows within a street canyon including the effects of traffic on turbulence, 4) the surface energy balance within an urban area, 5) the dispersion of tracer into, out of and within buildings, and 6) the dispersion of tracer throughout the tall-building core and out to four km downwind from the release. The scientific elements of the study were accomplished using state-of-the-art meteorological and tracer instruments including lidars, sodars, radars, sonic anemometers, airplane-based meteorological sensors, fast-response tracer analyzers and helicopter-based remote tracer detectors. Winds and other meteorological quantities were measured continuously at nearly 200 locations in and around downtown Oklahoma City.

Ten intensive operation periods (IOPs) of 8-hours each were completed during the 34-day study period where detailed meteorological, turbulence and tracer measurements were made. Sulfur hexafluoride tracer was released in downtown Oklahoma City and sampled in and around downtown and as far as four km downwind. During four of the ten IOPs the infiltration of tracer into four downtown buildings was studied with detailed measurements of tracer and flows within and surrounding some buildings. Tracer was sampled using over 200 integrated samplers and 25 fast response analyzers. Vertical measurements of tracer were made by placing samplers on the tops of nearly 20 buildings and by sampling tracer at 7 levels on a 90 m crane.

Figure 1. Oklahoma City looking east in top panel and looking southeast in bottom panel.

An overview of the Joint Urban 2003 field study is presented identifying scientific objectives and the deployment of instruments to accomplish the scientific objectives. Study participants, experimental periods and meteorological conditions during the study period are briefly discussed.

* *Corresponding author address*: K. Jerry Allwine, Pacific Northwest National Laboratory, Richland, WA 99352; email: jerry.allwine@pnl.gov.

2. SCIENTIFIC OBJECTIVES

The primary objective of the Joint Urban 2003 field study was to collect meteorological and tracer data resolving atmospheric dispersion at scales-of-motion ranging from flows in and around a single city block, in and around several blocks in the downtown Central Business District (CBD), and into the suburban Oklahoma City area a few km from the CBD. Indoor tracer and flow measurements within four downtown study buildings were also made in conjunction with detailed outdoor measurements investigating the outdoor-indoor exchange rates and mechanisms. The movement of tracer within the study buildings was also studied.

The tracer and meteorological data collected in Oklahoma City will be used to evaluate and improve existing indoor and outdoor dispersion models, including fine-scale computational fluid dynamics (CFD) models, mesoscale numerical weather prediction models with sub-grid scale urban parameterizations, and fast-response dispersion models that typically rely on empirical or semi-empirical relationships describing the atmospheric processes. The data will lead to improved algorithms and parameterizations within these models.

Specific objectives included:

- Use state-of-the-art remote sensing instruments (radar profilers, lidars, sodars) to continuously measure the detailed wind and turbulence characteristics of the urban atmosphere from the ground through several kilometers above the ground. These relatively new instruments when applied in a dense network give a view of the three-dimensional flow in and above cities that has not been possible in the past.

- Collect tracer data at various distances from specified release points to provide data for validating a variety of urban dispersion models. Networks of sampling capabilities and meteorological instruments will be deployed to observe the concentrations at the various distances downwind, and to simultaneously investigate the physical processes that govern the dispersion.

- Use state of the art in-situ meteorological instruments (sonic anemometers, IR thermometers) to observe the winds and turbulence within the urban canopy layer. Together with time-resolved in-situ tracer sampling, these observations provide data necessary not only for validating current dispersion models, but also for improving current and formulating new dispersion algorithms and relationships.

- Conduct urban canyon experiments with high resolution winds and turbulence measurements together with tracer data to investigate the processes that disperse material within the canyon and the exchange of material between the canyon and the overall urban circulation.

- Conduct indoor experiments designed to investigate the exchange of tracer material through a building envelope. Tracer samplers and sonic anemometers will be deployed inside the building and immediately outside the building in high-density configuration to estimate the exchange rate. Perfluorocarbon tracers will be released and sampled inside the building to estimate transport within the building.

- Provide an archived data set that has been quality controlled and consistency checked based on a detailed data management plan. The data from all instruments will be available for general release within one year from the completion of the experiment.

The Joint Urban 2003 experimental objectives were accomplished during the study and work is progressing on reducing and quality assuring the data for final submission to the data archive by February 2004. After submission of the final data to the archive it will be available to Joint Urban 2003 investigators and modelers for analyses and validation of urban dispersion models.

3. ORGANIZATION

The Joint Urban 2003 field study was a major effort, bringing together over 150 scientists, engineers, technicians and students from over 20 U.S. and foreign organizations to accomplish the study objectives. Organizations participating included six from the U.S. Department of Defense, five U.S. Department of Energy and Homeland Security national laboratories, two U.S. National Oceanic and Atmospheric Administration laboratories, eight U.S. universities, and other U.S. federal agencies and private companies. The U.S. organizations participating were:

Department of Defense:
- Defense Threat Reduction Agency (DTRA)
- Army Research Laboratory (ARL)
- Army Research Office (ARO)
- Army Soldier and Biological Chemical Command (SBCCOM)
- Dugway Proving Ground (DPG)
- Defense Advanced Research Projects Agency (DARPA);

Departments of Homeland Security & Energy:
- Argonne National Laboratory (ANL)
- Los Alamos National Laboratory (LANL)
- Lawrence Berkley National Laboratory (LBNL)
- Lawrence Livermore National Laboratory (LLNL)
- Pacific Northwest National Laboratory (PNNL)

National Oceanic and Atmospheric Administration:
- Air Resources Laboratory - Field Research Division (FRD)
- Air Resources Laboratory - Atmospheric Turbulence and Diffusion Division (ATDD)

Other Federal Organizations:
- Department of Transportation – Volpe Center
- Center for Disease Control (CDC/NIOSH)
- National Severe Storms Laboratory (NSSL)

Universities:
- Arizona State University (ASU)
- Central Florida University (CFU)
- Texas Tech University (TTU)
- University of Indiana (IU)
- University of Houston (UH)
- University of Oklahoma (OU)
- University of Utah (UU)
- Washington State University (WSU)

State of Oklahoma:
- Oklahoma Climatological Survey (OCS)
- Department of Environmental Quality (DEQ)

Private Companies:
- Northrop Grumman Information Technology
- ITT Industries, Advanced Engineering & Sciences
- Maccini Construction Company
- Allied Steel Construction Company

The foreign participants were the United Kingdom Defence Science and Technology Laboratory and the Defence Research and Development Canada who participated in Joint Urban 2003 under the auspices of the U.S. Department of Defense Technical Panel 9 (TP9) of The Technical Cooperation Program (TTCP) Chemical, Biological and Radiological Defense (CBD) Group.

Planning for Joint Urban 2003 was very extensive and began nearly two years prior to conducting the study in July 2003. As part of the planning, preliminary meteorological studies were conducted during the summer of 2002 to help determine the tracer release locations and the tracer sampler locations based on the predominant wind directions. Historically the winds in Oklahoma City during July are predominantly from the south during both night and day, and this pattern was confirmed during the preliminary meteorological studies.

Further refinement of the tracer sampling network during the design phases of Joint Urban 2003 was accomplished using results from wind tunnel studies performed by the Meteorological Institute, University of Hamburg and from preliminary modeling studies performed by LLNL and CFD Research Corporation, Huntsville, Alabama. The design-phase wind tunnel and modeling studies were very useful in finalizing the locations and sampling intervals of the tracer samplers.

4. STUDY OVERVIEW

The Joint Urban 2003 study had many instruments fielded in Oklahoma City and the surrounding area. The instruments consisted of 215 tracer bag samplers, 25 fast-response tracer analyzers, one 5-level tracer profiling system, airborne remote sensing tracer instruments and meteorological sensors, 142 3-D sonic anemometers for surface-based measurements and tower-based measurements, nine 2-D sonic anemometers, 22 surface meteorological stations, six surface energy budget stations, two Coherent Technologies, Inc. Wind Tracer lidars, two radiosonde systems, two tethersonde systems, two wind profiler/RASS systems, one FM-CW radar, three ceilometer, and nine sodars (including single-beam and mini-sodars). Additionally, the Oklahoma Climatological Survey collected meteorological data from its Oklahoma Mesonet.

Most of the meteorological instruments operated continuously throughout the entire study period, with a subset of the instruments operating only during IOPs. The majority of the meteorological and tracer instruments were sited within or near the CBD with some tracer and meteorological measurements extending out to approximately six kilometers from the CBD. Figure 2 shows some of the meteorological instruments covering the study region.

Sulfur hexafluoride tracer was released from one of three release locations (Figure 3) during all 10 IOPs. The release location was chosen dependent on the wind direction and building configuration. The “Westin” release was used when the winds were expected from the S through SSE and the “Botanical” release was used when the winds were expected from the S through SSW. The “Park” release was used when studying the Park Avenue urban street canyon effects in more detail. The release location during each IOP is identified in Table 1 and Figure 4.

The first six IOPs occurred during daylight hours typically beginning at 0800 CST and ending 8 hours later at 1600 CST. The last four IOPs occurred during the night beginning at typically 2200 CST and ending at 0600 CST. During each IOP typically seven near ground-level point releases occurred – three continuous releases of ½ hour duration and four instantaneous releases where balloons filled with tracer were popped. Tables 1 and 2 summarize the times and rates of the tracer releases.

The meteorological conditions during the July 2003 study period are summarized in Figure 4. The period of each IOP is identified showing the wind directions from primarily the SSW through SSE directions during the IOPs. The release locations and “indoor study” IOPs are also identified in Figure 4. The four buildings studied as part of the indoor component of Joint Urban 2003 were located near the intersections of Park & Broadway and McGee & Harvey (Figure 3). During

indoor IOPs the release location was chosen such that the tracer plume would move in the direction of the indoor study buildings based on the forecast wind directions.

Figure 5 shows the winds for a nine-day period from two levels of the PNNL sodar located upwind of the Oklahoma City CBD. Essentially, no wind direction shear is evident day or night between the two levels and the wind speed profile shows wind speeds much lighter at the lower level during the night and the profile is nearly flat during the day.

5. ACKNOWLEDGEMENTS

Joint Urban 2003 would not have been possible without the support of the City of Oklahoma City, the University of Oklahoma Health Sciences Center, private land owners and the general public. The City of Oklahoma City Public Works Department provided considerable help by allowing study participants to use some of their facilities for staging areas, allowed instrumentation to be placed on streets and public facilities, and provided parking downtown for study staff during experimental periods. The University of Oklahoma Health Sciences Center was very generous in providing laboratory and meeting space within their facilities in Oklahoma City.

The success of Joint Urban 2003 was critically dependent on many individuals, not the least of which was the scientists, engineers, technicians, students and contractors from the participating organizations and companies. The authors would like to thank several individuals who played key roles during various stages of planning and conducting the study. Ms. Jennifer Reichert of the U.S. DOE's Chemical Biological National Security Program (CBNP) was the CBNP program manager for the project and was instrumental in coordinating and integrating CBNP objectives with DTRA objectives. Ms. Leslie Burchett followed-on for Ms. Reichert and ensured that DOE objectives were met in the field and also facilitated the smooth transition of Joint Urban 2003 from DOE to the new Department of Homeland Security (DHS), where the DHS portion of Joint Urban 2003 is now under the guidance of Ms. Teresa Lustig. One of the authors (JP) was the DTRA Urban Modeling Program manager responsible for integrating DTRA objectives with CBNP objectives for Joint Urban 2003. Mr. Richard Fry is now the DTRA program manager responsible for the DTRA portion of Joint Urban 2003.

The National Environmental Policy Act (NEPA) documentation for the study was prepared by Ms. Regan Weeks of PNNL and Mr. Goeff Harvey, PNNL, served as the lead public affairs contact for Joint Urban 2003. Ms. Cheri Abdelnour and Major Linda Ritchie were responsible for the public affairs on Joint Urban 2003 for DTRA, and Ms. Michelle Petrovich was responsible for DHS public affairs. Ms. Cerry Leffler of the Oklahoma Climatological Survey was the local public affairs contact for the study.

Table 1. Summary of IOPs.

IOP #	Begin Date 2003	Beg / End Time (CST)	Day/ Night	In-door	Release Location	# Releases; Puff (P)/ Continuous (C)
1	6/29 - Sun	08 / 14*	D		Westin (E side of St.)	8; P,P,P,P,P,P,C,C
2	7/02 - Wed	08 / 16	D		Westin	7; P,P,P,P,C,C,C
3	7/07 - Mon	08 / 16	D		Botanical	7; P,P,P,P,C,C,C
4	7/09 - Wed	08 / 16	D	I	Botanical	6; P,P,P,C,C,C
5	7/13 - Sun	08 / 16	D	I	Botanical	7; C,C,C,P,P,P,P
5a	7/15 - Tue	11 / 13	D		N 4th b. Hudson-Walker	3; C,C,C
6	7/16 - Wed	08 / 16	D	I	Botanical	7; C,C,C,P,P,P,P
7	7/18 - Fri	22 / 06	N	I	Botanical	7; C,C,C,P,P,P,P
8	7/24 - Thu	22 / 06	N		Westin	7; C,C,C,P,P,P,P
9	7/26 - Sat	22 / 06	N		Park	7; C,C,C,P,P,P,P
10	7/28 - Mon	20 / 03*	N		Park	6; C,C,C,P,P,P

* Stopped early because of wind shift off sampling grid.

Table 2. Summary of IOP Tracer Release Rates and Times.

IOP #	Release Start Times (CST) and Release Rates [(g) for puffs and (g/s) for continuous]. Puff releases are numbers > 200; All cont. releases are 30 min, except #5a which are 20 min.								
(CST)	0800	0810	0820	0830	0845	0900	1000	1200	1400
1	1000	1003	1000	1000	500	508	4.9	4.8	x
(CST)	0800	0820	0840	0900	1000	1200	1400		
2	1001	1010	1000	1041	5.0	5.0	5.0		
3	1000	1005	1000	1004	5.0	3.0	3.0		
4	996	1002	504	x	3.1	3.0	3.0		
(CST)	0800	1000	1200	1400	1420	1440	1500		
5	2.2	3.0	3.1	499	500	500	500		
6	3.0	3.2	3.0	498	499	510	500		
(CST)	2200	0000	0200	0400	0420	0440	0500		
7	3.0	2.0	2.0	303	300	304	298		
8	3.1	3.0	3.0	500	500	300	305		
9	2.0	2.0	2.1	300	300	300	300		
(CST)	2000	2200	0000	0200	0220	0240	0300		
10	2.2	1.9	2.2	300	300	300	x		
(CST)	1100	1130	1200						
5a	8.0	5.0	3.0						

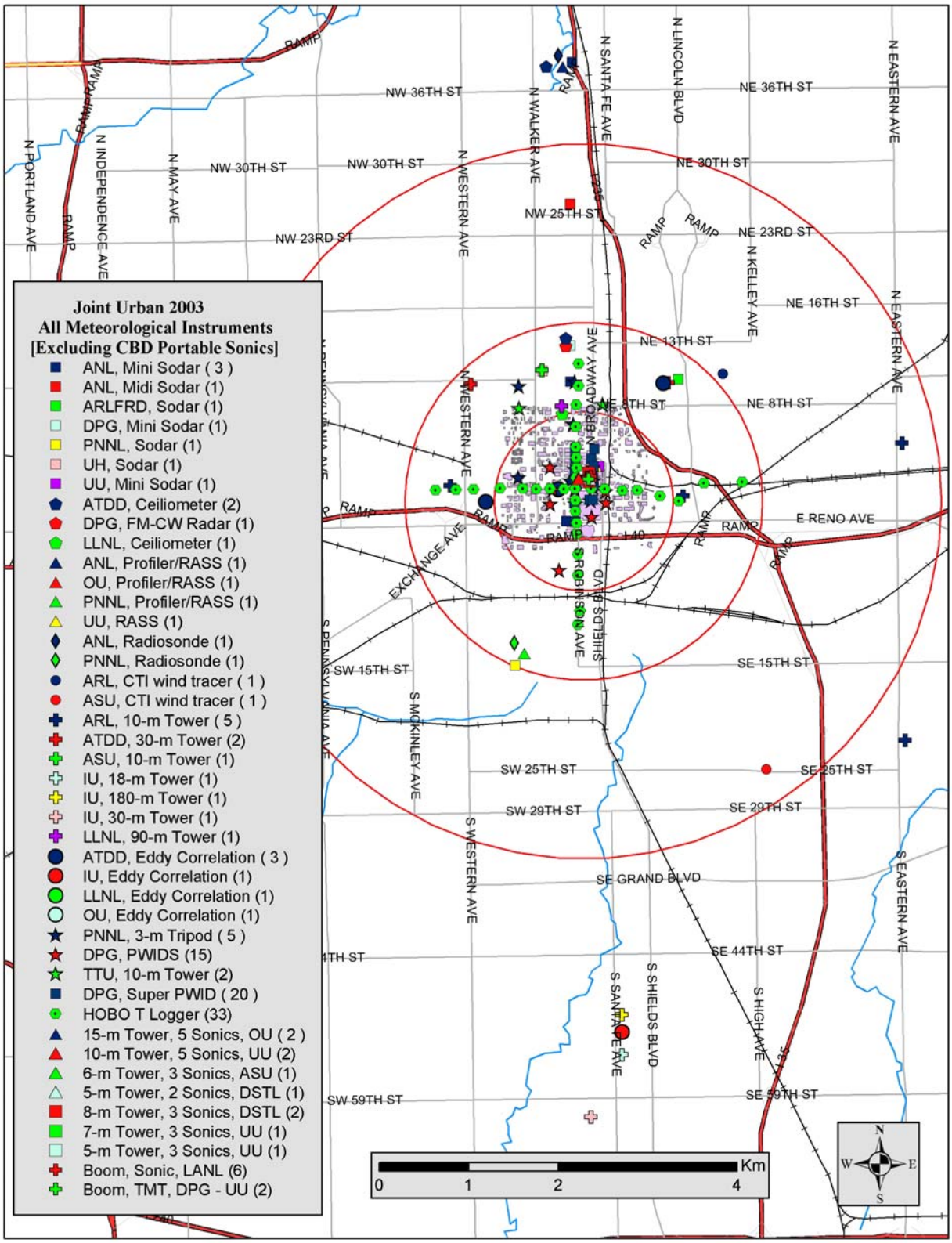

Figure 2. All meteorological instruments deployed in the Oklahoma City area for Joint Urban 2003. Many symbols in the legend are not unique. Plot intended to simply show coverage. Additionally, some instrument locations may not be correct because the final coordinates are being developed and plots will be updated in the future.

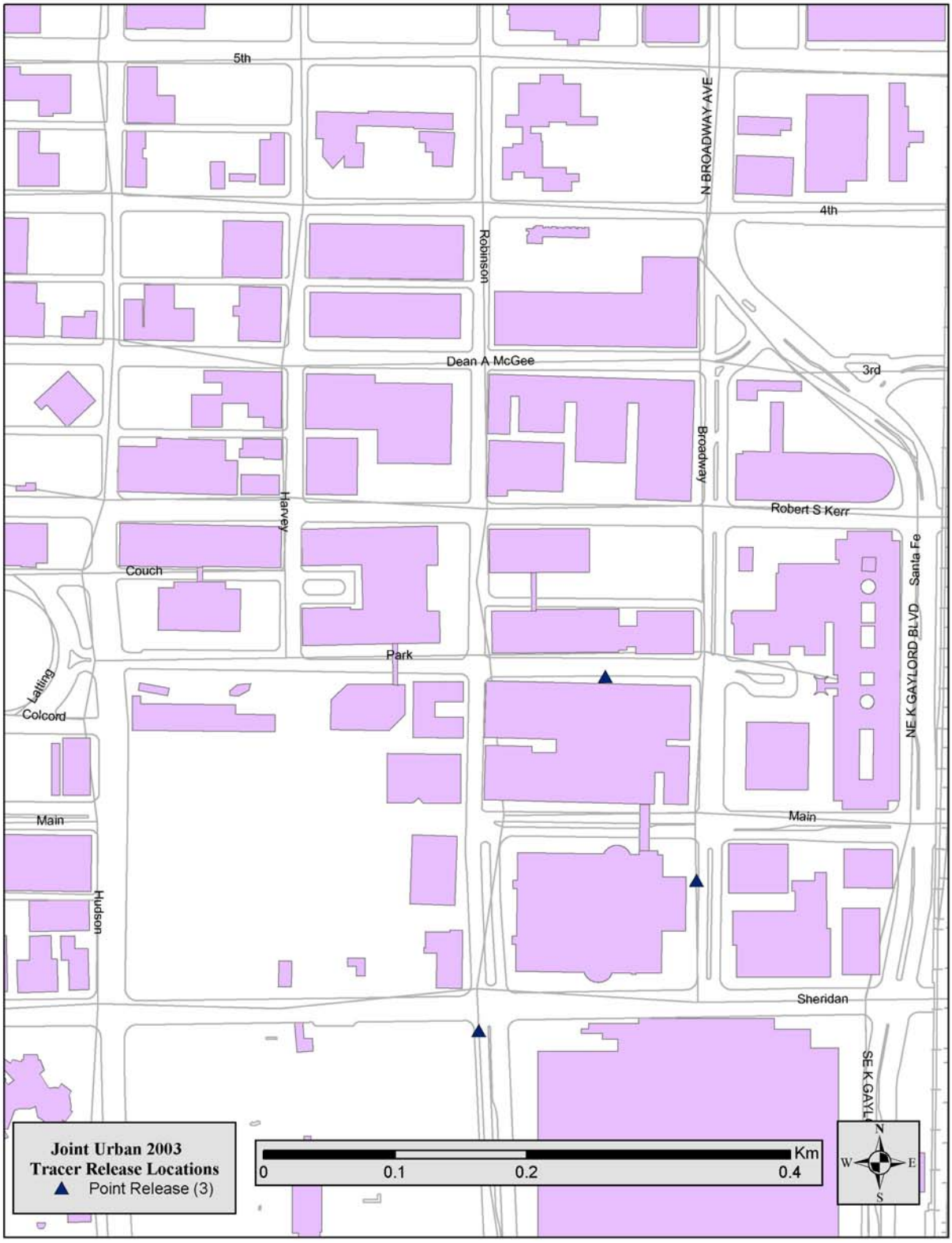

Figure 3. Three sulfur hexafluoride release locations in downtown Oklahoma City used during Joint Urban 2003. Proceeding from south to north the release locations are identified as “Botanical,” “Westin,” and “Park.”

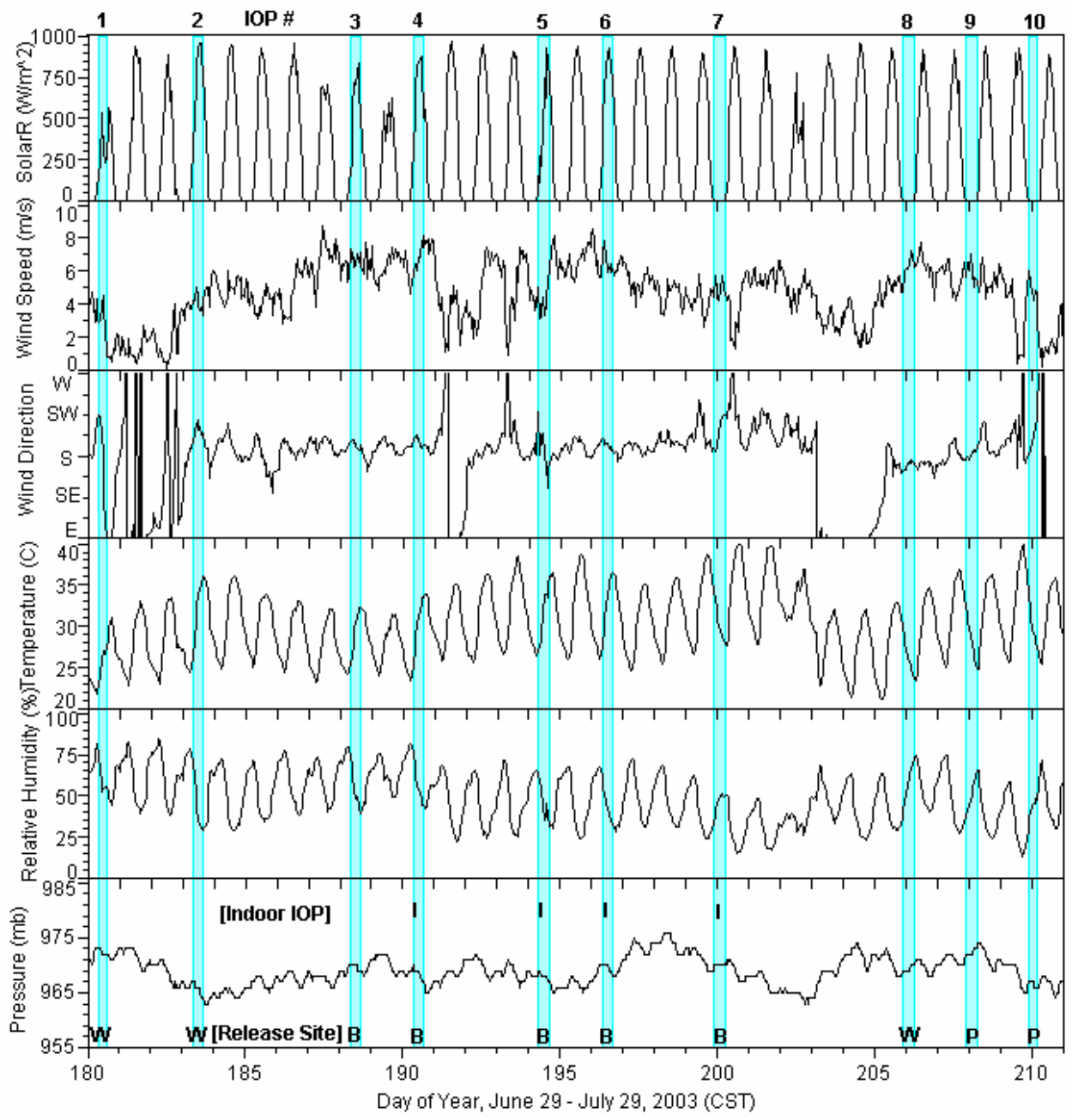

Figure 4. Hourly averaged meteorological conditions for July 2003 measured at 3 m above the rooftop on a 42-m-high building with unobstructed exposure to the winds. The weather station is located on St. Anthony's hospital (NW 10th & Dewey) approximately 1 ½ km NW of downtown Oklahoma City. The atmospheric pressure is from a weather station on the rooftop of the 34-m-high Civic Center Music Hall (Colcord & Lee) just west of downtown OKC. The blue lines indicate the times of the intensive operation periods (IOPs) during which tracers were released. The labels "W", "B" and "P" (Westin, Botanical and Park) identify the tracer release location for each IOP (Table 1).

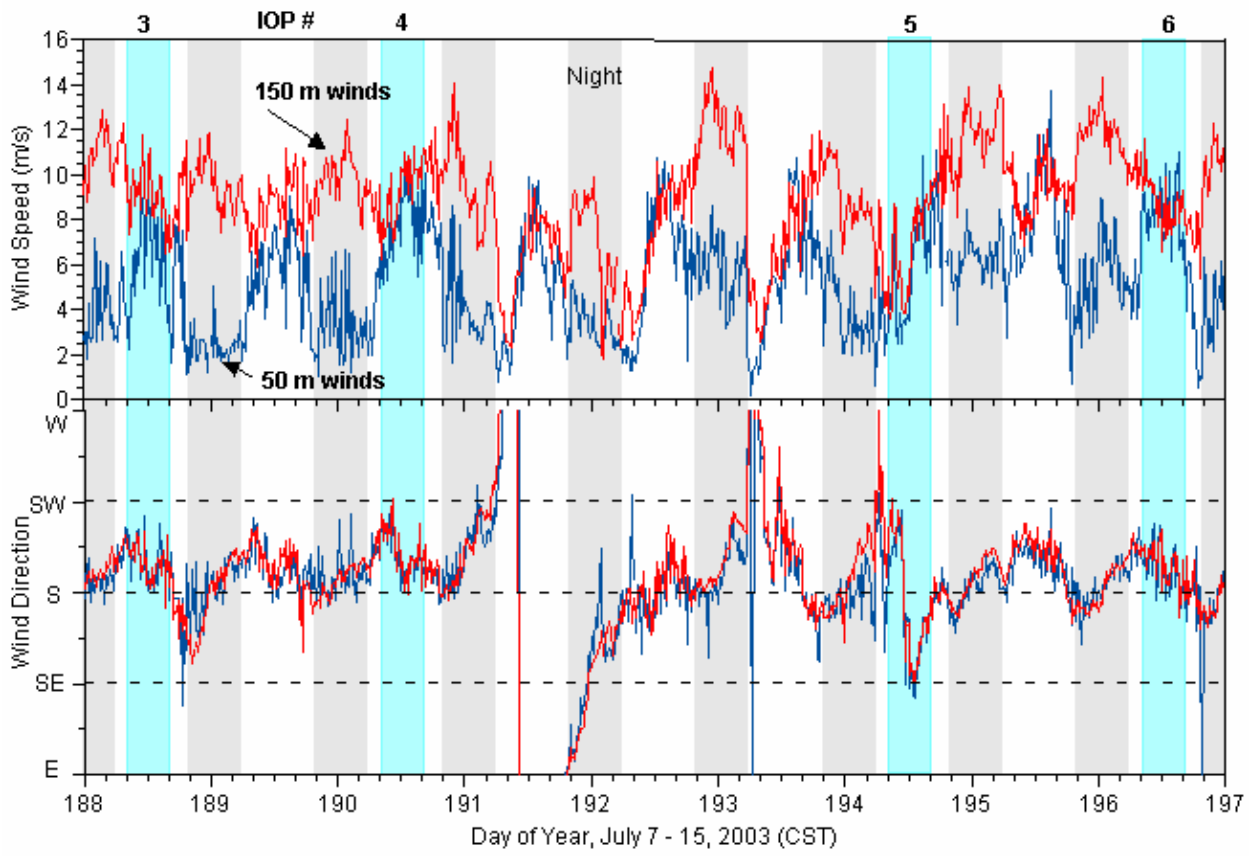

Figure 5. Fifteen minute averaged wind speed and direction at two levels (50 m and 150 m above ground) from the PNNL sodar located approximately 2 km south-southwest of downtown OKC (Wheeler Park near Shartel & SW 12th). The period shown is the nine-days from July 7 – 15, 2003 covering four of the ten intensive operation periods (IOPs). The IOP periods are shown in blue.