NOAA Technical Memorandum OAR ARL-254

JOINT URBAN 2003 (JU03) SF_6 ATMOSPHERIC TRACER FIELD TESTS

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noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Office of Oceanic and Atmospheric Research

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UNITED STATES DEPARTMENT OF COMMERCE

Carlos M. Gutierrez
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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ABSTRACT

This report summarizes the release, measurement, and analysis of the nontoxic, invisible, inert atmospheric tracer sulfur hexafluoride (SF_6) and meteorological measurements by the Air Resources Laboratory Field Research Division (ARLFRD) during the Joint Urban 2003 (JU03) Experiment. The experiment's purpose was to study atmospheric dispersion in an urban environment. JU03 was conducted during July 2003 in Oklahoma City, Oklahoma. SF_6 was released as a tracer during ten Intensive Observation Periods (IOPs). Each IOP included two or three quasi-continuous (30-min.) point releases, and three to six instantaneous puff releases. The 10 IOPs produced data for a total of 29 continuous releases (17 daytime, 12 nocturnal) and 40 puff releases (25 daytime and 15 nocturnal). SF_6 concentrations were sampled and measured as the tracer dispersed through Oklahoma City. Sampling was done using programmable integrating gas samplers (PIGS) and new Super PIGS, and quasi-instantaneous measurements were taken using fast-response trace gas analyzers (TGAs). The samplers were positioned at approximately 150 locations within Oklahoma City, which included street level, rooftop, and pedestrian tunnel locations within the central business district (CBD), and on arcs at distances of 1, 2, and 4 km from the point of tracer release. Quality control samplers were also positioned at selected stationary sampler locations. Ten van-mounted TGAs were also driven to varying locations within Oklahoma City to intercept dispersing tracer plumes. ARLFRD deployed meteorological equipment at the release site and on the Oklahoma School of Science and Mathematics campus in support of the JU03 project. This report contains ARLFRD release and tracer data summaries for each IOP, descriptions of tracer sampling equipment, information on how the data were obtained and processed, and the associated quality control procedures. Analysis of the sampler data leads to the following conclusions: (1) concentrations measured at street level often exceeded rooftop-level measurements by a factor of 3 or greater; (2) tracer dissipation is retarded by roughness elements to a greater degree at street level than at rooftop levels; (3) tracer released at street level during moderate winds rapidly disperses to rooftop levels near the release location; (4) tracer released at street level can be channeled down street canyons at angles approaching 60 to 80 degrees from the downwind direction; (5) tracer dissipation is significantly faster during the day than at night; (6) rooftop-level wind speed more strongly influences dissipation rates at night than during the day; (7) street-level turbulence measurements can be useful predictors of tracer dissipation rates; and (8) tracer accumulation and dissipation in underground pedestrian tunnels happens at time scales of at least an order of magnitude greater than those experienced in the open air. All accessible JU03 experimental data are available on the web from archives administered by the U.S. Army Dugway Proving Ground Meteorology Division. Access to the JU03 data website is through https://ju2003-dpg.dpg.army.mil.

INTRODUCTION

The U.S Department of Homeland Security (DHS) and the Defense Threat Reduction Agency (DTRA) sponsored an urban field tracer experiment in Oklahoma City during July 2003. National Oceanic and Atmospheric Administration's (NOAA) strategic plan outlines a goal to provide critical infrastructure and atmospheric dispersion expertise to homeland security. The Joint Urban 2003 (JU03) was designed to measure the dispersion of an inert atmospheric tracer (sulfur hexafluoride, SF_6) through the center of a metropolitan area. The experimental design included tracer and meteorological measurements over multiple time and distance scales, creating a data set suitable for evaluating nested urban atmospheric dispersion models. These models are integral to the DHS and DTRA national security programs which utilize emerging science and technology to counter the threat of chemical and biological weapons attacks on civilian populations. These atmospheric dispersion models are being developed, tested, and evaluated to provide users in intelligence, law enforcement, and emergency management with an integrated set of computerized modeling tools.

Oklahoma City (Fig. 1) was selected for JU03 using an extensive evaluation process. Factors that favored Oklahoma City included a substantial but consolidated core of tall buildings in its central business district (Fig. 2), relatively flat terrain and simple topography, the availability of accessible, secure, but well-exposed measurement sites, an established meso-meteorological network [the Oklahoma Mesonet (Brock et al., 1995)], availability of local technical, forecasting, and student support, cooperative local officials, and the prospect of reasonably consistent winds from the southeast through the southwest. The month of July was selected for JU03 to maximize the occurrence of steady southerly winds while minimizing the possibility of severe weather.

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

JU03 participants included investigators from many government laboratories, universities, and private companies. Principal investigators formed a Science Team and a Management Team (Table 1) to manage various aspects of JU03. A Public Affairs Team was also formed to

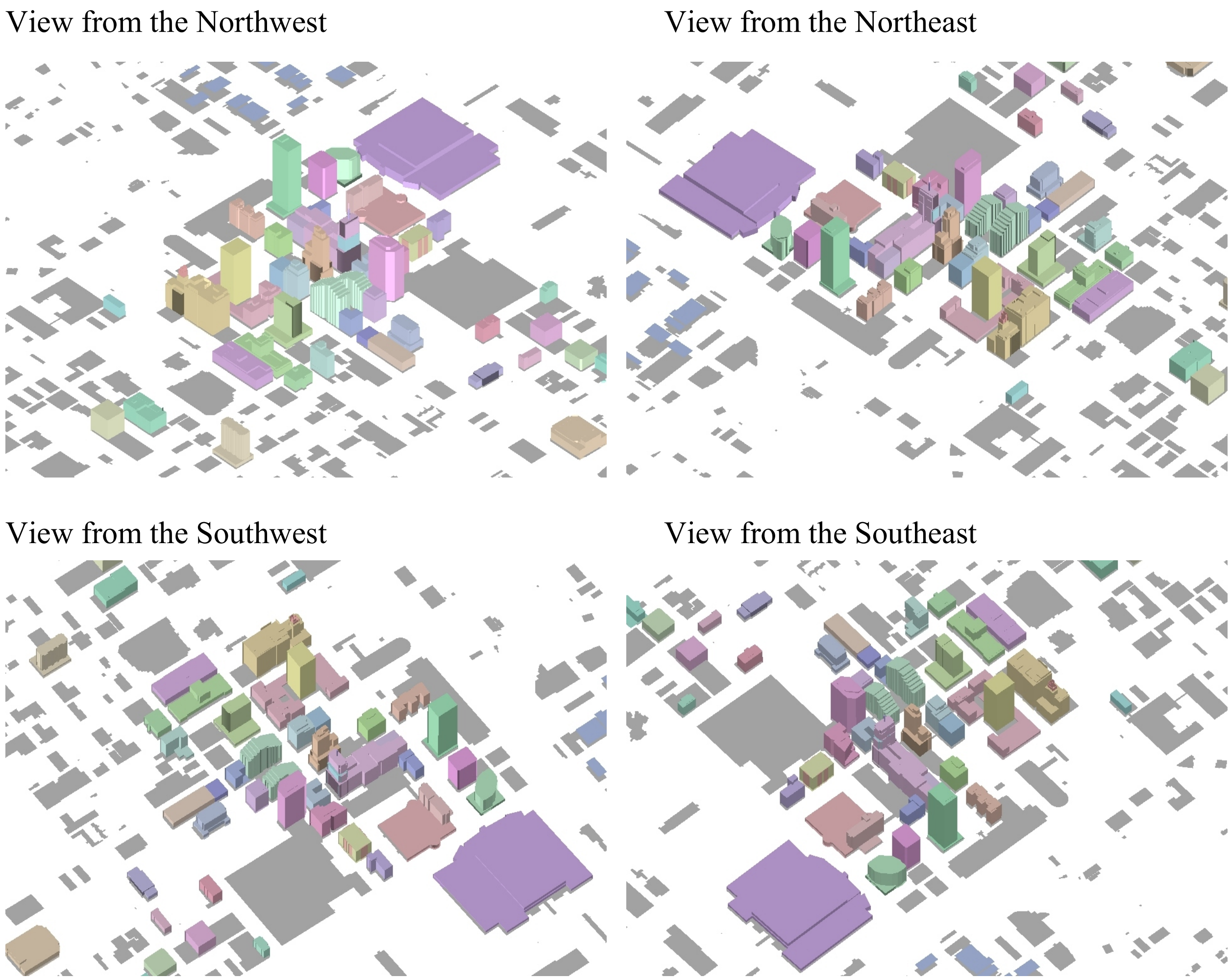

Figure 2. Three-dimensional views of the Oklahoma City CBD. Images courtesy of Mike Brown (LANL), and May Yuan (Oklahoma University).

interact with cooperating local officials and to provide information to the public. Additional international participation by the UK Defence Science and Technology Laboratory (DSTL) and the Defence Research and Development Canada (DRDC) were under the auspices of Technical Panel 9 (TP9) of the Technical Cooperation Program (TTCP) Chemical, Biological and Radiological Defense (CBRD) Group. Allwine et al. (2004) provide an overview of JU03 and a full list of participating organizations.

The primary purpose of JU03, as stated in the experimental plan (Allwine et al., 2003), was to "collect meteorological and tracer data resolving atmospheric dispersion (transport and diffusion) 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 several km from the CBD." Additional indoor tracer and flow measurements were made to investigate outdoor-indoor exchange rates and mechanisms. Specific objectives included: (1) using state-of-the-art remote sensing and in-situ meteorological instruments to

Table 1. JU03 management, public affairs, and science teams.

INVESTIGATOR	ORG	FOCUS
MANAGEMENT TEAM		
Allwine, Jerry	PNNL	Science Team Lead
Bowers, Jim	DPG	DTRA Urban Modeling Technical Expert, TP9 Chair
Burchett, Leslie [lead]	DHS	Modeling Initiative Program Manager
Ermak, Don	LLNL	DHS Modeling Initiative Lead
Hosker, Ray	ATDD	Urban Dispersion Technical Expert
Pace, John [lead]	DTRA	Urban Modeling Program Manager
PUBLIC AFFAIRS TEAM		
Abdelnour, Cheri	DTRA	Department of Defense
Harvey, Geoff	PNNL	Pacific Northwest National Laboratory
Leffler, Cerry	OCS	Oklahoma Climatological Survey
Petrovich, Michelle	DHS	Department of Homeland Security
Ritchie, Linda [lead]	DTRA	Department of Defense
SCIENCE TEAM		
Allwine, Jerry [lead]	PNNL	Urban mixed layer structure, tracer dispersion
Bach, Walter	ARO	Lidar dual-Doppler approach
Basara, Jeff	OU	Synoptic meteorology & boundary layer structure
Bowers, Jim	DPG	Canopy layer turbulence, tracer dispersion
Brown, Mike	LANL	Canopy layer turbulence, urban street canyon
Calhoun, Ron	ASU	Lidar remote sensing of winds, urban mixed layer
Cionco, Ron	ARL	Urban canopy layer and surface layer profiles, lidar
Clawson, Kirk	NOAA	Tracer dispersion
D'Amico, Francis	SBCCOM	Remote detection of tracer using helicopter
Fleming, Gregg	DOT	Tracer dispersion
Griffiths, Ian	DSTL	Urban surface layer turbulence
Grimmond, Sue	IU	Urban surface layer energy balance
Hosker, Ray [lead]	NOAA	Urban surface layer turbulence, surface energy balance
Kastner-Klein, Petra	OU	Traffic produced turbulence, urban street canyon
Leach, Marty	LLNL	Turbulence, tracer dispersion, energy balance
Pardyjak, Eric	UU	Canopy layer turbulence, urban street canyon
Sextro, Rich	LBNL	Indoor dispersion and outdoor-indoor infiltration
Stockham, Leo	DTRA	Overall design
Smith, Vern	ITT	Urban canopy layer turbulence, tracer dispersion
Yee, Eugene	DRDC-S	Coordination of all turbulence measurements

continuously measure wind and turbulence of the atmosphere from the ground through several kilometers above the ground; (2) collecting flow and tracer concentration data at various distances from the release point; (3) investigating tracer exchange through a building envelope; (4) creating a quality controlled and consistency-checked data archive suitable for modeling and research use. This report documents SF_6 tracer releases and measurements made by the NOAA Air Resources Laboratory Field Research Division (ARLFRD). It provides information about the tracer experimental design, the tracer release system, the ARLFRD time-integrated bag samplers and mobile real-time tracer detectors, the ARLFRD deployed meteorological instruments, and summaries of the tracer concentrations obtained during each intensive operating period (IOP). The report also documents ARLFRD analysis and quality control (QC) methodology, data archival, tracer measurement results, and conclusions.

This report includes samples, summaries, and analyses designed to help the user select data sets of interest. An accompanying CD also includes plots of sampler results. Available JU03 data are stored at the U.S. Army Dugway Proving Ground (DPG) and are available on the Joint Urban 2003 secure database website (https://ju2003-dpg.dpg.army.mil or 140.196.88.35). All ARLFRD JU03 data were acquired with respect to a common time base, collected in Central Daylight Time (CDT), with conversion to Coordinated Universal Time (UTC = CDT +5 hrs.) for archival. Data files are accompanied by a readme text file that describes the data and their formats. A username and password are required to establish an account to access the DPG data archive.

THE EXPERIMENTAL PLAN

The JU03 experimental plan (Allwine et al., 2003) called for tracer releases from one of several downtown locations in Oklahoma City, with samplers stationed in a dense downtown array and in arcs downwind of the selected release position. The plan was executed in 10 IOPs, each of approximately 8 hour’s duration that included a series of puff releases and quasi-continuous (30 min. duration) point source releases. The releases were spaced in time to permit tracer dissipation from one release before the beginning of a subsequent release. IOPs were scheduled for both daytime (0900-1700 CDT) and nighttime (2300-0700 or 2100-0400 CDT) periods. Four of the ten IOPs also included indoor tracer dispersion studies. The indoor studies were conducted by Lawrence Berkeley National Laboratory and were reported by Thatcher et al., (2005).

Predominant surface winds for Oklahoma City during July are from a southerly direction (SSW through SE) both day and night with speeds of 5-7 m s^{-1}. Consequently, provision was made for tracer releases from several different locations immediately south of the central business district (CBD). The release system was mounted inside a U-Haul truck for ease of positioning at a selected release site. Likewise, samplers were placed along approximately 120º segments of the sampling arcs depending on the forecast of SSW or SE winds.

Tracer samplers were positioned within the CBD and along sampling arc segments located at distances of 1, 2, and 4 km from the release points. Samplers within the CBD were placed at street level, below the streets in pedestrian tunnels, or on building roofs. Some street level and rooftop samplers were programmed at 5-minute sampling intervals for use in tracer dissipation analysis. Other samplers were programmed for 30-min. sampling. Most of the street-level samplers within the CBD were placed on street corners, however, 3 samplers were located at mid-block sites, 10 samplers on building rooftops (to measure the vertical profile of the plume), and 4 samplers in the pedestrian tunnel located beneath the CBD. The ARLFRD tracer study design was constrained by the availability of bag samplers. Available samplers included 100 existing tracer samplers (PIGS), each holding a cartridge containing 12 sampling bags operating on fixed (15- or 30-min.) sampling times, and 50 new tracer samplers (Super-PIGS) with 12 sampler bags and variable sampling times.

Quality assurance was integral to the experimental plan. Quality control procedures included collecting and analyzing duplicate, blank, and control samplers. Duplicate samplers were samplers placed at the same location as the primary sampler and programmed with the identical start and stop times. Blank samplers were special samplers programmed and placed in like manner as the duplicate samplers along with primary samplers. These samplers sequentially pumped a nitrogen sample from a series of 12 supply bags into 12 sample bags. Control samplers were similar to blank samplers except that the supply bags contained various known concentrations of SF_6. Fifteen duplicate samplers, 15 blank samplers, and 15 control samplers were randomly placed on the sampling arcs and in the downtown street-corner grid array to comply with the procedure to have 10% duplicate, blank, and control samplers. Appendix A discusses sampler quality control (QC), and Table B-7 contains locations of these QC samplers. No QC samplers were placed on building tops or in the pedestrian tunnel.

Execution of the experimental plan required the on-site analysis of PIGS and Super PIGS sampler bags. This was done at a tracer analysis facility (TAF) set up at the Oklahoma University Health Sciences Center (801 NE 13th Street) located northeast of the CBD. Activities at the TAF included measuring tracer concentrations in the sampler bags, cleaning the bags, and returning the samplers for use on a subsequent IOP. This multi-step process included stringent quality control procedures governed by a detailed quality assurance protocol. The ability of the TAF operators to quickly analyze and clean the sampler bags on site meant that the sampler cartridges could be re-cycled for use on subsequent IOPs.

An additional tracer detection capability was provided by 10 fast-response Electron Capture Detector (ECD) SF_6 analyzers (TGA-4000) staged in vans. The fast-response (~1 Hz) analyzers are important for measuring within-plume SF_6 tracer concentration variations, and for tracking the leading and trailing edges of the tracer cloud as it moved through the study domain. Vans housing the TGA-4000 fast-response samplers were also equipped with global positioning systems (GPS). Time and location coordinates were logged by the data acquisition system along with the measured tracer concentrations. Operator-determined position locations were also manually recorded.

In support of the JU03 project, ARLFRD deployed meteorological instrumentation at two locations across downtown Oklahoma City. A sonic anemometer was set up during each of the IOPs to characterize the winds and atmospheric turbulence at the release site. A phased array Doppler sodar was also set up at the Oklahoma University School of Science and Mathematics campus to provide boundary layer wind speed and direction profile measurements. Except on a few short occasions, the sodar was set up and remained in continuous operation through the entire JU03 testing period. Together the data collected from the sonic anemometer and sodar were able to help meet the objectives stated in the JU03 experimental plan (Allwine et al., 2003).

THE SF_6 TRACER RELEASE SYSTEM

Releases of SF_6 were either from a point source or a puff source. The two systems are described in detail in the following sections. The point source release system allowed SF_6 to be continuously released into the atmosphere over a 30-min. period. Conversely, the puff release (a meteorological balloon filled with SF_6) was designed to instantaneously eject all of the SF_6 into the atmosphere. Tables 2 and 3 list the type of dissemination, i.e., point or puff source, for the various IOPs together with the beginning and ending dissemination periods for the daytime and nocturnal releases respectively.

Continuous Point Source Release System

The continuous point source SF_6 release mechanism was custom-built for the JU03 program by NOAA at the ARLFRD office in Idaho Falls, ID. The system was placed inside a U-Haul rental truck (Fig. 3) so that it could be quickly and easily deployed to and removed from the release sites. The complete release system (Fig. 4), other than the dissemination device, was entirely self-contained in the U-Haul truck and only required access to 115 VAC 2000 watt generator power.

Figure 3. UHAUL truck containing the entire SF_6 release system except for the dissemination device.

The heart of the SF_6 release system was a computerized mass flow controller. The system included both digital and analog output as well as computer and manual controls. The mass flow controller monitored the gaseous tracer leaving a cylinder containing liquid SF_6 mounted on electronic scales. Flow rate from the mass flow controller and cylinder weight change were continuously monitored and recorded with a data logger. The total quantity of SF_6 released for each test was determined using the beginning and ending weight of the SF_6 cylinder. A schematic of the release mechanism is shown in Fig. 5.


Figure 4. The SF_6 release mechanism housed on a ledge inside the U-HAUL.

During a point source release the SF_6 flowed from the storage cylinder through the mass flow controller, past the visible flow meter and into a flexible 13 mm diameter Tygon® tube connected to the dissemination device. A heater was used to maintain constant pressure in the SF_6 cylinder and to assist with the vaporization of the liquid SF_6. The

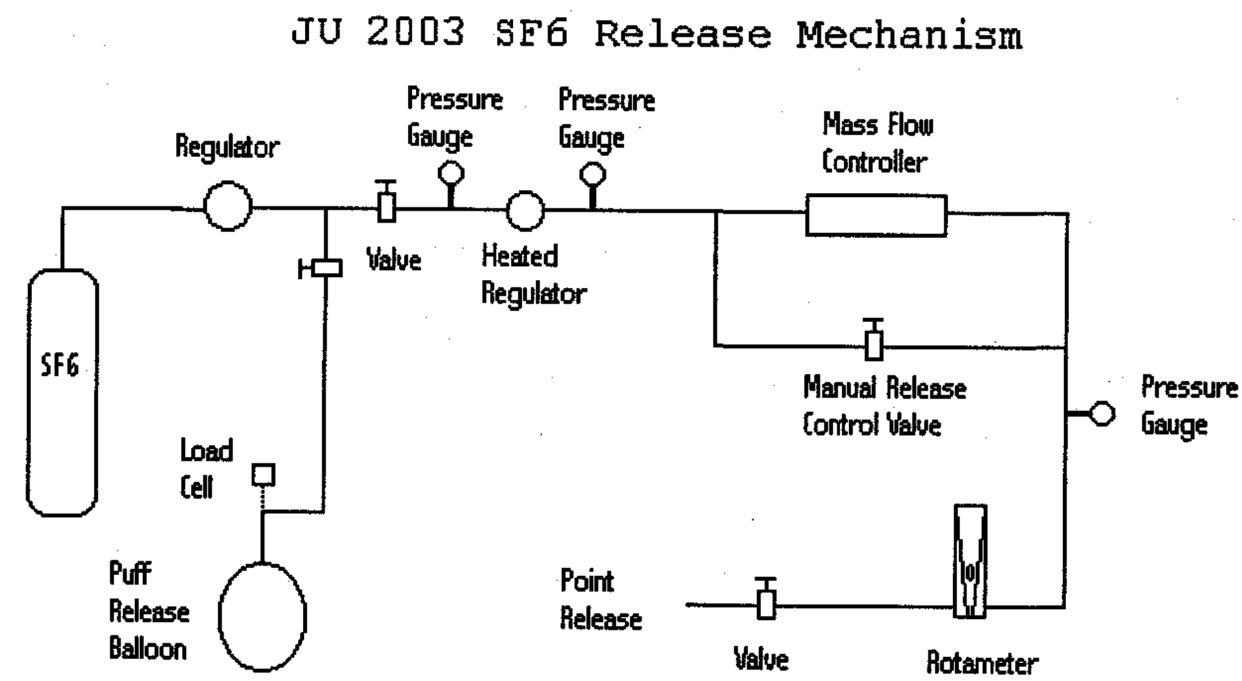

Figure 5. Schematic for both a puff and continuous point source SF_6 release mechanism.

system was designed to release SF_6 at a rate of 2 to 5 g s^{-1}, but this rate could be adjusted within the range of 0.1 to 10 g s^{-1}. The dissemination device was a garden hose 4.5 m in length. One end of the hose was connected to a valve at the end of the release mechanism while the other end, the point of dissemination (Fig. 6), was mounted onto a tripod outside the U-Haul truck about 2 meters above ground level (AGL).

Figure 6. Point source dissemination from a tripod-mounted garden hose at 2 meters AGL. Sonic anemometer (top) and temp/ RH sensor (inside gray cylinder) is also attached to the tripod.

Puff Release System

Puffs were released by bursting SF_6-filled meteorological balloons. The filling device was a ceiling-mounted load cell in the U-Haul truck that provided measurements of balloon weight before and after it was filled. SF_6 flowed from a storage cylinder through a flexible 13 mm diameter Tygon® tube which was attached to a polyvinyl chloride (PVC) pipe glued in the shape of a T. This T-shaped PVC pipe was placed over a 5.08 cm section of 1.91 cm PVC pipe and placed inside the opening of a meteorological weather balloon (Fig. 7). The balloon was then suspended from the ceiling-mounted load cell. The filling procedure was complete when the weight of the filled balloon, corrected for its buoyancy in air minus the beginning weight of the empty balloon, equaled the desired amount of SF_6 to be released. Puff dissemination was achieved by simply taking the SF_6-filled balloon outside of the U-Haul truck and bursting it.

Figure 7. A meteorological balloon being filled with SF_6 and weighed inside the U-haul in preparation for a puff release.

Release Locations and Summary

The SF_6 releases for each IOP took place in one of three locations: (1) In front of the Westin Hotel (or Mid-America Tower); (2) Near the Myriad Botanical Gardens; (3) Park Avenue midway between Broadway and Robinson Avenues. The desired location in front of The Westin Hotel was occupied for IOP 1. Therefore, the IOP 1 releases took place on the east side of Broadway across from the Westin Hotel in front of the Mid-America Tower at parking meter #2047 (35.4675167˚ N, 97.5144˚ W). During IOP 2 and IOP 8, the release was moved to its desired location near the Westin Hotel on the west side of Broadway and 2.4 meters north of parking meter #1461 (35.467333˚ N, 97.5146000˚ W). For IOPs 3 through 7, the releases took place near the Myriad Botanical Gardens at the SW corner of the intersection of Ronald Norick Boulevard and Sheridan next to the 30 mph sign (35.466167˚ N, 97.5165˚ W). For IOP 9 and IOP 10, the release took place on the south side of the Park Avenue, 1.8 meters north of the large manhole cover and 2.7 meters west of the center meteorological tower (35.4687167˚ N, 97.515567˚ W).

The SF_6 releases were designed to provide multiple separate disseminations during a given IOP. For the first IOP, which was a trial test of the SF_6 release and real-time analyzer detection systems, 6 puffs and 2 continuous releases were conducted. Each succeeding tracer IOP consisted of 3 or 4 puffs and 3 continuous SF_6 releases. The puffs were initially separated by 10 minutes, and finally by 20 minutes, while the point releases were separated by one and one-half hours. These intervals were selected to permit transport of the SF_6 out of the area and a return to the background concentration level between releases. Tracer dissemination summaries are given in Tables 2 and 3. Note that all puffs are treated as a single "release" in the archived data.

Meteorological conditions mandated lower target release rates for both the point release and puff release after IOPs 3 and 4, respectively. Target release rates were originally set at either 5 g s^{-1} for a point release or 1000 grams for a puff release. However, fairly weak winds allowed large concentrations of SF_6 to accumulate near the closest real-time analyzers. In some cases these high concentrations caused over-ranging (railing) of the TGAs. Also, with weak winds the SF_6 concentration sometimes did not recover to background levels prior to the start of the next release. After IOP 3, point release rates were lowered to 2-3 g s^{-1} in an attempt to minimize over-ranging the closest detectors. Puff releases were also lowered to 300-500 grams following IOP 4 for the same reason. Additional release information is available in Appendix D and in the release readme file that accompanies the archived data.

Three special SF_6 disseminations, which did not include FRD sampler measurements, were conducted at 1200, 1230, and 1300 CDT on Tuesday, 15 July 2003. Continuous 20-min. releases of 8.1 g s^{-1}, 4.9 g s^{-1}, and 3.1 g s^{-1} were made from parking meter # 0347 between Hudson and Walker on 4th Street (Fig. 8). More specifically, the release took place at 35º 28.325' N, 97º 31.200' W. These disseminations targeted Washington State University's vertical profiler samplers hung in a vertical array on a cable suspended from a crane located near the corner of 8th Street and Robinson Avenue. A mobile sampler was also mounted on a military helicopter that flew transects across the dispersing plume.

Figure 8. Location of the special release.

Table 2. Summary of SF_6 tracer releases, including location, release date and time, type of release (continuous or puff), target release rate, actual average release rate from the mass flow meter, and the total mass of SF_6 released for each daytime IOP.

IOP	Location	Tracer Start Date	Time (CDT)	Tracer End Date	Time (CDT)	Release Type	Release Target	Actual Release Rate (g s^{-1})	Total Amount Released (g)
1	The Westin	29-Jun	900			Puff	1000		1000
		29-Jun	910			Puff	1000		1003
		29-Jun	920			Puff	1000		1000
		29-Jun	930			Puff	1000		1000
		29-Jun	945			Puff	500		500
		29-Jun	1000			Puff	500		508
		29-Jun	1100	29-Jun	1130	Point	5	4.86±0.006	8754
		29-Jun	1300	29-Jun	1330	Point	5	4.81±0.010	8664
2	The Westin	2-Jul	900			Puff	1000		1000
		2-Jul	920			Puff	1000		1010
		2-Jul	940			Puff	1000		1000
		2-Jul	1000			Puff	1000		1041
		2-Jul	1100	2-Jul	1130	Point	5	5.01±0.083	9026
		2-Jul	1300	2-Jul	1330	Point	5	4.96±0.032	8936
		2-Jul	1500	2-Jul	1530	Point	5	4.99±0.009	8981
3	Myriad Botanical Gardens	7-Jul	900			Puff	1000		1000
		7-Jul	920			Puff	1000		1005
		7-Jul	940			Puff	1000		1000
		7-Jul	1000			Puff	1000		1004
		7-Jul	1100	7-Jul	1130	Point	5	4.94±0.004	8890
		7-Jul	1300	7-Jul	1330	Point	3	3.02±0.004	5443
		7-Jul	1500	7-Jul	1530	Point	3	3.02±0.047	5443
4	Myriad Botanical Gardens	9-Jul	900			Puff	1000		996
		9-Jul	920			Puff	1000		1002
		9-Jul	940			Puff	1000		504
		9-Jul	1100	9-Jul	1130	Point	3	3.13±0.006	5625
		9-Jul	1300	9-Jul	1330	Point	3	3.00±0.063	5398
		9-Jul	1500	9-Jul	1530	Point	3	3.02±0.003	5443
5	Myriad Botanical Gardens	13-Jul	900	13-Jul	930	Point	2	2.22±0.006	3992
		13-Jul	1100	13-Jul	1130	Point	3	3.04±0.061	5466
		13-Jul	1300	13-Jul	1330	Point	3	3.09±0.005	5557
		13-Jul	1500			Puff	500		499
		13-Jul	1520			Puff	500		500
		13-Jul	1540			Puff	500		500
		13-Jul	1600			Puff	500		500
6	Myriad Botanical Gardens	16-Jul	900	16-Jul	930	Point	3	3.02±0.004	5443
		16-Jul	1100	16-Jul	1130	Point	3	3.18±0.006	5715
		16-Jul	1300	16-Jul	1330	Point	3	2.97±0.006	5352
		16-Jul	1500			Puff	500		498
		16-Jul	1520			Puff	500		499
		16-Jul	1540			Puff	500		510
		16-Jul	1600			Puff	500		500

Table 3. Summary of SF_6 tracer releases, including location, release date and time, type of release (continuous or puff), target release rate, actual average release rate from the mass flow meter, and the total mass of SF_6 released for each nocturnal IOP.

IOP	Location	Tracer Start Date	Time (CDT)	Tracer End Date	Time (CDT)	Release Type	Release Target	Actual Release Rate ($g\ s^{-1}$)	Total Amount Released (g)
7	Myriad	18-Jul	2300	18-Jul	2330	Point	3	3.00±0.007	5398
	Bottanical	19-Jul	100	19-Jul	130	Point	2	1.99±0.081	3583
	Gardens	19-Jul	300	19-Jul	330	Point	2	2.02±0.004	3629
		19-Jul	500			Puff	300		303
		19-Jul	520			Puff	300		300
		19-Jul	540			Puff	300		304
		19-Jul	600			Puff	300		298
8	The	24-Jul	2300	24-Jul	2330	Point	3	3.07±0.014	5534
	Westin	25-Jul	100	25-Jul	130	Point	3	3.05±0.004	5488
		25-Jul	300	25-Jul	330	Point	3	2.97±0.003	5352
		25-Jul	500			Puff	500		500
		25-Jul	520			Puff	500		500
		25-Jul	540			Puff	300		300
		25-Jul	600			Puff	300		305
9	Park Ave.	26-Jul	2300	26-Jul	2330	Point	2	1.99±0.004	3583
		27-Jul	100	27-Jul	130	Point	2	2.02±0.003	5488
		27-Jul	300	27-Jul	330	Point	2	2.09±0.004	3765
		27-Jul	500			Puff	300		300
		27-Jul	520			Puff	300		300
		27-Jul	540			Puff	300		300
		27-Jul	600			Puff	300		300
10	Park Ave.	28-Jul	2100	28-Jul	2130	Point	2	2.24±0.004	4037
		28-Jul	2300	28-Jul	2330	Point	2	1.94±0.004	3493
		29-Jul	100	29-Jul	130	Point	2	2.19±0.003	3946
		29-Jul	300			Puff	300		300
		29-Jul	320			Puff	300		300
		29-Jul	340			Puff	300		300

TIME INTEGRATING TRACER SAMPLERS

Programmable Integrating Samplers

Stationary time-integrating sampling of SF_6 for the JU03 project was performed using programmable integrating gas sampler (PIGS) and enhanced PIGS called Super PIGS. These samplers acquired time-sequenced air samples in bags, which were subsequently analyzed for the concentration of tracer gas. The PIGS and Super PIGS collected 12 samples by sequentially pumping air into each of 12 individual Tedlar® bags. A good time-dependent record of the tracer plume concentration was determined for each sampling period by placing a relatively large number of PIGS and Super PIGS on arcs or on a grid across the experimental area.

A PIGS consists of a weatherized waxed cardboard sampler box measuring 61cm x 41cm x 33 cm (Fig. 9) and a cardboard sampler cartridge (Fig. 10). The cartridge contains 12 Tedlar bags. The sampler box housed 12 microprocessor-controlled air pumps designed to sequentially fill the cartridge bags at a pre-programmed fill rate. Prior to deployment, the cartridge was placed into each sampler box (Fig. 11) and connected by latex rubber tubing to the sampler pumps. An identical fill rate was used for each bag, producing a set of 12 time-sequenced bag samples over the total sampling period. With its cover in place (Fig. 12), each sampler box had a total mass of 4.08 kilograms and was powered by a single D-cell battery (Fig. 11). The PIGS have been extensively tested and used on field experiments for many years.

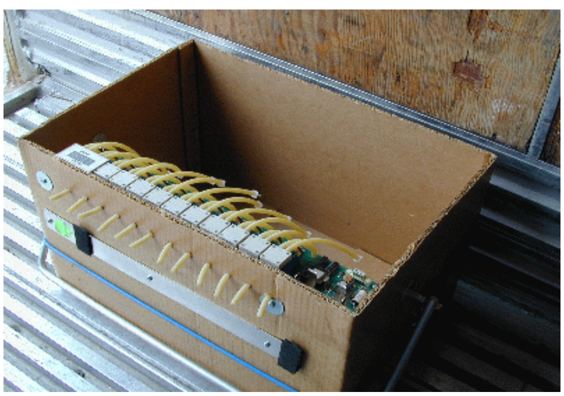

Figure 9. PIGS sampler box with the cartridge removed.

Figure 10. PIGS cartridge containing 12 Tedlar bags.

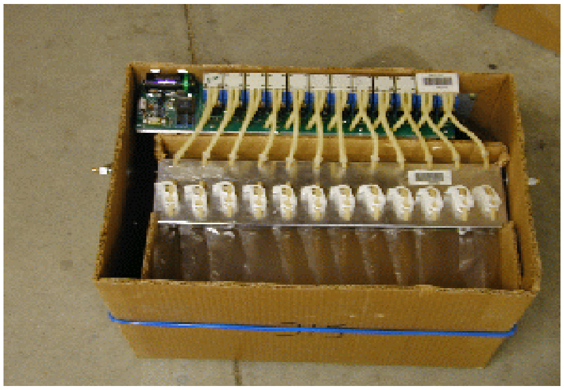

Figure 11. PIGS with sampler cartridge and D-cell battery (upper left) installed.

Figure 12. PIGS with the cover on and secured with a bungee cord.

In contrast, the Super PIGS is a newly designed sampler that had not been used in the field prior to JU03. They were built to have many more capabilities than the standard PIGS, including the ability to program differing fill rates for each bag and to pause sampling between bags. The Super PIGS module was a metal 6.5 cm x 7.5 cm x 35 cm cartridge (Fig. 13) comprised of 12 microprocessor-controlled valves and an air pump capable of filling 12 Tedlar® bags using different programmed fill rates for each bag. It also features a sample metering system designed to provide a more constant volume in each sample bag. This increased capability means that the samplers are more complicated and require more power (3 D-cell batteries) than the original PIGS. The Super PIGS assembly consists of a cartridge containing 12 Tedlar bags in a grey weatherproof plastic container measuring 41 cm x 30 cm x 33 cm (Fig. 14) and a metal sampler module, that sits inside the cartridge (Fig. 15). The complete Super PIGS assembly with sampler cartridge module, box, and attached lid (Fig. 16) has a total mass of 4.5 kilograms.

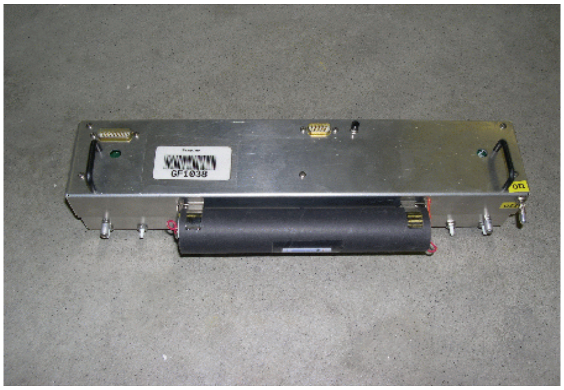

Figure 13. Super PIGS sampler module with black cylinder containing the 3 D-cell batteries.

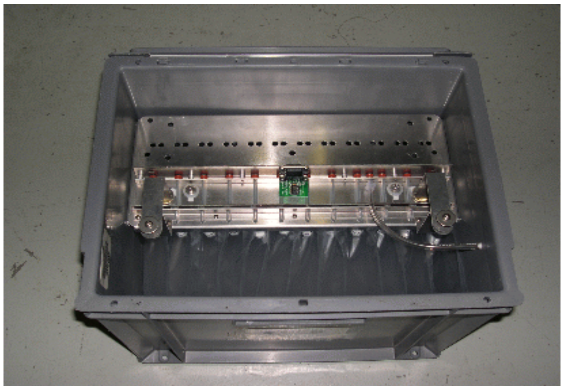

Figure 14. Super PIGS cartridge with sampler module removed.

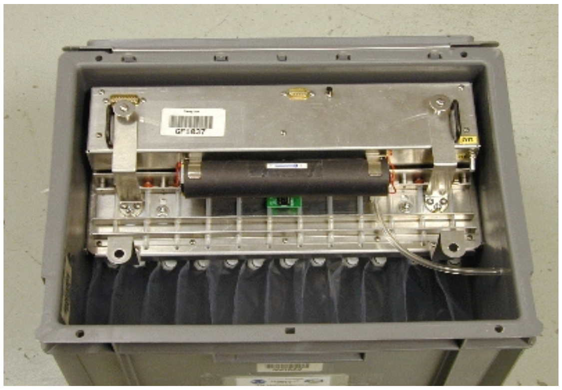

Figure 15. Super PIGS installed in a cartridge.

Figure 16. Super PIGS cartridge with the cover closed.

Unfortunately, the increased complexity of the Super PIGS also meant increased opportunities for failures. Since these were new instruments when deployed for JU03, some initial problems were expected. In spite of the difficulties, the Super PIGS did provide important experimental data. The majority of them functioned properly, though not perfectly. While the analyzed Super PIGS data were found to be consistent with data obtained from nearby PIGS, the Super PIGS field blanks and controls exhibited problems that were not consistent with normal field samples or the duplicate samples. This discrepancy is explained in Appendix A.

Sampler Handling

PIGS and Super PIGS were placed at pre-selected sites prior to the start of each IOP, and were programmed to collect samples over the period of the IOP. The samplers were hung approximately 3 m above ground level (AGL) at pre-selected sites using special hangers as seen in Fig. 17, on top of roofs as in Fig. 18, or attached to a permanent fixture for tunnel locations as in Fig. 19. A small hand-held computer called a Timewand (Fig. 20) was used during PIGS deployment to record the location number, sampler number and cartridge number. The Timewand then downloaded the start time and sample time per bag into the memory of each PIGS. The downloader used for the Super PIGS (Fig. 21) was slightly different but performed

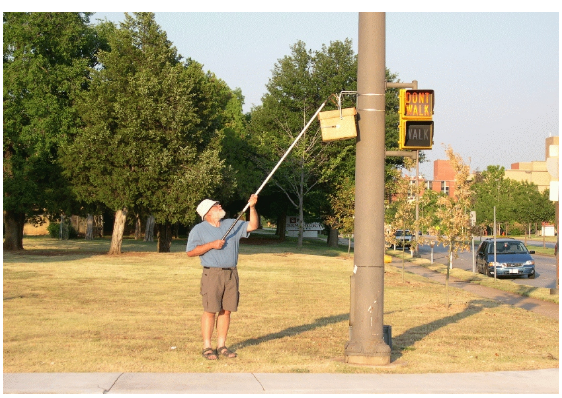

Figure 17. Sampler being hung on a utility pole.

Figure 18. Sampler positioned on the rooftop of the East Kerr Tower.

essentially the same functions as the Timewand. When all the PIGS and Super PIGS were deployed, the Timewands and downloaders were taken back to the tracer analysis facility (TAF) and the data they contained were uploaded to the history files maintained on an ARLFRD-designed automated tracer gas analysis system (ATGAS) computer. After the end of each IOP, the cartridges were taken to the TAF for analysis using the ATGAS. A fresh set of sample cartridges were then loaded into the PIGS and Super PIGS boxes in preparation for the next test while the analysis of the previously-removed sampler cartridges took place.

Figure 19. Sampler attached to a railing in the pedestrian tunnel.

Attached to both PIGS and Super PIGS samplers and cartridges were unique bar coded serial numbers. These labels, along with location numbers placed at each sampling location, were used to automatically generate a chain of custody record for each sample. Prior to the start of the project, each sampling location was identified and tagged with a location number. For PIGS locations, this was a weatherproof barcode label. A read-only memory chip enclosed in a small plastic box was used at each Super PIGS location. Once the sampling locations were identified, the labels and memory chips were semi-permanently attached and the longitude and latitude for each location from a GPS unit was recorded on a laptop computer. This information was then uploaded to the ATGAS computer and saved in the history files.

Figure 20. PIGS Timewand.

Figure 21. Super PIGS downloader.

Sampler Cartridge Analysis

Once sampling for an IOP was complete, the cartridges were collected and taken to the TAF for analysis. The TAF included four ATGASs (Figs. 22 and 23). Each ATGAS is a gas chromatograph (GC) connected to an auto-sampler module and a small black handheld controlling computer seen sitting on top of the ATGASs in Figs. 22 and 23. All data were then downloaded to one PC (Fig. 23) that simultaneously monitored the four ATGASs. Analysis of

Figure 22. Two of the ATGAS in operation analyzing two PIGS cartridges.

Figure 23. The PC and an ATGAS analyzing a Super PIGS cartridge.

the PIGS and Super PIGS cartridges was performed by the ATGAS system. When a cartridge was placed on the ATGAS for analysis, its cartridge serial number was scanned into the ATGAS. The history files were automatically searched for the record of its download made by the downloader or Timewand when it was placed in the field. Once the download record was found, the location number, the sampling start time, the sample time per bag, project identification, IOP number, etc. were included with the analysis result without any hand entry of the information. The history files were also searched to identify the sampling location type (field sample or quality control sample) and its latitude and longitude. Thus the process of operating the samplers provided a computer-generated chain of custody of each sample as well as automatically associating each sample with a sampling time and location. This process minimized the possibility of errors caused by mistakes in manually recording, copying or entering of location information.

The GC for each ATGAS included an oven maintained at 65˚ C that housed two Supelco 60/80 Molecular Sieve-5A columns (5' x 1/4" and 2' x 1/4"), a 10-port sample valve, and a sample loop. Two columns (pre-column and main column) were used to reduce analysis time and to vent interferents, i.e. oxygen, that can damage the columns and detector. After the SF_6 sample has been injected onto and eluted by the first (2 foot) pre-column (Fig. 24), the gas flow was switched to back-flush this pre-column while the sample loop was filled with the next sample (Fig. 25). The SF_6 continued on to the main (5 foot) column where further separation occurred and then passed to the detector (Fig. 24). Detection of SF_6 was accomplished using a Valco Instrument Co., Inc., Model 140BN electron capture detector (ECD) containing 5 millicuries of Ni-63. The ECD operating temperature was kept at 170º C. The ECDs and columns were protected by a Supelco High Capacity Gas Purifier tube heated inside an oven to remove oxygen, water, carbon monoxide and carbon dioxide as well as a Supelcarb HC hydrocarbon trap to remove organic impurities. Ultra high purity (UHP) nitrogen served as the carrier gas and was also used as the valve actuator. Concentration ranges from 2 parts per trillion by volume (pptv) to about 200,000 pptv were analyzed using this methodology.

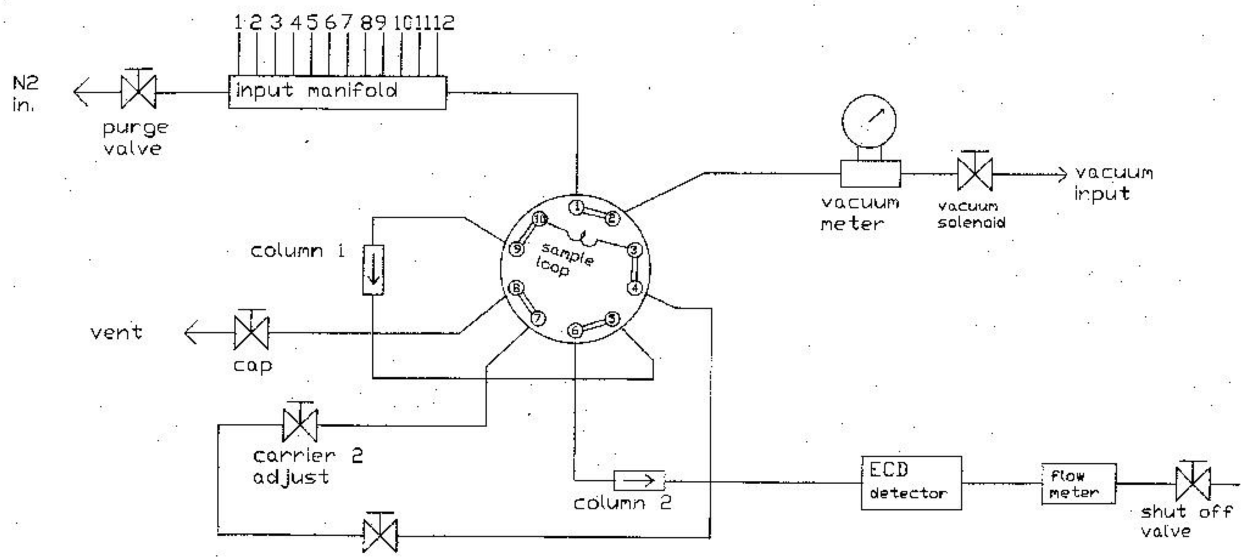

Figure 24. Schematic of injection to column 1 (pre-column) and on to column 2 (main column).

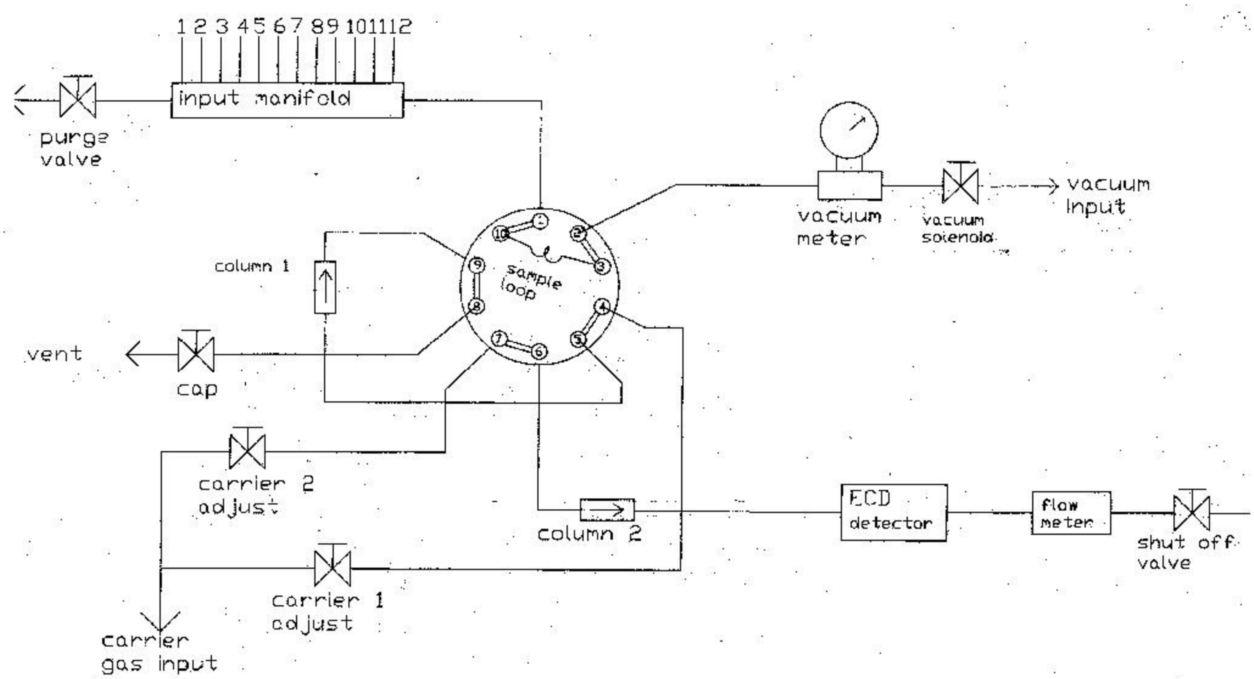

Figure 25. Schematic of sample loop fill and column 1 (pre-column) back-flush position.

Four new Automated Tracer Gas Analysis Systems (ATGAS) were built prior to field deployment. All ATGASs functioned almost flawlessly during the laboratory analysis of the cartridges. One ATGAS needed a column replacement due to a timing error for the back flush of the oxygen peak. This error was corrected about halfway through the project and the instrument exhibited no additional problems. Another ATGAS had intermittent baseline noise at certain voltage outputs. The problem was not fixed in the field due to time constraints, but the ATGAS was still fully functional for lower concentration levels where most of the sample concentrations fell. No other ATGAS instrument problems occurred.

The ATGAS computer software (Carter, 2003) was developed in-house and is used to analyze trace gases on the ATGAS. Enhancements were made to the ATGAS software for this project to incorporate specific QC protocols and to increase efficiency. The software incorporates a history file system that records all operations done on an ATGAS. The history files are records of all events involving the PIGS, Super PIGS, and cartridges, including the sampler start record, analysis record, cartridge cleaning record, location number, cartridge check record and cartridge pick-up record. The combined history file provides an invaluable source of information in the event of a discrepancy or a question about the data. All chromatograms are also stored in the database together with the resulting calculated concentrations. This provided the capability to review the raw chromatograms at a later date if needed.

Quality Assurance/Quality Control

Laboratory quality control procedures consisted of the following 29 steps that are described in detail in Appendix A:

1. Pre-project maintenance of PIGS.
2. Re-tubing of all PIGS cartridges.
3. Re-bagging of all PIGS cartridges.
4. Testing of all sample bags.
5. Pre-project analysis of PIGS and Super PIGS cartridges.
6. Development of analysis protocols for the expected sample concentration ranges.
7. Pre-project calculation of Instrument Limit of Detection (ILOD) and Instrument Limit of Quantitation (ILOQ).
8. Pre-project estimation of Method Limit of Detection (MLOD) and Method Limit of Quantitation (MLOQ).
9. ILOD and ILOQ re-determination after field deployment and prior to project initiation.
10. Re-analysis of 17% of cartridges used in previous IOP.
11. Sampler Servicing Procedure and handwritten Sampler Servicing Records.
12. Chain of custody procedures.
13. Sample check-in procedures.
14. Daily calibration of ATGAS.
15. Initial ATGAS Calibration Verification (ICV).
16. Continuing ATGAS Calibration Verification (CCV).
17. Atmospheric background checks of SF_6 at the tracer analysis facility (TAF).
18. Analysis of laboratory (instrument) blanks.
19. Analysis of laboratory duplicates.
20. Analysis of laboratory controls.
21. Analysis of field blanks.

22. Analysis of field duplicates.
23. Analysis of field controls.
24. Software quality control checks.
25. Data verification.
26. Post project determination of MLOD and MLOQ.
27. Method verification.
28. Data handling.
29. Holding time studies.

Explanations of the method limit of detection (MLOD) and the method limit of quantitation (MLOQ) along with the quality objectives and project statistics are included here to provide a summary of data and project quality.

Method Limit of Detection (MLOD)/Method Limit of Quantitation (MLOQ)

All PIGS and Super PIGS data are flagged according to the MLOD and MLOQ calculated from the analysis results of low-level field controls. By doing this, the method variability is fully accounted for by using results generated by samples that have been subjected to the rigors of field sampling. The MLOD is defined as the lowest concentration that can be determined to be statistically different from zero and also upon the method's ability to differentiate a low-level concentration standard from instrument and method noise. It was calculated as three times the standard deviation of repeated analyses of the low level standard. The MLOQ is the method's limit of quantitation and is defined as the lowest concentration that can be determined within 30% of the actual concentration. The MLOQ was calculated as ten times the standard deviation of the same low level standard used for calculating MLOD. Since using different concentrations will yield different MLODs and MLOQs, the following guidance was used by the analyst to make the optimum choice:

The lowest concentration standard should be chosen to meet as many of the following criteria as possible:

- Has a relative standard deviation (RSD) (the standard deviation divided by the mean multiplied by 100) of less than 15%.

- Has a signal to noise ratio (the mean divided by the standard deviation) between 3 and 10 (a higher value does not invalidate the result; rather it indicates that a lower concentration standard should be used).

- Has a percent recovery (analyzed value divided by the certified value multiplied by 100) between 90% and 110%.

The estimated MLOD and MLOQ results were calculated for each IOP and the flags for that IOP were set after each IOPs completion to give an indication of method performance and an estimation of the lowest field concentration level that could be determined with some degree of certainty. The MLOD and MLOQ for the PIGS were determined to be 1 pptv and 4 pptv respectively. The MLOD and MLOQ for the Super PIGS were determined to be 33 pptv and 111 pptv respectively. Due to time constraints between IOPs, each result could not be reviewed closely or samples re-analyzed. After completion of the project, the controls were graphed and scrutinized to determine if additional flags should be added to the data, and the final MLOD and MLOQ were calculated based upon the above criteria. Instrument and method precision were checked by the use of lab and field duplicates respectively. The relative percent differences (RPD), the difference of the two results divided by their mean, were calculated and required to meet the following quality guidelines.

The Quality Objectives for the SF_6 sampling and analysis during the JU03 project are shown in Table 4. As can be seen, all quality objectives for the PIGS were met. The method bias and completeness objectives were not met for the Super PIGS. The reasons for these failures are discussed further in Appendix A. Results not meeting the quality objectives were reviewed closely to determine if they were the result of normal random error or if there was indeed a methodology or analysis problem.

Table 4. Quality Objectives and results for the ATGAS instrument, PIGS and Super PIGS samplers.

Data Quality Indicator	Objective	Average Instrument Results	Average PIGS Results	Average Super PIGS Results
Between Instrument Precision (background checks)	<10% RSD	8% RSD ± 4%	N/A	N/A
Instrument Bias (lab blanks)	< 1 pptv	0.21 pptv ± 0.49 pptv	N/A	N/A
Instrument Precision (lab duplicates)	<5% RPD	2% RPD ± 2%	N/A	N/A
Instrument Accuracy and Precision (Lab control)	<10% RSD	5% RSD ± 3%	N/A	N/A
Method Bias (field blanks)	<5 pptv	N/A	1.1 pptv ± 3 pptv	31 pptv ± 46 pptv
Method Precision (field duplicates)	<15% RPD	N/A	8% RPD ± 11%	10% RPD ± 9%
Method Accuracy and Precision (field controls)	<15% RSD	N/A	7% RSD ± 4%	14% RSD ± 21%
Data Completeness	90%	N/A	92%	71%

Due to many months of pre-planning, a full IOP analysis cycle was completed in approximately 3-4 days' time. This analysis cycle included: (1) analyzing all field and quality control (QC) samples; (2) verifying the data by a second analyst; (3) re-analyzing any samples that were inadvertently missed or that failed QC protocols; (4) re-cleaning all 195 cartridges; (5) analyzing every 6th cleaned cartridge; and (6) moving the cartridges back to the staging area for future use. The total number of analyzed samples plus QC samples for the project was 23,400. This number does not include any re-analyses that were performed. IOP 1 provided the highest measured concentration of 106,172 pptv. The 18,000 PIGS and Super PIGS sample data points for the entire project fell into the percentage categories presented in Table 5.

Table 5. Distribution (percent) of combined PIGS and Super PIGS sampled concentrations by concentration range.

Concentration Range (pptv)	Sample Percentage
No Data	7.9
< 5	25.2
5 to 9	32.5
10 to 49	18.5
50 to 499	5.9
500 to 999	2.5
1,000 to 4,999	5.6
5,000 to 9,999	1.2
10,000 to 106,172	0.6

Sampler Data File Format & QC Flag

The data from the PIGS and Super PIGS were provided to the DPG data archive in a set of comma-delimited files. There is one file for each IOP with the file name format IOPxx.CSV, where xx is the IOP number (01 to 10). Information in each file includes sampler location and bag number, sampling start date and time, day of the year, UTC time, latitude, longitude, analyzed concentration (pptv), and data QC flag. These data were transferred from each data file into the DPG data archive.

The following should be kept in mind when using the PIGS data:

1. The latitude and longitude for some sampler locations were measured with GPS units. Others, primarily in the central business district, were read off of Terraserver.com because the GPS readings near tall buildings were suspect.

2. Double precision variables should be used when processing the latitude and longitude fields. Single precision numbers may not provide the expected resolution.

3. A given sampler location number always refers to the same place, but not all sampler locations were used during a particular IOP. The set of samplers that was used depended on the anticipated wind direction and release location. The "Dissemination and Sampling" section of this report describes the numbering system. Tables in the Individual IOP Summaries sections list the sampling locations used in each IOP.

4. The data quality flag is an integer between 0 and 5 indicating quality of the concentration measurement. The values are:

   0 Good data.
   1 Concentration less than method limit of quantitation (MLOQ), but greater than method limit of detection (MLOD); treat as an estimate. Refer to Appendix A for a detailed discussion of the QC process and for definitions of figures of merit such as MLOD and MLOQ.
   2 Concentration less than MLOD; not statistically different than 0; treat as 0 or null value.
   3 View concentration as an estimate because of problems in analysis.
   4 Data is unusable because of problems with the field sampling. For example: missing sample, improperly connected tubes, flat bags, problems with clips, damaged bags, etc. Concentrations are set to -999.
   5 Data is unusable because of problems during laboratory analysis. Concentrations are set to -999.

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MOBILE TRACER ANALYZERS

The TGA-4000

Continuous SF_6 concentration measurements were made using ARLFRD-built mobile tracer gas analyzers (TGA) shown in Fig. 26. The heart of the system is the TGA-4000 manufactured by Scientech Inc. of Pullman, Washington. It also included a modified plumbing system, a computer controlled calibration system, an integrated global positioning system (GPS), an automatic cleaning system, and an integrated computer. The TGA-4000 measures atmospheric SF_6 concentrations with a response time of just under one second (Benner and Lamb, 1985). Ten van-mounted TGAs were deployed for the JU03 experiment (Fig. 27). The rapid response time and mobile nature of the analyzers make them ideally suited for the determination of plume widths and structure. They have been utilized to determine both cross- and along-wind diffusion parameters commonly used in transport and dispersion models and Gaussian plume models (Watson et al., 1998, Watson et al., 2000). A schematic representation of the TGA is shown in Fig. 28.

Figure 26. NOAA mobile tracer gas analyzer system, consisting of a laptop computer, a TGA-4000 below the laptop, and a calibration gas cartridge (lower right) installed in the rear seat of an SUV.

Figure 27. NOAA mobile van fleet of real-time SF_6 analyzers deployed during JU03.

The TGA-4000 real-time SF_6 analyzer is a fast response instrument designed specifically to measure the concentration of SF_6 in ambient air. The TGA-4000 uses a tritium based electron capture detector (ECD) to detect the SF_6. The ECD is very sensitive to halogenated compounds such as chloro-fluorocarbons and SF_6 as well as oxygen. Oxygen interferes with the ECD operation and is therefore removed from the sample prior to introducing it into the ECD. This is done by reacting the oxygen with hydrogen in a catalytic reactor and removing the resultant water through a semi-permeable membrane. The instrument limit of detection (ILOD) of the TGA-4000 is about 10 parts per trillion by volume (pptv) under optimal laboratory conditions. The maximum concentration measurement capability is about 10,000 pptv, but can be doubled with the aid of a dilution system.

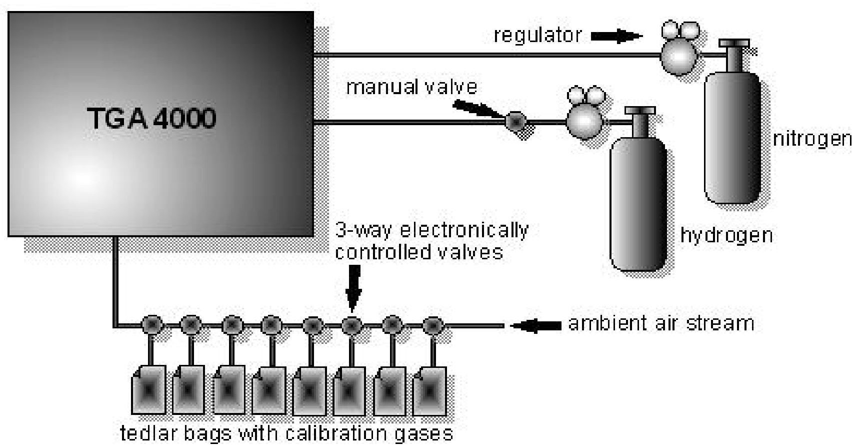

Figure 28. Schematic representation of the NOAA continuous SF_6 tracer gas analyzer.

During JU03, the TGA tagged each concentration measurement with sampling time and location from an attached GPS system. The TGA-4000 signal along with real-time GPS position, instrument temperatures, and ambient pressure were collected on a computer at the rate of 2 Hz. The computer stored the data for later post-processing and also simultaneously displayed the TGA-4000 signal for operator interpretation and control. Using this display, operators performed real-time calculations of plume concentrations, using software controls to mark the beginning and ending of the plume trace. The operator then communicated this information along with plume location details to personnel directing the test.

TGA calibration is accomplished by allowing it to sample calibration mixtures of known concentrations of SF_6 and recording the output corresponding to each concentration. SF_6 concentrations of sample air are then determined by linearly interpolating between the calibration concentrations whose output values bracket the sample output. The calibration functions are all controlled by the integrated computer when initiated by the operator.

The SF_6 calibration standards were stored in Tedlar® bags identical to those used in the PIGS, which are described in Appendix A. The bags were connected to the TGA sample stream by a series of electrically operated three-way valves. The computer switched the sample stream from outside air to a given calibration mixture by activating the corresponding valve. Eight calibration standards were used ranging in concentration from pure air (0 pptv) to over 10,000 pptv SF_6. A full set of eight calibrations was run on each analyzer both before the release began and after sampling was completed. Operators also ran calibration verification sets during the tests as needed. Usually, these were complete sets, but in some cases lack of time forced these to be partial sets.

After data collection for an IOP was completed, the data analyst followed a written procedure and calculated the method limit of detection (MLOD) and method limit of quantitation (MLOQ) for each instrument using two methods: from the baseline noise and from the variation of instrument response to each calibration gas used during the testing. (See Appendix B for a description of these methods.) The procedure called for comparing the MLOD from the lowest concentration calibration with a signal to noise ratio between 3 and 10 with the MLOD from the baseline calculation. The larger of these two values was generally selected as the instrument MLOD for that IOP. However, other factors such as number of calibrations available for the calibration variation calculation, consistency of the calculated numbers from different calibration concentrations and availability of good calibrations in the MLOD range were also considered. In some cases, adjustments were made or another value selected. Every effort was made to ensure that the selected MLOD accurately represented instrument performance or registered an error by being higher than necessary. Setting the MLOD too low allows some data to be flagged as valid when it should not be, and is unacceptable by ARLFRD standards.

The MLOD/MLOQs for each instrument and each IOP are listed in Table 6. The MLODs for this project were noticeably higher than the 10 pptv laboratory specification for the ILOD. This was largely because the analyzers were adjusted to cover 0 to 10,000 pptv, which was a much larger range than typically used. Some low-end sensitivity was sacrificed making the MLODs higher. The environmental effects of monitoring in a van and sampling in the field also add variability, making the MLOD higher than the laboratory measured ILOD. There were also some cases of exceptionally high MLODs. These were due to instrument problems. Often, operational problems first affect low-end sensitivity of the instrument, which causes the calculated MLOD to be much higher. Generally speaking, an MLOD of 150 pptv or greater indicates that the analyzer was experiencing difficulties during that IOP.

Table 6. Method Limit of Detection (MLOD)/Method Limit of Quantitation (MLOQ) values in pptv for the real-time SF_6 analyzers for each IOP.

IOP	Real-Time Analyzer Number				
	0	1	2	3	4
1	24/79	105/350	14/46	35/115	14/45
2	43/142	1252/4173	9/31	15/51	36/118
3	32/107	58/194	8/26	45/151	23/75
4	23/76	148/492	8/27	25/84	27/89
5	87/291	150/500	10/35	42/141	35/115
6	40/133	87/291	10/35	10/34	33/109
7	50/167	233/779	8/26	16/53	55/183
8	34/114	250/834	21/69	12/41	265/882
9	23/75	87/291	10/35	19/62	35/117
10	19/63	101/338	12/40	14/47	90/299
IOP	Real-Time Analyzer Number				
	5	6	7	8	9
1	10/32	16/52	46/153	29/96	21/70
2	7/24	12/39	29/97	7/23	50/166
3	9/30	14/46	25/82	12/41	28/92
4	8/25	14/47	79/264	8/26	43/144
5	14/45	21/70	102/339	11/37	32/105
6	8/26	14/46	18/61	6/20	33/111
7	9/30	11/36	24/79	5/16	37/122
8	10/33	22/75	22/74	12/40	34/113
9	8/26	28/95	11/37	17/57	108/360
10	8/28	25/84	39/128	11/36	108/361

Quality Control

The quality control (QC) procedure for the real-time analyzers included 12 steps that ensure the real-time analyzer data is as reliable as possible. During field operations, operators were required to follow written checklists that included all QC steps. A written procedure was also followed during post-test processing. The QC steps are:

1 Pre-project preparation.
2 Monitoring of key operational parameters during the study.
3 Daily instrument calibrations.
4 Real-time monitoring of QC parameters during testing.

5 Operator logging of all measurements.
6 Post-test screening of calibrations.
7 Post-test determination of MLOD/MLOQ.
8 Post-test screening of data.
9 Verification of all calculations and data by a second analyst.
10 Identification of data problems and setting of QC flags.
11 Identification of latitude/longitude for stationary analyzers.
12 Review of final data files.

These steps are discussed in Appendix B. After the final review, each data point was assigned a QC flag with a value between 0 and 11 that indicate the quality of the data point. The meaning of these flags are defined as:

0 Good data.
1 Concentration less than MLOQ but greater than MLOD; treat as an estimate. (See note on dilution system below.)
2 Concentration less than MLOD; not statistically different than 0; treat as 0 or null value. (See note on dilution system below.)
3 Concentration is greater than 115% of the highest calibration; treat as an estimate.
4 Instrument over ranged its output; concentration is unusable.
5 Null values. Analyzer was in position and operating correctly and no SF_6 was found. Treating these concentrations as 0 is appropriate.
6 Analyzer was not in use. No data available. Do NOT treat these as 0. Flag 6 indicates a human decision to not operate the instrument. For example: leave and do calibrations, move to a new place, we don't need you this test, etc.
7 Analyzer was broken. No data available. Do NOT treat these as 0 values. Concentrations are unknown.
8 Analyzer was operating, but was experiencing problems. Treat all concentrations as estimates.
9 Concentrations are unusable because of instrument problems, but are included for qualitative indications only. In this case, the instrument was operating and collected data, but problems discovered later made it impossible to have any confidence in the concentrations. Since the data was available it was included and may be useful for some purposes such as determining plume arrival times, etc. Calculations should not be done with these concentrations.
10 Concentrations unusable because of external problems. For example: fugitive sources, noise caused by trucks passing, etc.
11 Concentrations are estimates because of external problems. This flag indicates that something external to the analyzer had a small effect on the data, making it less certain but not totally unreliable. For example: a passing truck creating a small amount of noise during a high concentration peak.

Mobile Tracer Analyzer Data File Format

TGA data are part of the JU03 archive. There was one comma-delimited file from each TGA for each release submitted to the DPG archive. Note that all of the puffs for each IOP are considered to be a single release for archive purposes. The file name convention was IxxRyVz.csv, where xx is the IOP number (1 to 10), y is the release number (1 to 4), and z is the analyzer (or van) number (0 to 9). Included in each file were: date and time (UTC and CDT), analyzer number and location, height above mean sea level (MSL), SF_6 concentration, and a data QC flag. Additional information about the TGAs, their operation, and their data files are provided in Appendix B and in the readme document that accompanies the archived TGA data files. TGA data summaries are presented in the individual IOP summaries below. These summaries include estimates of the maximum measured concentration for each puff or continuous release.

ARLFRD METEOROLOGICAL MEASUREMENTS

JU03 meteorological measurements were primarily performed by other program participants. However, ARLFRD did operate a sound detection and ranging (sodar) instrument, a sonic anemometer, and a temperature/relative humidity probe. The sodar's purpose was to provide boundary layer wind speed and direction profile measurements. It was located on the Oklahoma School of Science and Mathematics Campus (35.48147 N, 97.50510 W, 384 m MSL), approximately 100 m SE of the corner of Stiles and 13th Street. The sonic anemometer provided wind and turbulence measurements and the probe collected temperature and relative humidity at the release site.

Sound Detection and Ranging


Figure 29. ARLFRD sodar used during JU03.

A sodar (Fig. 29) is a remote wind-sensing instrument. It generates acoustic pulses that propagate through the atmosphere, and samples acoustic returns scattered from thermal inhomogeneities in the atmosphere. Sodars use planar arrays of acoustic transmitter-receivers that form acoustic pulses into a beam and steer the beam in desired directions. The emitted acoustic beam experiences scattering and attenuation as it travels through the atmosphere. A small fraction of the emitted acoustic energy is subsequently back scattered to the receiver with a Doppler frequency shift proportional to the velocity of the scattering surface that created the acoustic returns. Returned signals are characterized by their intensity, spectral width, Doppler-shifted frequency, and elapsed time from initial pulse transmission. Distance of the scattering surface from the sodar is calculated using lapsed time and speed of sound information. Using one beam oriented in the vertical and others tilted towards the (N-S) and (E-W) directions, the sodar can provide wind speed and direction measurements at heights ranging from several tens of meters to several kilometers above the instrument.

Sodar Records and Data Management

ARLFRD used a Radian model 600 PA phased-array Doppler sodar during JU03. It was set to operate at a transmitted frequency of 3 KHz and to provide wind measurements averaged over 15-min. periods at 10-m height intervals. Sampling was set for heights ranging from 40 to 300 m above the instrument, although few valid returns were recorded at the lowest and highest range gates. Winds from each range gate height represent a temporal (15-min.) and spatial average over a conical beam section. Thus, the 1500 CDT wind measurement at the 100-m level represents a temporal average of winds measured between 1445 and 1500 CDT over a 10-m spatial volume between 95 to 105 m above the sodar.

The sodar began collecting data on 03 July 2003 and continued to operate until shut down on 01 August 2003. There were several periods where sodar data collection was interrupted for short periods to re-orient the antenna, but the equipment otherwise remained in continuous operation. The re-orientation was done to minimize interference from traffic noise and from fixed echoes off nearby buildings that degraded data quality in the 140 through 170 m height ranges.

The sodar data records were recorded in a common data format (CDF) files produced by the data collection computer at the SODAR location. Wind direction and speed data were plotted for 12 hours at a time using a custom computer program. Heights and times of invalid data points were marked and stored in an ASCII computer file. Another file containing heights and times of invalid data, including times of the re-orientation of the antenna, were also generated. A program was written to read the original CDF files generated by the SODAR collection computer and the ASCII invalid data files into daily comma-delimited text files (CSV) with the flagged data. The data were plotted again to check for missed flags.

The CSV sodar data records were named, with the filename jut03MMDD, where MM is the numerical month (07), and DD is the day of the month. Each file began at midnight (0000 CDT) and continued in a 15-min. time sequence through the day. Each sodar file included date, day of the year, and file end time in CDT, wind and wind component data, and data QC information. These data were submitted to the DPG data archive. A sodar readme file accompanies the archived sodar records. It provides additional detail on the sodar, its installation, and data processing procedures. A table of 100-m sodar wind data during the time of each IOP is included (when available) with each IOP summary below.

The Release Site Sonic Anemometer

A three-dimensional sonic anemometer was set up at the beginning of each IOP to measure the wind field at the release site. This sonic anemometer was a Windmaster Pro model, manufactured by Gill Instruments, Ltd. The sonic anemometer was mounted on a tripod at about 2 meters AGL at the SF_6 release position (Fig. 6). For location information, the reader is referred to the previous SF_6 dissemination section. A sonic anemometer consists of a transducer array with paired sets of acoustic transmitter/receivers, a system clock, and microprocessor circuitry to measure transit time between the transmission and reception of sound pulses. This time information was subsequently used to obtain the speed of sound and velocity component measurements along each transducer axis. The advantages offered by a sonic anemometer over conventional mechanical wind instruments are: (1) no moving parts; (2) simultaneous measurement of wind and temperature; (3) linear response at very low wind speeds; (4) resolution of turbulent motions at the scale of 1 meter or less. These attributes make the sonic anemometer a preferred instrument for measurements within an urban environment.

Sonic Anemometer Data Management

The sonic anemometer data were recorded at a rate of 10 Hz and were stored in binary format. These data are stored in files with the name and extension FDDDTTTT.RAW, where F stands for Final, DDD=Julian date, and TTTT=Time (HHMM CDT). HHMM, the only time stamp for a given file, is the beginning time of each 30-minute data file. The sonic anemometer data acquisition program was manually synchronized to within 1/4 of a second of a time standard clock adjusted to WWV at the beginning of each IOP.

The raw 30-minute binary sonic anemometer data files acquired during each IOP were subsequently processed into ASCII (.DAT) files. The processed data include the vertical velocities (w), the west-east wind component (u), and the north-south wind component (v), and virtual air temperature (ºC). The data was then manually checked and marked with any data quality flags. The .DAT files were then processed into .CSV files with the Julian date, time stamp, and flags added to the data.

During the quality control process, slight differences in the total scan numbers were found in each 30-minute data file. For a full 30-minute file, the total scan numbers ranged from 17,998 to 18,002. This is a very small error rate of approximately 0.01%. The difference in initialization of the recording program is larger than the sonic anemometer clock error. Even though there were slight differences in the total scan numbers in each 30-minute file, a time stamp was included in the .CSV files. Therefore most of the 1/2 hour data files have 1 or 2 overlapping or missing time frames between each 1/2 hour data files when the number of scans in a file is not equal to 18,000 scans.

The 30-minute .CSV files were then used to create summary statistics with .NRT, .FLX, and .ERR file extensions. The .CSV, .NRT, .FLX, and .ERR files were all submitted to the DPG data archive. The .NRT data includes means, variances, and covariances of velocity components and temperature without rotation of the u and v axes into the mean wind. A 2-dimensional coordinate rotation was then used to orient the u axis into the along-wind direction, producing .FLX files. The rotated file statistics includes mean wind speed and direction, covariance of u with w, variances of the rotated wind components, and the covariance of w with virtual air temperature. Skewness and kurtosis information for quality control use were placed in .ERR files. Details of the .CSV, .NRT, .FLX, and .ERR files are provided in the readme file that accompanies the archived sonic anemometer data.

The Release Site Temperature/Relative Humidity

A Vaisala HMP-45C probe deployed during JU03 provided air temperature and relative humidity measurements at the release site. The combined sensors were mounted in a naturally aspirated 10-plate Gill radiation shield on a tripod containing the continuous point source dissemination device and the sonic anemometer (Fig. 6). The probe was positioned about 1.9 meters AGL in each of the IOPs. Exact locations of the probe can be found earlier in the SF_6 Tracer Release System section. The data were recorded at 1 Hz using a Cambell Scientific CR-

23 data logger. The data was manually checked and marked with any quality flags. The data was then plotted to check for any missed flags. Additional details of the temperature and relative humidity probe can be found in the readme file that accompanies the archived records. Plots of the temperature and relative humidity data can be found in Appendix E of this document.

DISSEMINATION AND SAMPLING

Release Locations

Wind regimes favorable for conducting IOPs were determined to be “SSW”, with winds from the south-southwest through south, and “SE” with winds from the east through south. Release locations for the SSW wind regime included the “Botanical” site on the west side of Ronald Norick Boulevard near the Myriad Botanical Gardens, and the “Park” site on the south side of Park Avenue between Robinson & Broadway. The release location used for the SE wind regime was the “Westin” site on the west side of Broadway near the Westin Hotel. Release location latitudes and longitudes for each IOP varied somewhat, depending on where parking was available. The release locations were measured at the beginning of each IOP, and are provided earlier in the SF_6 Tracer Release System section. These release locations are also shown as blue stars on Figs. 30 and 31 below.

Time-Integrated Sampler Positions

The PIGS and Super PIGS were mounted on hangers approximately 3 m AGL along sampling arcs at distances of 1-, 2-, and 4-km from the release position. Specific mounting locations along those arcs were determined for each IOP by the forecast wind regime (SSE or SW). The mounting locations for each wind regime spanned approximately 120 degrees of arc. Tabulated in Table 7 below are PIGS locations for each arc. Some sampling locations had additional blank, duplicate, or control samplers used for quality control purposes (see Appendix A) mounted beside the regular samplers. PIGS and Super PIGS locations along each arc together with sampling sectors used for the SE (red) and SSW (blue) flow regimes are presented in Fig. 30. Samplers placed on the 1-, 2-, and 4-km arcs were confined to the PIGS type only.

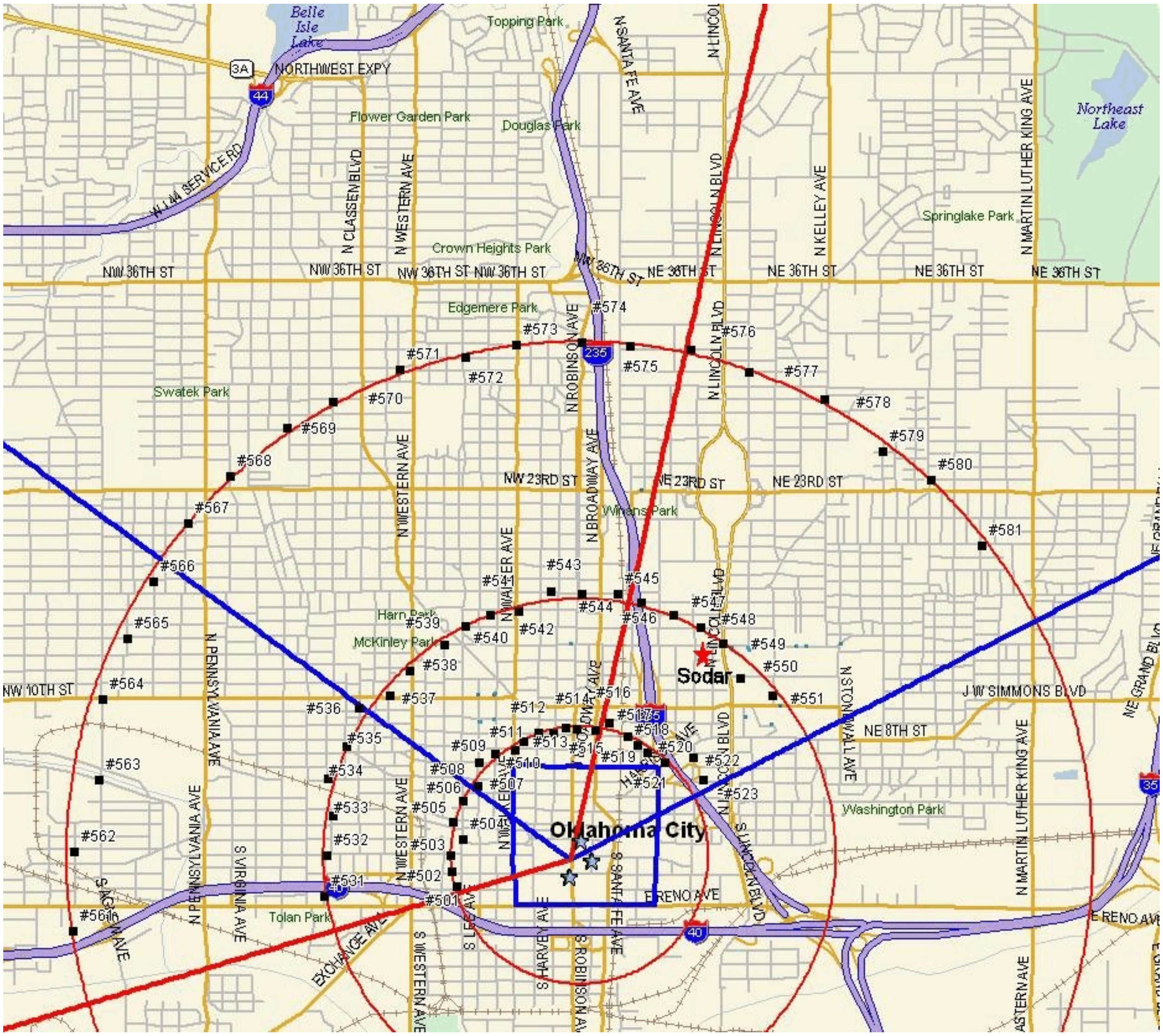

Figure 30. JU03 release locations (blue stars), central business district (blue box), sodar location (red star), numbered sampler locations (black boxes) along the 1-, 2-, and 4-km arcs (red circles), and the sectors used for SE flow (red) and SSW flow (blue) scenarios.

Table 7. Time-integrated sampler (PIGS) location numbers on the 1-, 2-, and 4-km arcs in decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) .

One Loc.	Km Latitude	Arc Longitude	Two Loc.	Km Latitude	Arc Longitude	Four Loc.	Km Latitude	Arc Longitude
501*	.46532	.5256	531*	.46488	.5374	561*	.46247	.5591
502*	.46663	.5266	532	.46773	.5373	562	.46802	.5590
503	.46777	.5266	533*	.47052	.5367	563*	.47307	.5568
504*	.46888	.5256	534	.47308	.5371	564	.47866	.5565
505	.47011	.5264	535*	.47538	.5355	565*	.48290	.5544
506*	.47160	.5256	536	.47809	.5345	566	.48690	.5521
507X	.47258	.5243	537*	.47895	.5319	567*	.49090	.5492
508*	.47427	.5242	538	.48065	.5302	568	.49424	.5456
509	.47485	.5228	539*	.48248	.5272	569*	.49760	.5406
510*	.47512	.5212	540	.48373	.5254	570	.49944	.5367
511	.47571	.5204	541*	.48453	.5232	571*	.50167	.5309
512*	.47630	.5191	542	.48477	.5207	572	.50255	.5254
513	.47632	.5178	543*	.48617	.5180	573*	.50342	.5210
514*	.47667	.5168	544	.48603	.5154	574	.50355	.5154
515	.47662	.5158	545*	.48598	.5123	575*	.50328	.5113
516*	.47653	.5142	546	.48538	.5102	576	.50308	.5061
517Y	.47702	.5130	547*	.48455	.5075	577*	.50150	.5010
518*	.47608	.5115	548	.48363	.5051	578	.49955	.4945
519	.47547	.5106	549*	.48258	.5033	579*	.49592	.4895
520*	.47490	.5098	550	.48015	.5018	580	.49398	.4855
521	.47425	.5082	551*	.47892	.4990	581*	.48938	.4810
522*	.47462	.5058	-	-	-	-	-	-
523*	.47303	.5050	-	-	-	-	-	-

* 30-minute sampling time per bag.
X indicates a 15-minute sampling time per bag during red regime days, 30-minute sampling time per bag during a blue regime day.
Y indicates a 30-minute sampling time per bag during red regime days, 15-minute sampling time per bag during a blue regime day.

Additional time-integrated samplers were placed at locations within the CBD (locations 003-087), in the pedestrian tunnel beneath the CBD (locations 401-404), and on rooftops above the CBD (locations 940-965). Decimal latitude and longitude positions for these samplers are presented in Table 8, and are shown on Fig. 31. The CBD samplers were a mixture of PIGS and Super PIGS.

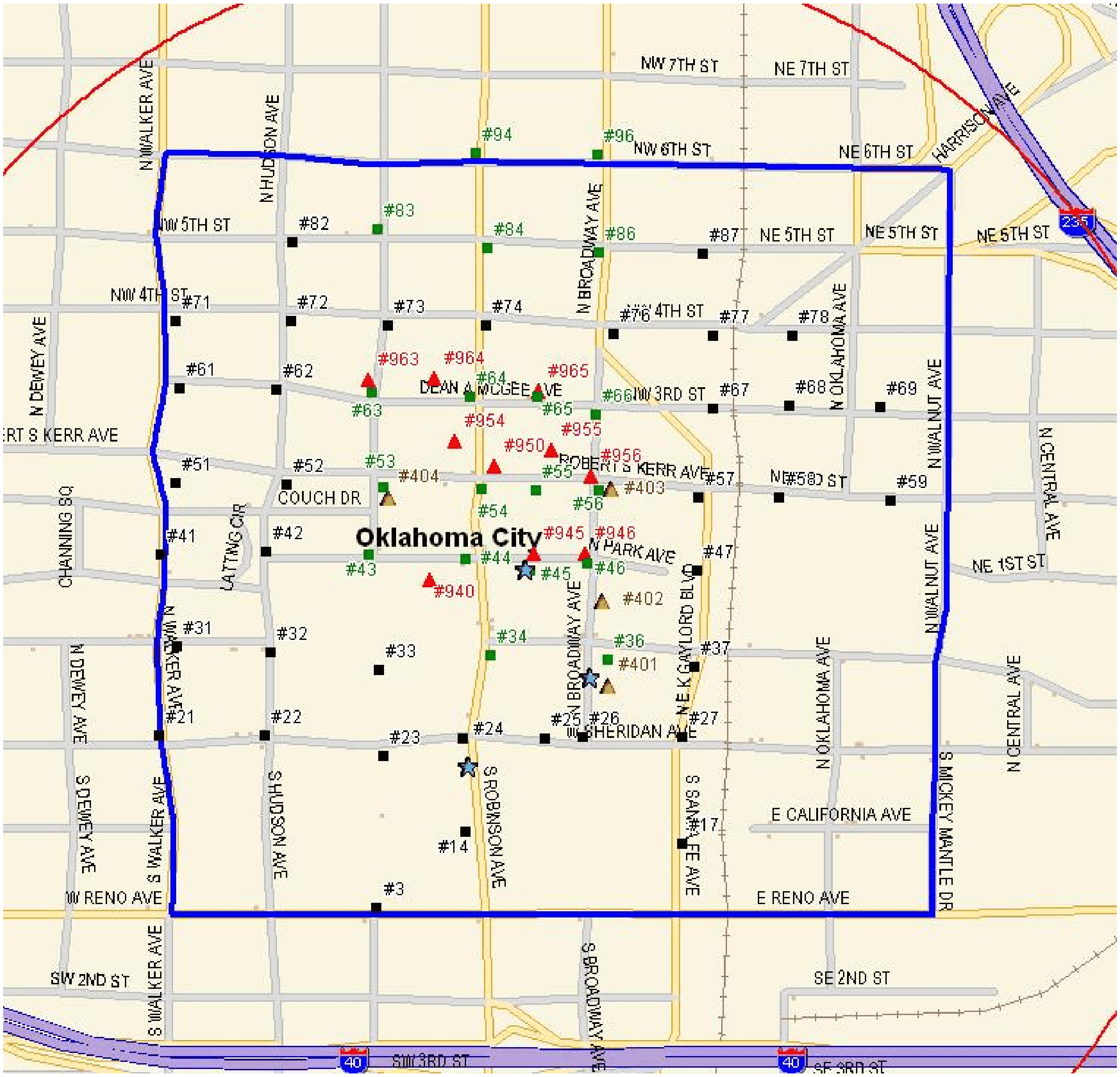

Figure 31. JU03 release locations (blue stars) and PIGS (black squares), Super PIGS (green squares), tunnel (brown triangles), and rooftop (red triangles) sampler locations within the Oklahoma City Central Business District (blue box).

Table 8. Time-integrated CBD, tunnel, and rooftop sampler locations in decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W).

	CBD			CBD		Tunnel	Or	Rooftop
Loc.	Latitude	Longitude	Loc.	Latitude	Longitude	Loc.	Latitude	Longitude
003	.46436	.5179	057	.46963	.5129	401	.46720	.5143
014	.46532	.5165	058	.46963	.5116	402	.46833	.5143
017	.46519	.5131	059	.46960	.5098	403	.46973	.5143
021	.46656	.5214	061	.47105	.5210	404	.46975	.5178
022	.46656	.5197	062	.47104	.5195	940*	.46854	.5171
023	.46630	.5178	063*	.47099	.5180	945*	.46888	.5155
024	.46653	.1566	064*	.47093	.5165	946*	.46888	.5147
025	.46654	.5153	065*	.47093	.5154	950*	.47001	.5161
026	.46655	.5147	066*	.47072	.5145	954*	.47032	.5167
027	.46654	.5131	067	.47078	.5126	955*	.47022	.5152
031	.46772	.5211	068	.47083	.5114	956*	.46988	.5146
032	.46764	.5196	069	.47080	.5100	963*	.47113	.5181
033	.46742	.5179	071	.47192	.5211	964*	.47114	.5170
034*	.46760	.5161	072	.47191	.5193	965*	.47098	.5154
036*	.46755	.5143	073	.47185	.5178	-	-	-
037	.46745	.5129	074	.41785	.5162	-	-	-
041	.46890	.5213	076	.47174	.5142	-	-	-
042	.46894	.5197	077	.47173	.5126	-	-	-
043*	.46890	.5181	078	.47172	.5114	-	-	-
044*	.46885	.5165	082	.47293	.5193	-	-	-
045*	.46869	.5155	083*	.47310	.5179	-	-	-
046*	.46880	.5146	084*	.47286	.5162	-	-	-
047	.46870	.5129	086*	.47279	.5144	-	-	-
051	.46983	.5211	087	.47278	.5128	-	-	-
052	.46980	.5193	094	.47408	.5164	-	-	-
053*	.46977	.5178	096	.47405	.5145	-	-	-
054*	.46974	.5163	-	-	-	-	-	-
055*	.46972	.5154	-	-	-	-	-	-
056*	.46969	.5142	-	-	-	-	-	-

* Super PIGS type sampler was located at the site.

CBD Street-Level Samplers

Street-level samplers were typically located at intersections of streets running north-south and east-west. The last 2 digits of the 3-digit sampler location number indicate its location on the street grid. The first of these digits indicates the sampler's location on an east-west oriented street, and the second digit indicates the sampler's location on a north-south oriented street. Table 9 contains the streets and their sampler location numbers, with Between * indicating locations midway between Robinson and Broadway. For example, a sampler on the corner of

Park and Broadway is location number 046. This code indicates approximate locations only. The latitudes and longitudes included in the data files and Table 8 above are the definitive sampler positions. An aerial image of these samplers can be seen in Fig. 32. The CBD street-level samplers were a mixture of PIGS and Super PIGS.

Table 9. Time-integrated CBD sampler location numbers and their approximate street corner or mid-block locations.

East-West Street	Location Number	North-South Street	Location Number
Reno	00x	Walker	0x1
California	01x	Hudson	0x2
Sheridan	02x	Harvey	0x3
Main	03x	Robinson	0x4
Park	04x	Between*	0x5
Kerr	05x	Broadway	0x6
McGee	06x	Gaylord	0x7
4th Street	07x	Oklahoma	0x8
5th Street	08x	Walnut	0x9
6th Street	09x	--	--

Tunnel Samplers

Many buildings within the Oklahoma City CBD are connected by a system of pedestrian tunnels. Sampler locations 401 through 404 were placed at the following locations in this tunnel system: (1) location 401 near the southern entrance to the Mid-America Tower; (2) location 402 at the northern entrance to Bank One; (3) location 403 at the tunnel intersection below Kerr Park at the street intersection of Kerr and Broadway; and (4) location 404 at the Bank of Oklahoma parking garage entrance on Kerr. Locations 401 and 402 were placed just outside the glass door entrances to the buildings and location 402 was very near to an outside entrance to the tunnel system. Location 403 was at a T-intersection in the tunnel and far removed from a tunnel entrance, and location 404 was at the base of the stairwell just below the entrance into the parking garage. The samplers placed in the tunnels were of the PIGS variety.

Rooftop Samplers

Samplers were placed on the rooftops of ten buildings in downtown Oklahoma to measure the vertical transport of the plume as it moved downwind of the release site. The samplers were placed on buildings where access to the roof was permitted and safe. The most desirous rooftop locations were buildings located on street corners and mid-block locations where samplers were already placed at the street level. Rooftop locations are numbered similar to the street-level samplers, although the first digit begins with a 9. The last two digits of the 3 digit location number indicates its location on the street grid (Table 9). There are 2 sampler locations that do not follow this rule: (1) sampler location number 940 (Oklahoma Tower top), is located on Park Ave between Robinson and Harvey; and (2) sampler location number 950 (West Kerr Tower), is located on the NW corner of Robert S. Kerr and Robinson. The latitude and longitude positions for all of the rooftop samplers are found in Table 8. The height of the rooftop locations are located in Table 10. Figure 31 shows a map of where the rooftop samplers were located. An aerial image of the rooftop samplers can be seen Fig. 33. Rooftop samplers were of the Super PIGS variety exclusively.

Table 10. Heights of the rooftop integrated samplers during JU03.

Location Number	Super PIGS Location	Height (m, AGL)
940	Oklahoma Tower Top	117
945	Chamber of Commerce Top	16
946	Sonic Building Top	47
950	West Kerr Tower	29
954	Bank of Oklahoma Top	78
955	Center Kerr Tower	115
956	East Kerr Tower	26
963	ONG Building	20
964	Old Post Office Top	37
965	Southwestern Bell Top	72

Each individual IOP summary below contains the distribution of the maximum reported concentrations (pptv) for that IOP. One table represents the maximum concentrations of the CBD street level samplers, rooftop samplers, and tunnel samplers. The second table represents the maximum concentrations of the samplers placed along the 1-, 2-, and 4-km arc. The maximum concentration for each street is noted in bold numbers. Missing data are represented by -999. Maximum concentrations that are less than the MLOQ or that include substantial missing or flagged data are presented in *italics*.

Each individual IOP summary also contain footprint maps of the temporal and spatial PIGS and Super PIGS tracer concentration. The first set of maps represent results from the CBD sampling array and the second set of maps represent the results of the samplers placed along the 1-, 2-, and 4-km arcs. The colored circles on the maps represent a certain range of concentration: grey (< 33 pptv), blue (33 to 100 pptv), green (100 to 1,000 pptv), brown (1,000 to 10,000 pptv), and red (> 10,000 pptv). An "x" indicates missing data.

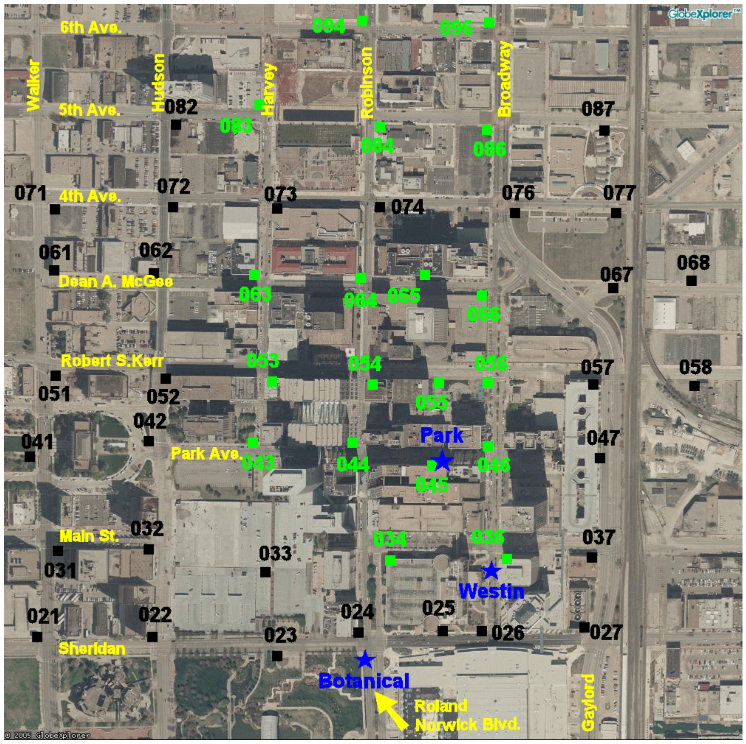

Figure 32. Aerial image of the PIGS (black squares), Super PIGS (green squares), and release locations (blue stars) during JU03.

Figure 33. Aerial image of rooftop sampler locations.

PIGS and Super PIGS Sampling Times

The PIGS and Super PIGS were only programmed to sample the tracer during the continuous point source releases. The PIGS located in the CBD were all programmed to sample in 30-minute intervals beginning at the start of the release. PIGS located out on the 1-, 2-, and 4-km arcs alternated sampling times at either 15- or 30-minute intervals. The goal of alternating the PIGS sampling times between samplers along the arcs were to increase the resolution of the time series as the plumed moved downwind. Therefore on the 1-km arc, every even numbered sampler was programmed to sample in 30-minute intervals while the odd numbered samplers were programmed to sample in 15-minute intervals. However 2 odd numbered samplers, 1 at both ends of the sampling arc, were added and programmed to sample at 30-minute intervals. The extra sampling locations were added out of concern of not being able to capture the entire width of the plume across the 1-km arc. These sampling location numbers were 501 and 517 during a red regime day and 507 and 523 during a blue regime day (Fig. 30). Sampler locations 507 and 517 were the only samplers located on the 1-km arc that were programmed with different sampling times (15- or 30 minutes) during JU03. On the 2- and 4-km arcs the odd numbered samplers were programmed to sample in 30-minute intervals while the even numbered samplers sampled in 15-minute intervals. A listing of the sampling location numbers and 15-minute sampling times can be found in Table 7. All of the PIGS regardless of the sampling time continued to sample through the entire IOP.

The Super PIGS, as mentioned earlier, had the capability to program different sampling times and pause sampling between bags. The Super PIGS (which started sampling at the start of the release) sampled 2 15-minute cycles followed by 6 5-minute cycles. The 5-minute cycles were to measure how fast the tracer concentration dissipated or decayed after the release had ended. After the 5-minute sampling period, the samplers paused for an hour before the process of sampling repeated at the start of the next continuous release.

TGA Positions

The van-mounted TGAs, numbered 0 through 9, were driven to positions in and around the CBD based on wind direction forecasts. The van housing TGA 5 was mobile, moving east and west primarily along 4th and 8th Streets to intercept tracer plumes transported north across Oklahoma City. There were a few occasions when the van was instructed to go a different route other than 4th or 8th Street to locate the plume. The other TGAs primarily remained stationary during an IOP, although these TGAs were also sometimes moved to more advantageous sampling locations as determined by wind direction and tracer concentration measurements. Plots of the TGAs along with a table describing their positions can be found in the individual IOP summaries. TGA 7 was placed at rooftop level above TGA 6 during IOPs 1, 3, 4, 5, 6, and 7. This was to measure the real-time vertical transport of the plume as it moved downwind of the release site.

The archived data contain TGA locations for each TGA-derived tracer concentration reading. Each IOP summary in the next section includes a table of estimated maximum concentrations sampled by the TGAs for each tracer puff or point release. Note that the archives treat the puffs collectively as a single release, although the tables below provide estimated maxima for each puff. Maximum concentrations which had QC flags other than zero (valid and accurate data) are presented in *italics*.

INDIVIDUAL IOP SUMMARIES

IOP 1, Sunday, 29 June 2003

1. Meteorological Synopsis. Light early morning rain-showers ended prior to the first release, with clouds dissipating by mid-day. Winds were predominately from the SSW during the puff releases, but backed to S for the first continuous release and then SE to E for the second continuous release. The third continuous release was cancelled due to winds from the NE. Note: No sodar data were available for IOP 1. Sodar installation at the Oklahoma School for Science and Mathematics Campus was completed by 15:20 CDT on 30 June 2003, in time to be used during all subsequent IOPs.

2. Release Summary. Releases were made on the east side of Broadway across from the Westin Hotel in front of the Mid-America Tower. Six puff and two continuous releases were made during IOP 1. The first four were 1000 g puffs at 0900, 0910, 0920, 0930 CDT, followed by 500 g puffs at 0945 and 1000 CDT. Latter puff quantities were reduced to minimize real-time analyzer railing, and 15-minute spacing allowed the tracer material to clear between puff releases. Thirty-minute continuous releases of 4.86 and 4.81 g s^{-1} were made at 1100 and 1300 CDT.

3. Sampler Deployment Summary. Integrating samplers were deployed within the CBD on rooftops of the Chamber of Commerce (location 940), Sonic building at 101 South Park (location 946), West Kerr Tower (location 950), Center Kerr Tower (location 955), East Kerr Tower (location 956), Bank of Oklahoma (location 954), and Southwestern Bell building (location 965). Samplers were not deployed on the Oklahoma Tower (location 940), ONG building (location 963), and the Old Post Office (location 964) since permissions were not granted. Samplers were also not deployed in the pedestrian tunnel at sampling positions 401 through 404. Southeast winds were forecast, so integrating samplers were set up along the red (SE) arc sector shown on Fig. 30, which included locations 501 through 517 (1 km arc), 531 through 545 (2 km arc), and 561 through 575 (4 km arc). Real-time analyzers (TGAs) were deployed in 10 vans, each assuming the number of their TGA unit. Nine of the vans (0-4, 6-9) were parked for the duration of the IOP. TGA 5 was mobile mainly along 4th Street. The TGA did travel for a short period during the 2nd continuous release along N. Sharpel Blvd, N. Lee Blvd, and N. Classen Blvd as a result of the SE winds. IOP 1 TGA deployment positions, including decimal latitudes and longitudes (35.xxxxx, 97.xxxx) are shown in Table 11. A plot of the TGA positions along with the general path of the mobile TGA can be found in Fig. 34.

Table 11. TGA locations including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W), and street locations for IOP 1.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile on 4th Street
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street Parking Garage
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

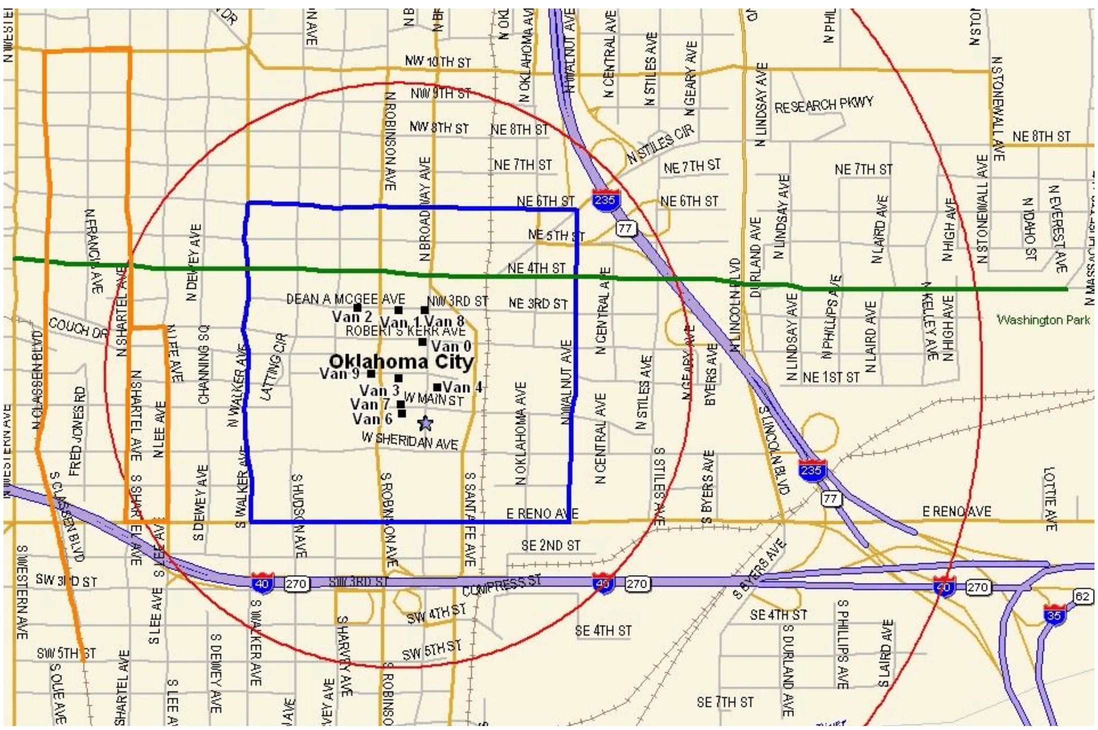

Figure 34. Stationary TGAs (black squares), general path of the mobile TGA (green line), short deviation of the general path of the mobile TGA during the 2nd continuous release (orange line), release site (blue star), CBD (blue box), and the 1- and 2-km arc (red circles) during IOP 1.

4. IOP 1 Results. Table 12 presents a summary of maximum reported concentrations (pptv) for each integrating sampler in the CBD at street level (locations 003-087) and on rooftops (locations 940-965). The table is plotted out as if the samplers were located on the street grid in the CBD. For example, location 046 (located on the corner of Park and Broadway) had a maximum concentration of 106,172 pptv during IOP 1. Rooftop sampler location numbers 940 and 950, whose numbers do not follow the street grid numbering system, are placed in the correct position on the map with their sampler location number in parenthesis. Maximum concentrations by east-west oriented streets are indicated in bold numbers. Missing data are represented by -999. Maximum concentrations that are less than the MLOQ or include substantial missing or flagged data are presented in *italics*. Figures 35 and 36 show both temporal and spatial PIGS and Super PIGS tracer concentration results from the CBD. Colored circles represent a certain range of concentration. Grey (< 33 pptv), blue (33 to 100 pptv), green (100 to 1,000 pptv), brown (1,000 to 10, 000 pptv), and red (> 10,000 pptv). An "x" indicates that the tracer concentration is missing. For presenting the Super PIGS data in the figures, the 5- and 15-minute bag samples were combined to make a 30-minute average. In addition, the Super PIGS did not sample during the 2nd hour after the start of the release and therefore the dots in the figures disappear during that time period. Tracer samples within the CBD were spotty, tending to yield high or fairly low concentrations. The plume mainly impacted the east side of the CBD. However, a bimodal distribution of maximum concentrations from eastern and western sampler locations was also observed and was likely caused by the wind shift from S to SE between the two continuous release periods. The highest reported concentration for all of the ARLFRD JU03 samplers (106,172 pptv) was observed at location 046 during this IOP. This sampler was located approximately 100 m north of the release site. Concentrations in excess of 40,000 pptv were also obtained from rooftop locations just north of the release site.

The maximum reported concentrations for integrating samplers positioned on the 1-, 2-, and 4-km arcs for IOP 1 are presented in Table 13. This table also shows the samplers in radial alignment meaning that the sampler numbers (with their concentrations) are positioned in the table as if they were still on the arc. Temporal and spatial tracer results along the arcs (similar to Figs. 35 and 36) are shown in Figs. 37 and 38. For presentation in the figures, the 15-minute PIGS were averaged over a 30-minute period similar to the Super PIGS in the CBD (Figs. 35 and 36). The rapid wind shift from S to SE prior to the 2nd continuous release likely caused the bi-modal distribution of concentration maxima seen in Table 13. The higher concentrations were observed near the north and west ends of the sampling arc segments (refer to Fig. 30).

Table 12. Summary of maximum reported concentrations (pptv) for integrating samplers in the CBD placed at street-level and on rooftops during IOP 1. "R" indicates the release site.

		Street-level Samplers								
		Walker 0x1	Hudson 0x2	Harvey 0x3	Robinson 0x4	Between 0x5	Broadway 0x6	Gaylord 0x7	Oklahoma 0x8	Walnut 0x9
6th St.	09y									
5th St.	08y		152	1,577	4,865		**6,756**	2,551		
4th St.	07y	14	103	536	1,934		**5,515**	2,992		
McGee	06y	26	42	2,477	*33*	10,885	**26,013**	2,955		
Kerr	05y	1,673	2,203	*29*	-999	*38*	*73*	**4,540**		
Park	04y	4,083	2,138	*120*	841	18,594	**106,172**	8,175		
Main	03y	5,479	6,730	**10,892**			R	875		
Sheridan	02y	**3,797**	3,415	3,475				*13*		
California	01y				**262**			13		
Reno	00y			**54**						

		Rooftop Samplers								
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			-999	-999	**7,640**				
Kerr	05y			*41* (950)	2,315	1,762	**47,595**			
Park	04y			-999 (940)		**42,916**	14,830			
Main	03y						R			
Sheridan	02y									
California	01y									
Reno	00y									

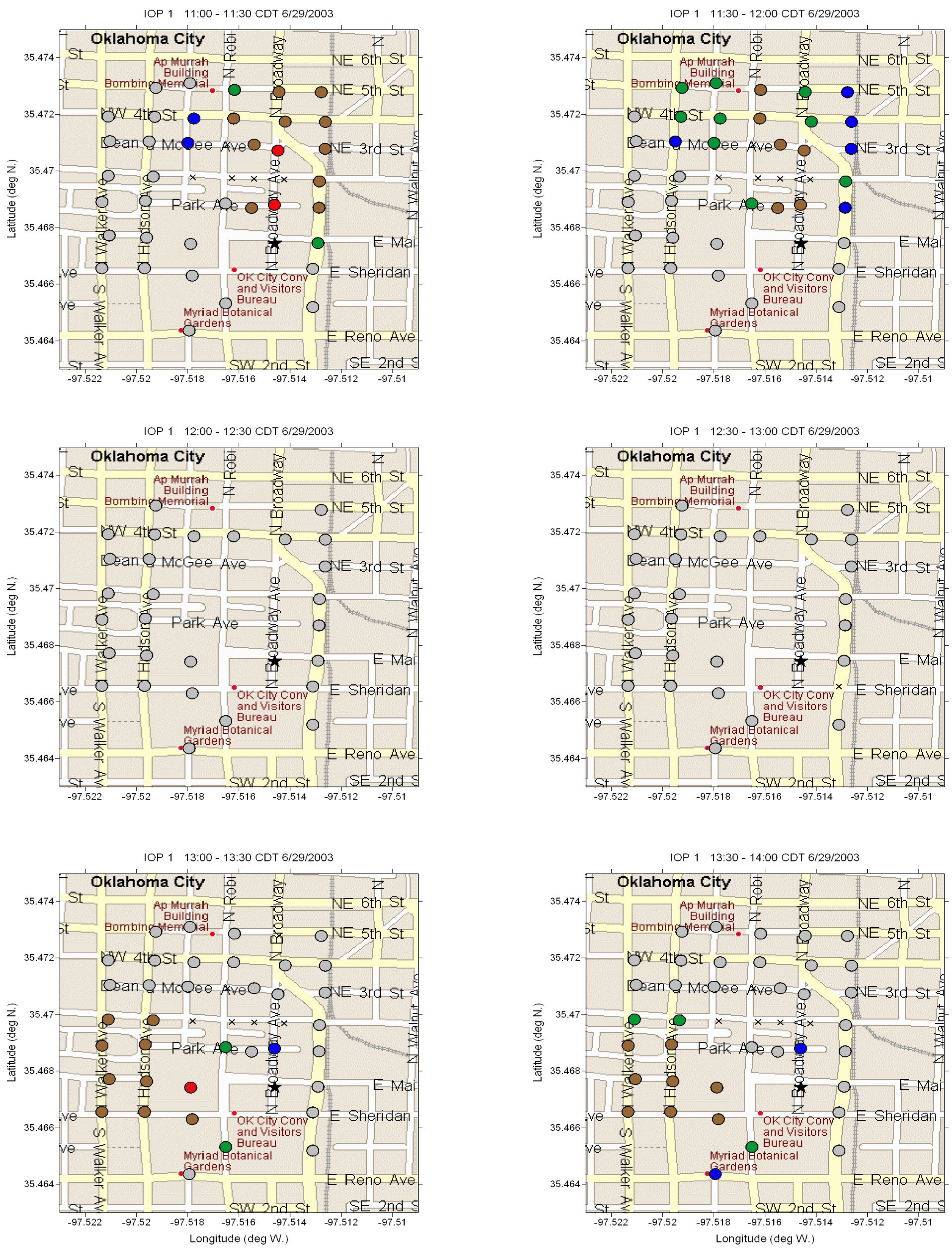

Figure 35. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 1 from 1100-1400 CDT. Tracer releases took place from 1100-1130 and 1300-1330 CDT.

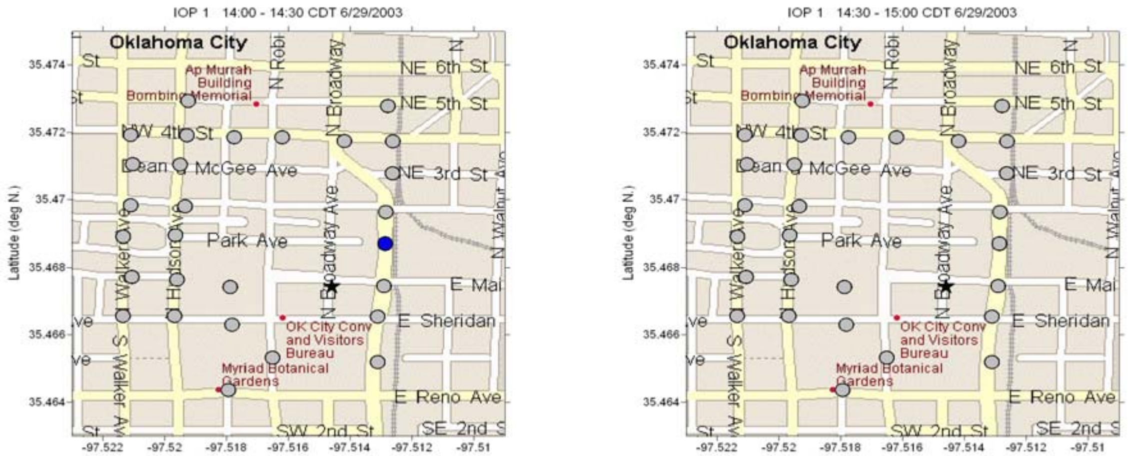

Figure 36. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 1 from 1400-1500 CDT. No tracer releases took place during this time frame.

Table 13. Summary of maximum reported SF_6 concentrations (pptv) for integrating samplers positioned on the 1-, 2-, and 4-km arcs during IOP 1.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
501	778	-	-	-	-
502	1,518	531	581	561	63
503	**2,920**	532	**1,411**	562	**461**
504	1,102	533	250	563	98
505	2,162	534	663	564	129
506	244	535	47	565	11
507	21	536	13	566	16
508	11	537	11	567	14
509	7	538	12	568	15
510	16	539	11	569	12
511	244	540	32	570	13
512	290	541	94	571	51
513	1,324	542	-999	572	136
514	647	543	205	573	103
515	1,038	544	356	574	-999
516	1,059	545	253	575	44
517	1,146	-	-	-	-

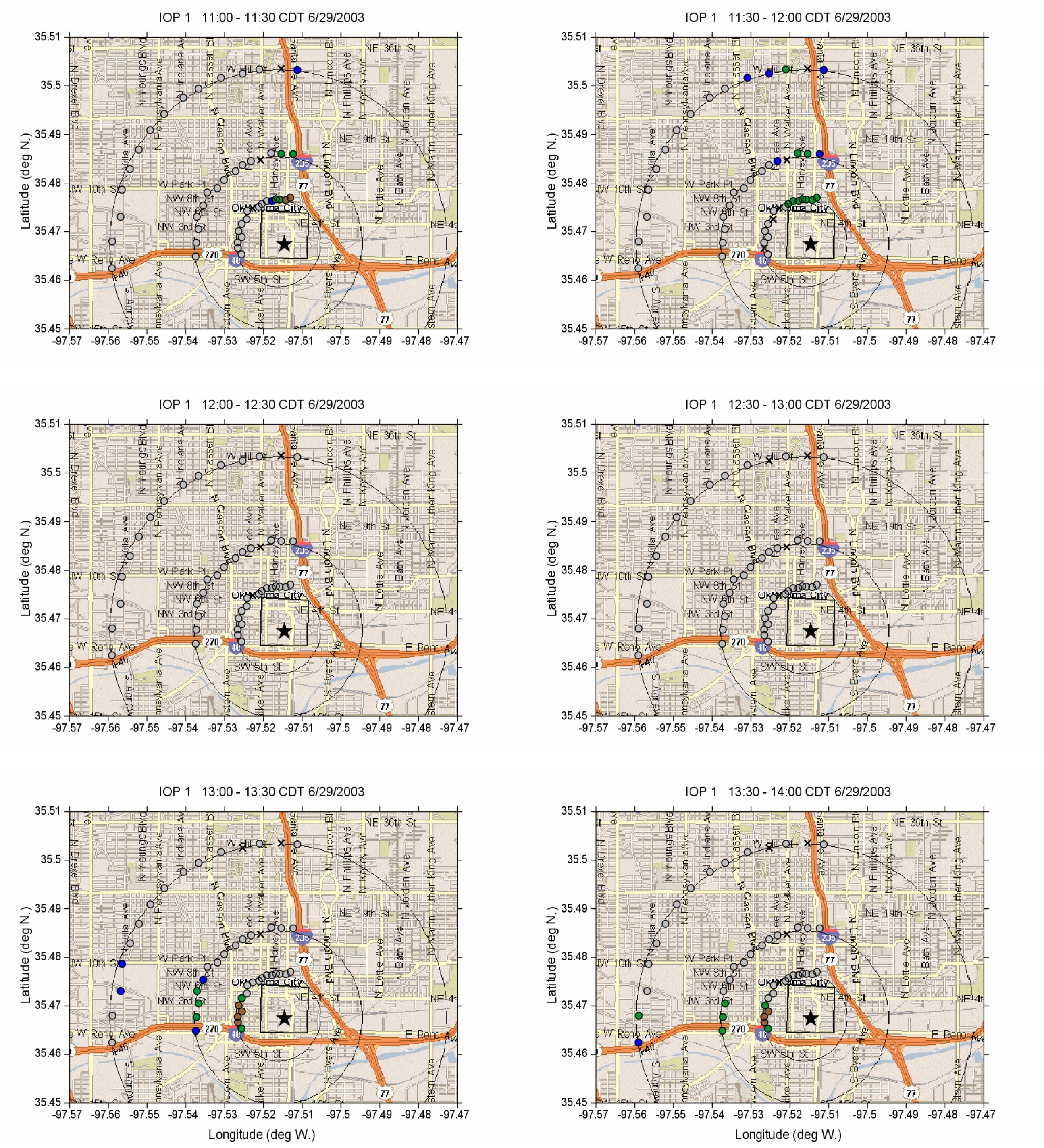

Figure 37. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 1 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and 1300-1330 CDT.

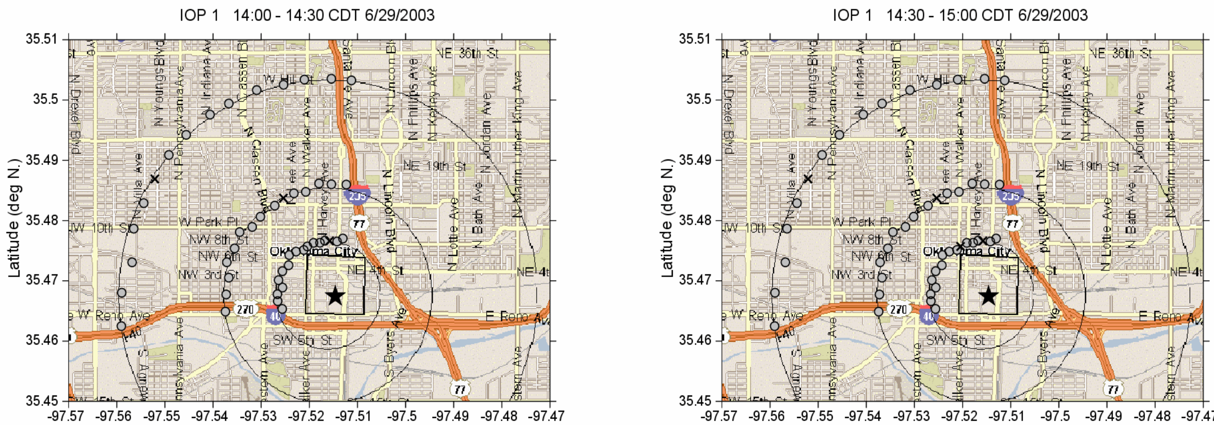

Figure 38. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 1 from 1400-1500 CDT. No releases occurred during this time period.

Maximum reported concentration results for each of the TGAs are presented in Table 14. The maximum concentration used to calibrate the TGAs was 10,120 pptv in IOPs 1 to 5. (IOPs 6 to 10 used 10,440 pptv.) Above this concentration the measurements become more uncertain because they are based on an extrapolation of the calibration curve. Consequently, all concentrations more than 15% above the highest calibration standard were flagged as estimates and appear in the tables in *italics*. Note that the maximum measured value may be flagged as an estimate while the majority of the data below this value are completely valid.

Beyond this over calibration range limit, the instrument eventually reaches a point where the electronic amplifiers are saturated and can go no higher. This condition is commonly referred to as "railing" and is characterized by a constant high output voltage. The concentration at which this occurs at depends on many factors and is different every time it occurs. When this condition occurrs, the maximum value is reported in the tables as "greater than" the railing concentration. These are also printed in *italics*. In addition, maximum values reported for peaks that contain substantial missing or flagged data are also in *italics*.

When the TGA dilution system is in use, the incoming sample air is mixed with an equal amount of Ultrapure air. Thus the sampled concentration is two times the concentration measured by the TGA. So when the TGA is measuring 10,000 pptv, the actual sampled concentration (and the reported concentration) is 20,000 pptv. This effectively doubles both the calibration range limit and the limit at which railing occurs. The tables take into account dilution system use. Non italicized values above 11,600 pptv were measured with the dilution system on. Railing occurred on TGAs 0, 1, 4, 5, 6, 7, and 9 during IOP 1. Close temporal spacing of the puffs made it difficult to determine which puff produced a given detected concentration, particularly for TGA 5 that made multiple passes through some puffs. TGA 4 (the eastern-most detector) was in the direct path of the dispersing tracer plume until point release 2 when the wind abruptly shifted to the SE, causing the plume to heavily impact the western-most detector (TGA 9). TGA 7 was stationed on the roof of a parking garage above TGA 6. Both locations were about 100 m north of the Westin release site. A comparison of their concentration measurements provides an indication of whether or not a plume rose to the building tops.

Table 14. Maximum TGA-sampled concentrations (pptv) during IOP 1.

TGA	Puff 1	Puff 2	Puff 3	Puff 4	Puff 5	Puff 6	Point 1	Point 2
0	0	0	0	0	560	*78*	*>23,700*	0
1	0	0	0	0	0	0	*>15,200*	0
2	0	0	0	0	0	0	*12,600*	0
3	*97*	*65*	*102*	*86*	142	*86*	*14,700*	0
4	*>24,600*	*>24,200*	*>24,500*	*>24,400*	*>24,400*	*>24,400*	*29,500*	0
5	*>14,000*	*13,700*	*12,500*	3,620	8,870	5,820	*13,000*	9,540
6	0	*>12,300*	714	0	0	0	1,890	*23,800*
7	0	78	0	0	0	0	481	*>12,400*
8	0	0	0	0	0	0	*12,100*	0
9	0	0	0	0	0	0	2,680	*>11,100*

IOP 2, Wednesday, 2 July 2003

1. Meteorological Synopsis. Skies were mostly clear. Winds were predominately SSW, except backing towards SSE at the surface level during the 3rd continuous release. The 100-m sodar winds, which trended toward the W and then toward the NW at the end of IOP 2, are presented in Table 15. Wind speeds at 100-m were fairly light, initially 4–7 m s^{-1}, diminishing to 2–3 m s^{-1} towards the end of IOP 2.

Table 15. Sodar winds (15-min. averages) at 100-m AGL during IOP 2.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
0900	4.8	204	1115	5.5	222	1330	4.3	294
0915	4.6	191	1130	7.6	233	1345	2.9	273
0930	5.3	184	1145	5.8	244	1400	3.7	272
0945	4.8	218	1200	7.5	241	1415	1.9	263
1000	4.5	210	1215	3.5	244	1430	2.7	284
1015	5.6	175	1230	4.9	250	1445	3.4	301
1030	4.9	197	1245	4.8	266	1500	4.3	295
1045	6.1	210	1300	5.6	267	1515	1.8	300
1100	6.6	213	1315	6.0	277	1530	2.9	273

2. Release Summary. The release van was positioned on Broadway in front of the Westin Hotel at parking meter #1461. Puff releases of 1,000 g were made at 0900, 0920, and 0940 CDT. The final puff release for this IOP was 1,041 g at 1000 CDT. Continuous 30-minute releases were initiated at 1100, 1300, and 1500 hrs CDT, with release rates of 5.01, 4.96, and 4.99 g s^{-1} respectively.

3. Sampler Deployment Summary. The integrated samplers were set out on the arcs in anticipation of a SE flow (red arc segment, Fig. 30). A full compliment of rooftop and pedestrian tunnel samplers were also installed. Van-mounted TGAs were initially deployed as shown in Table 16. A plot of the TGA positions including the general path of the mobile analyzer is shown in Fig. 39. This was the only daytime IOP where TGA 7 was not placed at rooftop level.

Table 16. Initial TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 2.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.47193	.5181	SW corner of 4th Street & Harvey, meter 1063
5	--	--	Mobile on 4th Street
6	.46980	.5181	SW corner of Kerr & Harvey, meter 1119
7	.46982	.5193	SE corner of Kerr & Hudson, meter 1112
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park and Robinson, meter 2113

At 1030 CDT, TGAs 1, 2, 4, 6, 7, and 9 were re-deployed to more easterly positions shown in Table 17. Except for TGA 9, all TGAs were in position for the 1100 CDT continuous release. TGA 9 arrived at the assigned position shortly after the release began. They remained at these positions for all three of the IOP 2 continuous releases.

Table 17. Final TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations during IOP 2.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47069	.5099	On 3rd Street between Walnut & Oklahoma
2	.47087	.5126	Corner of 3rd & Gaylord, meter 0034 (just west of the railroad overpass)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway
4	.47168	.5119	Corner of 4th & Gaylord (just east of the railroad overpass)
5	--	--	Mobile on 4th Street
6	.46963	.5108	SW corner of 2nd & Oklahoma
7	.46966	.5117	Corner of 2nd & Gaylord (just east of the railroad overpass)
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.47194	.5092	NW corner of 4th & Walnut

Figure 39. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1-km arc (red circle) during IOP 2.

4. IOP 2 Results. Table 18 summarizes maximum tracer concentrations reported by the time-integrated samplers positioned in the CBD (locations 003-087), in the pedestrian tunnel (locations 401-404), and on rooftops (locations 940-965). Samplers on the eastern edge of the CBD array (see Fig. 31) received the greatest tracer concentrations due to SW flow, although the 1500 CDT release impacted most of the CBD. Preferential flow for the entire IOP was along Broadway and Gaylord. Concentrations at samplers near the release site were particularly high due to slow dispersion in light winds (Figs. 40 and 41). Summaries of time-integrated sampler maxima for the 1-, 2-, and 4-km arcs are presented in Table 19. The dispersing plume intercepted the north end of the 1 km sampler arc segment, but continued further east and missed most of the 2 and 4 km arcs (Figs. 42 and 43). In fact, there was no significant impact of the plume on any of the arc-based samplers during the first point source release at 1100-1130 CDT.

Table 18. Summary of maximum reported concentrations (pptv) for integrating samplers positioned in the CBD at street-level, the pedestrian tunnel, and on rooftops during IOP 2. “R” indicates the release site.

		Walker	Hudson	Harvey	Robinson	Between	Broadway	Gaylord	Oklahoma	Walnut
Street-level Samplers		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y		15	239	1,959		**3,975**	1,382		
4th St.	07y	6	17	253	2,624		**6,203**	3,380		
McGee	06y	5	9	826	4,910	6,273	**9,992**	5,616		
Kerr	05y	3	6	-999	7,635	21,240	**38,730**	11,220		
Park	04y	5	6	9	299	7,437	**69,894**	18,031		
Main	03y	5	7	6			R	**5,140**		
Sheridan	02y	6	6	5				**9**		
California	01y				**6**			**6**		
Reno	00y			**6**						
Rooftop Samplers		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			793	2,099	**5,438**				
Kerr	05y			8,665 (950)	1,064	2,953	**33,558**			
Park	04y			12 (940)		14,489	**27,139**			
Main	03y						R			
Sheridan	02y									
California	01y									
Reno	00y									
Tunnel Samplers										
401	-999									
402	**3,311**									
403	2,555									
404	399									

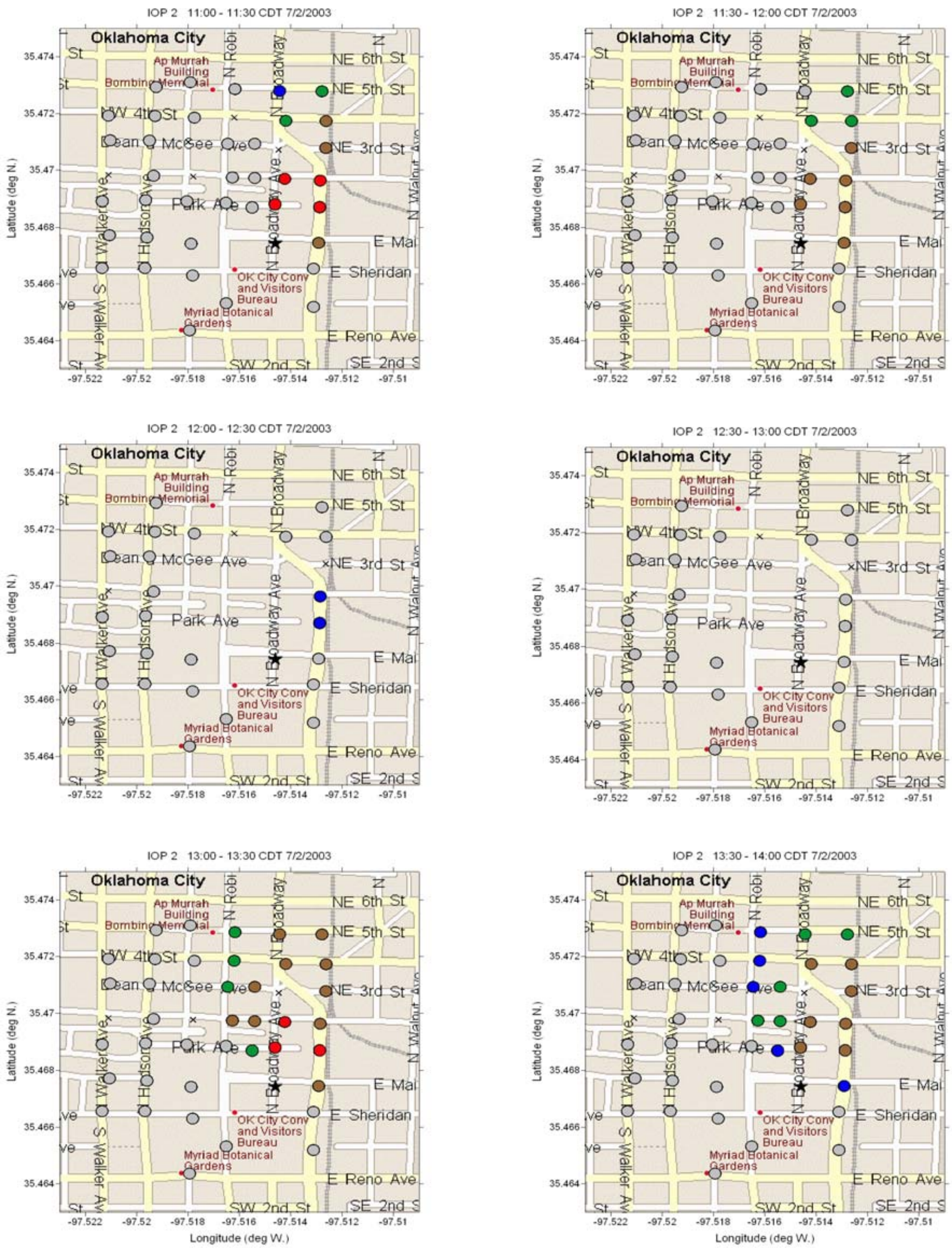

Figure 40. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 2 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and 1300-1330 CDT.

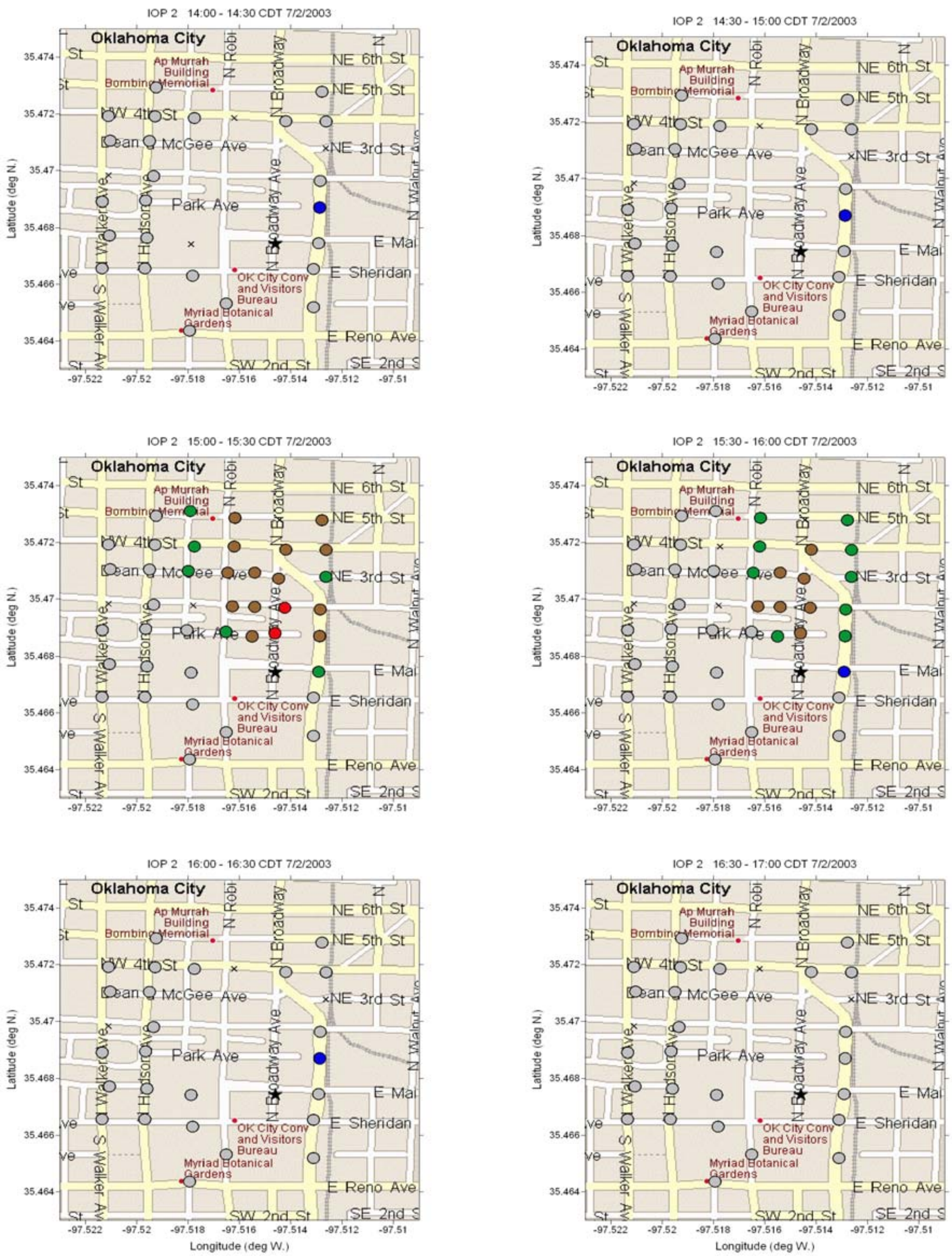

Figure 41. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 2 from 1400-1700 CDT. Tracer release occurred from 1500-1530 CDT.

Table 19. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 2.

1-km arcs		2-km arcs		4-km arcs	
Location	Conc.	Location	Conc.	Location	Conc.
501	6	-	-	-	-
502	6	531	6	561	6
503	6	532	6	562	6
504	7	533	6	563	6
505	5	534	5	564	6
506	6	535	5	565	6
507	7	536	6	566	6
508	5	537	6	567	5
509	6	538	5	568	5
510	6	539	5	569	5
511	10	540	5	570	6
512	11	541	7	571	6
513	*352*	542	34	572	6
514	95	543	96	573	6
515	**1,359**	544	210	574	9
516	1,125	545	**268**	575	**35**
517	1,004	-	-	-	-

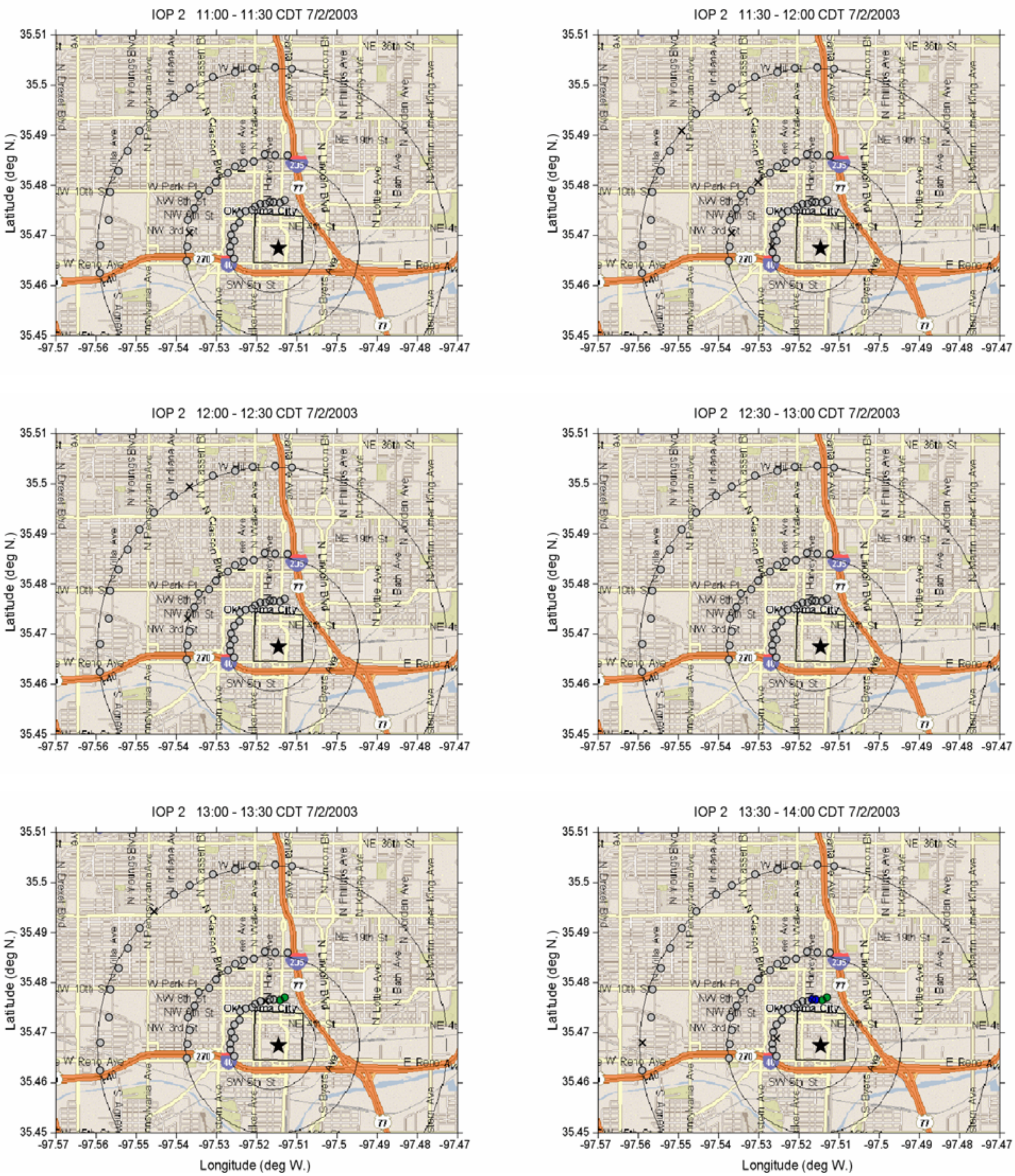

Figure 42. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 2 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and1300-1330 CDT.

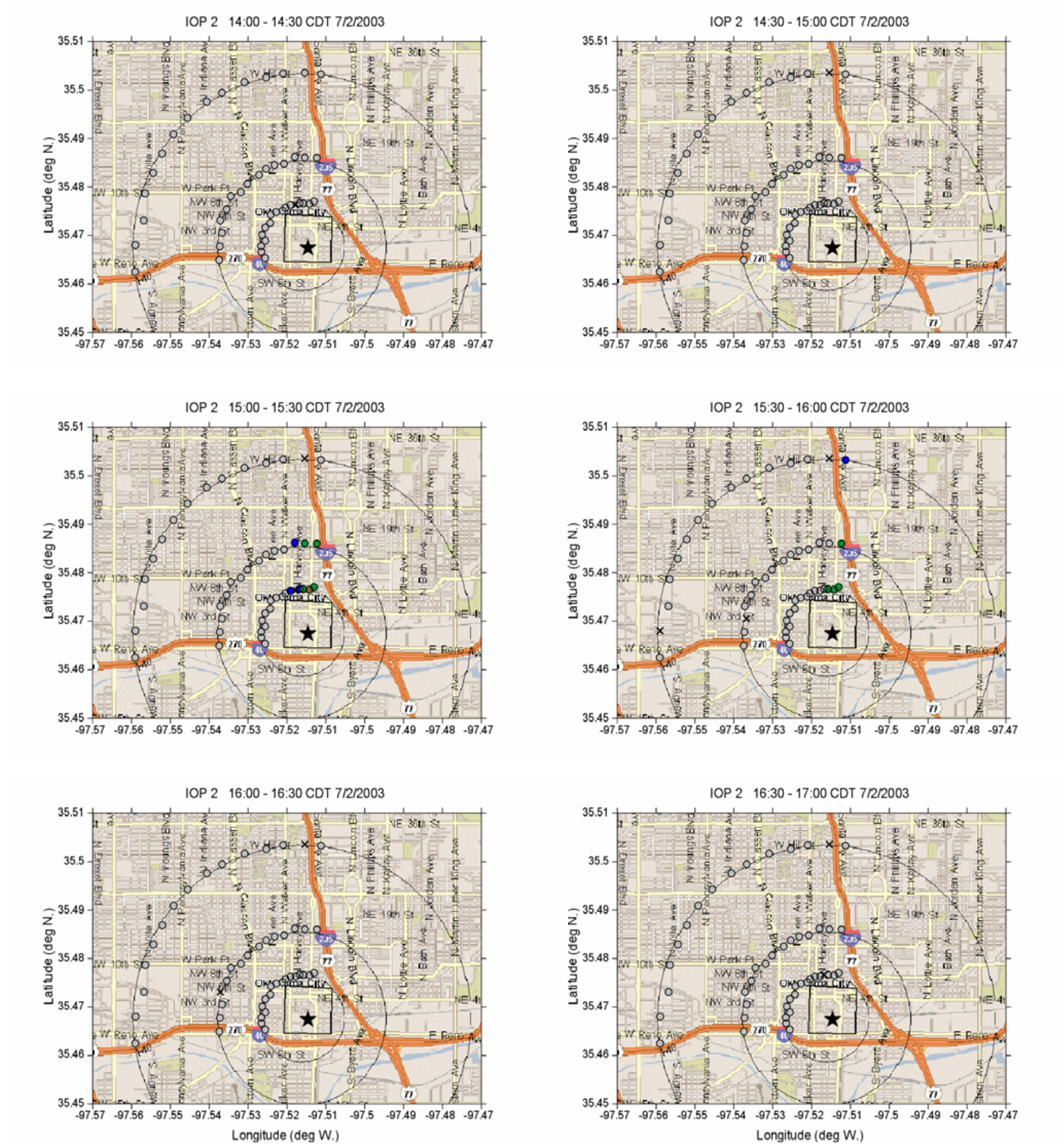

Figure 43. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 2 from 1400-1700 CDT. Tracer release occurred from 1500-1530 CDT.

The plume missed most of the stationary TGAs during the puff releases, but was sampled by the mobile van (TGA 5) as it traversed along 4th Street. Re-deployment of the TGAs to more easterly positions provided improved exposure to the dispersing plumes during the point releases. TGA 0 at the corner of Kerr and Broadway measured the highest tracer concentrations during the point releases, confirming the preferential tracer flow along Broadway. TGAs 0, 6, and 7 experienced railing due to tracer concentrations in excess of instrument limits. Maximum TGA concentrations reported for IOP 2 are presented in Table 20. As in IOP 1, results that include substantial missing data, are over-range, railed or otherwise flagged are presented in italics.

Table 20. Maximum TGA-sampled concentrations (pptv) during IOP 2.

TGA	Puff 1	Puff 2	Puff 3	Puff 4	Point 1	Point 2	Point 3
0	0	958	0	0	*26,900*	*>26,800*	*>26,700*
1	*378*	*251*	*311*	*211*	*11,800*	7,130	*1,440*
2	0	0	0	0	*12,200*	*13,000*	11,300
3	137	114	74	97	290	11,200	*15,100*
4	0	0	0	0	*12,300*	*12,100*	9,430
5	2,750	*12,400*	4,520	4,590	10,700	9,970	*12,600*
6	0	0	0	0	*>12,400*	7,400	1,300
7	206	0	0	*60*	*>12,500*	>12,800	1,340
8	0	34	106	61	0	*12,100*	11,600
9	0	0	0	0	9,270	7,090	397

IOP 3, Monday, 7 July 2003

1. Meteorological Synopsis. Skies were mostly cloudy during the morning puff releases, but began clearing at mid-day and were mostly clear by the third continuous release (1500 CDT). Surface winds remained S at 7-10 m s^{-1} for the entire IOP, although 100-m winds shown in Table 21 indicate a trend from SW through SE.

Table 21. Sodar winds (15-min. averages) at 100-m AGL for IOP 3. (Note: The number -950 indicates missing data.)

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
0900	-950	-950	1115	8.7	220	1330	5.6	198
0915	9.8	205	1130	10.0	209	1345	10.5	181
0930	6.7	201	1145	7.8	225	1400	9.9	169
0945	5.8	204	1200	9.1	201	1415	10.5	166
1000	5.9	211	1215	-950	-950	1430	9.5	170
1015	6.7	221	1230	8.1	204	1445	10.3	176
1030	7.7	202	1245	8.8	196	1500	8.4	178
1045	7.7	211	1300	-950	-950	1515	10.7	165
1100	8.7	213	1315	8.9	198	1530	9.5	174

2. Release Summary. The release van was located on Roland Norick Blvd next to the Myriad Botanical Gardens. The balloon slipped off the fill nozzle at 0855 CDT during preparation for the first puff release, releasing approximately 100 g of SF_6. This unintended puff release was reported by TGA 8. The first scheduled puff of 1,000 g was released at 0900 CDT. Puffs of 1,005, 1,000, and 1,004 g were released at 0920, 0940, and 1000 CDT. Thirty-minute continuous releases of 4.94, 3.02, and 3.02 g s^{-1} were made at 1100, 1300, and 1500 hrs CDT.

3. Sampler Deployment Summary. A full complement of integrated samplers was set out in the CBD, in the pedestrian tunnel, and on rooftops. The forecast of southwesterly winds led to decoration of the SSW arc segments (blue arc segment, Fig. 30), with time-integrating samplers at positions 507 through 523 (1 km arc), 537 through 551 (2 km arc), and 567 through 581 (4 km arc). The real-time analyzers were also fully deployed as shown in Fig. 44. During the puff releases, TGA 5 remained on 4th Street. However, during the 1st continuous release of IOP 3 the TGA started out on 10th Ave and zigzagged its way up to 13th Ave, then to 16th Ave and eventually ended sampling on 23rd Ave. TGA 5 was moved back down to 8th Street at the start of the 2nd continuous release. No plume was found on 8th Street during the 2rd continuous release and so the TGA headed toward 4th Street, however, the driver of the TGA took a wrong turn and ended up heading south on the I-235 freeway. The TGA then went west on I-40 and took the 1st exit going north onto Broadway before eventually returning to its correct sampling destination. During the 3rd continuous release, the TGA remained on 8th Street. The rest of the TGAs were deployed as shown in Table 22 for IOP 3.

Table 22. TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 3.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46870	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile on 4th, 8th, 10th, 16th, and 23rd Streets
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street parking garage
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park and Robinson, meter 2113

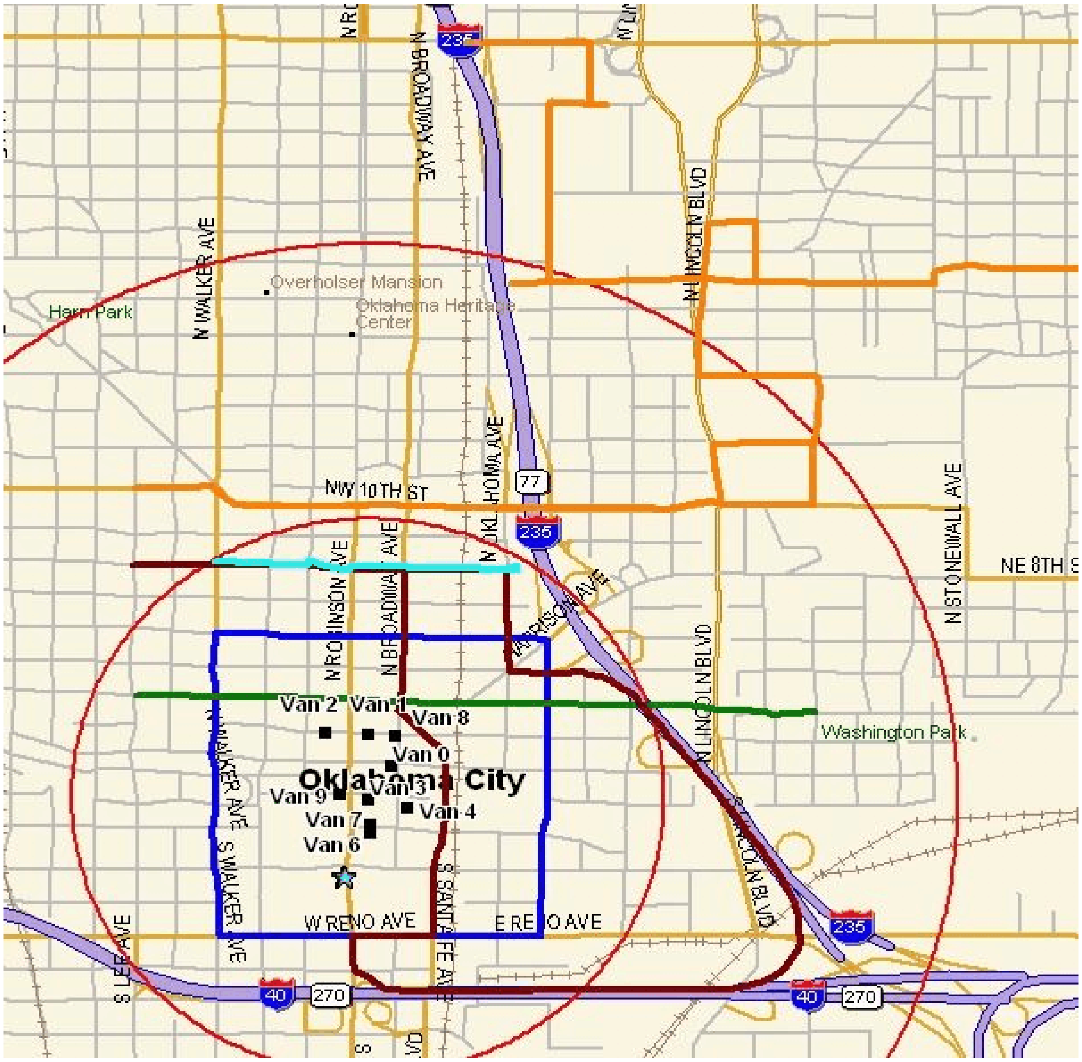

Figure 44. Stationary TGAs (black squares), general path of the mobile TGA during the puff releases (green line), 1st continuous release (orange line), 2nd continuous release (maroon line), 3rd continuous release (light blue line), release site (blue star), CBD (blue box), and the 1- and 2-km arc (red circles) during IOP 3.

4. IOP 3 Results. The tracer plumes were widely distributed through sections of the CBD north of the release position (Fig. 45 and 46). While substantial, the tracer concentrations within the CBD (Table 23) were lower than those obtained during the lighter wind conditions found in either IOP 1 or 2. Preferential tracer flow was again along Broadway. This was the first IOP where maximum rooftop concentrations were similar to street level samplers. The highest concentration for tunnel samplers (4,755 pptv) was measured at location number 401. The tracer plume also passed north through the center of the three sampling arcs (Figs. 47 and 48). Maximum concentrations along the arcs were not as high as the previous IOP but more samplers recorded concentrations above the MLOQ (> 111 pptv) suggesting a wider plume during this IOP (Table 24).

Table 23. Summary of maximum reported concentration (pptv) for integrating samplers placed in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 3. "R" indicates the release site.

		Walker	Hudson	Harvey	Robinson	Between	Broadway	Gaylord	Oklahoma	Walnut
Street-level Samplers										
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y		158	483	*580*		**1,332**	545		
4th St.	07y		114	556	1,893		**2,385**	1,411	609	
McGee	06y	20	74	1,460	1,637	*2,763*	**2,800**	1,417	791	228
Kerr	05y	16	169	*319*	*3,180*	*1,905*	**4,263**	411	729	66
Park	04y		238	-999	4,174	**7,452**	3,499	2,386		
Main	03y		22	**7,317**				2,022		
Sheridan	02y			531	R			**5,866**		
California	01y				**45**			6		
Reno	00y			**8**						
Rooftop Samplers										
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			*1,280*	2,277	**2,607**				
Kerr	05y			3,350 (950)	**3,667**	3,643	3,629			
Park	04y				1,545 (940)	6,397	**6,650**			
Main	03y									
Sheridan	02y				R					
California	01y									
Reno	00y									

Tunnel Samplers

401	**4,755**
402	969
403	2,673
404	102

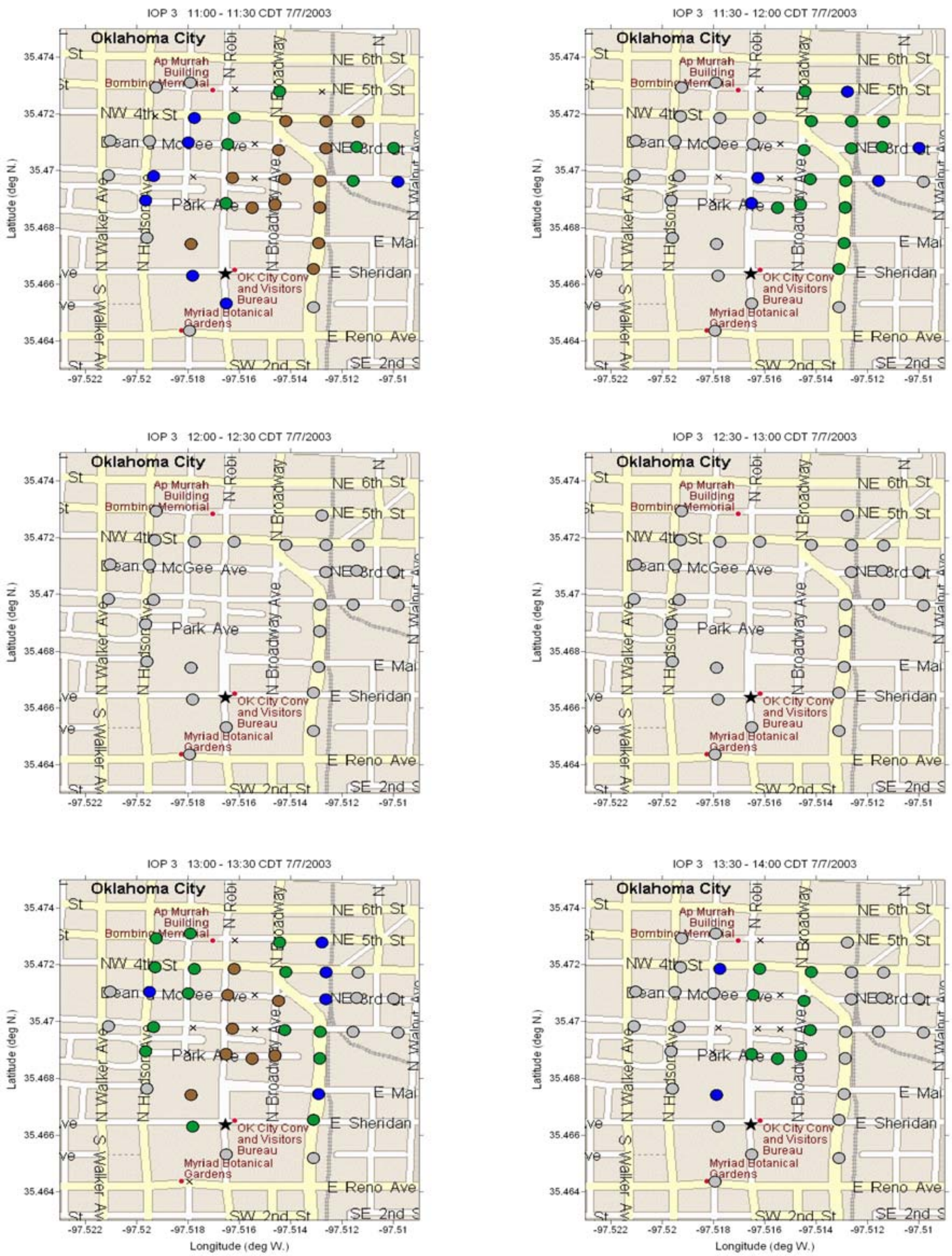

Figure 45. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 3 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and 1300-1330 CDT.

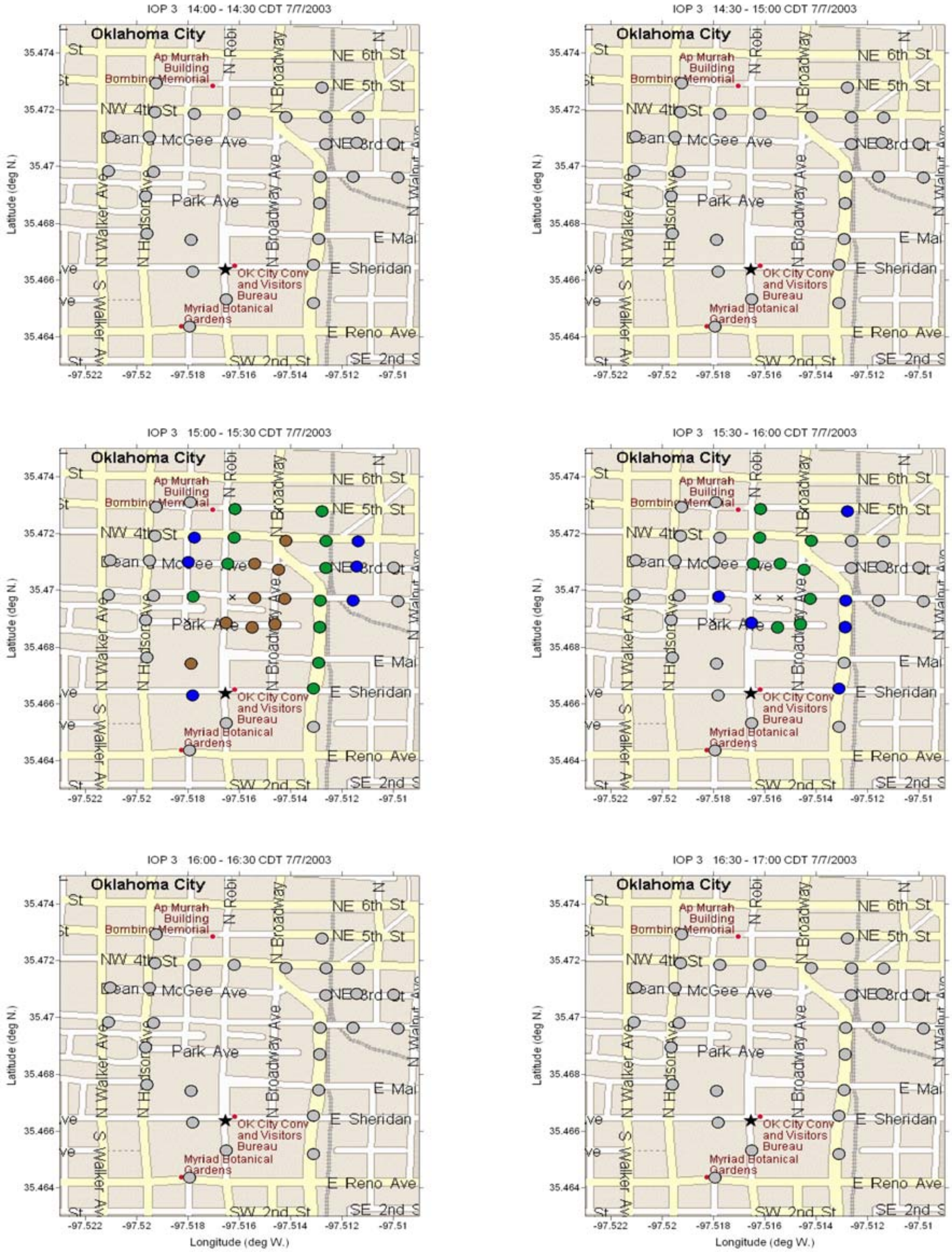

Figure 46. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 3 from 1400-1700 CDT. Tracer release occurred from 1500-1530 CDT.

Table 24. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 3.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	5	-	-	-	-
508	5	537	5	567	*7*
509	6	538	5	568	7
510	7	539	5	569	6
511	102	540	6	570	5
512	144	541	5	571	-999
513	361	542	27	572	7
514	318	543	70	573	10
515	981	544	341	574	47
516	453	545	140	575	58
517	566	546	228	576	*39*
518	*791*	547	324	577	38
519	**1,011**	548	**420**	578	**149**
520	450	*549*	*145*	579	47
521	495	*550*	*68*	580	*5*
522	8	551	*7*	581	*6*
523	5	-	-	-	-

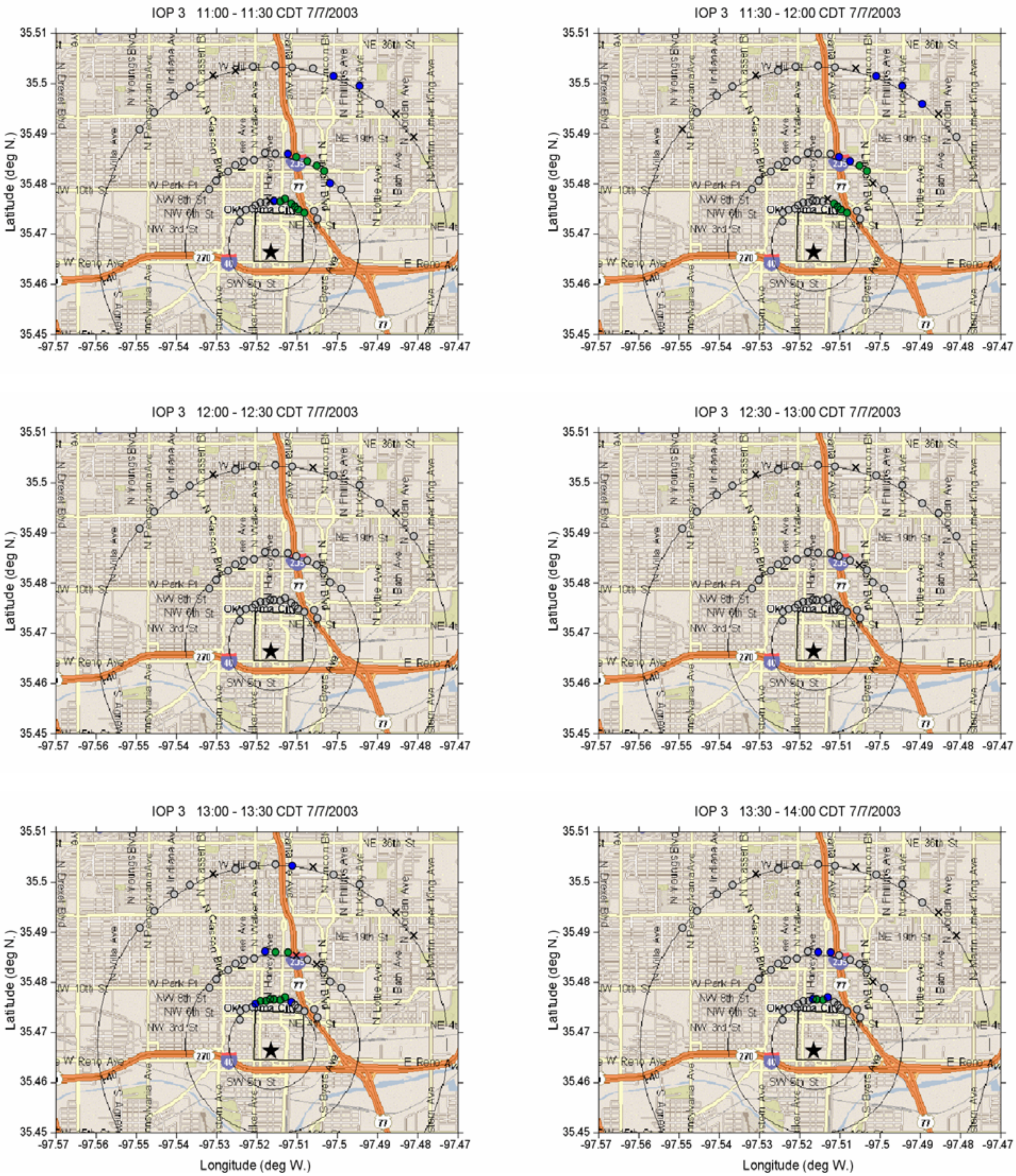

Figure 47. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 3 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and 1300-1330 CDT.

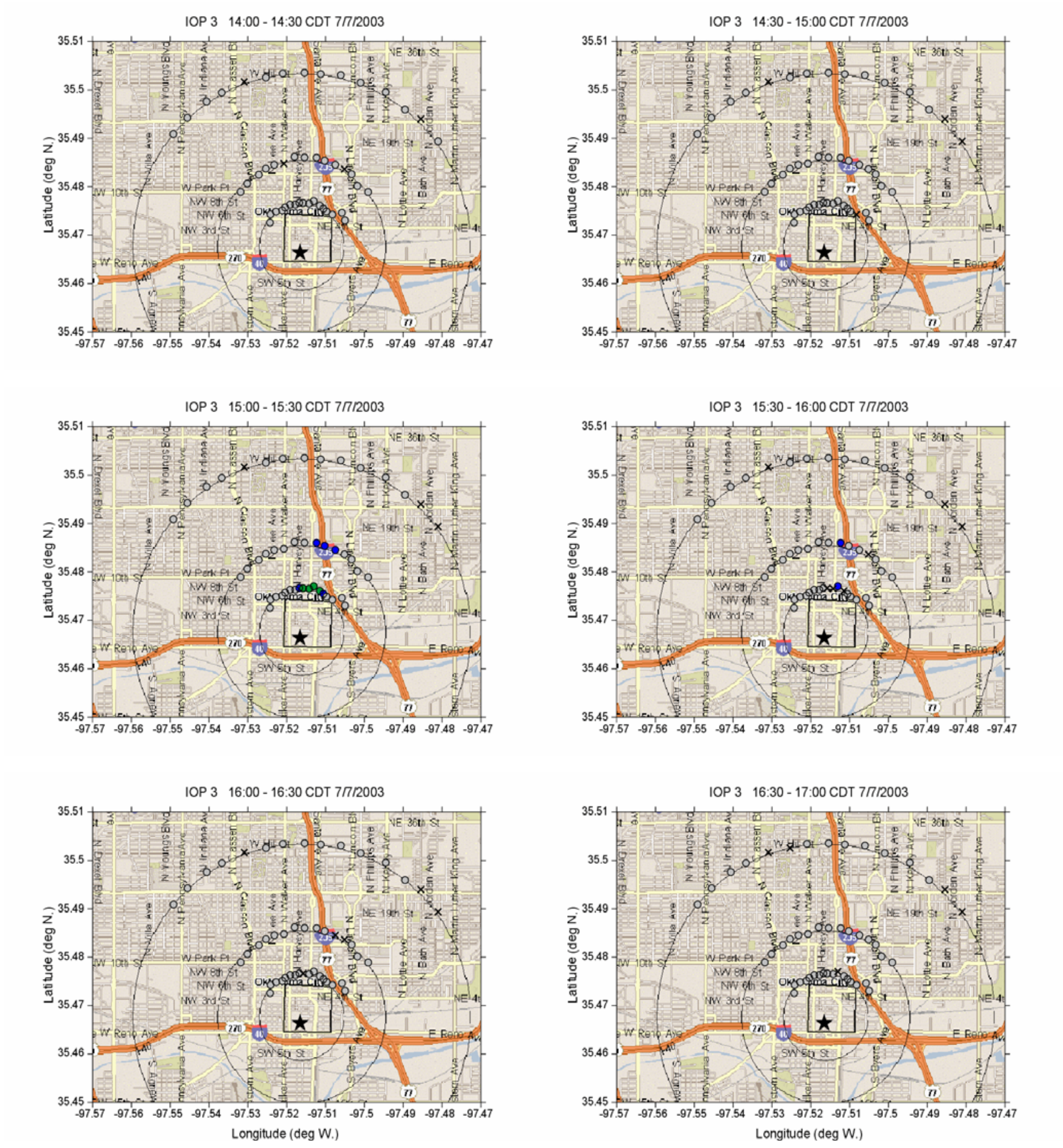

Figure 48. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 3 from 1400-1700 CDT. Tracer release occurred from 1500-1530 CDT.

Southerly through southwesterly winds provided substantial tracer concentrations on most of the TGAs (Table 25). TGAs 4, 6, 7, and 9, located within 300 m of the release site, experienced railing during continuous or puff releases as SF_6 concentrations exceeded instrument limits. TGA 4, located to the NE of the release point, received very high concentrations in the early part of the IOP when winds were more from the SW, and TGA 9 received high concentrations later when the wind was more southeasterly. Both TGAs 6 and 7 experienced high SF_6 concentrations, indicating that the tracer dispersed rapidly from street level to building tops throughout IOP 3. Note: No data were obtained from TGA 7 during the first continuous release due to dilution system problems.

Table 25. Maximum TGA-sampled concentrations (pptv) for IOP 3.

TGA	Puff 1	Puff 2	Puff 3	Puff 4	Point 1	Point 2	Point 3
0	12,600	12,300	19,600	9,140	12,900	11,500	8,930
1	3,130	0	4,180	3,260	9,830	9,930	8,070
2	0	0	202	0	4,640	7,290	5,490
3	10,100	1,710	*12,500*	4,730	*13,800*	*12,000*	*14,400*
4	*>13,000*	*>12,800*	*>25,800*	0	*24,100*	16,800	*12,300*
5	11,000	11,200	2,800	2,350	1,650	7,970	2,730
6	*>11,900*	21,600	*>23,700*	*23,700*	*23,900*	*>23,800*	*>23,800*
7	*>12,200*	*>12,100*	*>11,900*	*>11,600*	-999	*>26,000*	*>25,700*
8	4,808	163	10,700	3,060	9,530	8,990	8,730
9	0	329	*11,700*	881	8,540	*>11,700*	*>11,700*

IOP 4, Wednesday, 9 July 2003

1. Meteorological Synopsis. Skies were mostly clear. Surface winds were from the SSW at 7-10 m s^{-1}. Sodar 100-m winds (Table 26) indicated a wind direction trend from SW through SE as wind speeds increased from 6-13 m s^{-1}.

Table 26. Sodar winds (15-min. averages) at 100-m AGL for IOP 4.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
0900	7.3	208	1115	6.1	213	1330	10.4	172
0915	8.0	203	1130	-950	-950	1345	-950	-950
0930	6.0	213	1145	10.9	169	1400	9.8	170
0945	6.4	224	1200	9.0	210	1415	12.1	170
1000	5.8	217	1215	8.1	179	1430	12.2	161
1015	9.3	201	1230	9.2	192	1445	10.7	168
1030	8.7	198	1245	9.4	170	1500	13.4	160
1045	6.4	200	1300	9.2	192	1515	12.3	162
1100	10.2	211	1315	9.6	173	1530	13.4	164

2. Release Summary. IOP 4 releases occurred at the Myriad Botanical Garden location. Puff releases of 1,000, 1,005, 1,000, and 1,004 g were made at 0900, 0920, 0940, and 1000 CDT respectively. These were followed by three 30-minute continuous releases of 4.94, 3.02, and 3.02 g s^{-1} beginning at 1100, 1300, and 1500 hrs CDT respectively.

3. Sampler Deployment Summary. The integrating samplers were set out in anticipation of SSW winds (blue arc, Fig. 30). The CBD, pedestrian tunnel, and rooftop samplers were also set out for IOP 4. TGAs were deployed as shown in Table 27. A plot of the stationary TGAs and the general path of the mobile TGA can be seen in Fig. 49.

Table 27. TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street positions for IOP 4.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile on 4th and 8th Streets
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street parking garage
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park and Robinson, meter 2113

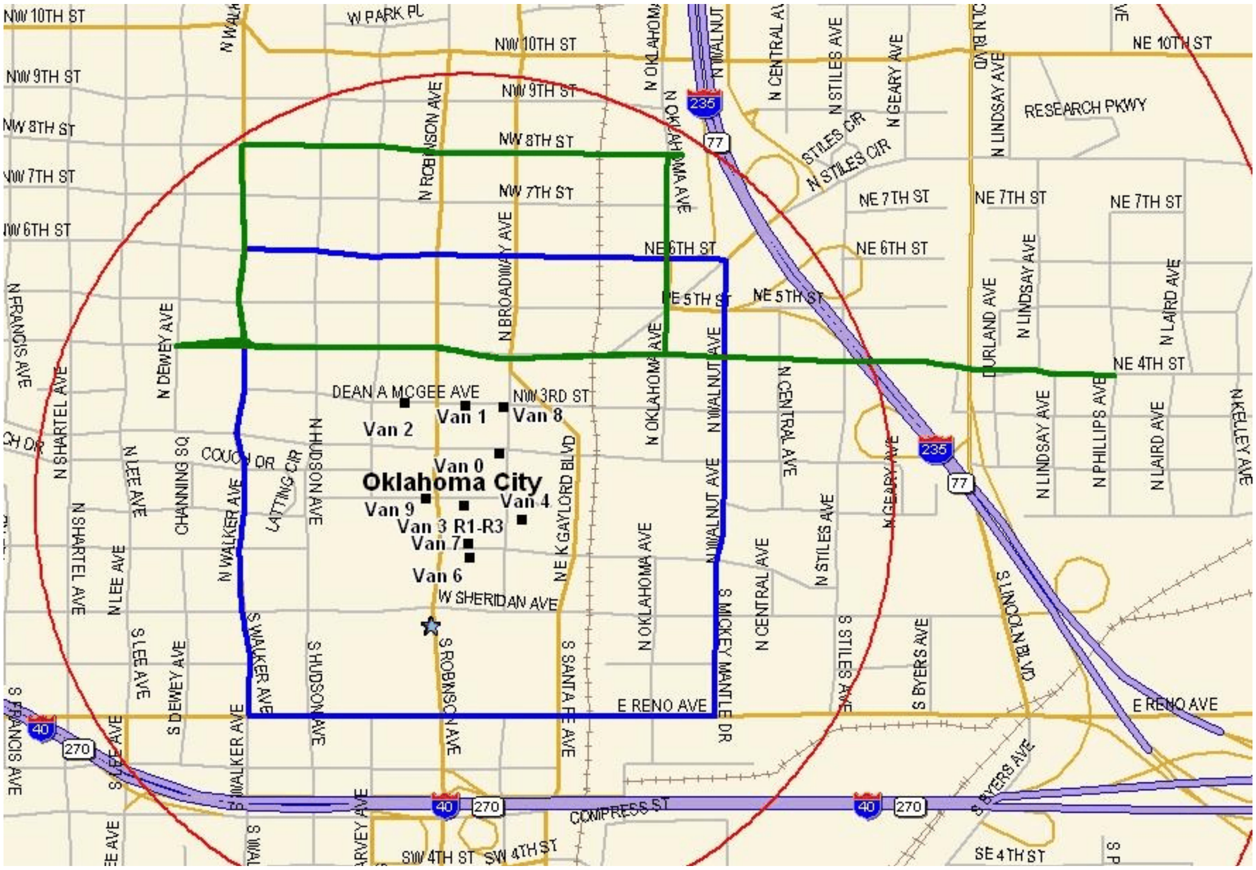

Figure 49. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1- and 2-km arc (red circles) during IOP 4.

4. <u>IOP 4 Results</u>. Overall maximum concentrations within the CBD were similar to IOP 3. The greatest tracer concentrations reported in Table 28 occurred at samplers with the final digits ending in 4 through 7, suggesting that the tracer plumes moved through the CBD in a northeasterly direction (Figs. 50 and 51). However preferential tracer flow did not appear to be along either Robinson or Broadway, but across the buildings between the two streets. The plumes then moved through the center of the 1-, 2-, and 4-km arcs as shown in Figs. 52 and 53. Maximum concentrations along the arcs were also similar to IOP 3 (Table 29).

Table 28. Summary of maximum reported concentrations (pptv) for integrating samplers positioned in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 4. "R" indicates the release site.

		Walker	Hudson	Harvey	Robinson	Between	Broadway	Gaylord	Oklahoma	Walnut
Street-level Samplers		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y		52	114	470		**1,354**	1,324		
4th St.	07y		83	159	1,510		1,454	**1,526**	908	
McGee	06y	5	68	*238*	2,455	**2,681**	*2,323*	1,388	924	454
Kerr	05y	5	131	*651*	***4,897***	*2,788*	4,434	1,615	701	164
Park	04y		155	923	3,159	**8,036**	6,149	2,350		
Main	03y		20	1,546				**1,972**		
Sheridan	02y			330	R			**6,440**		
California	01y				**51**			7		
Reno	00y			**5**						
Rooftop Samplers		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			*172*	586	**2,536**				
Kerr	05y			**3,968 (950)**	*1,089*	2,728	3,501			
Park	04y				581 (940)	**6,587**	6,363			
Main	03y									
Sheridan	02y				R					
California	01y									
Reno	00y									
Tunnel Samplers										
401	**4,560**									
402	*603*									
403	1,790									
404	*60*									

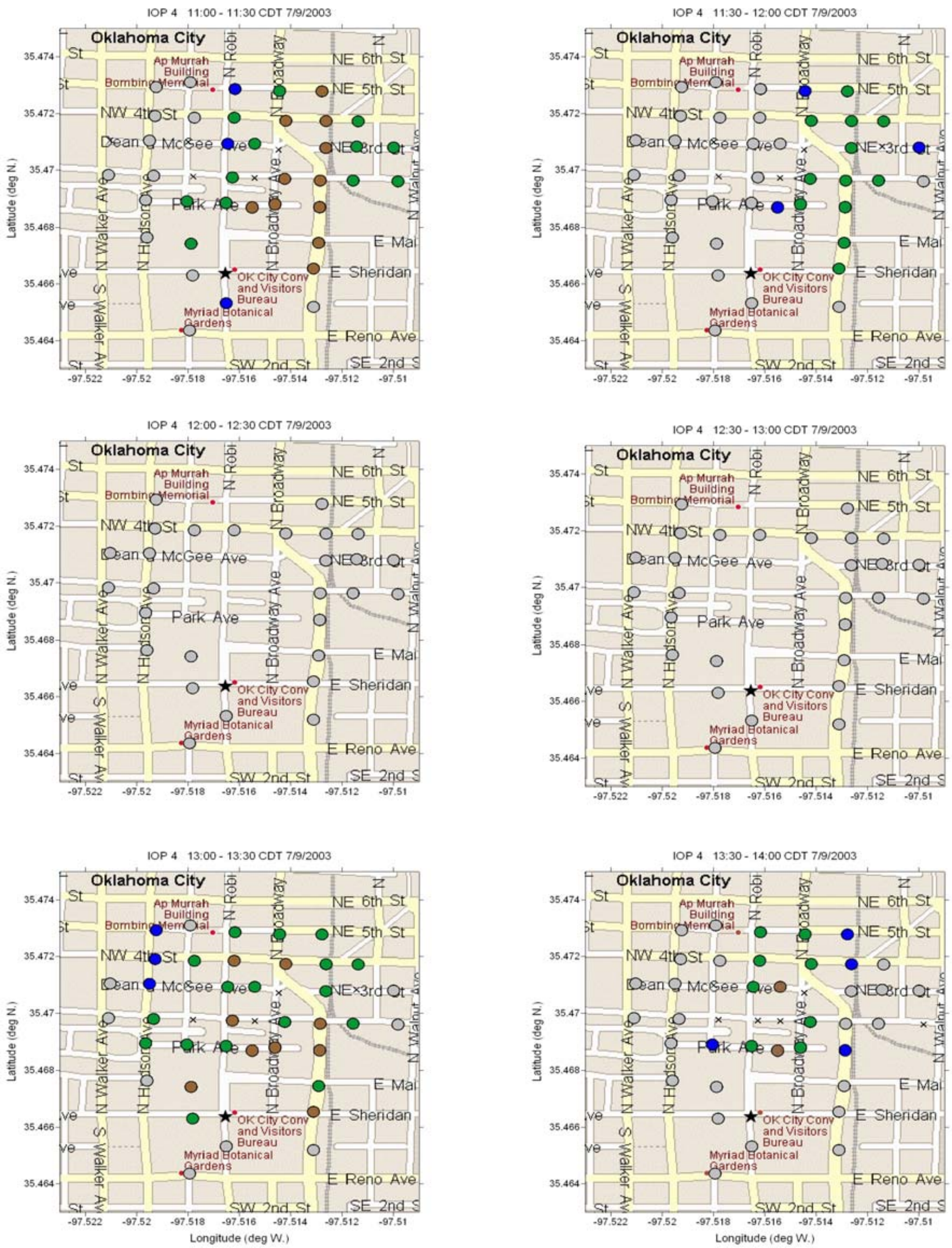

Figure 50. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 4 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and 1300-1330 CDT.

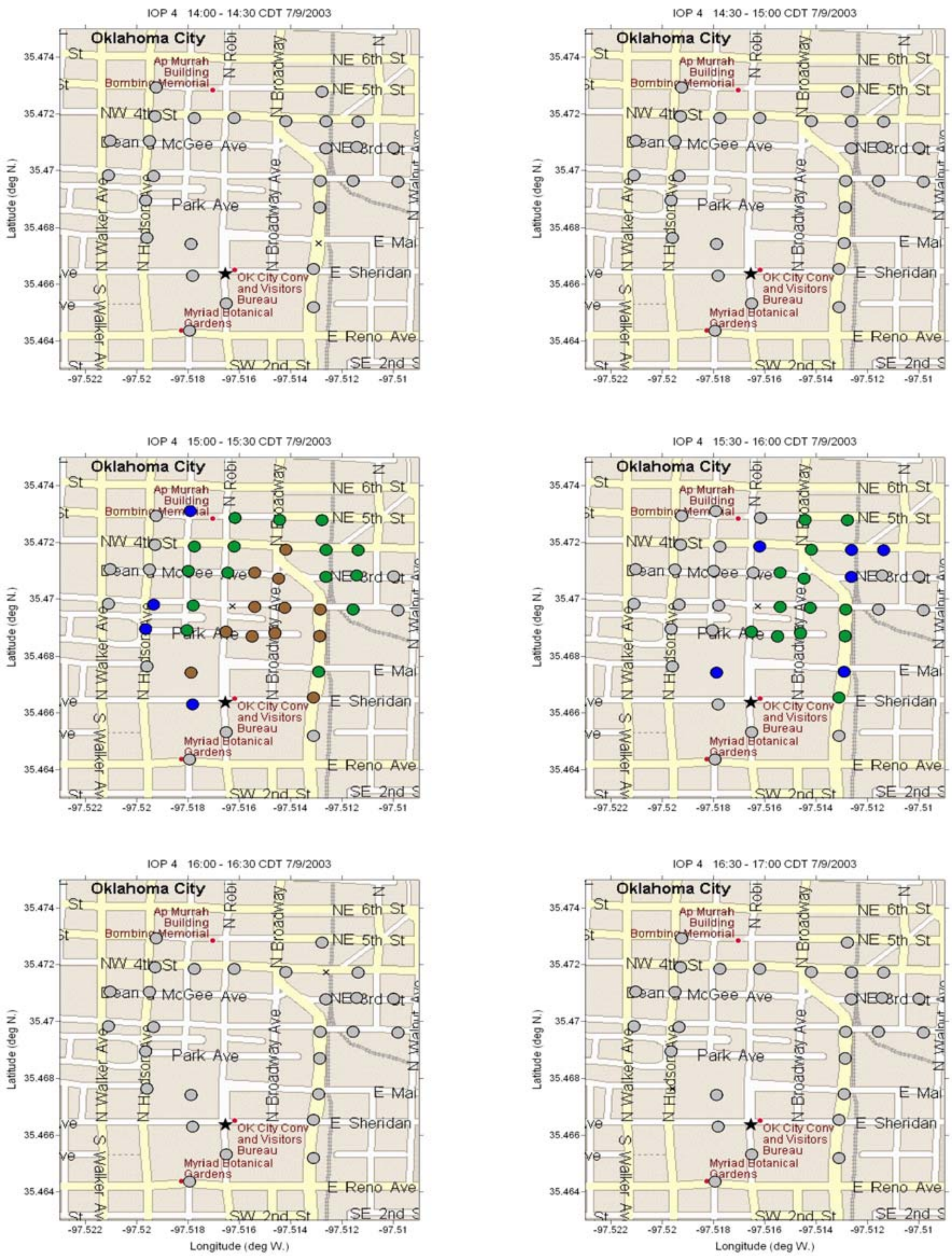

Figure 51. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 4 from 1400-1700 CDT. Tracer release occurred from 1500-1530 CDT.

Table 29. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 4.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	5	-	-	-	-
508	5	*537*	*5*	567	5
509	6	538	*7*	568	6
510	5	539	6	569	5
511	6	540	5	570	7
512	21	541	5	571	5
513	168	*542*	*5*	572	*5*
514	178	543	15	573	5
515	550	544	108	574	21
516	532	545	182	575	47
517	483	*546*	***227***	576	54
518	520	547	*145*	577	**56**
519	**980**	548	-999	578	54
520	580	549	140	579	46
521	345	550	162	580	11
522	104	551	18	581	*6*
523	28	-	-	-	-

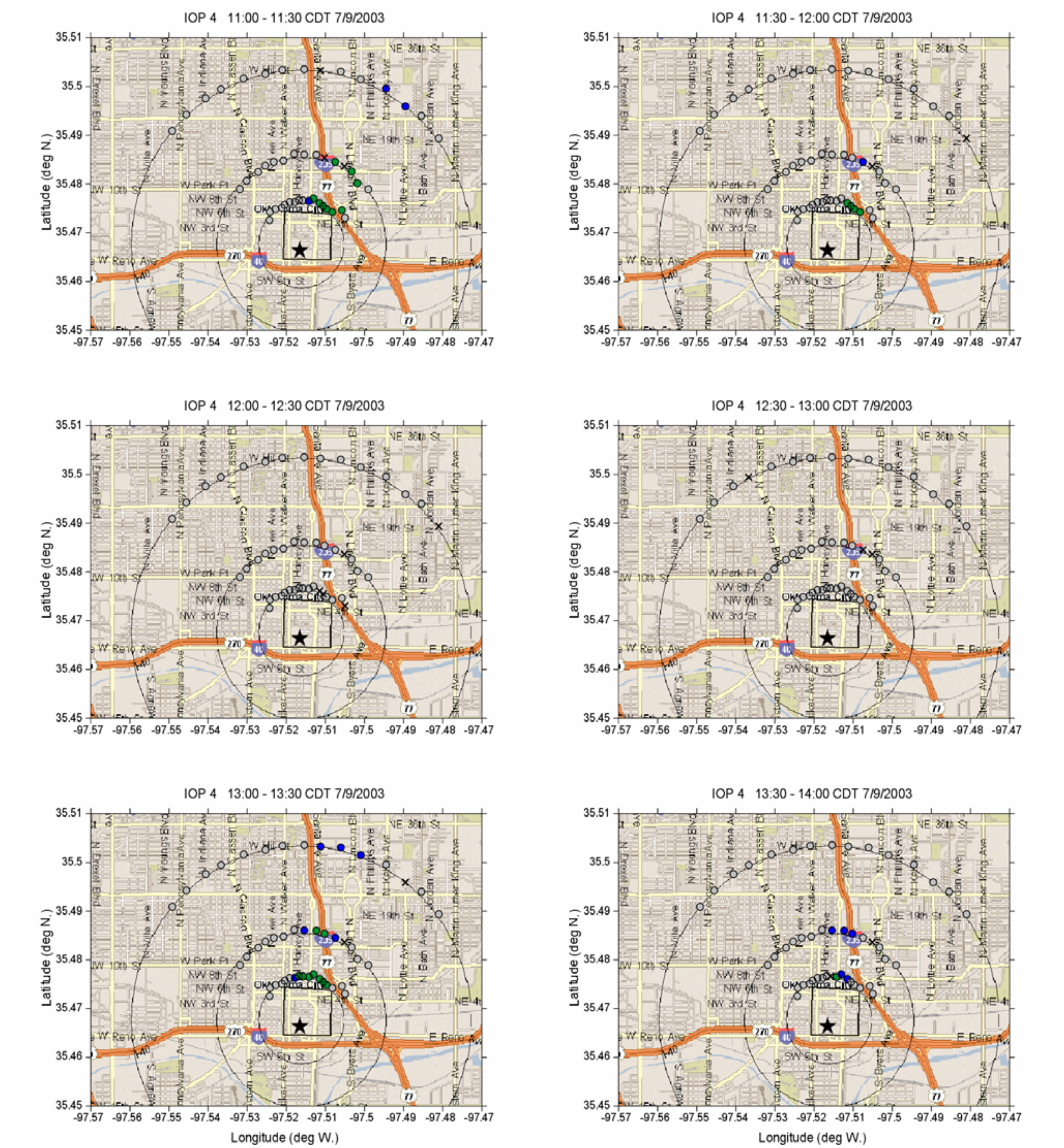

Figure 52. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 4 from 1100-1400 CDT. Tracer releases occurred from 1100-1130 and 1300-1330 CDT.

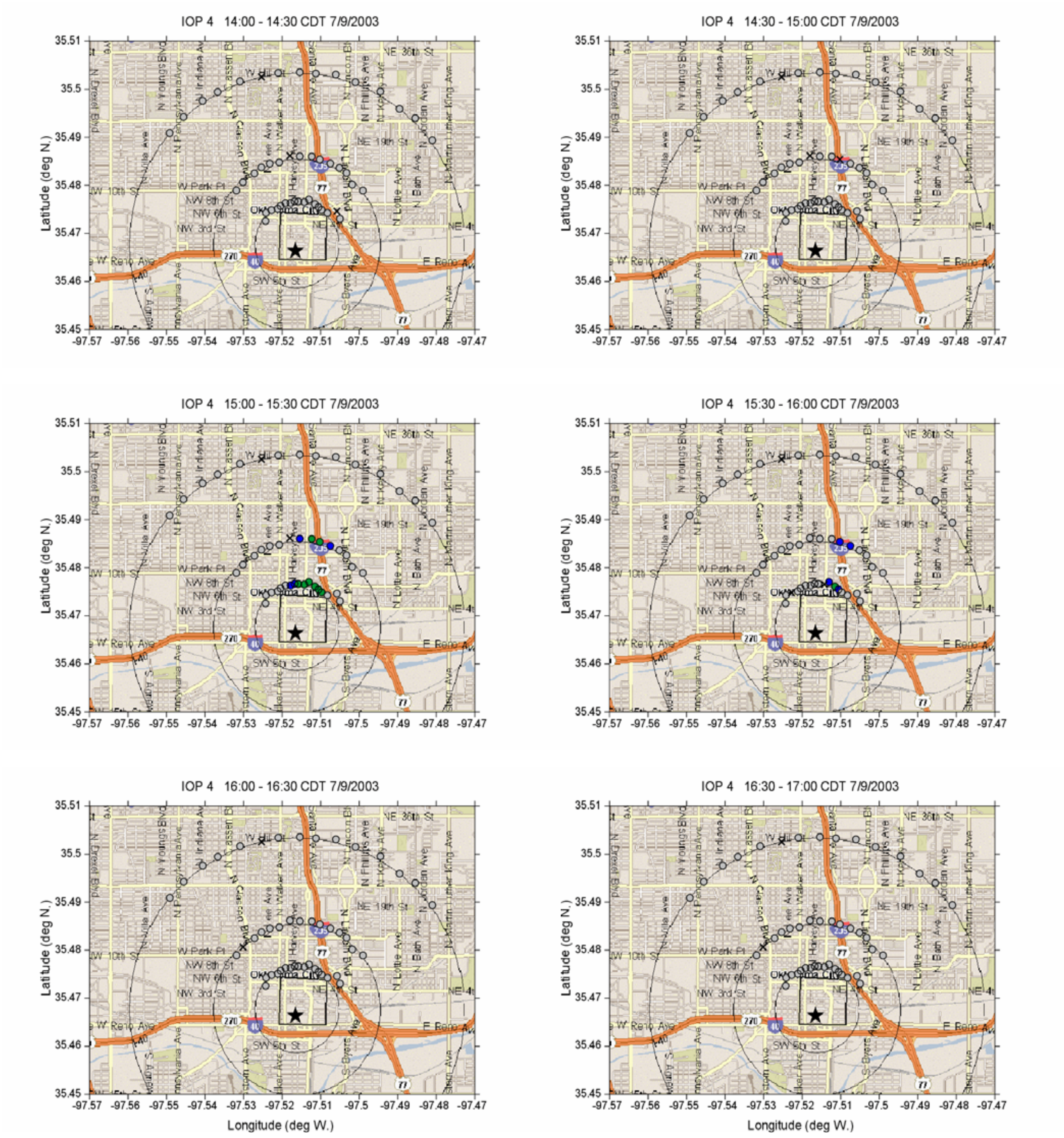

Figure 53. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 4 from 1400-1700 CDT. Tracer release occurred from 1500-1530 CDT.

The tracer plume initially passed over the eastern half of the TGA positions, but a substantial portion of the plume meandered west of north for the last two releases. TGAs 6, 7, and 9 experienced railing due to tracer concentration in excess of instrument limits. IOP 4 TGA concentration maxima are presented in Table 30. High SF_6 concentrations at TGA 7 indicate that the puffs and plumes rose rapidly to rooftop heights in the CBD.

Table 30. Maximum TGA-sampled concentrations (pptv) during IOP 4.

TGA	Puff 1	Puff 2	Puff 3	Point 1	Point 2	Point 3
0	973	11,500	1,160	8,370	*12,400*	*16,600*
1	*289*	837	0	4,630	8,660	6,420
2	0	0	0	421	6190	3,000
3	2,000	5,540	82	*13,200*	*13,800*	*14,400*
4	*25,200*	12,300	*25,500*	22,900	*24,300*	*12,100*
5	2,390	7,440	1,410	4,430	5,240	1,440
6	*>12,000*	*>23,900*	661	*>23,800*	*>23,600*	*>23,700*
7	*>26,300*	*>26,000*	*274*	*>26,200*	*>26,500*	*>26,400*
8	235	954	0	4,970	7,440	8,270
9	496	0	0	9,000	*>11,600*	*>11,600*

IOP 5, Sunday, 13 July 2003

1. Meteorological Summary. The morning began mostly cloudy, with scattered light rain-showers that ended after the 1st continuous release. A light shower wet the surface during the first continuous release. Skies gradually cleared by the 3rd continuous release (1330 CDT). Morning surface winds were SW at 4-5 m s^{-1}. Winds diminished to near calm during the 2nd continuous release, and remained light while backing to the SE in the afternoon. Sodar 100-m winds (Table 31) were generally in the 5-8 m s^{-1} range except for a period of lighter winds between 1200 and 1330 CDT. Wind directions trended from SW to SE during IOP 5.

Table 31. Sodar winds (15-min. averages) at 100-m AGL for IOP 5.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
0900	5.5	198	1130	5.3	225	1400	8.2	149
0915	6.5	198	1145	4.6	217	1415	8.0	152
0930	6.2	222	1200	3.9	184	1430	-950	-950
0945	6.0	225	1215	2.8	133	1445	-950	-950
1000	5.0	215	1230	2.1	117	1500	5.5	151
1015	6.7	214	1245	4.5	143	1515	6.0	136
1030	6.1	208	1300	1.5	125	1530	7.0	144
1045	6.8	216	1315	1.9	114	1545	8.1	162
1100	7.7	219	1330	2.5	102	1600	-950	-950
1115	7.8	218	1345	8.1	160	1615	7.8	157

2. Release Summary. The release van was positioned for a botanical release in front of the Myriad Botanical Gardens on Roland Norick Blvd. IOP 5 began with 30-minute continuous releases of 2.22, 3.04, and 3.09 g s^{-1} at 0900, 1100, and 1300 CDT. These were followed by puff releases of 499, 500, 500, and 500 g at 1500, 1520, 1540, and 1600 hrs CDT.

3. Sampler Deployment Summary. CBD and arc integrated samplers were set out in anticipation of a SW flow regime (blue arc segment, Fig. 30). There was no access to the underground walkways on the weekend and so no tunnel samplers were deployed during this IOP. TGA 5 was mobile on 4th and 8th Streets during the 1st and 2nd continuous releases. However after starting on 8th Street during both the 3rd continuous and 1st puff release, TGA 5 moved and sampled into the CBD for most of the release period. The other TGAs were deployed as shown in Table 32. A plot of the stationary TGAs and general path of the mobile TGA can be seen in Fig. 54.

Table 32. Initial TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations during IOP 5.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.46987	.5154	N. side of Kerr between Robinson & Broadway (in front of Kerr Tower)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of the Hallmark Store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile along 4th and 8th Streets, and CBD
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street parking garage
8	.47098	.5145	NW corner of McGee & Broadway
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

Lighter winds during the 2nd and 3rd continuous releases required the movement of TGAs 0, 1, 2, 3, and 8. Final TGA locations are shown in Table 33.

Table 33. Final TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations during IOP 5.

TGA	Latitude	Longitude	Location
0	.46980	.5181	SE corner of Harvey and Kerr
1	.47080	.5156	McGee Ave between Broadway and Robinson, meter 0459
2	.47194	.5192	4th St just east of Hudson, meter 1055
3	.46776	.5198	SW corner of Main and Hudson
4	.46903	.5194	SE corner Hudson and Park Ave., meter 1090
5	--	--	Mobile along 4th and 8th Streets, and CBD
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street parking garage
8	.47091	.5193	SE corner of Hudson and McGee, meter 1090
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

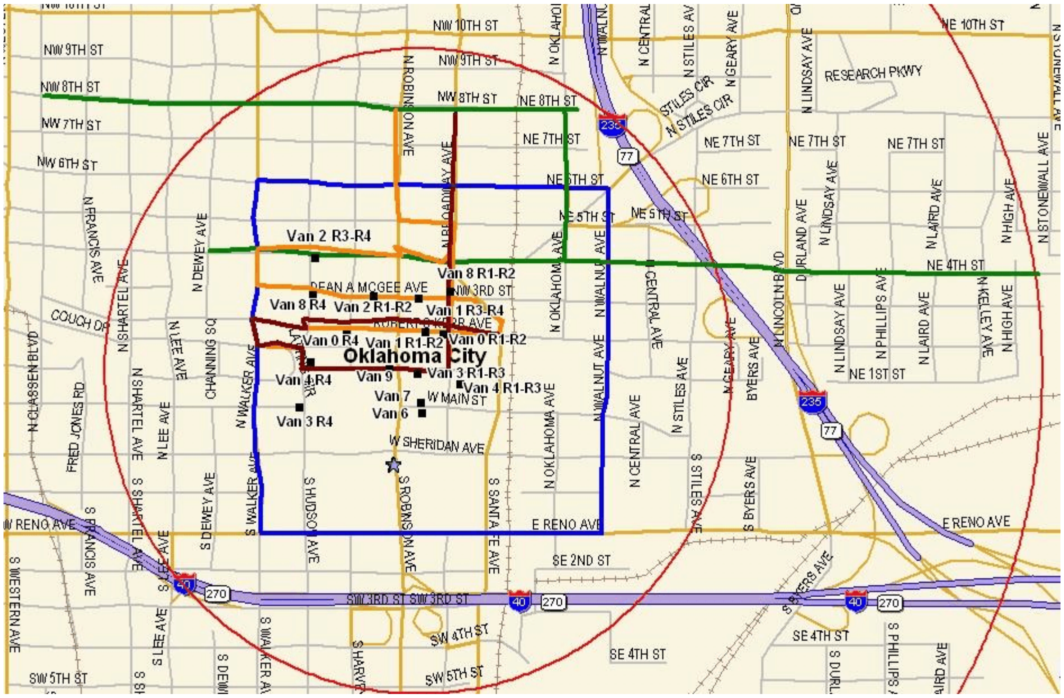

Figure 54. Stationary TGAs (black squares), general path of the mobile TGA (green line), deviation of mobile TGA during the 2nd continuous release (orange line) and 3rd continuous release (maroon line), release site (blue star), CBD (blue box), and the 1- and 2-km arcs (red circles) during IOP 5.

4. <u>IOP 5 Results</u>. High tracer concentrations at locations 027 (east of the disseminator) and 033 (west of the disseminator) suggest that winds within the CBD were quite variable during this IOP. Substantial SF_6 concentrations were observed over most of the CBD (Table 34) during at least one of the three continuous releases. The first two continuous releases mainly impacted the eastern half of the CBD, while the third continuous release heavily impacted the CBD's western half (Figs. 55 and 56). There did not appear to be a preferred tracer flow direction during this IOP. Rooftop maximum concentrations (5,280 pptv) from location number 954 were much lower and misleading when compared to the maximum street level sampler (44,980 pptv) from location number 027. As will be shown in the TGA section, the tracer did rise to the rooftop levels similar to the previous IOPs. The reason for the discrepancies during this IOP was the center of plumes never advected directly over any of the rooftop samplers. In fact, several rooftop samplers had larger maximum concentrations when compared with the samplers placed below at the surface which has been seen occasionally in the earlier IOPs.

Consistently wide tracer concentration distributions were also obtained over the three arcs (Figs. 57 and 58), although the higher concentrations tended to be in the northeast ends of the arcs (Table 35). A significant amount of tracer concentration (1,254 pptv) was still seen on the 4-km arc at location number 580. Substantial portions of the plumes apparently passed east of the sampling arcs.

Table 34. Summary of maximum reported concentrations (pptv) for integrating samplers deployed in the CBD at street-level and on rooftops for IOP 5. "R" indicates the release site.

		Street-level Samplers								
		Walker	Hudson	Harvey	Robinson	Between	Broadway	Gaylord	Oklahoma	Walnut
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y		926	**1,719**	1,296		*1,168*	1,038		
4th St.	07y		709	2,041	1,602		1,005	1,756	**3,299**	
McGee	06y	41	659	3,707	2,751	1,488	*1,219*	4,084	**4,331**	2,967
Kerr	05y	17	1,319	1,454	4,257	2,201	*86*	4,634	**4,743**	2,583
Park	04y		628	6,964	**12,444**	7,689	6,293	7,565		
Main	03y		368	**30,378**				13,018		
Sheridan	02y			108	R			**44,980**		
California	01y				58			**521**		
Reno	00y			6						

		Rooftop Samplers								
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			3,442	**4,637**	1,143				
Kerr	05y			3,968	**5,280**	-999	1,948			
Park	04y			1,723	(940)	**4,177**	2,959			
Main	03y									
Sheridan	02y				R					
California	01y									
Reno	00y									

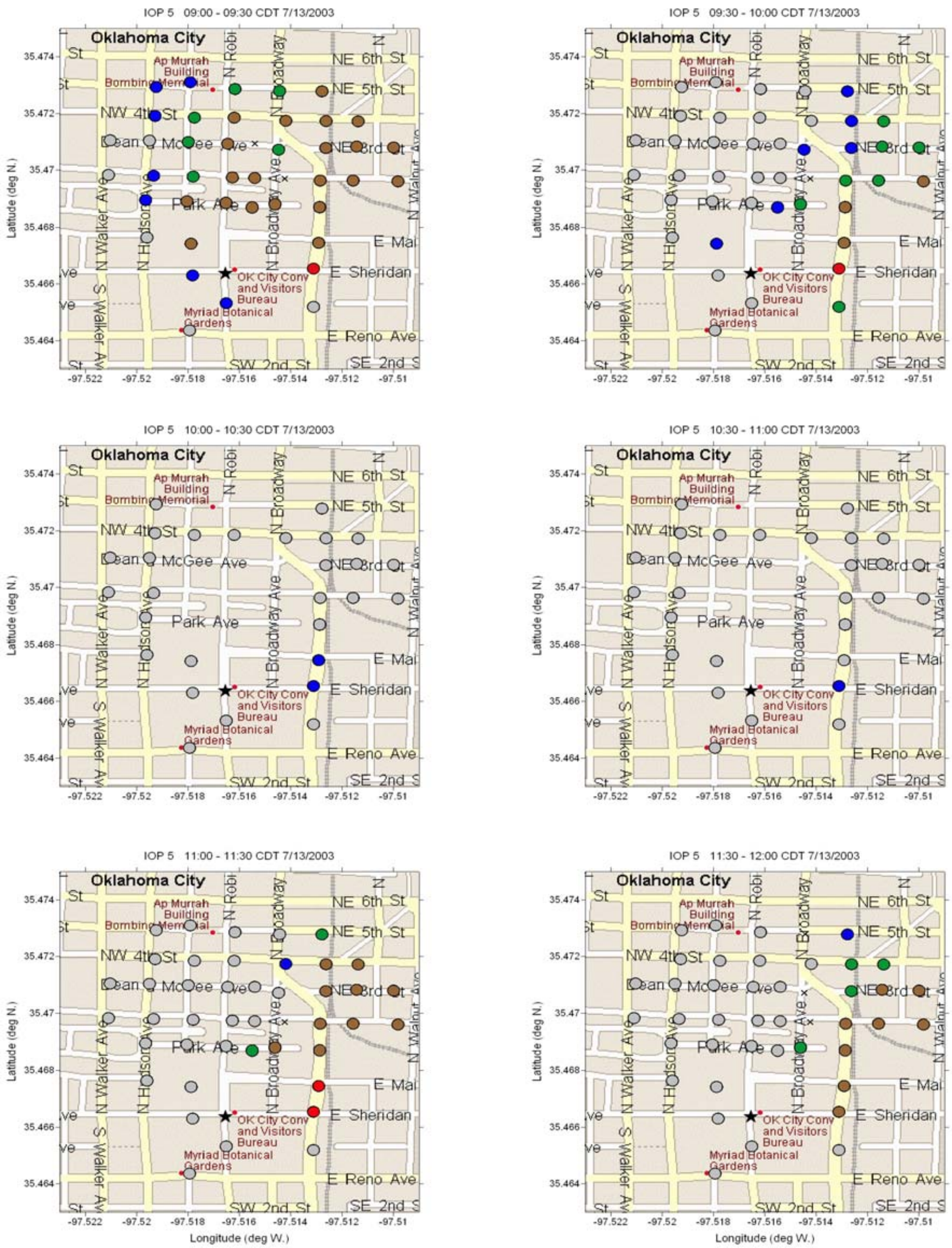

Figure 55. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 5 from 0900-1200 CDT. Tracer releases occurred from 0900-0930 and 1100-1130 CDT.

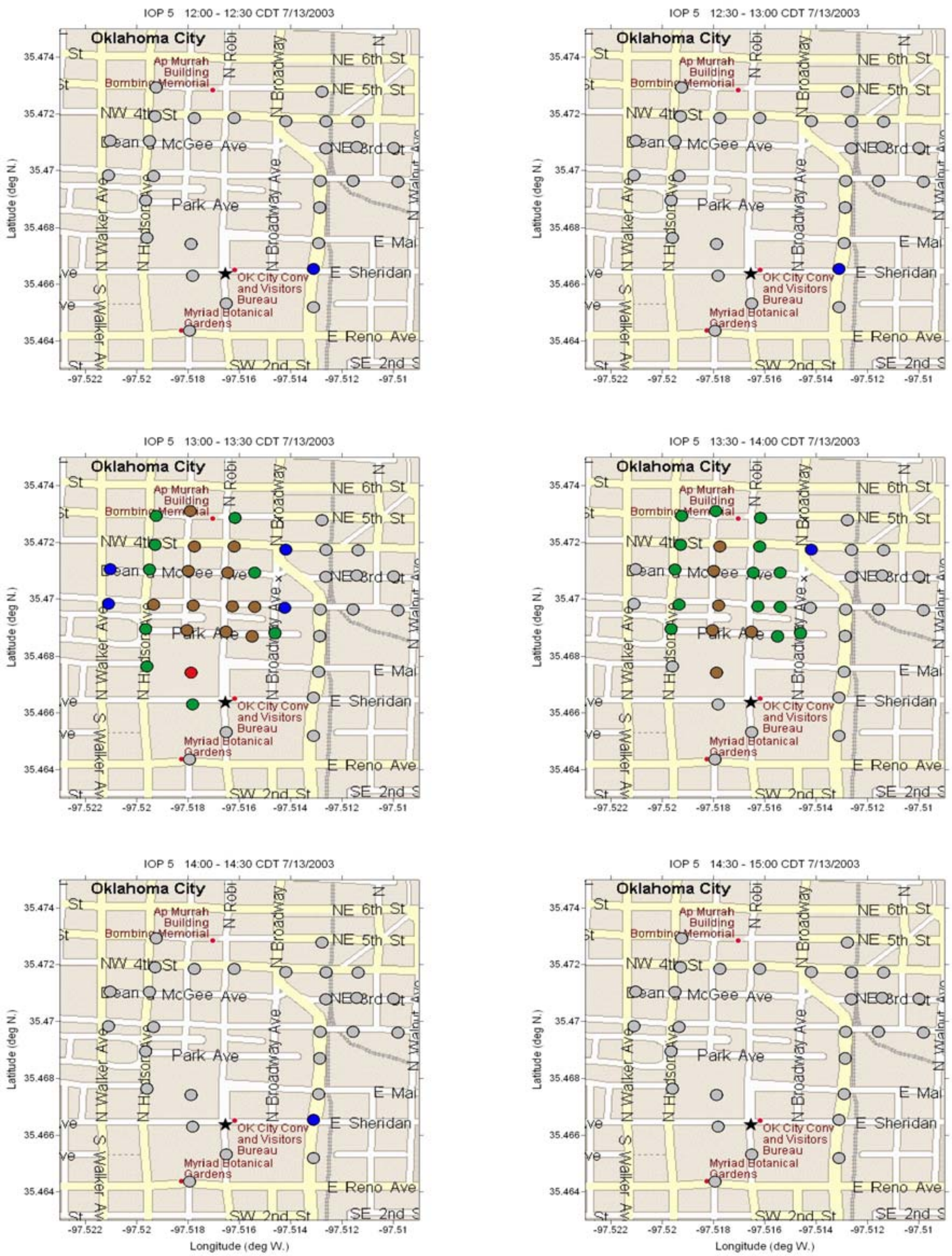

Figure 56. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 5 from 1200-1500 CDT. Tracer release occurred from 1300-1330 CDT.

Table 35. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 5.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	9	-	-	-	-
508	11	537	5	567	5
509	*18*	538	11	568	5
510	59	539	6	569	10
511	283	540	41	570	*22*
512	421	541	99	571	35
513	804	542	189	572	47
514	209	543	62	573	46
515	152	544	67	574	*19*
516	266	545	23	575	23
517	*42*	546	49	576	94
518	645	547	158	577	96
519	618	548	1,319	578	348
520	1,846	549	639	579	775
521	**2,785**	550	**1,481**	580	**1,254**
522	1,276	551	1,431	581	83
523	1,537	-	-	-	-

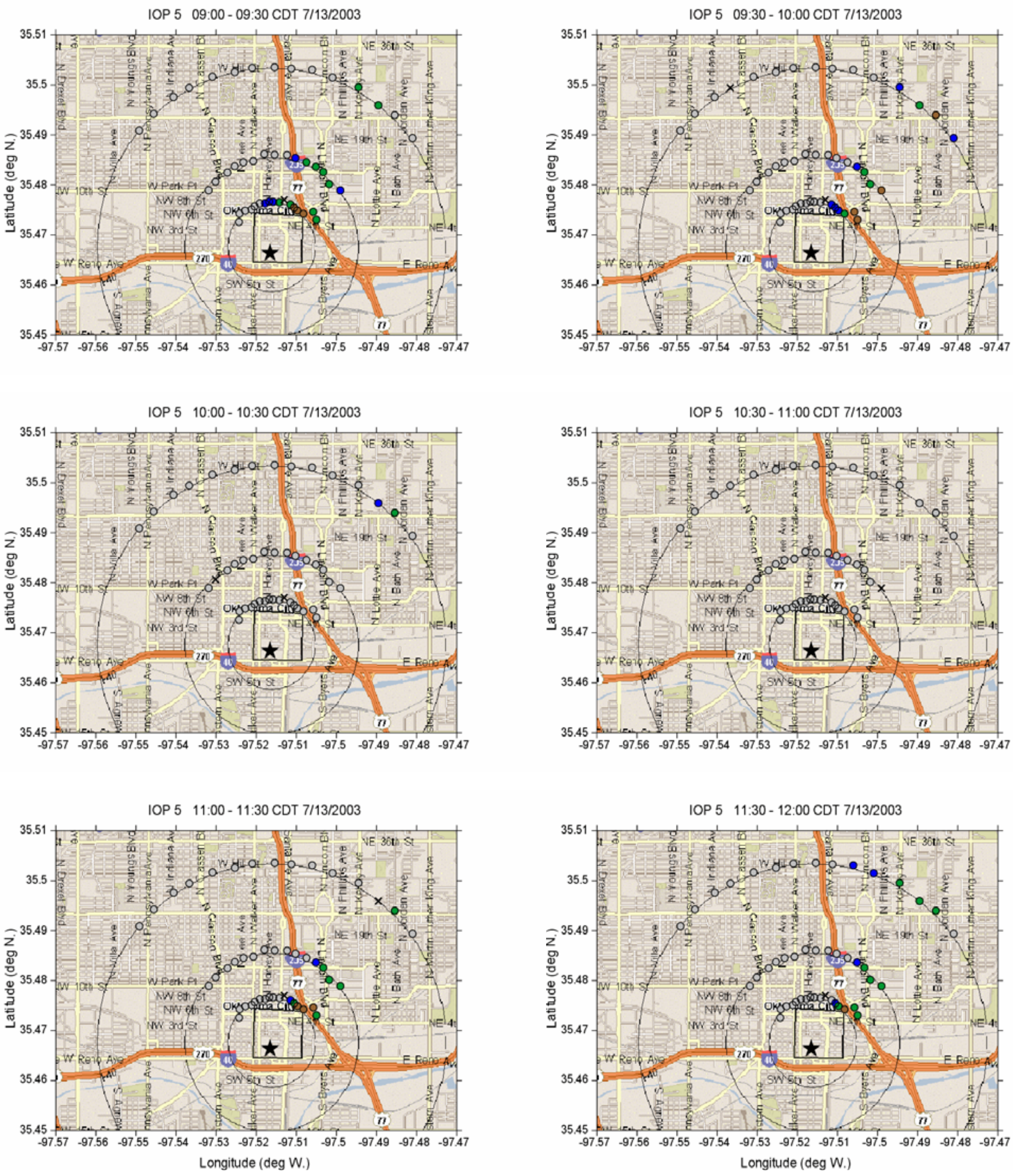

Figure 57. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 5 from 0900-1200 CDT. Tracer releases occurred from 0900-0930 and 1100-1130 CDT.

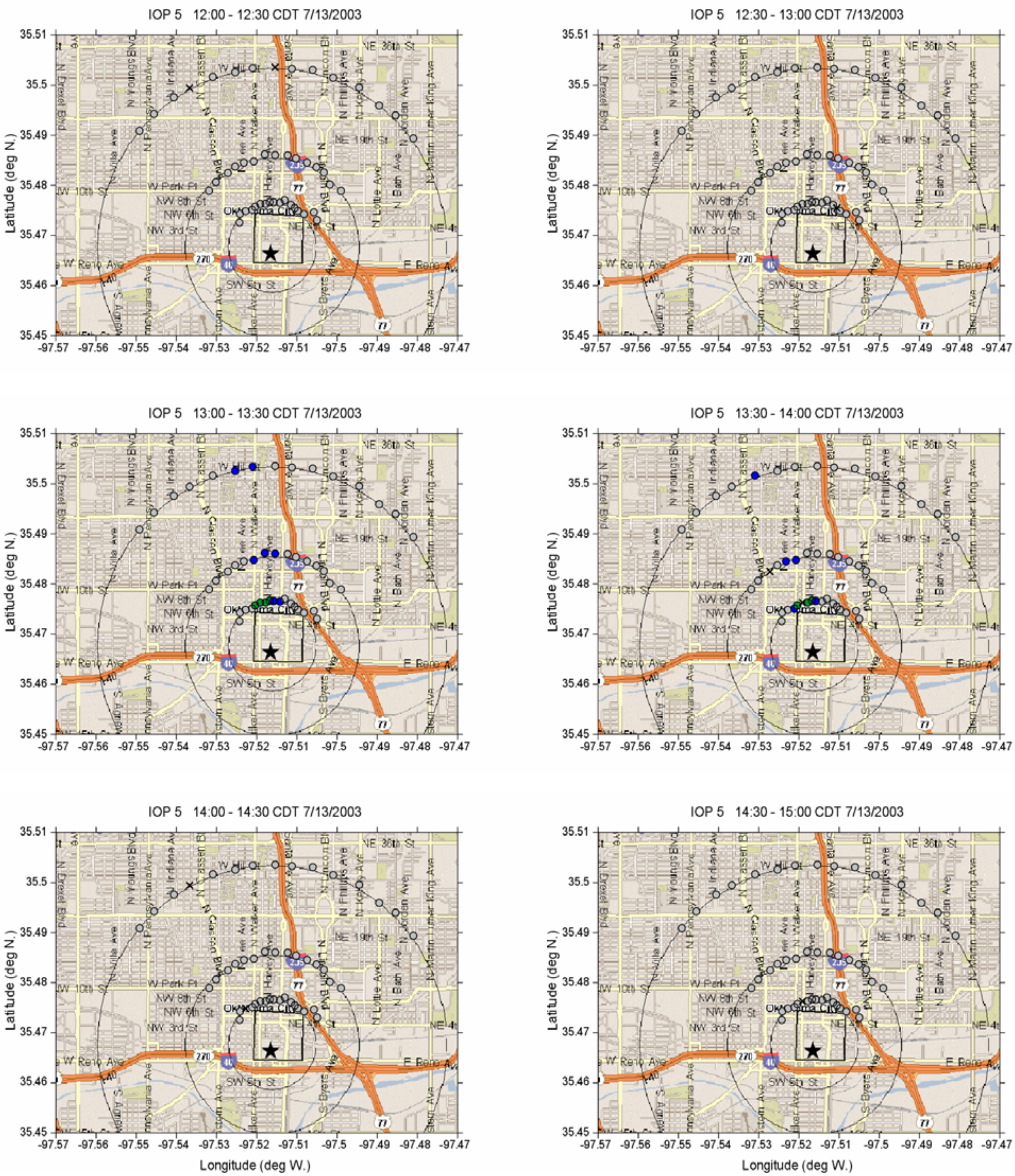

Figure 58. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 5 from 1200-1500 CDT. Tracer release occurred from 1300-1330 CDT.

Substantial tracer concentrations were observed over the entire TGA array, as shown in Table 36. The wide variability in the reported tracer concentrations suggest meandering plumes. Railing was observed on TGAs 4, 6, 7, and 9 due to exposure to SF_6 concentrations in excess of TGA measurement capabilities. Railing with TGA 7 showed that the plume did rise to the rooftop levels. TGA 8 experienced operational problems of unknown cause for part of the IOP.

Table 36. Maximum TGA-sampled concentrations (pptv) during IOP 5.

TGA	Point 1	Point 2	Point 3	Puff 1	Puff 2	Puff 3	Puff 4
0	10,300	1,080	1,320	9,890	5,810	5,800	212
1	*14,300*	0	5,500	-999	-999	663	0
2	10,600	0	2,920	*13,500*	4,570	1,870	7,290
3	*13,000*	1,130	12,600	256	295	0	11,300
4	17,100	*>25,500*	1,290	*>25,300*	4,380	2,250	*>12,400*
5	9,790	9,560	3,670	2,370	994	318	887
6	*>23,600*	*>23,600*	*>23,000*	*48*	6,710	*>23,100*	300
7	*>25,000*	*>25,900*	*>25,400*	0	8,870	*>24,500*	0
8	6,700	-999	6,780	*12,100*	4,290	2,020	8,100
9	*>12,300*	0	*>12,300*	9,210	*>12,100*	*>12,200*	0

IOP 6, Wednesday, 16 July 2003

1. Meteorological Synopsis. 16 July began as a clear day, with SW winds trending towards S by the end of the IOP. The 100-m sodar winds (Table 37) showed initial speeds of 4-6 m s^{-1}, increasing to 8-9 m s^{-1} during the middle of the IOP, and then diminishing to light and variable towards the end of the period.

Table 37. Sodar winds (15-min. averages) at 100-m AGL for IOP 6.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
0900	4.6	200	1130	7.9	186	1400	2.3	121
0915	5.2	214	1145	8.3	176	1415	2.6	136
0930	5.3	196	1200	9.6	172	1430	0.8	087
0945	5.7	212	1215	6.7	175	1445	-950	-950
1000	6.1	203	1230	8.5	167	1500	1.8	348
1015	7.3	208	1245	4.4	156	1515	0.3	269
1030	7.1	196	1300	5.8	139	1530	2.1	209
1045	6.5	187	1315	5.4	155	1545	-950	-950
1100	8.6	180	1330	2.4	132	1600	-950	-950
1115	7.9	180	1345	2.6	160	1615	-950	-950

2. Release Summary. IOP 6 was a Botanical release from Roland Norick Blvd at the Myriad Botanical Gardens. Thirty-minute SF_6 point source releases of 3.02, 3.18, and 2.97 g s^{-1} began at 0900, 1100, and 1300 hrs CDT. Puff releases followed at 1500, 1520, 1540, and 1600 hrs CDT with releases of 498, 499, 510, and 500 g, respectively.

3. Sampler Deployment Summary. The integrating samplers were set out in the CBD for a SSW wind direction (blue arc segment, Fig. 30). Sampling was done in the underground pedestrian walkway during IOP 6. The TGAs were in their usual locations, as shown in Table 38. A plot of the stationary TGAs and the general path of the mobile TGA can be seen in Fig. 59.

Table 38. TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations during IOP 6.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile along 4th and 8th Streets
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street parking garage
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

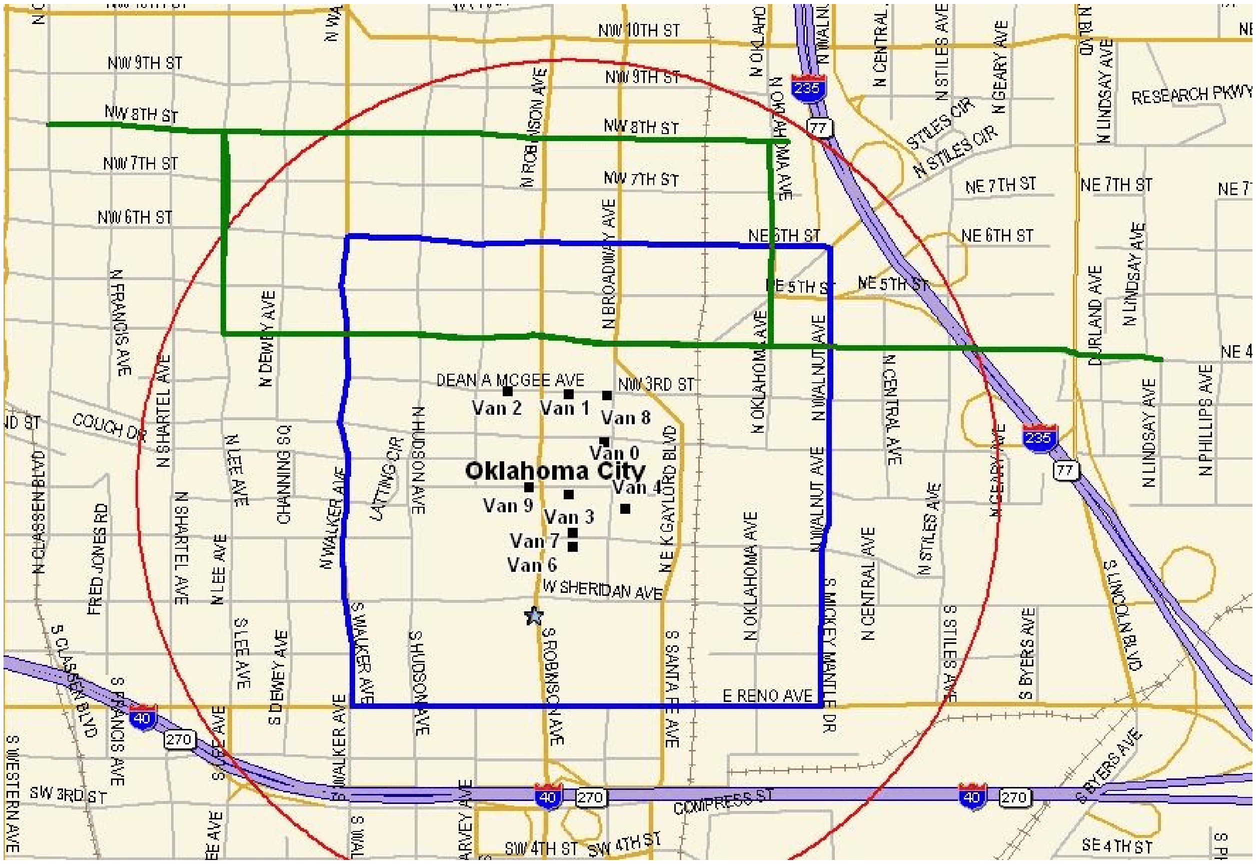

Figure 59. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1- km arc (red circle) during IOP 6.

4. <u>IOP 6 Results</u>. Overall maximum concentrations were similar to IOPs 3 and 4. Table 39 shows that CBD sampler locations with the 3rd digit ending in 3 through 7 experienced substantial tracer concentrations, indicating considerable variability in winds through the CBD. The plume from the first continuous release traveled across the eastern part of the CBD, while plumes from the next two releases traveled through the middle of the CBD (Figs. 60 and 61). However, no extremely high concentrations were recorded in spite of low wind speeds. All of the rooftop samplers received substantial SF_6 concentrations, although the maximum concentration was slightly below the maximum street level concentration. Tunnel sampler concentrations were lower than in previous IOPs. The maximum tunnel concentration was 1,903 pptv and recorded from location number 403. The tracer was also well distributed over the sampling arcs (Figs. 62 and 63) but again without high concentrations (Table 40).

Table 39. Summary of maximum reported concentration (pptv) for integrating samplers deployed in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 6. “R” indicates the release site.

		Street-level Samplers								
		Walker 0x1	Hudson 0x2	Harvey 0x3	Robinson 0x4	Between 0x5	Broadway 0x6	Gaylord 0x7	Oklahoma 0x8	Walnut 0x9
6th St.	09y									
5th St.	08y		295	550	893		*1,222*	1,003		
4th St.	07y		450	710	1,256		**1,616**	1,259	594	
McGee	06y	14	373	*2,065*	*2,217*	**2,621**	1,779	920	570	145
Kerr	05y	12	727	3,668	**5,327**	3,014	4,820	938	*322*	83
Park	04y		582	5,956	5,403	**7,415**	6,747	1,238		
Main	03y		41	**6,525**				1,395		
Sheridan	02y			37	R			**2,967**		
California	01y				**74**			5		
Reno	00y			**7**						
		Rooftop Samplers								
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			1,238	1,539	**1,920**				
Kerr	05y			*1,766 (950)*	2,144	2,280	**3,525**			
Park	04y				1,583 (940)	**6,531**	6,313			
Main	03y									
Sheridan	02y				R					
California	01y									
Reno	00y									
		Tunnel Samplers								
401	398									
402	246									
403	**1,903**									
404	*480*									

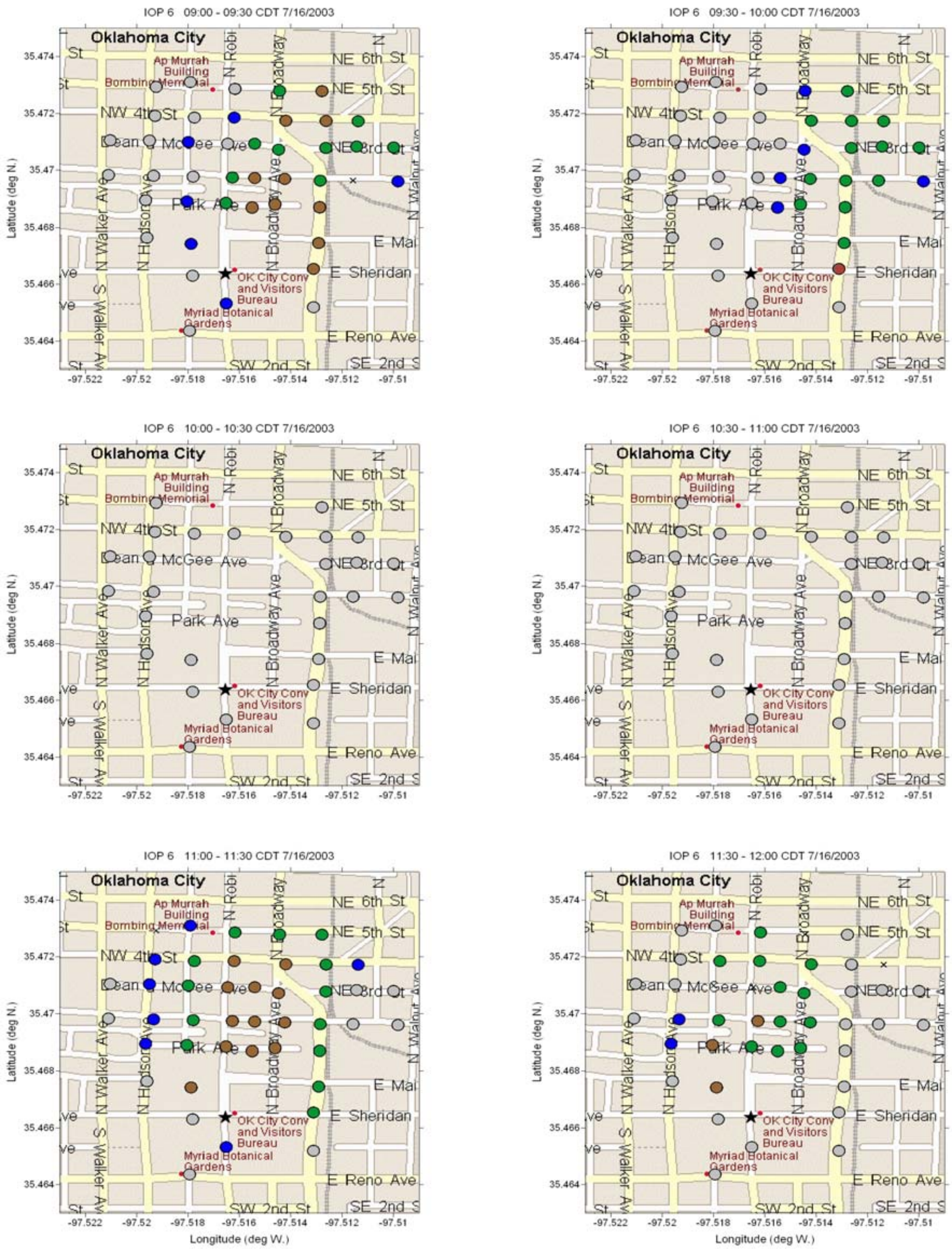

Figure 60. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 6 from 0900-1200 CDT. Tracer releases occurred from 0900-0930 and 1100-1130 CDT.

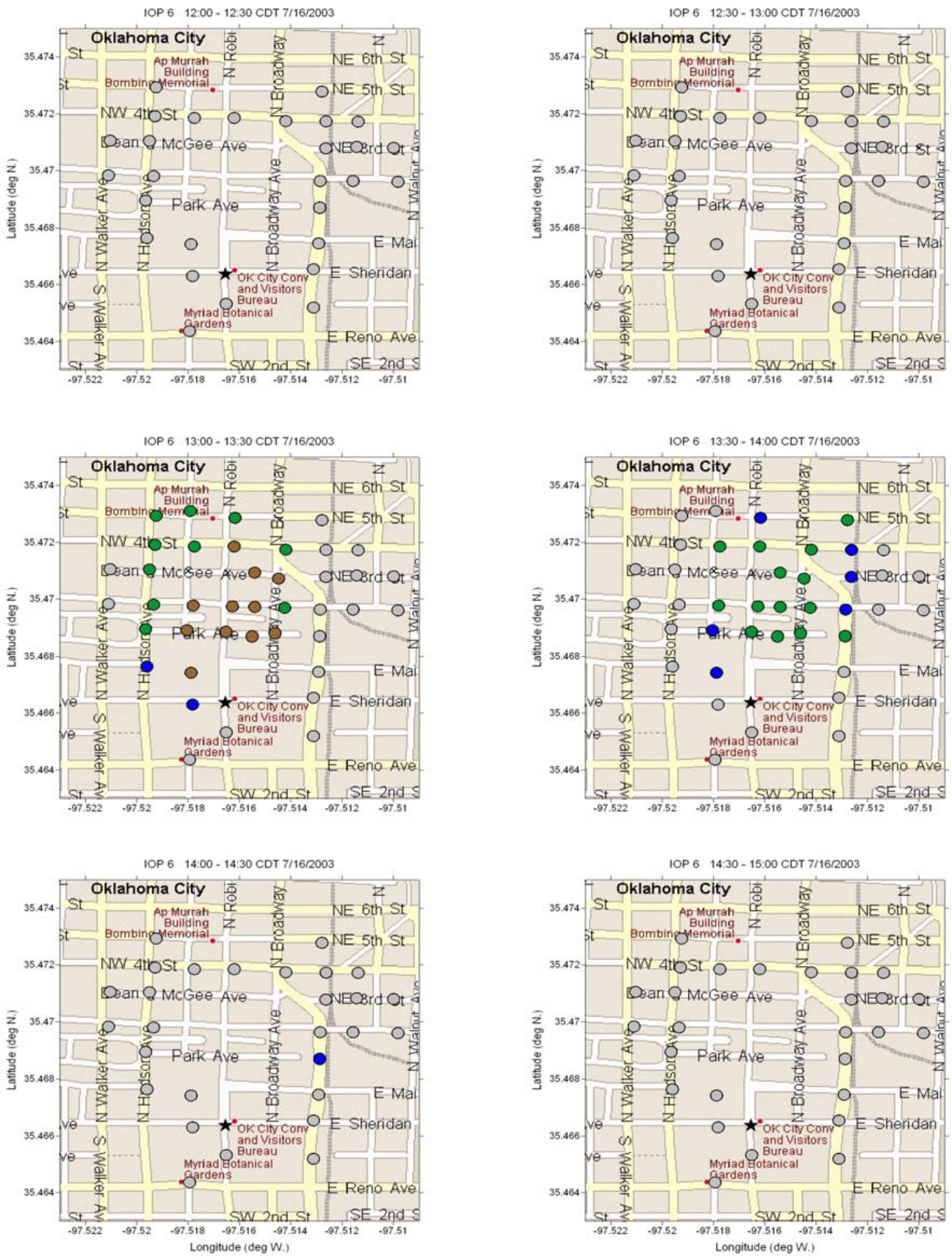

Figure 61. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 6 from 1200-1500 CDT. Tracer release occurred from 1300-1330 CDT.

Table 40. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 6.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	6	-	-	-	-
508	5	537	6	567	12
509	5	538	5	568	5
510	21	539	-999	569	5
511	150	540	5	570	6
512	269	541	6	571	5
513	522	542	33	572	7
514	246	543	37	573	7
515	357	544	136	574	60
516	331	545	71	575	42
517	338	546	178	576	58
518	583	547	119	577	80
519	**680**	*548*	***306***	578	**197**
520	593	549	*113*	579	53
521	*287*	550	167	580	7
522	40	551	17	581	6
523	16	-	-	-	-

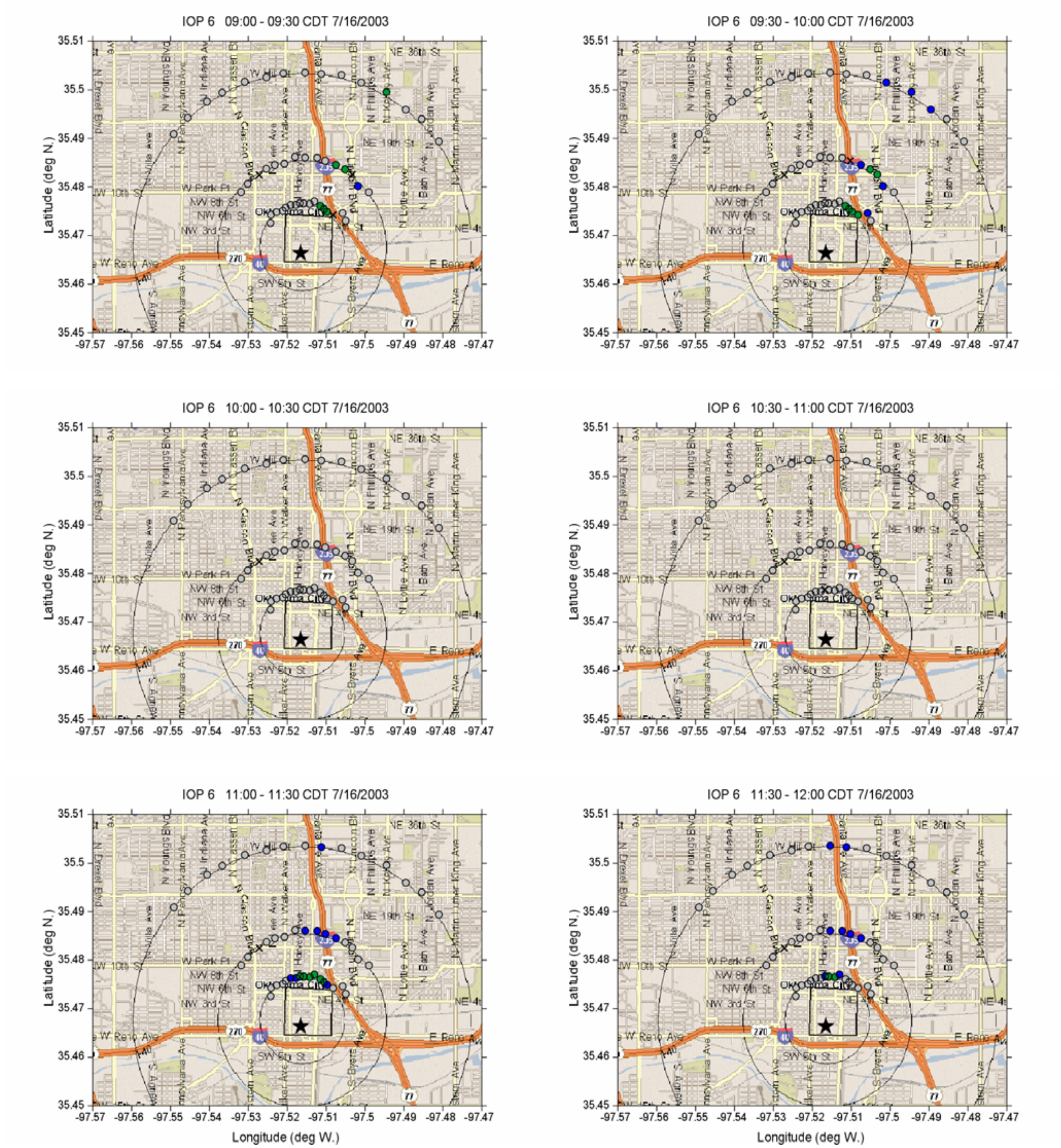

Figure 62. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 6 from 0900-1200 CDT. Tracer releases occurred from 0900-0930 and 1100-1130 CDT.

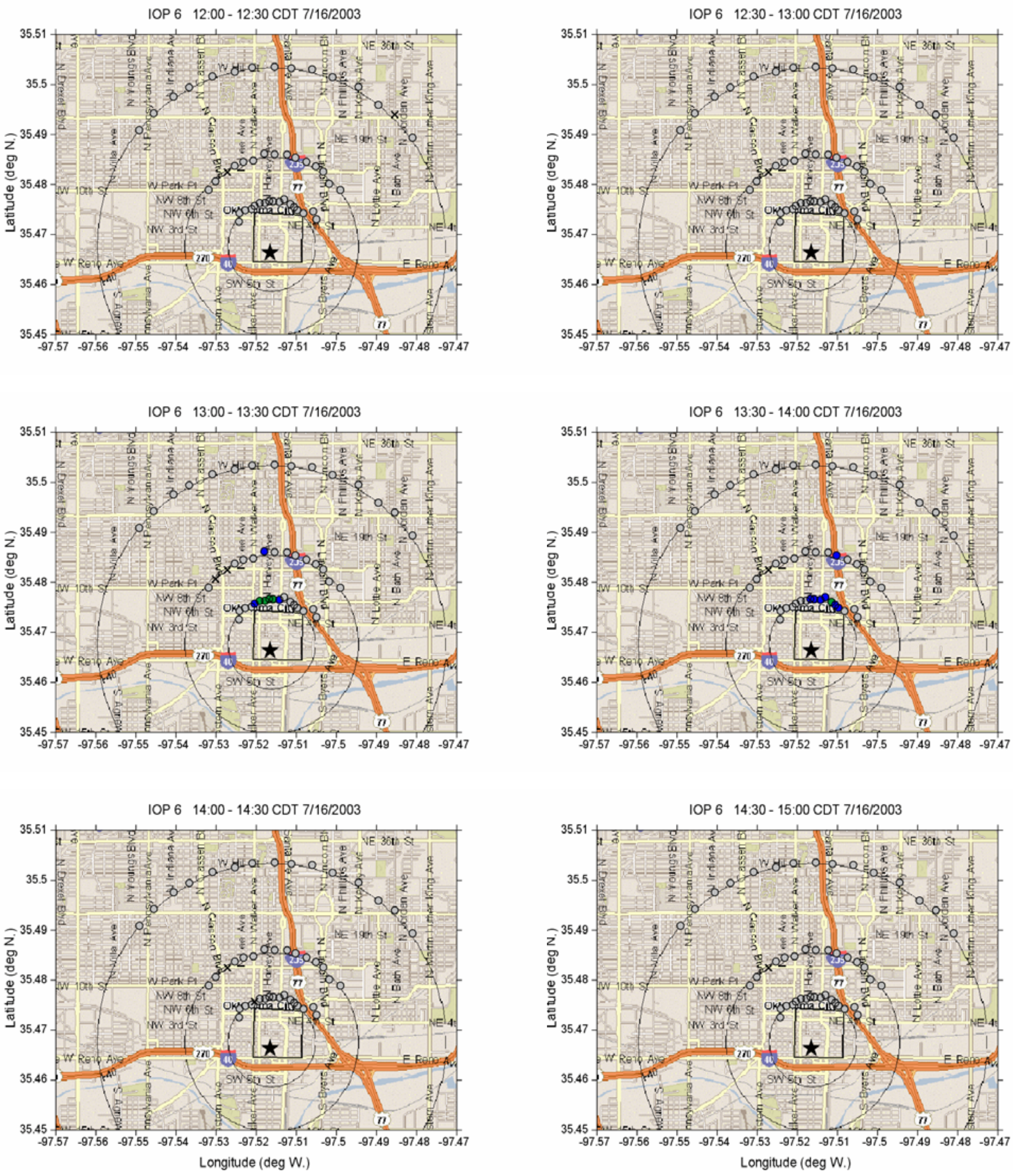

Figure 63. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 6 from 1200-1500 CDT. Tracer release occurred from 1300-1330 CDT.

High tracer concentrations at TGAs 4 and 9 (Table 41) indicate considerable plume meandering during IOP 6. Railing occurred on TGAs 6, 7, and 9 due to tracer concentrations in excess of instrument limits. Consistently high concentrations on TGAs 6 and 7 suggest rapid vertical transport of the tracer between the street level and rooftop during IOP 6. The winds became light and variable at the start of the first puff release and kept most of the TGAs from seeing any tracer. TGA 9, the closest stationary TGA to the release, saw only 800 pptv during this release. Winds remained relatively light but became more out of the south which allowed most of the TGAs to see some tracer concentration during the rest of the puff releases.

Table 41. Maximum TGA-sampled concentrations (pptv) during IOP 6.

TGA	Point 1	Point 2	Point 3	Puff 1	Puff 2	Puff 3	Puff 4
0	11,300	10,500	6,260	0	1,530	0	2,330
1	2,650	5,990	7,190	0	10,400	364	4,930
2	78	6,610	9,960	0	653	2,970	4,360
3	*12,700*	*14,800*	*13,200*	0	*16,300*	3,690	*17,200*
4	*24,900*	*26,700*	14,500	0	0	96	5,490
5	4,750	5,020	1,430	313	575	156	1,210
6	*>22,600*	*>22,700*	*>22,800*	0	9,580	2,700	*>22,600*
7	*>25,800*	*>25,100*	*>24,200*	0	2,590	2,840	22,800
8	9,240	6,930	6,220	0	8,430	247	4,970
9	6,800	*>12,000*	*>12,000*	800	7,650	0	0

IOP 7, Friday-Saturday, 18-19 July 2003

1. Meteorological Summary. This was the first of four IOPs conducted at night. Skies were mostly clear. Winds were S-SSW at the start of IOP 7, veering to SW by 0230 CDT on 19 July and continuing a trend towards the west. Surface wind speeds remained in the range of 4-5 m s^{-1}, while sodar-reported 100-m winds (Table 42) were 8-10 m s^{-1}.

Table 42. IOP 7 sodar winds (15-min. averages) at 100-m AGL.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
2300	9.7	195	0130	6.6	204	0400	10.0	228
2315	9.3	190	0145	8.3	205	0415	8.6	237
2330	8.1	199	0200	9.1	210	0430	8.9	239
2345	7.3	205	0215	9.4	213	0445	10.2	240
0000	6.4	189	0230	7.7	223	0500	9.3	244
0015	7.1	206	0245	8.1	223	0515	9.4	241
0030	7.4	201	0300	9.5	224	0530	8.9	243
0045	7.8	206	0315	9.4	223	0545	10.1	244
0100	9.1	217	0330	8.5	219	0600	9.5	242
0115	8.6	215	0345	9.9	221	0615	10.1	240

2. Release Summary. The release took place at the Myriad Botanical Gardens. Continuous 30-minute releases were made at 2300 CDT on 18 July, and at 0100 and 0300 CDT on 19 July. Release rates were 3.00, 1.99, and 2.02 g s^{-1}. Puff releases of 303, 300, 304, and 298 g were made at 0500, 0520, 0540, and 0600 CDT on 19 July.

3. Sampler Deployment Summary. The integrating samplers were placed within the CBD, in the pedestrian underground, on building rooftops, and on the sampling arcs in anticipation of a SSW flow (blue arc segment, Fig. 30). The TGAs were initially deployed as shown in Table 43. Plot of the stationary TGAs and the general path of the mobile TGA is shown in Fig. 64.

Table 43. Initial TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 7.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile on 4th Street
6	.46760	.5155	S. side of Main Street between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street Parking Garage
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

In response to a more westerly trend in the wind beginning at 0230 CDT on 19 July, TGAs 1, 2, and 9 were relocated to positions east of the CBD, as shown in Table 44.

Table 44. Subsequent TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 7.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47069	.5099	On 3rd St between Walnut & Oklahoma
2	.47087	.5126	Corner of 3rd & Gaylord, meter 0034 (just west of the railroad overpass)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile along 4th and 8th Streets
6	.46760	.5155	S. side of Main St. between Robinson & Broadway, meter 2092 (in front of Subway store & Main Street Parking Garage)
7	.46790	.5155	Top of Main Street parking garage
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46966	.5117	Corner of 2nd & Gaylord (just east of the railroad overpass)

A continued westerly trend in the winds prior to the start of the puff releases prompted movement of TGAs 0, 3, 6, 7, and 8 to more easterly positions prior to the puff releases as shown in Table 45.

Table 45. Final TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 7.

TGA	Latitude	Longitude	Location
0	.46963	.5092	SW corner of 2nd & Walnut (in front of the Finley Bldg.)
1	.47069	.5099	On 3rd St between Walnut & Oklahoma
2	.47087	.5126	Corner of 3rd & Gaylord, meter 0034 (just west of the railroad overpass)
3	.47171	.5091	SW corner of 4th & Walnut (in front of Bricktown Auto Bath & Shine)
4	.46841	.5141	Park Avenue east of Broadway, meter 0012 (in front of Skirvin Hotel)
5	--	--	Mobile along 4th and 8th Streets
6	.46754	.5131	SW corner of Gaylord & Main, meter 2050
7	.47145	.5059	100 feet south of Stiles on 4th Street
8	.47066	.5076	SW corner of 3rd & Central
9	.46966	.5117	Corner of 2nd & Gaylord (just east of the railroad overpass)

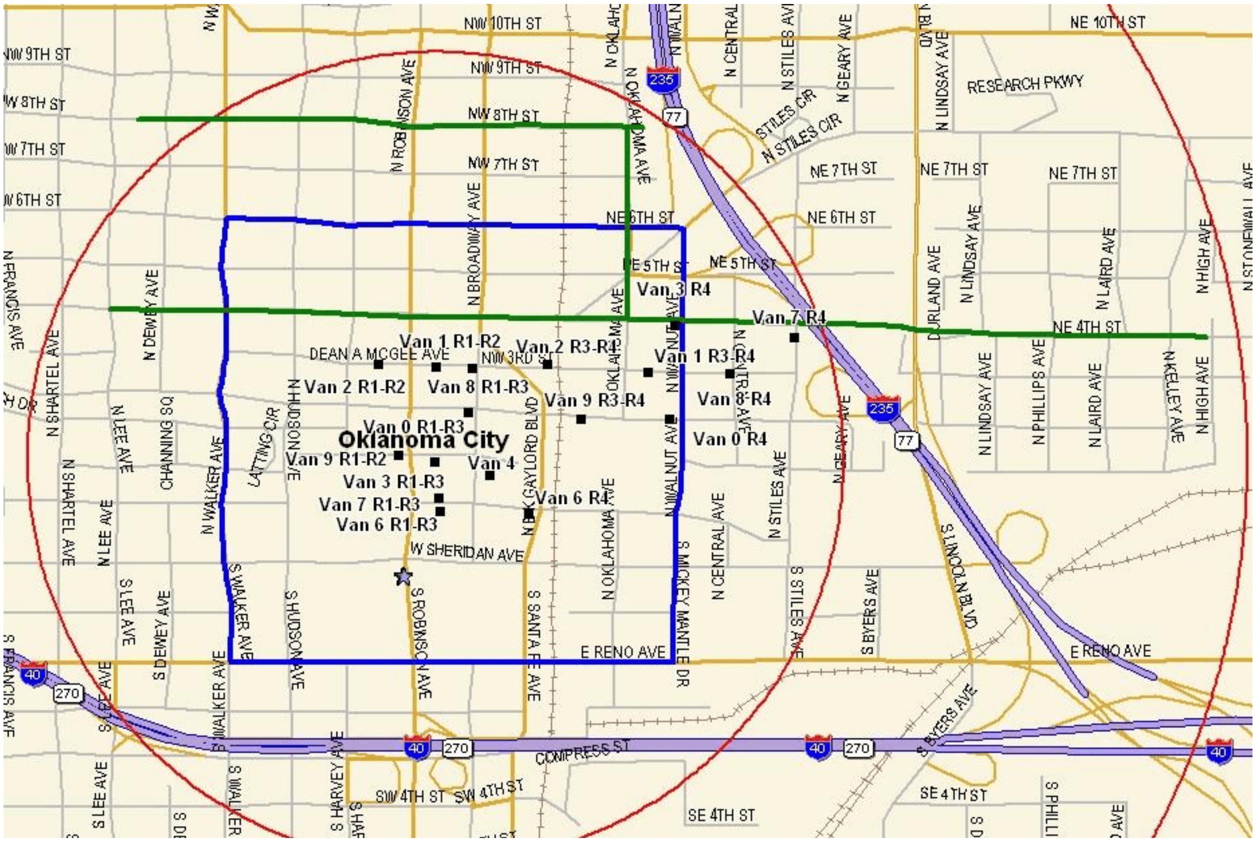

Figure 64. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1- and 2-km arcs (red circles) during IOP 7.

4. <u>IOP 7 Results</u>. The dispersing tracer primarily impacted the eastern half of the CBD (Figs. 65 and 66), with the highest concentrations (Table 46) occurring at locations 027 and 037, which were east of the botanical release site. The preferred path of travel for the tracer was along Broadway. Some rooftop locations also experienced high concentrations, although not nearly as high as the street level samplers. Several tunnel samplers saw significant concentrations as well. The highest tunnel sampler had a maximum concentration of 3,283 pptv at location number 402. Likewise, Figs. 67 and 68 shows that the tracer plume moved through the eastern half of the sampler arcs, and a portion of it passed beyond the southeast end of the arcs. Table 47 indicates that several samplers recorded high concentrations (>2,000 pptv) along the 1-km arc.

Table 46. Summary of maximum reported concentrations (pptv) for integrating samplers deployed in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 7. "R" indicates the release site.

		Walker	Hudson	Harvey	Robinson	Between	Broadway	Gaylord	Oklahoma	Walnut
Street-level Samplers		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y		60	109	*6*		**2,623**	1,452		
4th St.	07y		64	219	2,329		**3,496**	2,163	1,597	
McGee	06y	5	58	538	2,486	3,637	**3,724**	2,314	1,940	2,833
Kerr	05y	7	136	697	*16*	5,297	**10,218**	3,032	2,132	4,105
Park	04y		95	1,044	1,292	8,432	**11,252**	7,751		
Main	03y		42	1,964				**20,009**		
Sheridan	02y			753	$\boxed{R}$			**43,966**		
California	01y				**26**			8		
Reno	00y			**6**						
Rooftop Samplers		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			436	906	**2,516**				
Kerr	05y			*3,720 (950)*	1,992	1,471	**8,372**			
Park	04y			92 (940)		8,539	**11,056**			
Main	03y									
Sheridan	02y				$\boxed{R}$					
California	01y									
Reno	00y									
Tunnel Samplers										
401	1,233									
402	**3,283**									
403	748									
404	*30*									

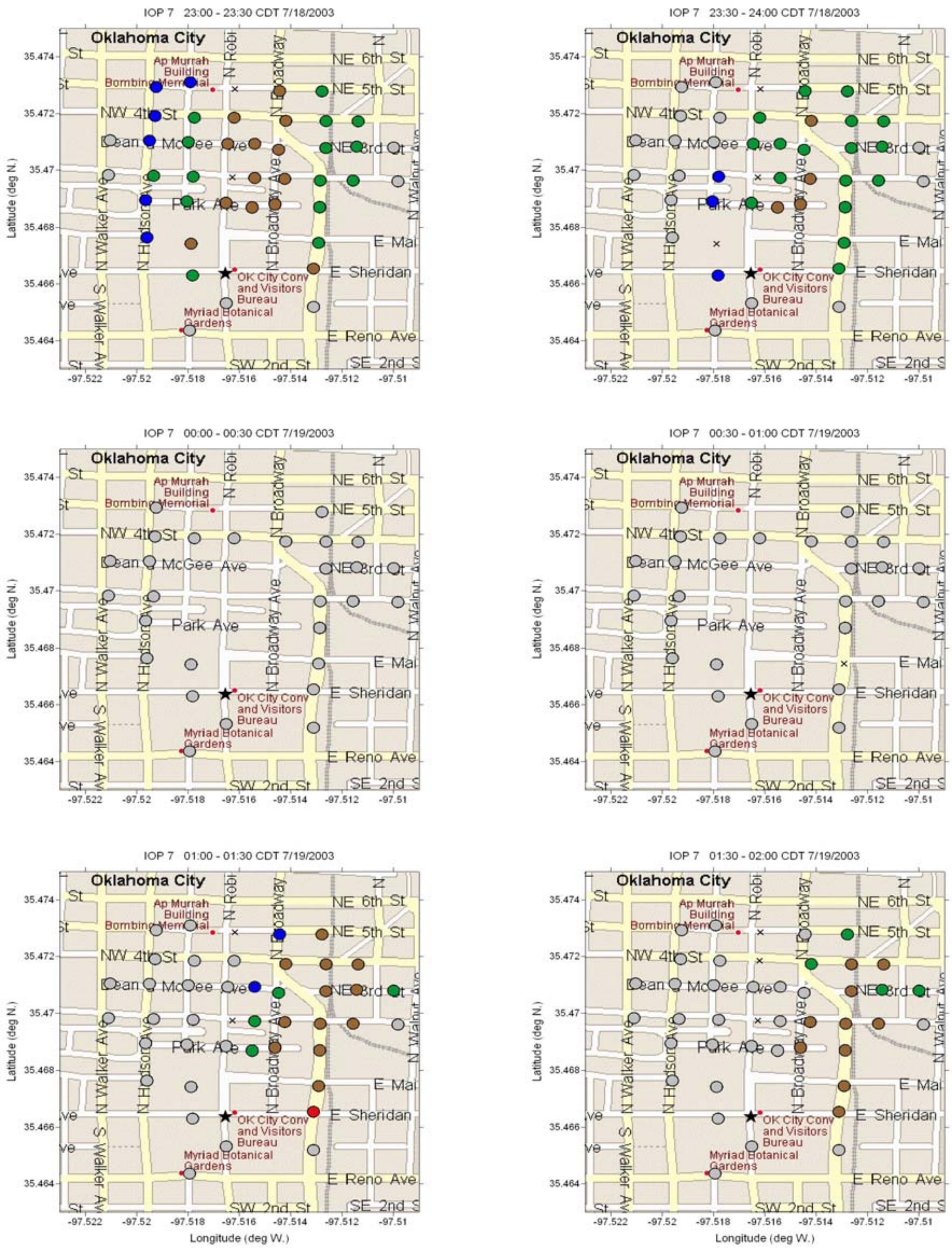

Figure 65. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 7 from 2300-0200 CDT. Tracer releases occurred from 2300-2330 and 0100-0130 CDT.

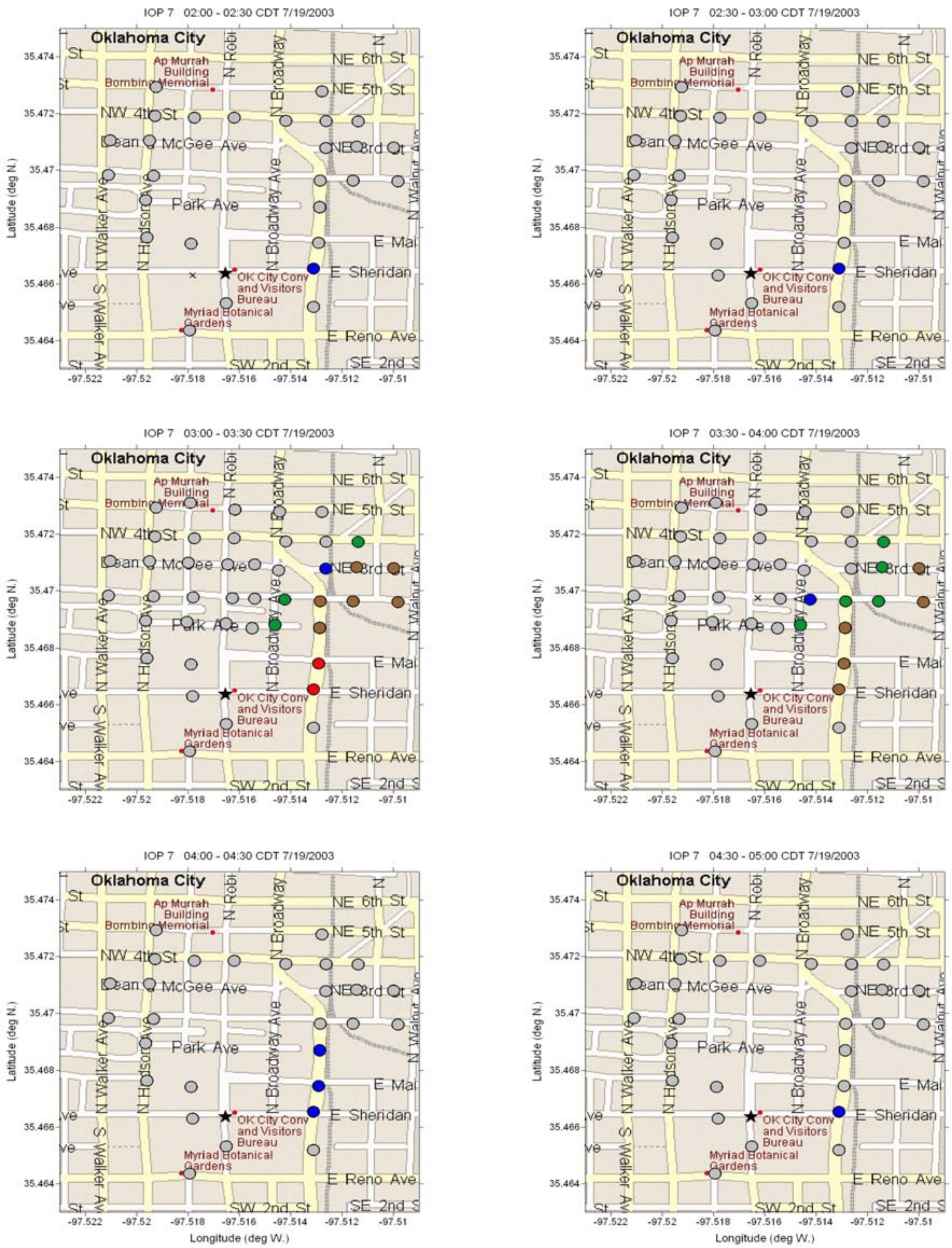

Figure 66. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 7 from 0200-0500 CDT. Tracer release occurred from 0300-0330 CDT.

Table 47. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs IOP 7.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	5	-	-	-	-
508	5	537	5	567	5
509	6	538	5	568	5
510	6	539	5	569	5
511	5	540	5	570	5
512	11	541	5	571	5
513	68	542	5	572	5
514	143	543	6	573	6
515	566	544	74	574	5
516	1,071	545	496	575	54
517	*1,769*	546	1,058	576	489
518	889	547	444	577	98
519	2,058	548	**1,212**	578	**603**
520	1,095	549	181	579	*8*
521	964	550	509	580	490
522	**2,069**	551	921	581	68
523	1,901	-	-	-	-

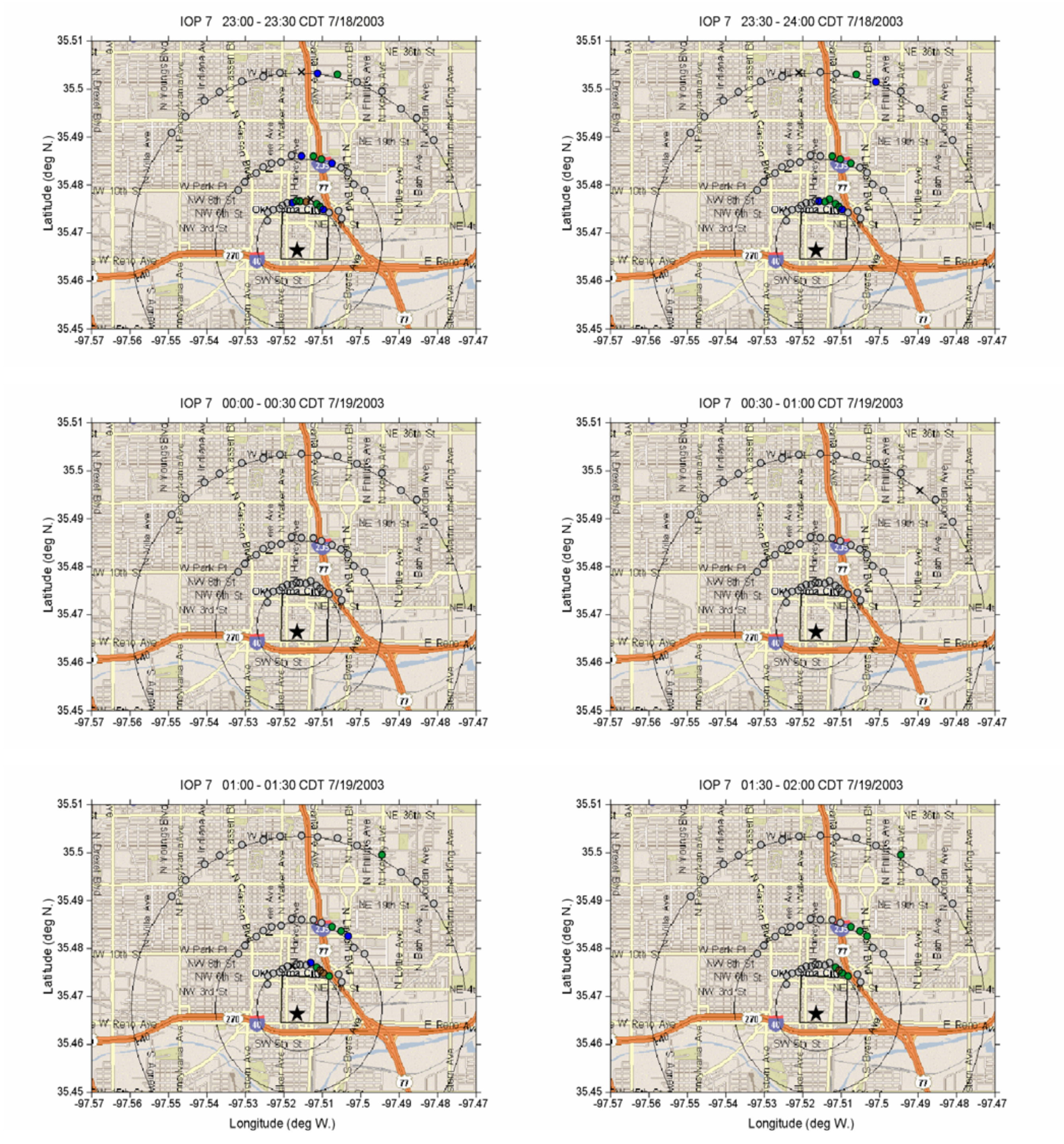

Figure 67. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 7 from 2300-0200 CDT. Tracer releases occurred from 2300-2330 and 0100-0130 CDT.

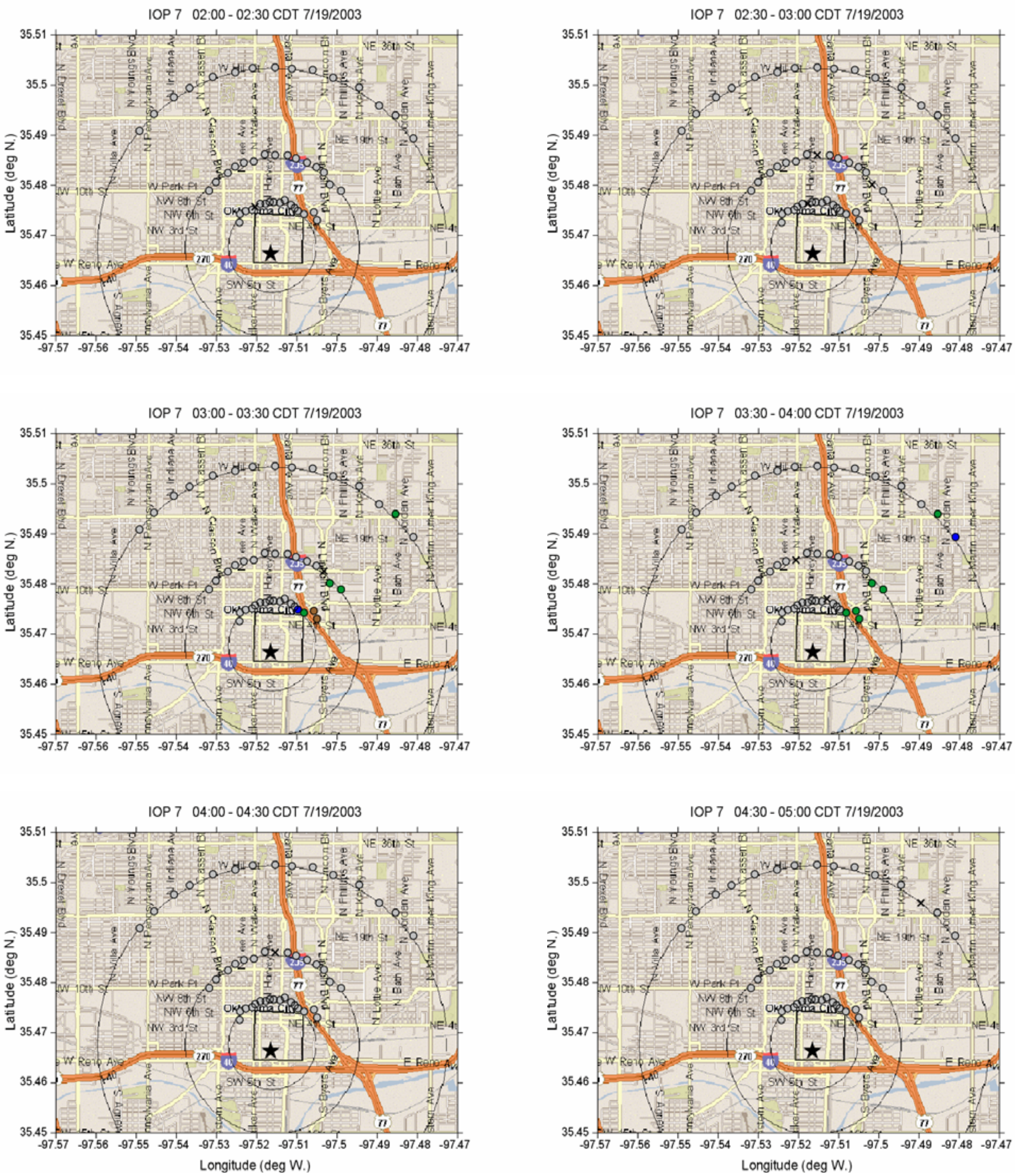

Figure 68. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 7 from 0200-0500 CDT. Tracer release occurred from 0300-0330 CDT.

Winds becoming more westerly required the movement of most TGAs during IOP 7. TGAs seeing only little or no tracer concentration were moved to more easterly positions to locate and measure the tracer plume. The only TGA that did not move was TGA 4 because of the close proximity to the release site and already easterly position. Railing was initially experienced by TGAs 4, 6, and 7 due to excessive tracer concentrations at locations NE of the Botanical release point. Table 48 reveals that relocating the TGAs to positions east of and at a greater distance from the release point provided substantial concentration coverage at all samplers without railing.

Table 48. Maximum TGA-sampled concentrations (pptv) during IOP 7.

TGA	Point 1	Point 2	Point 3	Puff 1	Puff 2	Puff 3	Puff 4
0	12,200	11,200	0	4,870	3,960	9,520	5,670
1	12,000	*397*	10,800	10,700	5,380	5,230	5,250
2	3,850	0	972	3,760	2,360	175	643
3	10,100	3,170	0	11,300	3,160	3,260	4,300
4	*24,000*	*>25,200*	*>11,600*	2,380	13,200	1,960	3,160
5	7,980	5,230	10,100	8,710	2,970	3,560	4,140
6	*>23,500*	*>23,300*	14,700	6,640	20,900	8,400	17,200
7	*>25,600*	*>26,300*	3,910	3,110	2,630	3,720	3,500
8	9,970	515	0	5,270	4,550	5,130	3,970
9	3,310	0	8,080	10,100	5,150	7,900	7,470

IOP 8, Thursday-Friday, 24-25 July 2003

1. Meteorological Summary. IOP 8 weather was characterized by clear skies and consistent winds from SSE through S at 4-5 m s^{-1}. Table 49 shows sodar winds remaining remarkably steady in the 7–8 m s^{-1} range.

Table 49. IOP 8 sodar winds (15-min. averages) at 100-m AGL.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
2300	7.2	164	0130	6.6	149	0400	7.5	171
2315	7.4	165	0145	6.9	155	0415	7.6	165
2330	8.1	156	0200	7.3	158	0430	7.7	154
2345	6.7	171	0215	6.9	172	0445	7.6	169
0000	7.5	155	0230	7.4	159	0500	6.8	163
0015	7.1	172	0245	7.7	173	0515	8.2	175
0030	7.6	163	0300	7.2	174	0530	8.4	173
0045	7.6	168	0315	7.3	165	0545	7.8	164
0100	7.5	168	0330	7.7	172	0600	7.6	170
0115	7.4	168	0345	8.1	170	0615	7.4	173

2. Release Summary. The release equipment was positioned on Broadway in front of the Westin Hotel and meter 1461. Continuous 30-minute releases were initiated at 2300 CDT on 24 July, and at 0100, and 0300 CDT on 25 July. Release rates were 3.07, 3.05, 2.97 g s^{-1}. Puff releases of 500, 500, 300, and 300 g were made at 0500, 0520, 0540, and 0600 CDT on 25 July.

3. Sampler Deployment Summary. The integrating samplers were positioned for a SE flow (red arc, Fig. 30), and samplers were placed on rooftops and in the pedestrian tunnel. TGAs 6 and 7 were initially deployed along Kerr in anticipation of a more easterly wind component (Table 50). In addition, TGA 4 was positioned on 4th Street for the forecast SSE winds. Plot of the stationary TGAs and general path of the mobile TGA can be seen in Fig. 69.

Table 50. Initial TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 8.

TGA	Latitude	Longitude	Location
0	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.47190	.5181	SW corner of 4th & Harvey, meter 1063
5	--	--	Mobile on 4th Street
6	.46980	.5181	SW corner of Kerr & Harvey, meter 1119
7	.46980	.5193	SE corner of Kerr & Hudson, meter 1112
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

At 0016 CDT on 25 July vans containing TGAs 0 and 4 switched places, as shown in Table 51.

Table 51. Final TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 8.

TGA	Latitude	Longitude	Location
0	.47190	.5181	SW corner of 4th & Harvey, meter 1063
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46869	.5156	S. side of Park Avenue between Robinson & Broadway (in front of Hallmark store)
4	.46980	.5147	NW Corner of Kerr & Broadway, meter 2085
5	--	--	Mobile on 4th Street
6	.46980	.5181	SW corner of Kerr & Harvey, meter 1119
7	.46980	.5193	SE corner of Kerr & Hudson, meter 1112
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46884	.5166	NW corner of Park & Robinson, meter 2113

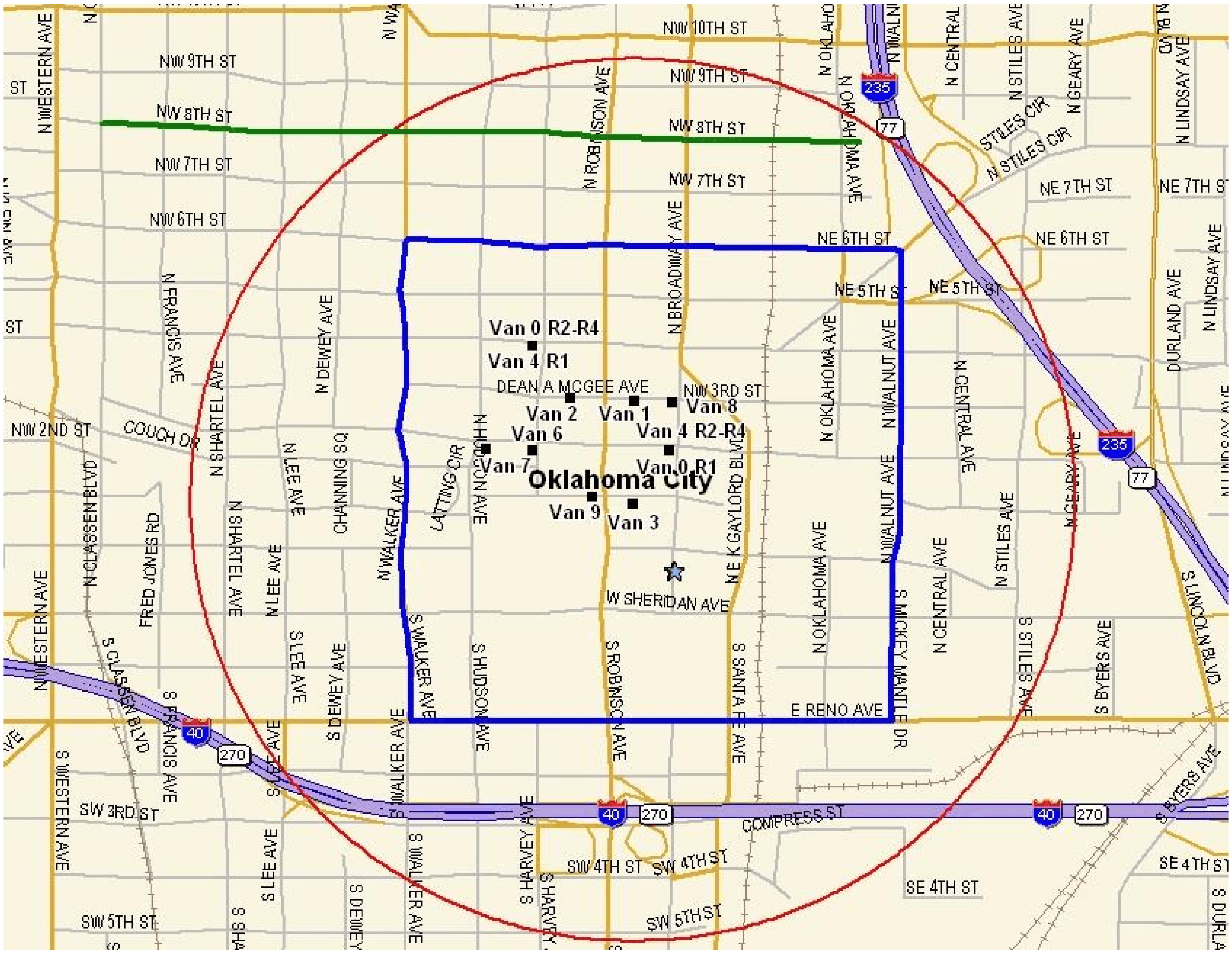

Figure 69. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1-km arc (red circle) during IOP 8.

4. IOP 8 Results. In contrast to IOP 7, a narrow tracer plume moved through the CBD during all three IOP 8 continuous releases, impacting integrating samplers north of the release site with the highest concentrations (Figs. 70 and 71). The highest concentration was over 42,000 pptv and observed at location number 046 (Table 52). The preferential path of the tracer was along Broadway to Kerr and then west along Kerr. The maximum rooftop location also received substantial concentrations but only about 2/3rds of the maximum concentration seen at the street level sampler. The highest pedestrian tunnel concentration of any IOP was observed during IOP 8. Location number 401 recorded a maximum concentration of 8,937 pptv. The plume passed narrowly through the northern half of the sampling arcs (Figs. 72 and 73). Location number 513 along the 1-km arc still recorded a maximum concentration over 2,000 pptv (Table 53).

Table 52. Summary of maximum reported concentrations (pptv) for integrating samplers deployed in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 8. "R" indicates the release site.

		Street-level Samplers								
		Walker 0x1	Hudson 0x2	Harvey 0x3	Robinson 0x4	Between 0x5	Broadway 0x6	Gaylord 0x7	Oklahoma 0x8	Walnut 0x9
6th St.	09y									
5th St.	08y		805	**3,395**	2,941		3,178	40		
4th St.	07y	21	242	2,268	**4,905**		4,726	19		
McGee	06y	12	106	3,794	5,135	6,602	**8,311**	25		
Kerr	05y	6	150	3,311	8,636	8,895	**16,780**	204		
Park	04y	7	115	108	2,019	10,514	**42,225**	454		
Main	03y	5	6	**21**			R	6		
Sheridan	02y	**6**	5	**6**				**6**		
California	01y				**6**			**6**		
Reno	00y			**7**						

		Rooftop Samplers								
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			1,516	**4,083**	3,980				
Kerr	05y			8,009 (950)	2,035	2,394	**15,215**			
Park	04y			23 (940)		**25,472**	19,505			
Main	03y						R			
Sheridan	02y									
California	01y									
Reno	00y									

Tunnel Samplers	
401	**8,937**
402	-999
403	3,298
404	498

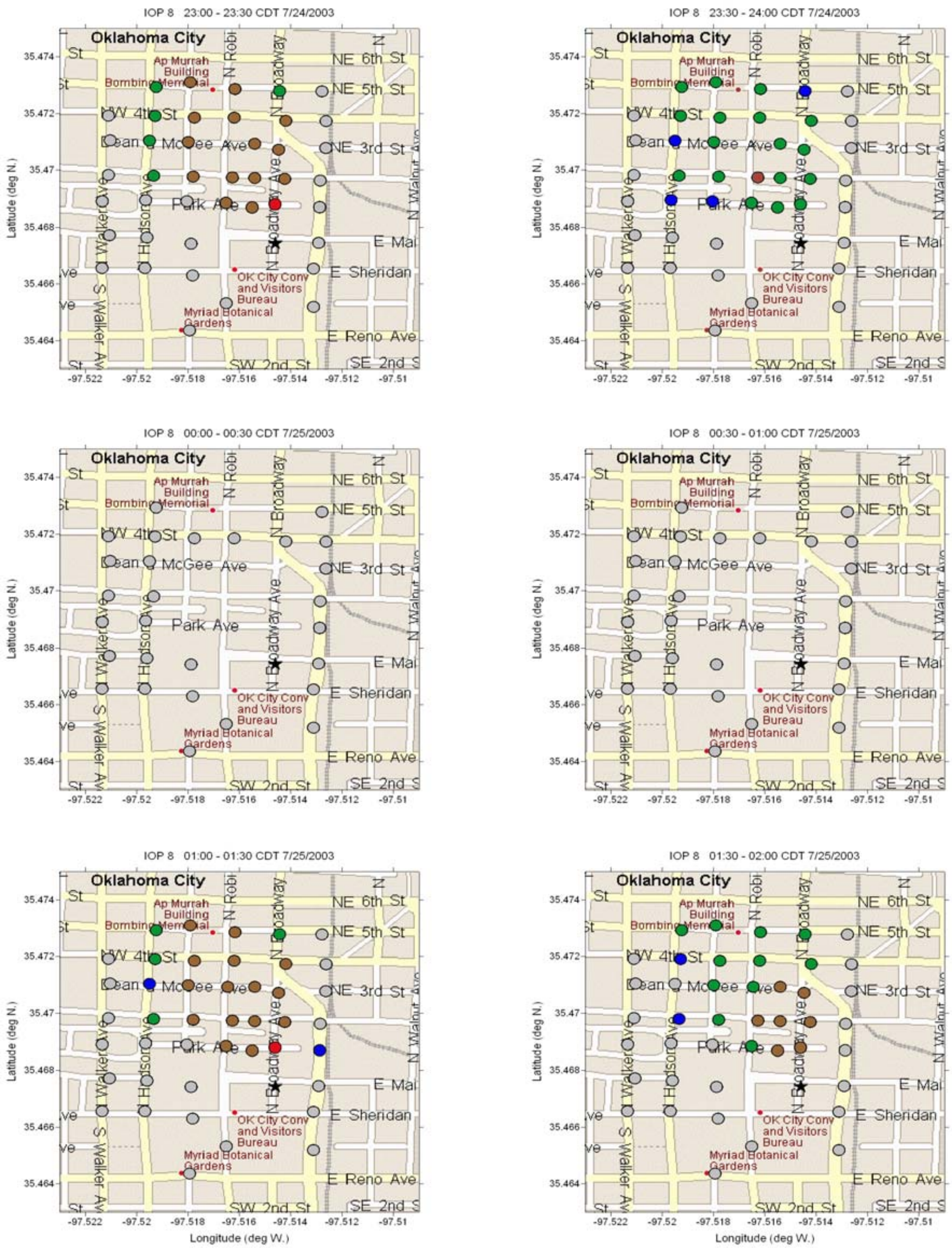

Figure 70. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 8 from 2300-0200 CDT. Tracer releases occurred from 2300-2330 and 0100-0130 CDT.

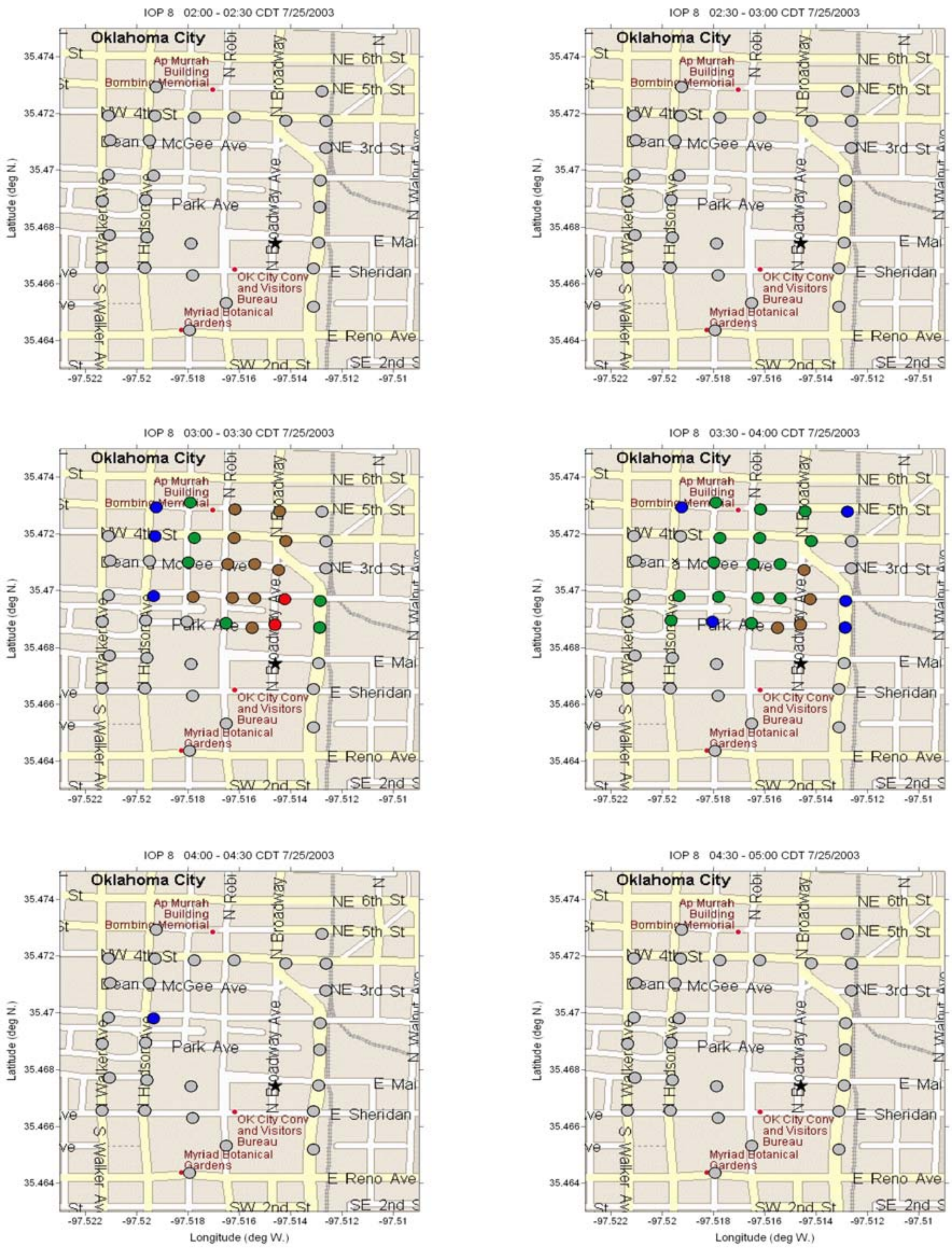

Figure 71. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 8 from 0200-0500 CDT. Tracer release occurred from 0300-0330 CDT.

Table 53. Summary of maximum reported SF_6 concentrations for integrating samplers deployed in the 1-, 2-, and 4-km arcs during IOP 8.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
501	6	-	-	-	-
502	6	*531*	*7*	561	5
503	*6*	532	*7*	562	5
504	6	533	6	563	-999
505	*7*	534	*6*	564	5
506	7	535	8	565	5
507	*6*	536	7	566	6
508	6	537	5	567	6
509	43	538	7	568	*6*
510	146	539	45	569	*5*
511	1,147	540	217	570	*14*
512	1,692	541	761	571	**320**
513	**2,053**	542	**927**	572	204
514	1,564	543	611	573	256
515	1,795	544	255	574	*16*
516	138	545	5	575	*5*
517	40	-	-	-	-

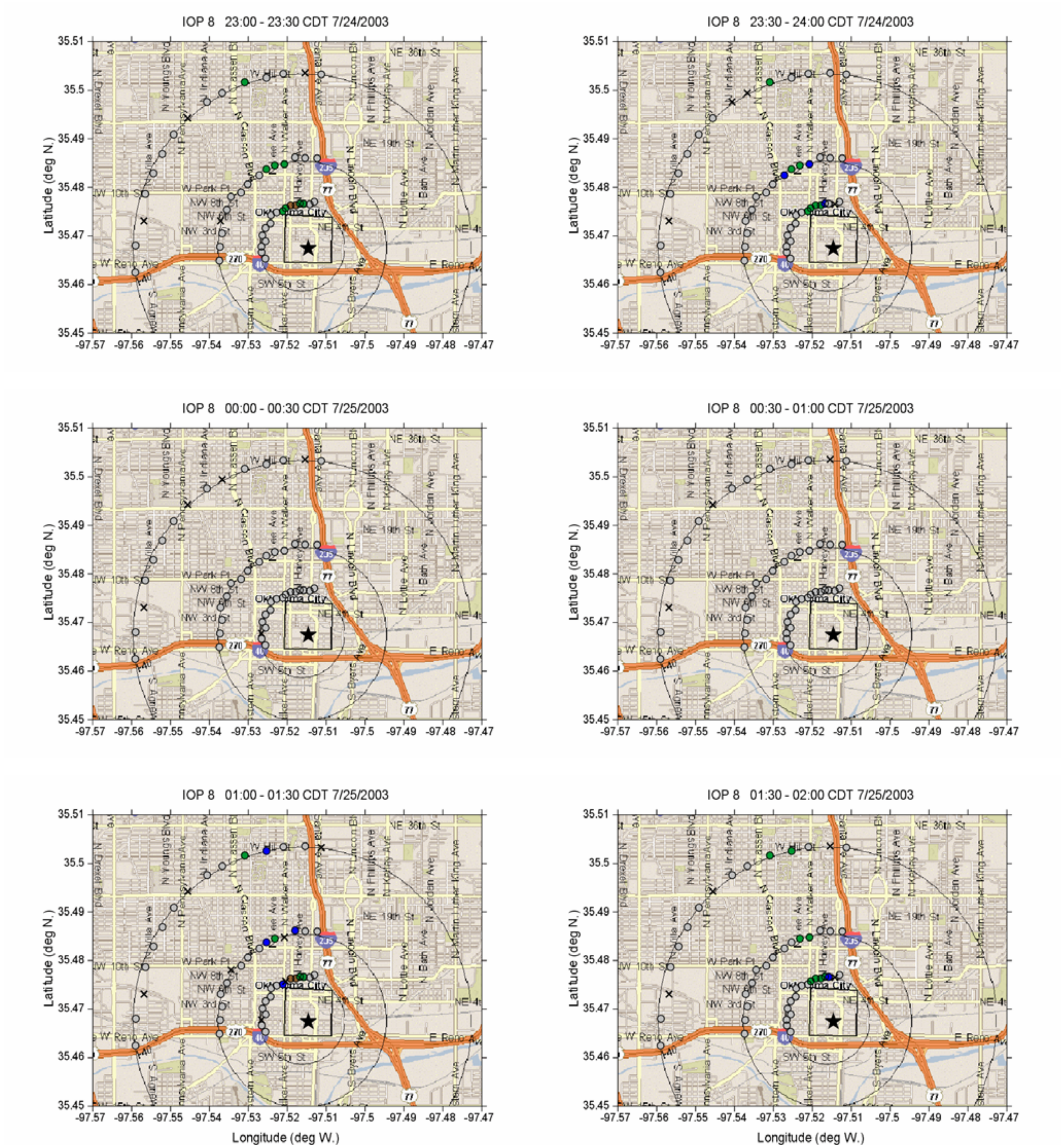

Figure 72. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 8 from 2300-0200 CDT. Tracer releases occurred from 2300-2330 and 0100-0130 CDT.

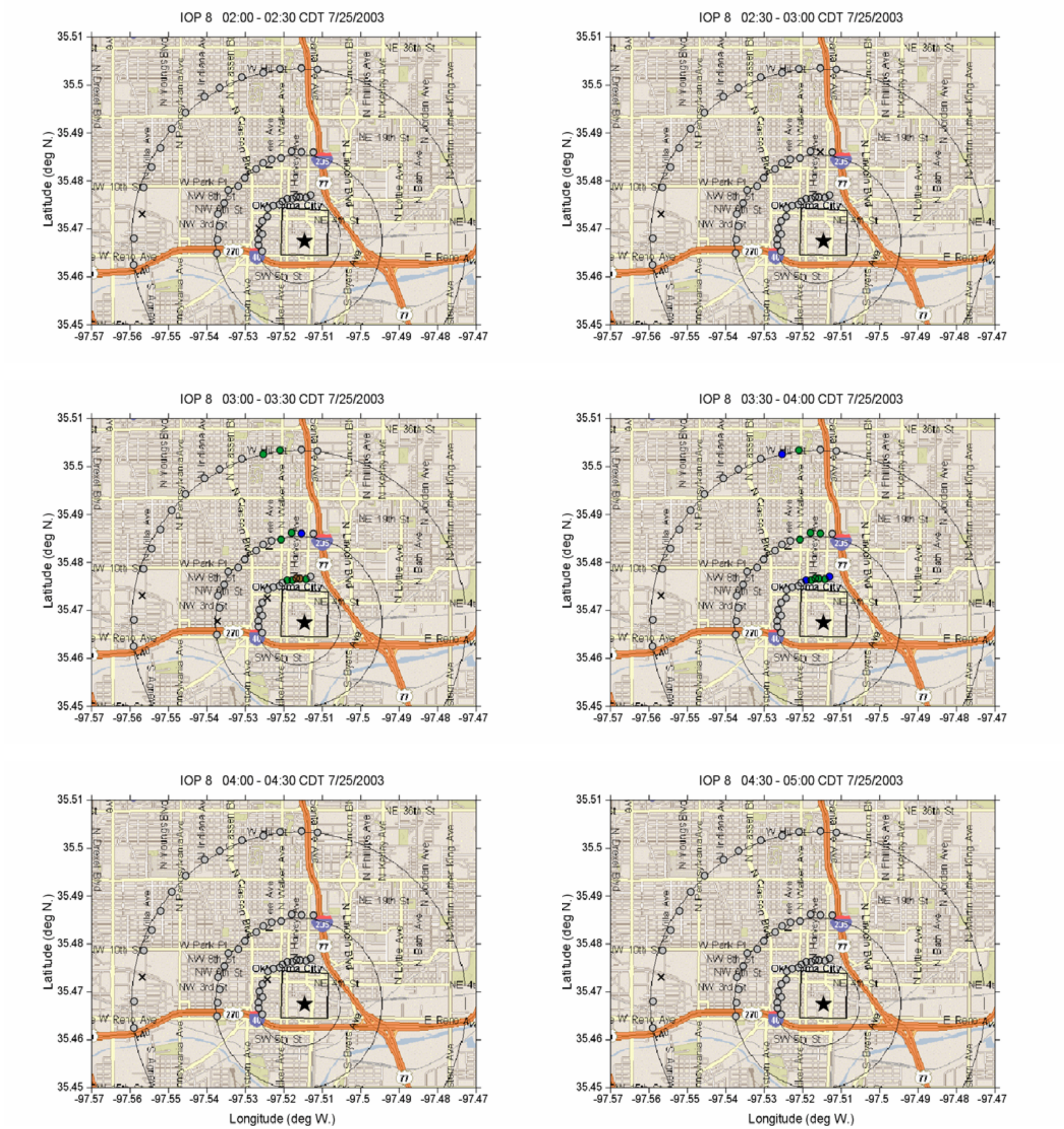

Figure 73. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 8 from 0200-0500 CDT. Tracer release occurred from 0300-0330 CDT.

All of the TGAs reported substantial tracer measurements during IOP 8 (Table 54). TGA 0, and then 4 and 9, experienced railing due to exposure to excessive tracer concentrations. Since TGA 0 railed after the first release it switched positions with TGA 4. TGA 4 had a dilution system that could be used closer to the release site to better measure the high concentrations of the plume. The dilution system, unfortunately, did not keep TGA 4 from railing.

Table 54. Maximum TGA-sampled concentrations (pptv) during IOP 8.

TGA	Point 1	Point 2	Point 3	Puff 1	Puff 2	Puff 3	Puff 4
0	*>12,900*	3,380	1,445	655	426	708	758
1	*14,600*	*12,700*	*12,800*	*12,300*	*14,500*	8,890	6,330
2	9,941	10,780	9,660	10,100	5,460	2,470	2,990
3	*16,600*	11,000	11,400	*14,800*	10,300	13,400	8,690
4	5,810	*>27,000*	*26,000*	*>27,000*	*>27,100*	*>27,200*	*17,700*
5	3,810	3,630	4,180	1,330	1,540	857	933
6	4,670	2,740	2,940	1,600	1,450	683	619
7	4,040	3,550	1,530	164	386	3,660	303
8	11,500	11,000	11,200	*12,100*	*12,500*	11,100	9,610
9	8,350	4,970	*>11,600*	2,300	*>11,600*	2,480	1,250

IOP 9, Saturday-Sunday, 26-27 July 2003

1. Meteorological Summary. IOP 9 weather was characterized by clear skies and winds from the S trending to SW. Sodar wind speeds (Table 55) remained steady at 7–9 m s^{-1}.

Table 55. IOP 9 sodar winds (15-min. averages) at 100-m AGL.

End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)	End Time (CDT)	Wind Speed (m s^{-1})	Wind Direction (deg)
2300	8.2	188	0130	6.6	178	0400	8.1	198
2315	8.2	186	0145	7.0	187	0415	8.0	190
2330	7.0	180	0200	5.7	180	0430	7.2	190
2345	7.2	183	0215	7.8	191	0445	7.4	194
0000	7.6	180	0230	7.9	199	0500	7.7	197
0015	7.8	186	0245	6.6	192	0515	8.5	198
0030	7.2	182	0300	7.3	198	0530	8.3	197
0045	8.6	191	0315	7.2	188	0545	7.9	188
0100	8.8	183	0330	5.8	188	0600	8.2	197
0115	9.1	191	0345	7.9	201	0615	8.5	201

2. Release Summary. The dissemination equipment was stationed for a Park Avenue release. This location was near the center of the CBD (see Fig. 31). Continuous 30-minute point source releases of 1.99, 2.02, and 2.09 g s^{-1} were made at 2300, 0100, and 0300 hrs CDT. These were followed by 300 g puff releases at 0500, 0520, 0540, and 0600 hrs CDT.

3. Sampler Deployment Summary. The time integrating samplers were set up for a SSW flow (blue arc, Fig. 30) and the CBD sampler locations were modified for the Park Avenue release. Some of the southern most samplers in the CBD, including rooftop sampler location number 945, were moved north to new locations to permit a more uniform sampling of the plume from the new release location. Pedestrian tunnel samplers were included in the setup for the CBD. Initial TGA positions for IOP 9 are shown in Table 56. The TGA locations were also moved to more northerly positions to adapt to the new release location. Plot of the stationary TGAs and the general path of the mobile TGA can be seen in Fig. 74.

Table 56. Initial TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 9.

TGA	Latitude	Longitude	Location
0	.46884	.5172	N. side of Park Ave. between Harvey & Robinson, meter 2121 (beneath the elevated walkway)
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46978	.5173	S. side of Kerr between Harvey & Robinson
4	.46965	.5137	S. side of Kerr between Broadway & Gaylord
5	--	--	Mobile along 8th Street
6	.46989	.5166	NW corner of Kerr & Robinson, meter 2131 (in front of Bank of Oklahoma)
7	.46980	.5147	NW corner of Kerr & Broadway, meter 2085
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46987	.5154	N. side of Kerr between Robinson & Broadway

Winds trending from S to SW prompted moving TGA 0 at 0440 CDT, with final TGA positions as shown in Table 57.

Table 57. Final TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations during IOP 9.

TGA	Latitude	Longitude	Location
0	.47168	.5126	S. side of 4th Street, just west of the tracks
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46978	.5173	S. side of Kerr between Harvey & Robinson
4	.46965	.5137	S. side of Kerr between Broadway & Gaylord
5	--	--	Mobile along NW 8th Street
6	.46989	.5166	NW corner of Kerr & Robinson, meter 2131
7	.46980	.5147	NW corner of Kerr & Broadway, meter 2085
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46987	.5154	N. side of Kerr between Robinson & Broadway

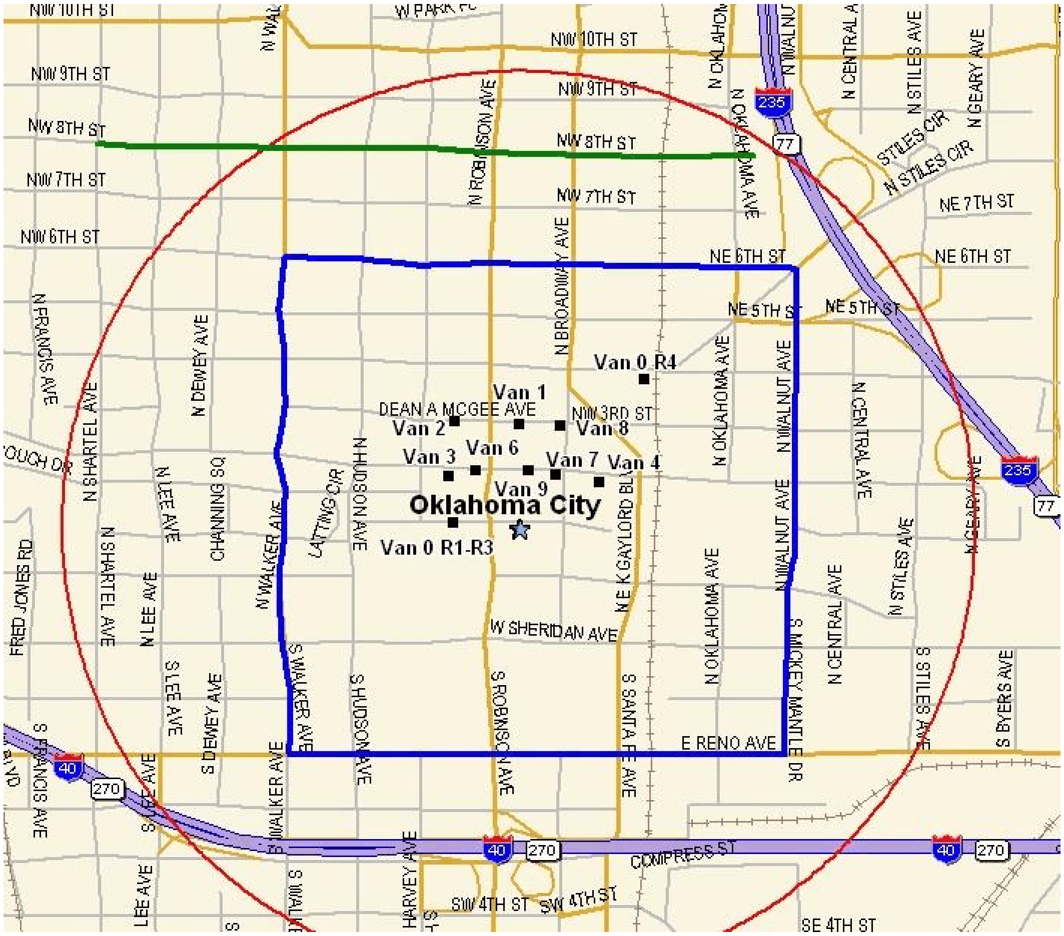

Figure 74. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1-km arc (red circle) during IOP 9.

4. <u>IOP 9 Results</u>. Maximum concentrations at the street level were not as high during IOP 9 compared to the 2 previous nocturnal releases (Table 58). Figures 75 and 76 shows evidence of a narrow plume moving north through the CBD during the first two continuous releases and heavily impacting samplers located north and northeast of the Park Avenue release site. The plume during the third continuous release drifted mainly through the eastern half of the CBD. Some of the very high SF_6 concentrations were sampled at rooftop locations. The maximum rooftop concentration of 69, 940 pptv occurred at location number 946 and was about 5 times higher than the highest measured street level sampler during IOP 9. CBD samplers located south of the release site remained at or near background concentration levels. Several tunnel samplers saw substantial amounts of material. The maximum tunnel concentration measured was 2,200 pptv and was observed from location number 402. The narrow plume dispersed north through the center of the sampler arcs (Figs. 77 and 78). The maximum concentration along the 1-km was 1,826 pptv and measured at location number 515 (Table 59).

Table 58. Summary of maximum reported concentrations (pptv) for integrating samplers deployed in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 9. “R” indicates the release site.

					Street-level Samplers					
		Walker	Hudson	Harvey	Robinson	Between	Broadway	Gaylord	Oklahoma	Walnut
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y				2,443		**2,594**			
5th St.	08y		120	413	3,614		**3,746**	301		
4th St.	07y		*99*	1,276	**4,608**		3,047	52	8	
McGee	06y	5	*42*	1,625	6,989	6,924	***8,793***	8	9	9
Kerr	05y	5	46	1,796	**13,802**	10,964	6,335	7	8	8
Park	04y		5	6		R		**8**		
Main	03y		5	6	7		**8**	**8**		
Sheridan	02y			5	6	6	**8**	**8**		
California	01y									
Reno	00y									

					Rooftop Samplers					
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			1,490	3,454	**4,818**				
Kerr	05y			10,661	774	631	**11,600**			
Park	04y			27 (940)		R	**69,940**			
Main	03y									
Sheridan	02y									
California	01y									
Reno	00y									

Tunnel Samplers	
401	13
402	**2,200**
403	1,351
404	*212*

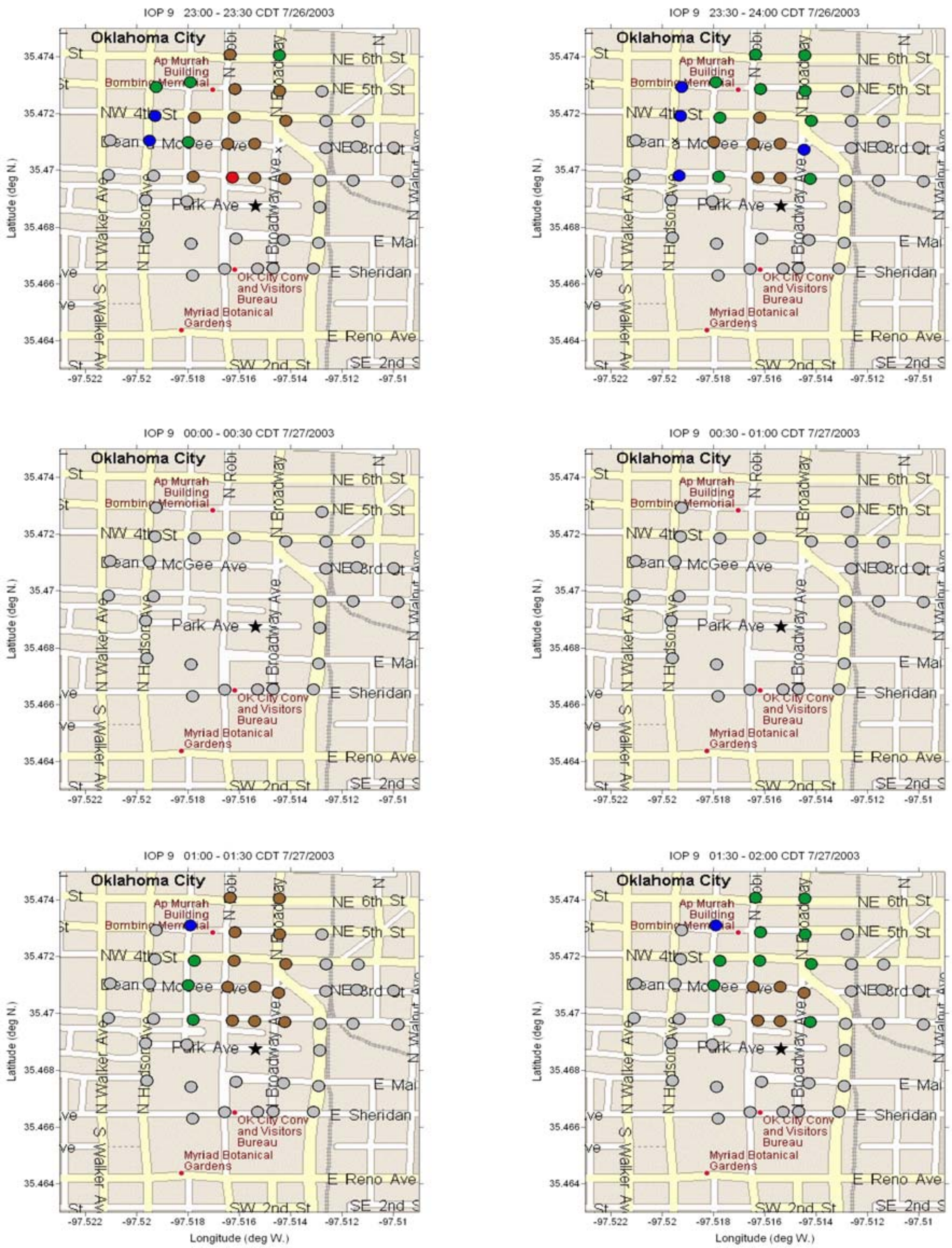

Figure 75. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 9 from 2300-0200 CDT. Tracer releases occurred from 2300-2330 and 0100-0130 CDT.

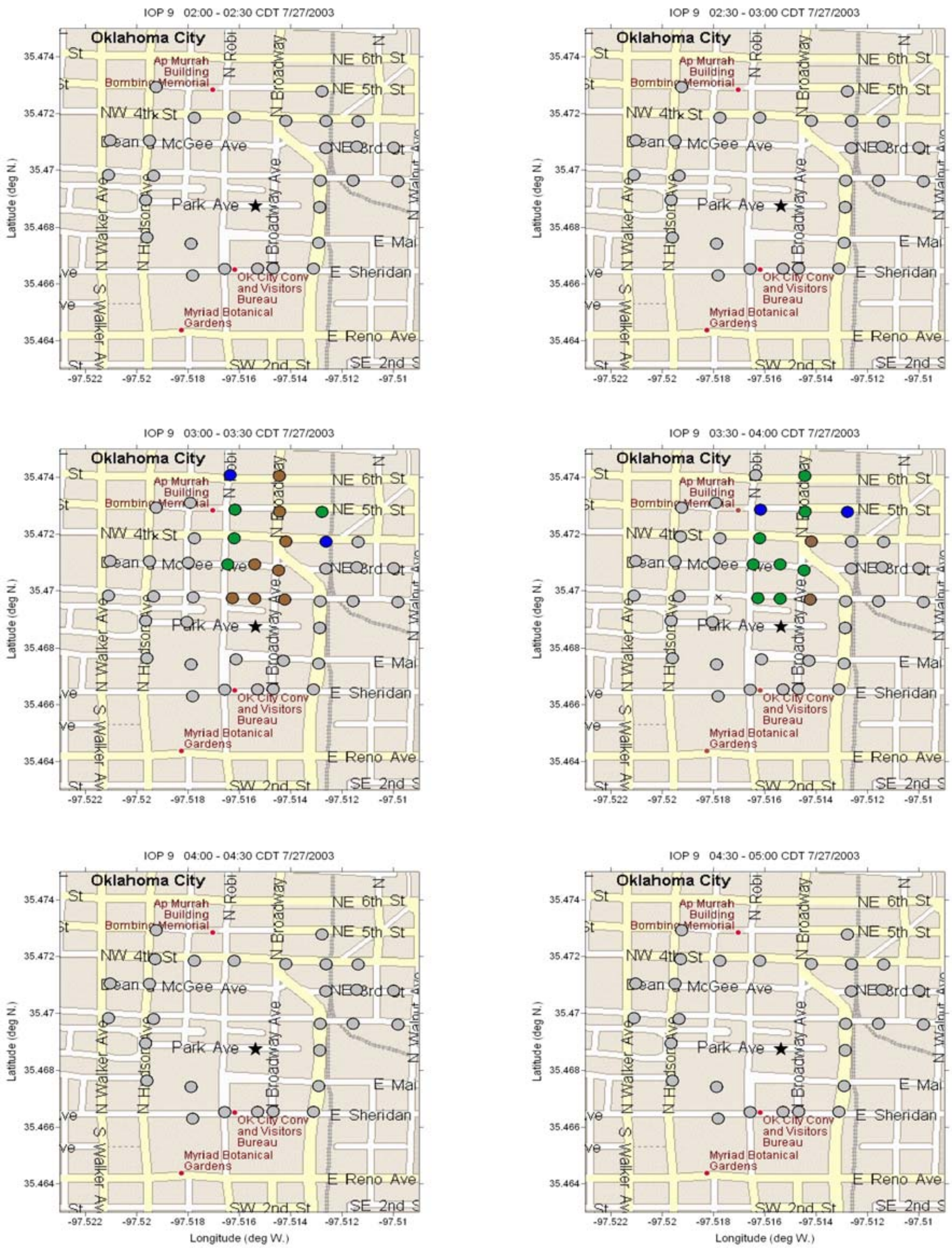

Figure 76. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 9 from 0200-0500 CDT. Tracer release occurred from 0300-0330 CDT.

Table 59. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 9.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	5	-	-	-	-
508	*5*	*537*	*5*	567	5
509	*5*	538	*5*	568	5
510	8	539	6	569	4
511	*73*	540	5	570	5
512	254	541	19	571	5
513	1,507	542	623	572	202
514	1,232	543	451	573	295
515	**1,826**	544	**821**	574	**332**
516	1,263	545	516	575	235
517	1,307	546	224	576	136
518	100	547	7	577	6
519	15	548	7	578	*6*
520	7	*549*	*6*	579	6
521	7	550	*6*	580	7
522	6	551	6	581	6
523	8	-	-	-	-

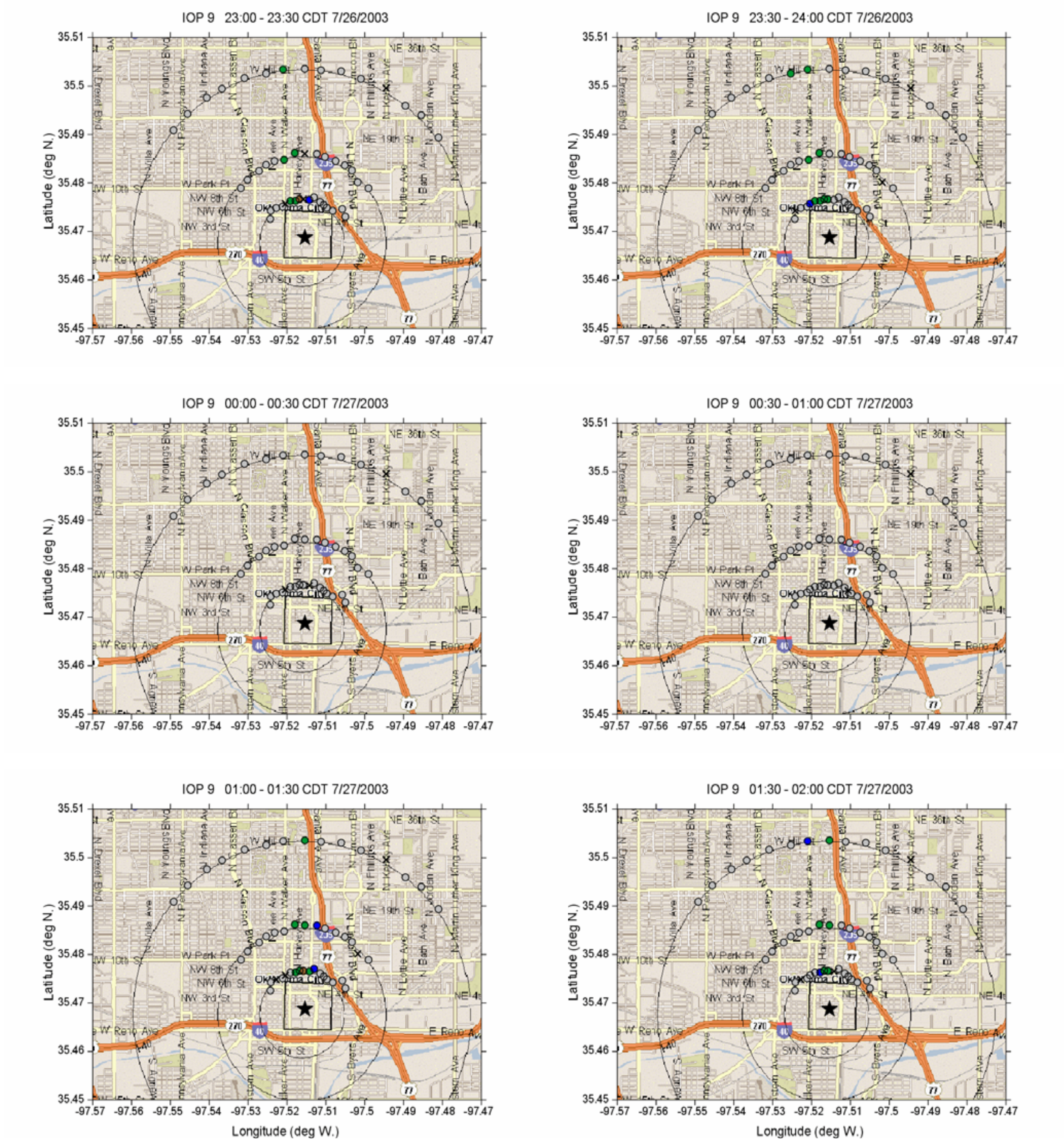

Figure 77. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 9 from 2300-0200 CDT. Tracer releases occurred from 2300-2330 and 0100-0130 CDT.

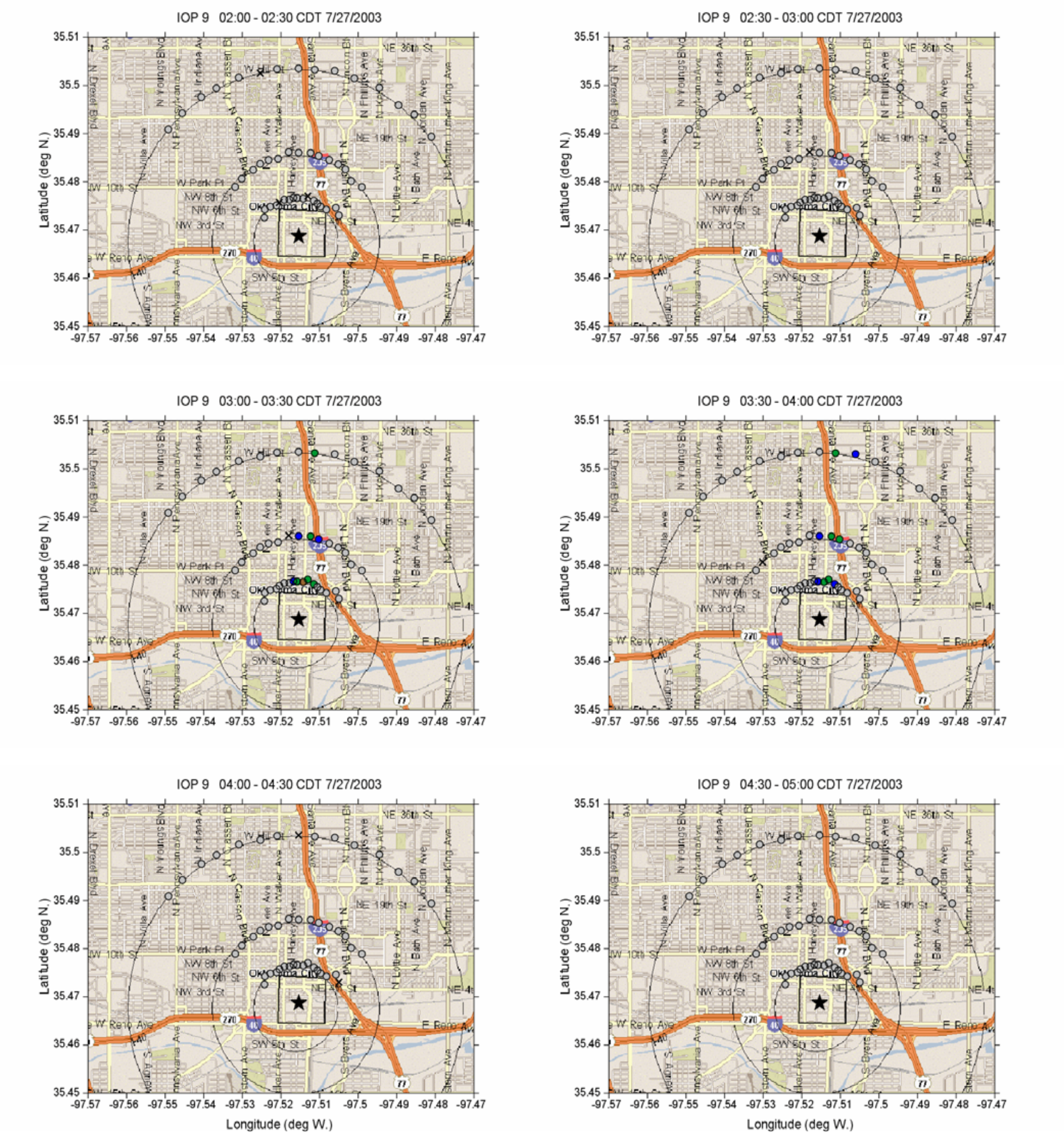

Figure 78. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 9 from 0200-0500 CDT. Tracer release occurred from 0300-0330 CDT.

The narrow plume heavily impacted TGAs located near the release site (Table 60). TGAs 4, 7, and 9 reported railing due to excessive tracer concentrations. Most TGAs saw substantial amounts of concentration during the first few continuous releases. TGAs in the western CBD began to see less concentrations as the IOP continued because the winds began to shift slowly southwesterly. TGA 0 was the only TGA that was asked to relocate since its location did not see any concentration during the continuous releases.

Table 60. Maximum TGA-sampled concentrations (pptv) during IOP 9.

TGA	Point 1	Point 2	Point 3	Puff 1	Puff 2	Puff 3	Puff 4
0	0	0	0	0	42	93	548
1	15,400	15,000	*8,820*	4,090	10,400	897	764
2	10,800	10,900	2,890	734	6,000	73	65
3	18,200	9,330	98	*53*	107	*48*	*48*
4	5,420	3,680	*>13,600*	2,010	783	1,060	5,860
5	3,690	4,370	4,410	1,830	2,760	2,560	1,190
6	20,800	20,400	708	203	249	0	0
7	17,200	*>23,800*	*>23,100*	9,460	*>23,300*	22,300	7,550
8	12,000	12,000	19,000	7,450	17,400	8,840	1,050
9	*>25,300*	*6,930*	19,100	*10,800*	*18,100*	0	0

IOP 10, Monday-Tuesday, 28-29 July 2003

1. Meteorological Summary. Winds were initially from S veering to SW, as shown by the 100-m sodar data in Table 61. IOP 10 was terminated prior to the fourth puff release due to an unfavorable westerly wind component.

Table 61. Sodar winds (15-min. averages) at 100-m AGL for IOP 10.

End Time (CDT)	Wind Speed ($m\ s^{-1}$)	Wind Direction (deg)	End Time (CDT)	Wind Speed ($m\ s^{-1}$)	Wind Direction (deg)	End Time (CDT)	Wind Speed ($m\ s^{-1}$)	Wind Direction (deg)
2100	6.0	197	2330	7.3	197	0200	7.0	216
2115	6.3	179	2345	7.3	197	0215	7.3	220
2130	5.1	205	0000	7.0	215	0230	5.7	226
2145	4.4	197	0015	6.6	206	0245	5.7	229
2200	7.0	209	0030	7.1	213	0300	4.0	247
2215	6.3	207	0045	7.4	207	0315	5.4	237
2230	6.8	205	0100	8.1	225	0330	6.8	251
2245	5.6	195	0115	6.0	224	0345	6.9	244
2300	6.9	195	0130	5.1	220	0400	8.5	246
2315	7.5	202	0145	5.6	234	0415	9.2	239

2. Release Summary. IOP 10 releases were performed from the Park Avenue position. Continuous 30-minute point source releases of 2.24, 1.94, and 2.19 $g\ s^{-1}$ occurred at 2100, 2300, and 0100 CDT. Puff releases of 300 g were made at 0300, 0320, and 0340 CDT. IOP 10 was then terminated.

3. Sampler Deployment Summary. The integrating samplers were set out for SSW winds (blue arc, Fig. 30). Sampler setup in the CBD included samplers in the pedestrian tunnel and rooftop samplers. Initial TGA deployment for IOP 10 anticipated southerly flow, as shown in Table 62. Plot of the stationary TGAs and general path of mobile TGA can be seen in Fig. 79.

Table 62. Initial TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 10.

TGA	Latitude	Longitude	Location
0	.46884	.5172	N. side of Park Ave. between Harvey & Robinson, meter 2121 (beneath the elevated walkway)
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.46978	.5173	S. side of Kerr between Harvey & Robinson
4	.46965	.5137	S. side of Kerr between Broadway & Gaylord
5	--	--	Mobile along 8th Street
6	.46989	.5166	NW corner of Kerr & Robinson, meter 2131 (in front of Bank of Oklahoma)
7	.46980	.5147	NW corner of Kerr & Broadway, meter 2085
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46987	.5154	N. side of Kerr between Robinson & Broadway

A westerly wind trend prompted relocation of TGAs 0 and 3 at 0038 CDT to positions shown in Table 63.

Table 63. Subsequent TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 10.

TGA	Latitude	Longitude	Location
0	.47279	.5145	SW corner of 5th & Broadway
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47085	.5172	S. side of McGee between Harvey & Robinson (in front of Old Post Office)
3	.47281	.5128	S. side of 5th Street between Broadway and the railroad tracks
4	.46965	.5137	S. side of Kerr between Broadway & Gaylord
5	--	--	Mobile along 4th and 8th Streets
6	.46989	.5166	NW corner of Kerr & Robinson, meter 2131 (in front of Bank of Oklahoma
7	.46980	.5147	NW corner of Kerr & Broadway, meter 2085
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46987	.5154	N. side of Kerr between Robinson & Broadway

The continued trend in wind direction from the west prompted movement of TGA 2 at 0236 CDT. TGA 9 also malfunctioned and was replaced by TGA 6. These changes are reflected in Table 64.

Table 64. Final TGA locations, including decimal latitude (35.xxxxx° N) and longitude (97.yyyy° W) and street locations for IOP 10.

TGA	Latitude	Longitude	Location
0	.47279	.5145	SW corner of 5th & Broadway
1	.47080	.5156	S. side of McGee between Robinson & Broadway, meter 0459 (in front of public library)
2	.47165	.5107	Corner of 4th & Oklahoma
3	.47281	.5128	S. side of 5th Street between Broadway and the railroad tracks
4	.46965	.5137	S. side of Kerr between Broadway & Gaylord
5	--	--	Mobile along 4th Street
6	.46987	.5154	N. side of Kerr between Robinson & Broadway
7	.46980	.5147	NW corner of Kerr & Broadway, meter 2085
8	.47078	.5146	SW corner of McGee & Broadway, meter 0464
9	.46987	.5154	Out of commission

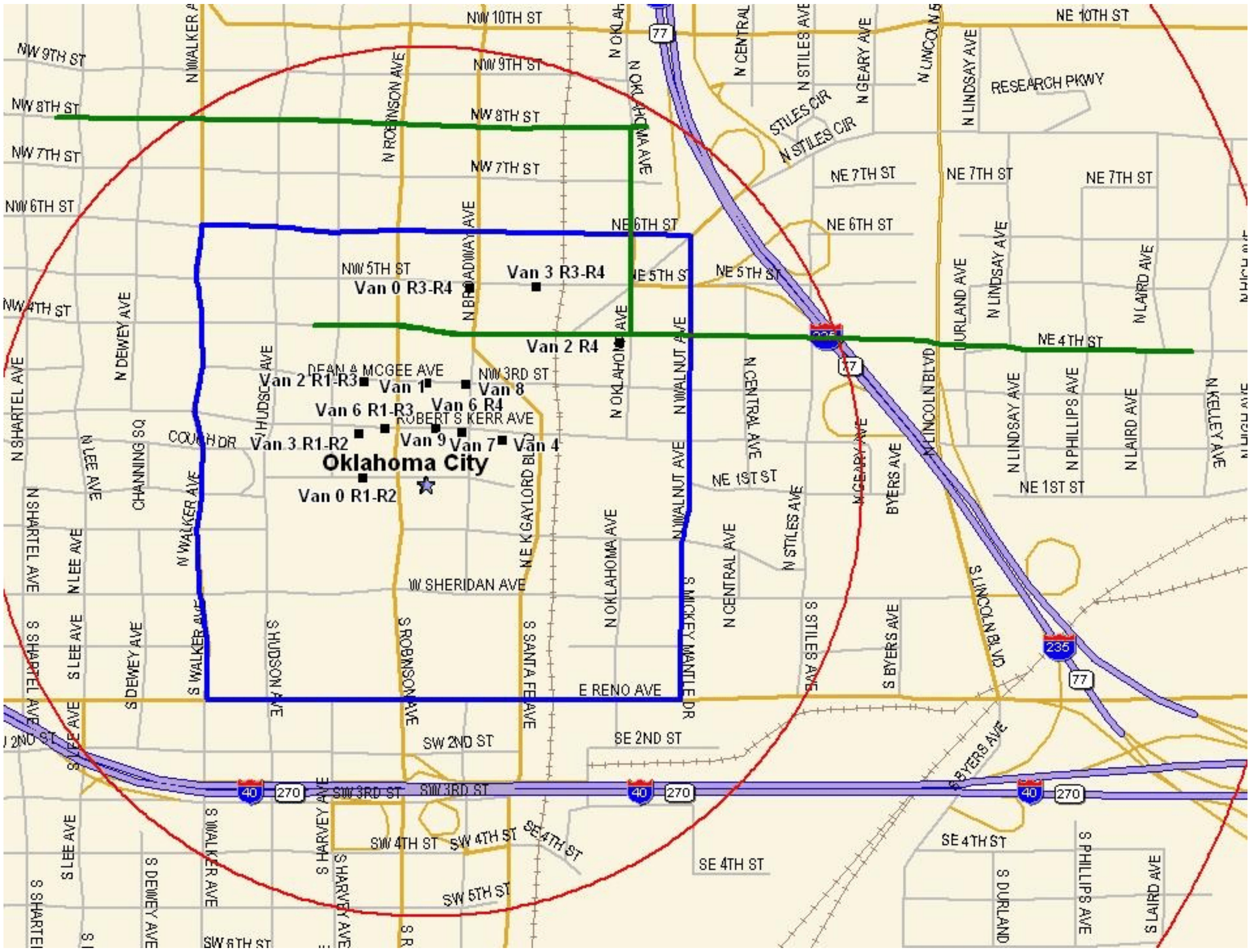

Figure 79. Stationary TGAs (black squares), general path of the mobile TGA (green line), release site (blue star), CBD (blue box), and the 1- and 2-km arcs (red circles) during IOP 10.

4. <u>IOP 10 Summary</u>. The Park Avenue release site is located near the center of the CBD samplers (Fig. 31). Consequently, most samplers located south of the release site received SF_6 concentrations near baseline. Plumes from the first two releases traveled through most of the CBD north of the release site, but the third plume veered to the east of the CBD (Figs. 80 and 81). A few street-level samplers (locations 054 – 056, and 064 – 067, 074 – 077) and rooftop samplers (locations 946, 950, 956, 964, and 965) received high concentrations, as shown in Table 65. Tunnel sampler location number 402 saw the highest concentration of 2,490 pptv. Good tracer concentrations were sampled along the arcs (Figs. 82 and 83) until the wind shifted so far to the west that the plume drifted to the east of these arcs. The maximum concentration along the 2- and 4-km arcs were slightly higher during IOP 10 compared to the previous IOP (Table 66).

Table 65. Summary of maximum reported concentrations (pptv) for integrating samplers deployed in the CBD at street-level, the pedestrian tunnel, and on rooftops for IOP 10. "R" indicates the release site.

		Street-level Samplers								
		Walker 0x1	Hudson 0x2	Harvey 0x3	Robinson 0x4	Between 0x5	Broadway 0x6	Gaylord 0x7	Oklahoma 0x8	Walnut 0x9
6th St.	09y				**1,237**		768			
5th St.	08y		53	383	2,090		**3,471**	*190*		
4th St.	07y		75	696	**3,708**		3,654	2,205	964	8
McGee	06y	6	7	1,433	5,077	9,426	**10,466**	2,170	225	11
Kerr	05y	5	7	1,461	9,845	9,503	**43,589**	126	26	6
Park	04y		5	6		R		**33**		
Main	03y		5	5	5		5	**6**		
Sheridan	02y			5	**8**	5	5	5		
California	01y									
Reno	00y									
		Rooftop Samplers								
		0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9
6th St.	09y									
5th St.	08y									
4th St.	07y									
McGee	06y			1,211	2,946	**5,394**				
Kerr	05y			8,225 (950)	1,277	1,214	**12,277**			
Park	04y			12 (940)		R	**77,634**			
Main	03y									
Sheridan	02y									
California	01y									
Reno	00y									
		Tunnel Samplers								
401	11									
402	**2,490**									
403	1,642									
404	38									

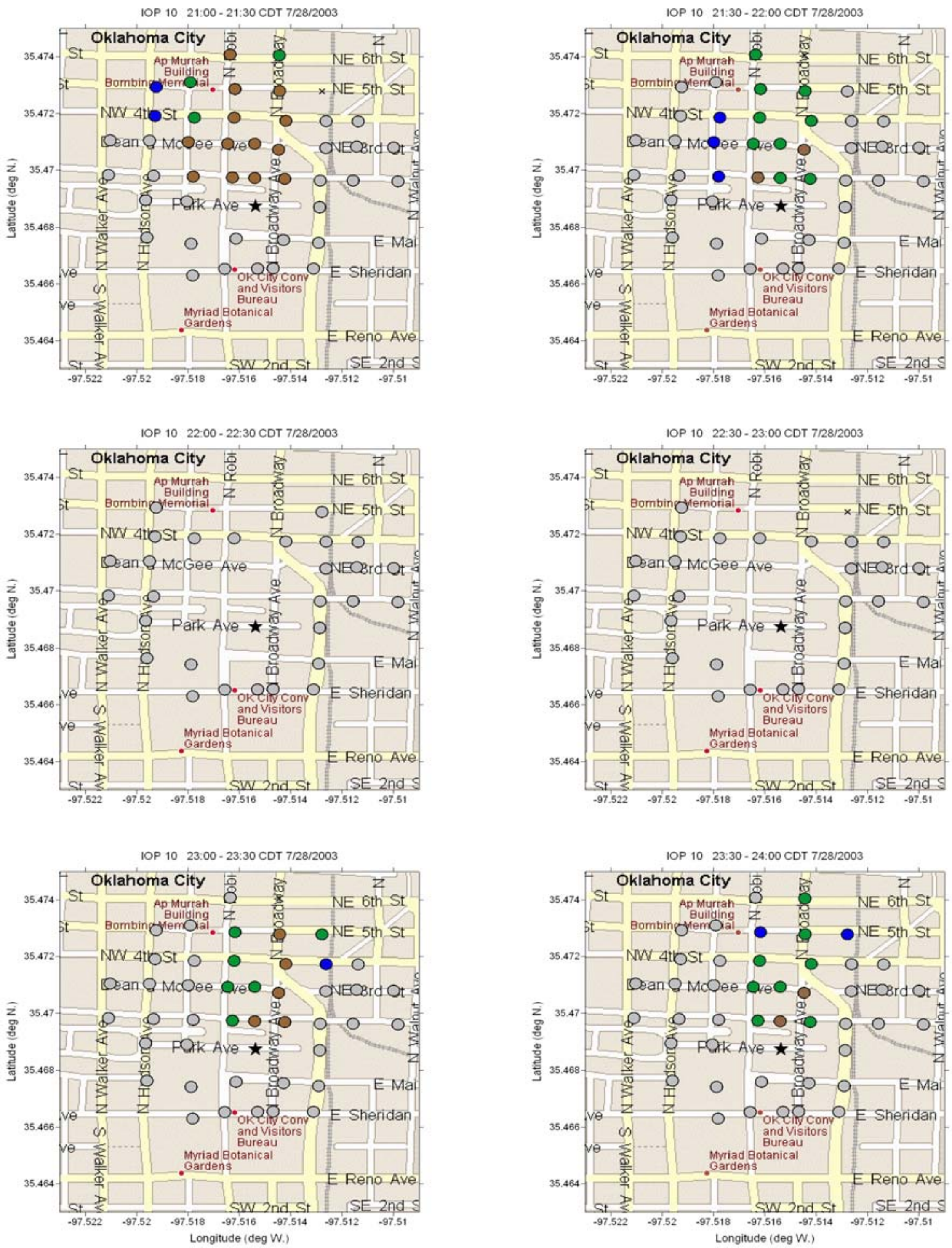

Figure 80. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 10 from 2100-2400 CDT. Tracer releases occurred from 2100-2130 and 2300-2330 CDT.

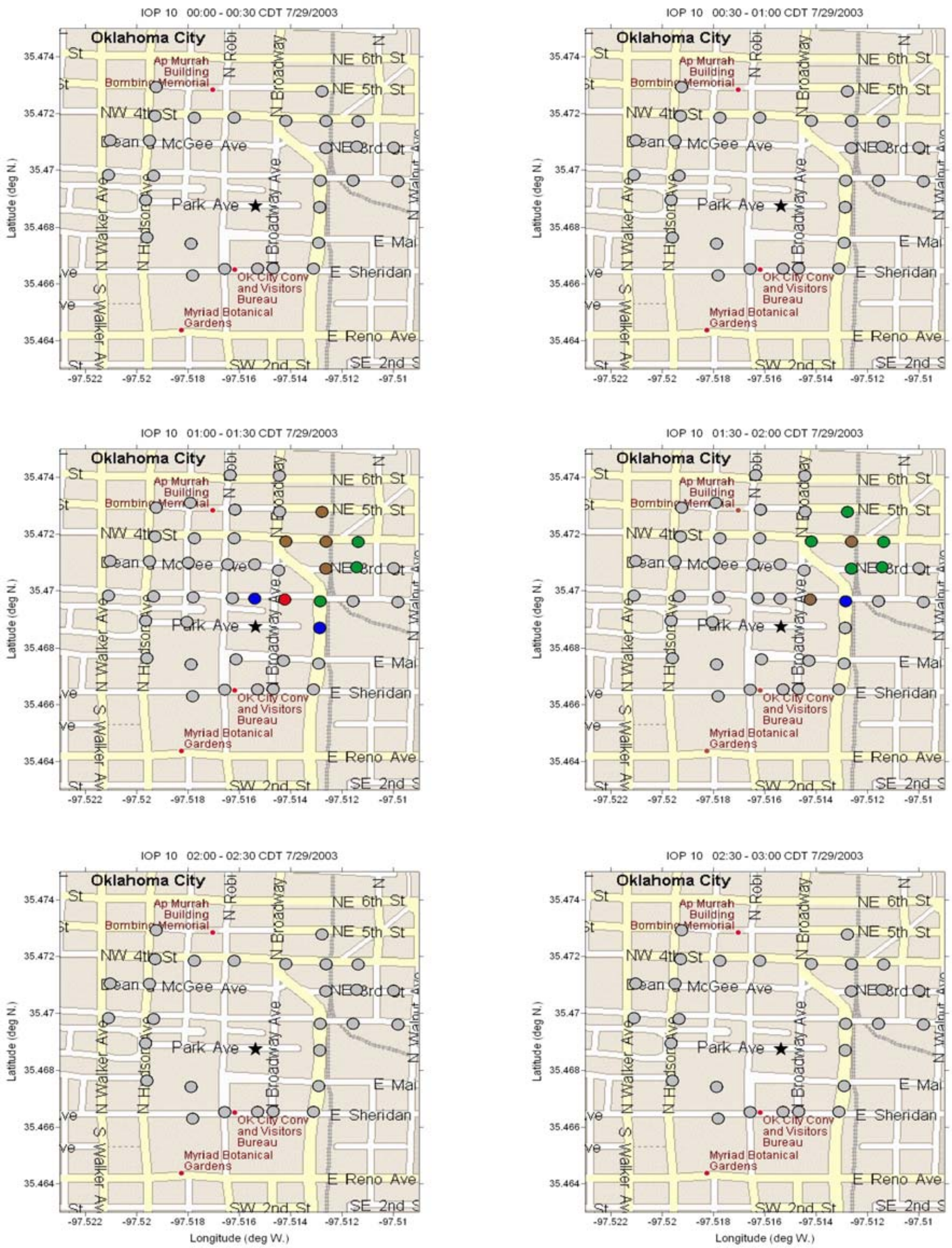

Figure 81. CBD PIGS and Super PIGS SF_6 tracer concentration footprints during IOP 10 from 0000-0300 CDT. Tracer releases occurred from 0100-0130 CDT.

Table 66. Summary of maximum reported SF_6 concentrations for integrating samplers deployed on the 1-, 2-, and 4-km arcs during IOP 10.

1-km arc		2-km arc		4-km arc	
Location	Conc.	Location	Conc.	Location	Conc.
507	6	-	-	-	-
508	5	537	5	567	5
509	*6*	538	-999	568	9
510	7	539	5	569	5
511	17	540	5	570	5
512	14	541	15	571	11
513	*408*	542	76	572	11
514	969	543	177	573	54
515	1,136	544	689	574	*232*
516	1,205	545	646	575	162
517	*1,215*	546	287	576	244
518	262	547	75	577	10
519	**1,804**	548	**1,056**	578	**739**
520	550	549	296	579	16
521	181	550	41	580	*6*
522	6	551	6	581	6
523	5	-	-	-	-

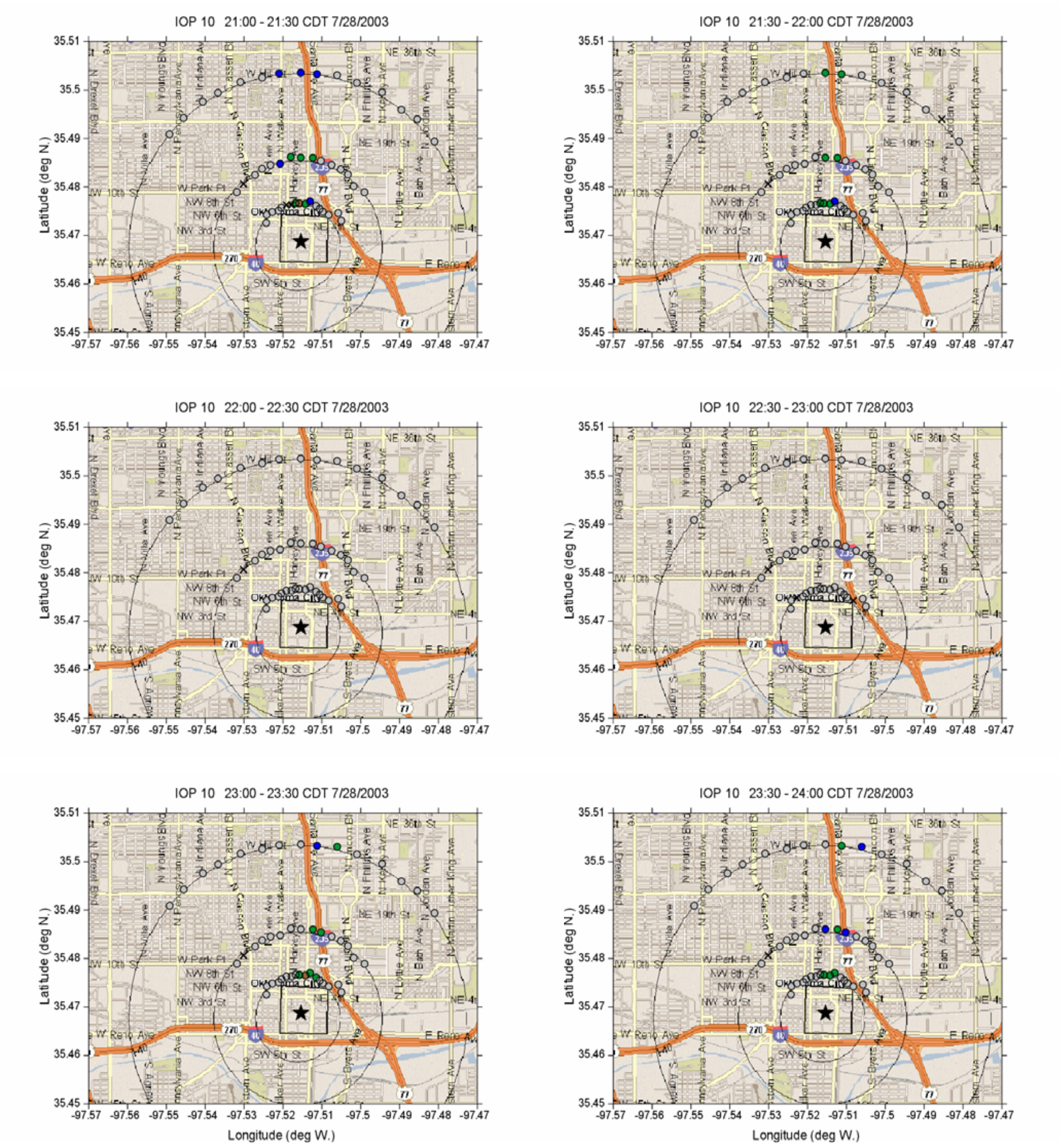

Figure 82. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 10 from 2100-2400 CDT. Tracer releases occurred from 2100-2130 and 2300-2330 CDT.

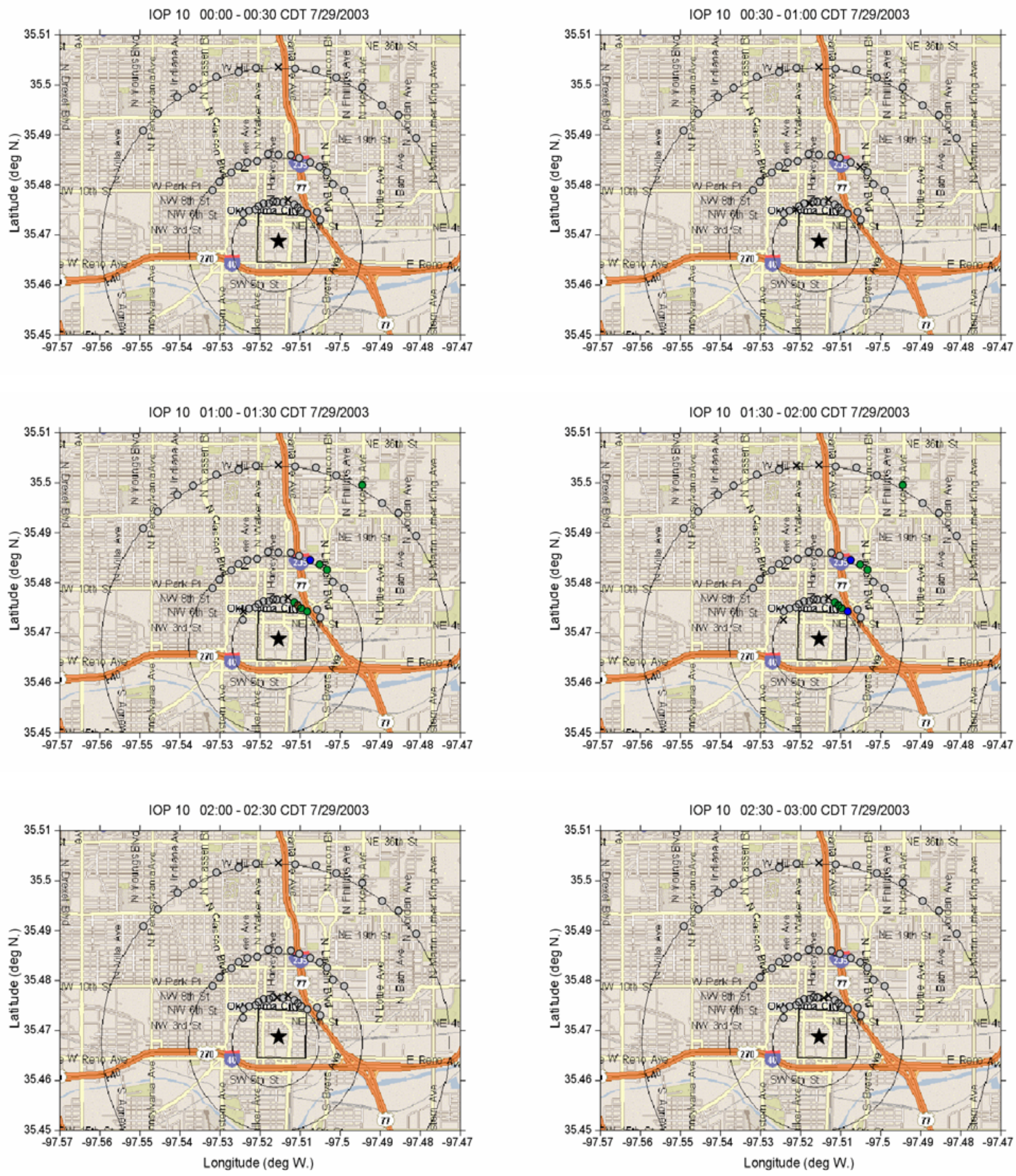

Figure 83. PIGS SF_6 tracer concentration footprints along the 1-, 2-, and 4-km arcs during IOP 10 from 0000-0300 CDT. Tracer release occurred from 0100-0130 CDT.

Southerly winds provided good plume coverage by the TGAs for the point source releases, as seen in Table 67. TGAs 4 and 7 railed due to high tracer concentrations. However, the westerly wind shift during the puff releases transported the plume east of most of the TGAs. TGA 4 was stationed in the most easterly position. Located on Kerr between Broadway and Gaylord, it alone received consistently high SF_6 concentrations during the puff releases.

Table 67. Maximum TGA-sampled concentrations (pptv) during IOP 10.

TGA	Point 1	Point 2	Point 3	Puff 1	Puff 2	Puff 3
0	163	0	679	0	0	0
1	*15,500*	8,800	*220*	0	0	0
2	10,900	481	0	4,390	1,460	4,900
3	8,730	122	8,320	43	37	0
4	1,600	11,800	*25,400*	*>27,000*	*>26,900*	*>27,200*
5	4,230	4,500	10,300	3,940	2,090	2,290
6	*24,000*	348	0	0	0	0
7	*>24,900*	*>25,600*	*>26,000*	108	*79*	60
8	11,600	9,600	112	0	0	0
9	*27,800*	-999	-999	-999	-999	-999

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ANALYSIS

Tracer Dissipation Analysis

Super PIGS located within the CBD at street level and on nearby rooftops were programmed to capture information on the rate at which the SF_6 concentration dissipated after the end of each 30-minute continuous dissemination. Variable interval programming was used to sample over two 15-minute periods corresponding to each 30-minute dissemination time, followed by a series of 5-minute samples designed to document in greater detail the decrease in tracer concentration as the tail of the plume passed the sampling sites.

Tracer dissipation rate is affected by many factors, to include variability in wind speed and direction, atmospheric turbulence, and flow obstruction from buildings within the CBD. Tracer concentration measurement results at any fixed site are due to diffusion, turbulence-dependent plume expansion, shredding of the plume by flow obstructions, and by lateral movements of parcels of varying tracer concentrations toward or away from the sampler. It is not possible to determine from a single sampler's results which of the abovementioned factors predominate. However, averaging over a sufficiently large number of samplers should minimize effects due to lateral motions. This leaves diffusion, wind-dependent longitudinal plume expansion, and turbulence as the major contributors to tracer dissipation.

Tracer dissipation can be described using a simple decay model $(\chi/\chi_0) = e^{-kt}$. Data from all Super PIGS that experienced passage of a major portion of the tracer plume were analyzed for the maximum integrated concentration (χ_0), and for subsequent concentrations (χ) sampled t minutes after the passage of $\chi_{0.}$ The objective of this analysis is to determine differences in dissipation coefficients (k) for day vs. night releases, for street-level vs. rooftop measurement sites, and to examine the effects of wind speed and turbulence on tracer dissipation.

Several non-meteorological factors also affect the magnitude of k and complicate its analysis. These factors include sampler integration time, concentration range, and background concentration level. The magnitude of k varies inversely with integration time. Therefore, the range of k's obtained from 5-minute integrations will include larger numbers than the range of k's obtained from 30-minute integrations. The present analysis includes only the 5-minute data to eliminate differences due to integration time effects. Tracer concentrations tend to diminish rapidly after reaching χ_0, and diminish slowly towards the tail of the plume. Consequently, this analysis focuses on the portion of the plume where tracer concentrations decrease from χ_0 to the MLOQ (111 pptv, see Time Integrating Tracer Sample Analysis), where χ_0 is typically one or two orders of magnitude greater than the MLOQ. Some samplers located very close to the release sites were exposed to tracer concentrations ranging between two and three orders of magnitude greater than the MLOQ. Sites exposed to very high concentrations tended to experience more rapid dissipation. The background concentration level also had a minor but persistent effect on k. The background concentration at the beginning of an IOPs first continuous dissemination typically ranged from 4 to 6 pptv. However, the background often did not return to this level prior to the beginning of subsequent disseminations. This effect caused some slightly smaller values of k for the subsequent disseminations, but these results were not found to be consistent or statistically significant. Consequently, no effort was made to separate the k's obtained from the first and subsequent disseminations. Summary statistics for the CBD tracer decay analysis are presented in Table 68.

Table 68. Summaries of decay coefficient and maximum concentration statistics for JU03 street and rooftop samplers, with IOPs 1 through 6 considered to the daytime cases and IOPs 7 through 10 considered nighttime cases, and calculated dissipation times in minutes from 100 χ_0 to χ_0.

Variable	Day Street	Day Roof	Night Street	Night Roof	All Street	All Roof
k Means (min^{-1})	0.5323	0.5145	0.3743	0.4058	0.4508	0.4647
k Medians (min^{-1})	0.5370	0.5306	0.3640	0.4130	0.4535	0.4866
k Std. Dev. (min^{-1})	0.1358	0.1207	0.1594	0.1371	0.1679	0.1391
k Sample Size	91	78	97	66	188	144
χ_0 Means (pptv)	7831	5322	5955	9652	--	--
χ_0 Medians (pptv)	3494	2764	3746	3717	--	--
χ_0 Std. Dev. (pptv)	15099	8551	6620	15638	--	--
χ_0 Sample Size	91	78	97	66	--	--
Dissipation Time (min.)	8.6	8.7	12.7	11.1	10.2	9.5

Both means and medians are reported in Table 68 as measures of central tendency. The mean is simply the sum of all included variables divided by sample size, while the median is the 50th percentile value. Because it is the 50th percentile, the median provides a measure of central tendency independent of the magnitudes of the data at the far range of the distribution. Because it is not influenced by the extremes of the sample distribution, the median can be a superior measure of central tendency when the sample includes a scattering of very large or very small numbers. The k means and medians reported in Table 68 are fairly comparable, but the χ_0 means are substantially greater than their corresponding medians. This is due to the inclusion of some samples where χ_0 was quite large. The samples with large χ_0 typically produced values of k at the high end of the distribution, but did not force a major difference between the k means and medians.

The data presented in Table 68 were subjected to t-tests for the statistical significance of differences between sample means (Panofsky and Brier, 1965). Five sets of t-tests were done: (1) daytime street vs. roof; (2) nighttime street vs. roof; (3) daytime vs. nighttime at street level; (4) daytime vs. nighttime at rooftop level; and (5) street level for all IOPs vs. roof level for all IOPs. Test results are presented in Table 69 below. Differences between street level day and night mean dissipation coefficients and rooftop day and night mean dissipation coefficients produced t scores significant at the 0.1% level (one chance in a thousand that the result could have come from random samples taken from the same underlying population). This is interpreted to mean that, on average, the tracer dissipated faster during the daytime than at night at both the street and rooftop levels, and that the differences between day vs. night dissipation rates are statistically significant.

Table 69. t-test scores and significance levels for dissipation coefficient data sets presented in Table 68.

Dissipation Coefficients	t-score	Significance level
Day, Street vs. Roof	0.9	None
Night, Street vs. Roof	1.3	None
Street, Day vs. Night	7.3	0.1%
Roof, Day vs. Night	5.0	0.1%
All Street vs. All Roof	0.8	None

The results were less certain for nocturnal street vs. roof and daytime street vs. roof dissipation coefficients. The means t-test revealed no level of significance for either case. On average, the tracer dissipated at night somewhat faster at the rooftop locations than at street level. During the day, the tracer dissipated somewhat faster at street level than at the rooftop level. Thus, the dissipation rate differences were not statistically distinguishable. In both cases the t-test revealed no level of significance.

When all the data were combined, the street and roof mean dissipation coefficients were not significantly different, although the mean roof k was slightly larger than the mean street level k. This result occurred because the street day and night dissipation coefficients were respectively higher and lower than those for the rooftop locations, and averaging them brought the street and rooftop mean dissipation coefficients closer to each other in magnitude.

The final row in Table 68 shows the median time in minutes needed for the tracer to dissipate from two orders of magnitude above the MLOQ to the MLOQ. During the day, the required times were 8.6 and 8.7 minutes for the street and rooftop dissemination times, respectively. This shows that the street on average required 1% less time to clear than the roof, a result that is not statistically significant. At night, the street level and roof dissipation times were respectively 12.7 and 11.1 minutes, producing a statistically insignificant 13% difference. The night and day mean dissipation times at street level were respectively 12.7 and 8.6 minutes, yielding a statistically significant 48% increase in the amount of time required to dissipate tracer at street level at night versus during the day. On the roof, night and day dissipation times were 11.1 and 8.7 minutes respectively, indicating a 28% dissipation rate decrease at night vs. day. This result was also statistically significant.

100-m Wind Effects on Dissipation

Wind speed is likely to affect the magnitude of the dissipation coefficients because along-wind plume expansion and turbulent mixing typically increase with wind speed. A preliminary estimate of above-rooftop wind effects were obtained by correlating 100-m sodar wind speeds with dissipation coefficients calculated as described above. Available 15-minute averaged sodar wind speeds were selected from the sodar wind summary tables for each IOP (see the IOP Summary section) to correspond with the end times of each 30-minute dissemination period. Correlations were computed for six sets of dissipation coefficient data: (1) daytime street level; (2) nighttime street level; (3) daytime rooftop; (4) nighttime rooftop; (5) day and night (all) street level; and (6) all rooftop. IOPs 1 through 6 provided the daytime dissipation coefficients, while IOPs 7 through 10 provided the nighttime coefficients. An F-test for the significance of linear correlation coefficients (Panofsky and Brier, 1965) was used to determine the statistical significance of correlation results. These results are presented in Table 70. This table also includes regression coefficients a and b, which are the zero intercepts and slopes for linear regression lines through the data.

Table 70. Summaries of correlations regression coefficients, and F-test results between 100-m wind speed and median dissipation coefficients stratified by daytime or nighttime releases and by rooftop or street level sampling.

Variable	Day Street	Day Roof	Night Street	Night Roof	All Street	All Roof
100-m Mean WS (m s^{-1})	6.75	6.99	6.92	6.92	6.83	6.96
WS Std. Dev. (m s^{-1})	3.55	3.63	0.96	0.96	2.78	2.79
Median k ($minute^{-1}$)	0.538	0.516	0.366	0.402	0.460	0.462
k Std. Dev. ($minute^{-1}$)	0.10	0.055	0.095	0.086	0.133	0.094
Correlation Coefficient	-0.12	0.33	0.71	0.61	-0.006	0.24
Intercept – a	0.56	0.482	-0.118	0.026	0.462	0.406
Slope – b	-0.0034	0.0049	0.07	0.054	-0.0003	0.008
Sample Size	11	10	9	9	20	19
F-Statistic	0.12	0.95	6.96	4.13	0.00065	1.04
Significance level	None	None	5%	None	None	None

F-test results for both daytime cases (roof and street level) provided no evidence of a significant correlation between wind speed and the dissipation coefficient. These results do not suggest that wind speed has no effect on dissipation during the daytime, but only that dissipation is not well correlated with the 100-m wind speed. In contrast, 100-m wind speed appeared to influence both the street level and roof top nocturnal dissipation coefficients, but produced correlations significant at the 5% level only with the street level k data. Steadier nocturnal winds and the absence of local convection may have contributed to the significant nocturnal wind speed correlation with the dissipation coefficient.

Sonic Anemometer Wind and Turbulence Effects

The sonic anemometer operating near the dissemination points provided wind and turbulence data for each dissemination. Any single point measurement, particularly one made in a complex urban environment, is unlikely to be representative of the turbulent flow encountered by the tracer as it disperses through the CBD. Nonetheless, it is useful to examine the correlations between these point measurements and the dissipation coefficients. This was done by correlating street level median dissipation coefficients with the 30-minute sonic anemometer data associated with each 30-minute continuous release. The results are presented in Table 71.

Table 71. Street- and roof-level summaries of correlations between CBD median dissipation coefficients and the following sonic anemometer-derived statistics: mean wind speed; turbulent kinetic energy (TKE); standard deviations of along-wind (Sigma-u), cross-wind (Sigma-v), and vertical (Sigma-w) velocities.

Street Level	Wind Speed ($m\ s^{-1}$)	TKE ($m^2\ s^{-2}$)	Sigma-u ($m\ s^{-1}$)	Sigma-v ($m\ s^{-1}$)	Sigma-w ($m\ s^{-1}$)
Mean	0.983	1.09	0.972	0.796	0.533
Std. Deviation	0.376	1.04	0.246	0.213	0.111
Sample Size	22	22	22	22	22
Correlation Coeff.	-0.15	0.457	0.497	0.502	0.422
Intercept - a	0.515	0.403	0.211	0.221	0.202
Slope - b	-0.05	0.057	0.262	0.307	0.049
F-Statistic	0.44	5.27	6.57	6.72	4.33
Significance	None	5%	5%	5%	None
Roof Level	**Wind Speed ($m\ s^{-1}$)**	**TKE ($m^2\ s^{-2}$)**	**Sigma-u ($m\ s^{-1}$)**	**Sigma-v ($m\ s^{-1}$)**	**Sigma-w ($m\ s^{-1}$)**
Mean	0.969	1.104	0.972	0.797	0.536
Std. Deviation	0.379	1.058	0.253	0.218	0.113
Sample Size	21	21	21	21	21
Correlation Coeff.	-0.122	0.466	0.535	0.476	0.480
Intercept – a	0.508	0.427	0.268	0.300	0.246
Slope – b	-0.032	0.045	0.214	0.221	0.430
F-Statistic	0.287	5.27	7.62	5.58	5.69
Significance	None	5%	5%	5%	5%

Street-level results shown in Table 71 show no correlation between dissipation coefficients and wind speed as measured at the dissemination position, but statistically significant correlations with TKE and with along-wind and cross-wind standard deviations. The correlation with sigma-w was slightly below the level of significance. These results suggest that street level wind speed measurements made at the JU03 dissemination point did not provide much useful information about street level tracer dissipation, but that concurrent turbulence data explained between 20 and 25 percent of the variance in tracer dissipation.

Turbulence measurements made at the dissemination site were surprisingly well correlated with roof-level dissipation coefficients, as shown in the bottom half of Table 71. While there was no correlation of the dissemination site wind speed with k, all of the turbulence statistics correlated at the 5% level of significance. This suggests that turbulence measured at street level might have some utility in predicting dissipation throughout the urban layer. It is also interesting to note that the correlation coefficients for TKE, sigma-w, and sigma-u are somewhat greater at rooftop than at street level. This counter-intuitive result may be due to a greater tendency for street level tracer trapping and venting.

Tunnel Tracer Analysis

Sampler locations 401 through 404 were in the pedestrian tunnel system that connected buildings within the CBD. Sampler locations 401 and 402 were near Broadway Street entrances to the Mid-America Tower and Bank One. Sampler location 403 was at a T-intersection in the tunnel below Kerr Park. Sampler location 404 was at the base of a stairwell into the entrance to the Bank of Oklahoma parking garage. The pedestrian tunnel system below the CBD produced tracer accumulation and dissipation rates at time scales much longer than those at the rooftop or street level. Tunnel tracer accumulation and dissipation are governed by site-specific air exchange rates and complicated by factors such as proximity to entrances and pedestrian traffic. These tracer patterns are shown in time series plots of SF_6 concentration (pptv) versus time for each IOP for which tunnel sampling was performed. No tunnel data were obtained for IOP 1 or during subsequent IOPs conducted on weekends.

IOP 2 continuous tracer releases from the Westin site produced a plume that traveled mainly north along the east side of the CBD, to include Broadway where it strongly impacted locations 402 and 403. These samplers responded to each release with concentration samples peaking within half an hour after the completion of each release (Fig. 84). Some tracer slowly accumulated at the Bank of Oklahoma parking garage stairwell (location 404), but remained well below the levels seen at the other samplers. Note that data is missing for the Mid-America Tower (sampler location 401) because of problems with the sampler clips.

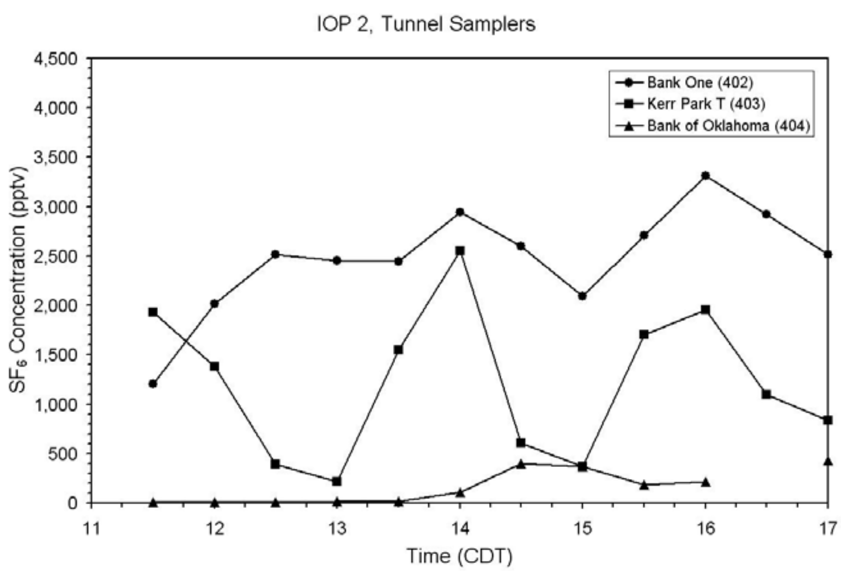

Figure 84. Pedestrian tunnel tracer concentration vs. sampling time (hours) for IOP 2.

IOP 3 was a Botanical site release. The first continuous plume traveled up Broadway and Robinson and to the east, while the subsequent releases spread over most of the CBD. The sampler at location 401 near the Mid-America Tower accumulated substantial tracer concentrations during the first two releases, while the sampler at location 402 near Bank One was nearly flat at low concentration levels until near the end of the sampling period (Fig. 85). Insufficient information is available to determine the cause of these disparate results, but differences in pedestrian traffic use may be a contributing factor. Location 403 at the Kerr Park T responded to all releases with slight peaks in tracer concentrations.

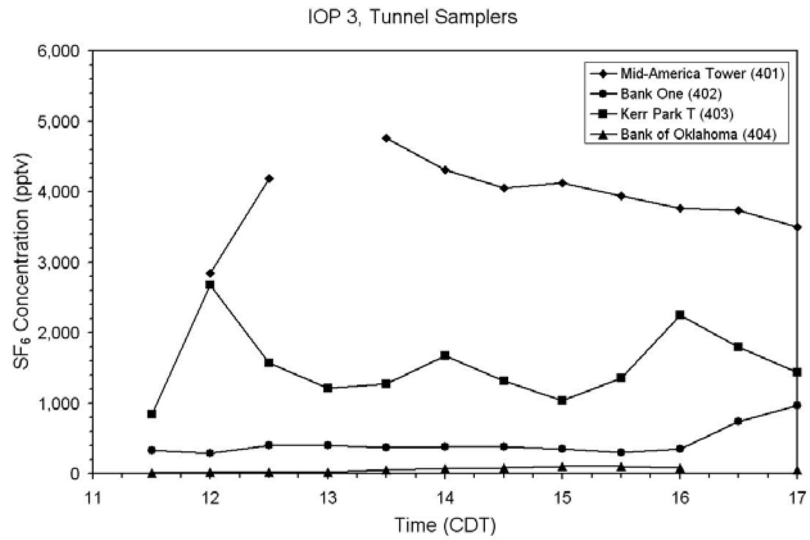

Figure 85. Pedestrian tunnel tracer concentration vs. sampling time (hours) for IOP 3.

The tracer from the Botanical site releases for IOP 4 spread mostly through the eastern half of the CBD, with substantial tracer concentrations showing at locations 401 and 403. These results are presented in Fig. 86. As with IOP 2, tracer concentrations obtained at the Bank One tunnel site (location 402) were well below the levels of nearby samplers. Little of the tracer apparently reached location 404.

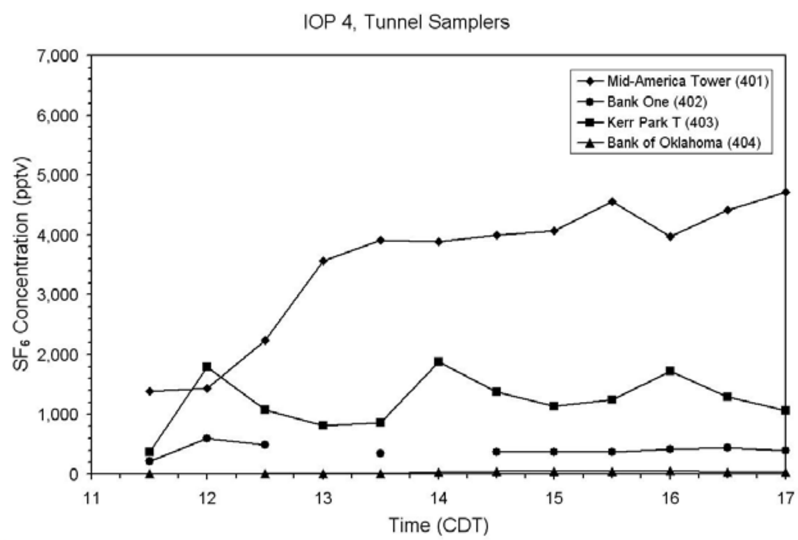

Figure 86. Pedestrian tunnel tracer concentration vs. sampling time (hours) for IOP 4.

There was no access to the underground walkways on the weekend and so no tunnel samplers were deployed during IOP 5.

The tracer during the first botanical site release for IOP 6 dispersed mostly through the eastern half of the CBD, while the 2nd and 3rd releases spread more generally through the CBD. Yet, only the Kerr Park T (location 403) responded with well-defined peaks within half an hour after the end of each dissemination. Figure 87 also shows little response at locations 401, 402, and 404.

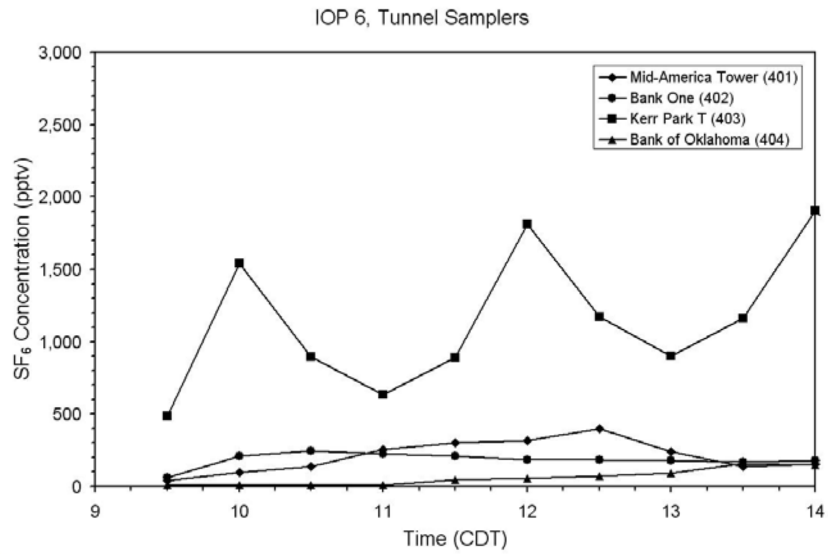

Figure 87. Pedestrian tunnel tracer concentration vs. sampling time (hours) for IOP 6.

IOP 7 was the first nocturnal release, and it was conducted at the Botanical site. Figure 88 shows an interesting tracer pattern that is different from the previous daytime releases. The first two continuous releases traveled through the eastern half of the CBD, while the 3rd continuous release drifted mostly east of the CBD. The sampler at location 402 at the Bank One site responded to the first continuous release with a well defined concentration peak, showed a smaller peak following the 2nd continuous release, and did not respond to the 3rd continuous release. Conversely, samplers at locations 401 and 403 responded only slowly to the 2nd and 3rd continuous releases.

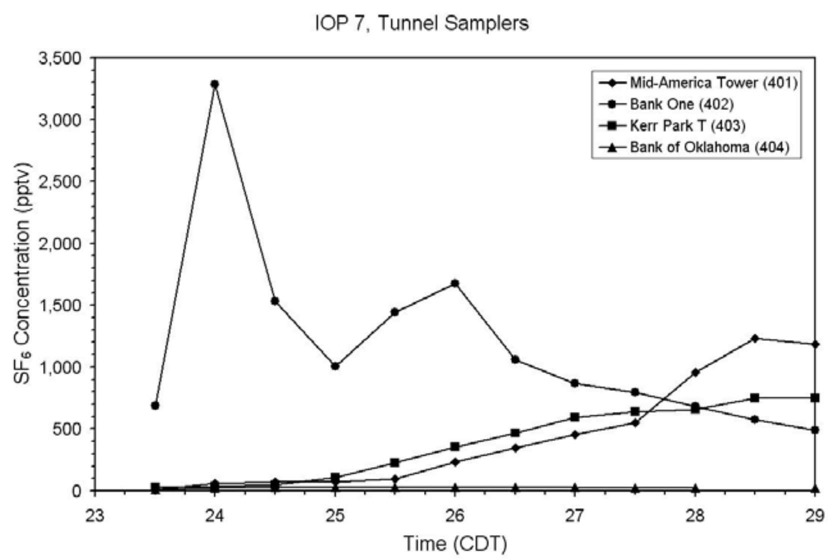

Figure 88. Pedestrian tunnel tracer concentration vs. sampling time (hours) for IOP 7. Note: The time scale (CDT) is greater than 24 because the IOP spanned for 2 days.

The Westin site was used for the IOP 8 nocturnal releases. All three continuous releases dispersed tracer over most of the CBD, causing a slow but steady buildup of concentration at the Mid-America Tower site (location 401), and much lower concentrations at the Kerr Park T (location 403), and the Bank of Oklahoma parking garage (location 404). The highest tracer concentration measured in the pedestrian tunnel during JU03 occurred during this IOP at location 401. It measured 8,937 pptv. Unlike results from the previous IOPs, the data in Fig. 89 show no release-related concentration spikes. This may simply be due to the absence of data from the sampler at location 402. Note that data for Bank One (sampler location 402) is missing because the sampler was not programmed.

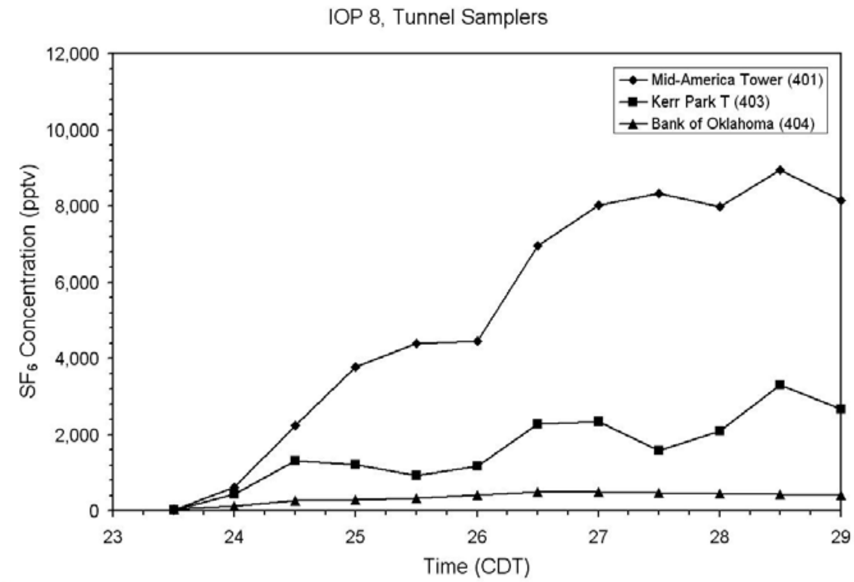

Figure 89. Pedestrian tunnel tracer concentration vs. sampling time (CDT) for IOP 8. Note: The time scale (CDT) is greater than 24 because the IOP spanned for 2 days.

As with IOP 8, all three continuous releases in IOP 9 spread tracer over most of the CBD. However, the Park Avenue release site was located close to the center of the CBD and was half a block west of Broadway, where samplers at locations 401, 402, and 403 were stationed. The sampler at location 402 was almost due east of the release position. Data from this site show distinct spikes following each tracer release (Fig. 90). In contrast, the Kerr Park tracer (location 403) data show a substantial increase over time, while

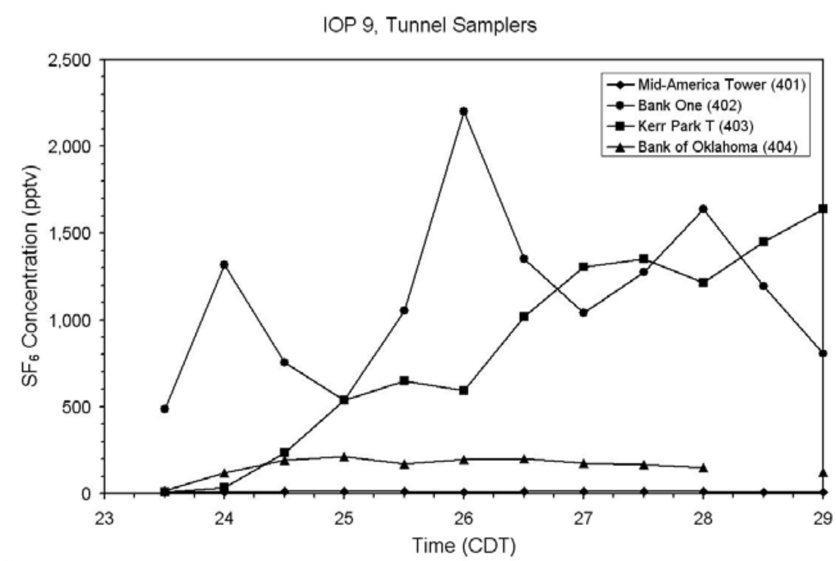

Figure 90. Pedestrian tunnel tracer concentration vs. sampling time (CDT) for IOP 9. Note: The time scale (CDT) is greater than 24 because the IOP spanned for 2 days.

tracer at the Bank of Oklahoma parking garage (location 404) remains steady at a low concentration level.

IOP 10 included three releases from the Park Avenue site. The results were similar to those of IOP 9 in that sampler at location 402 showed spikes following the first two releases, while the sampler at location 403 exhibited a slow but steady concentration increase (Fig. 91). Much of the tracer from the third continuous release drifted up Broadway to the east side of the CBD, but did not produce a spike in location 402 concentration data.

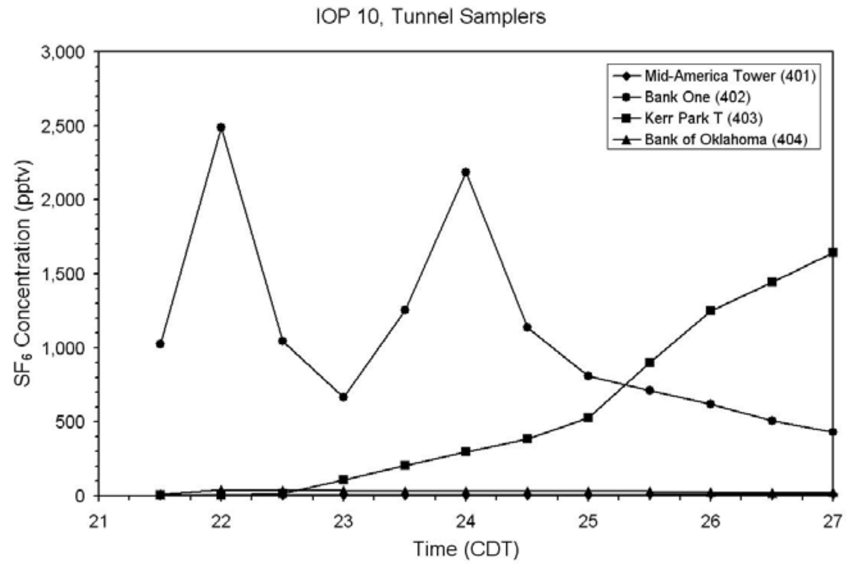

Figure 91. Pedestrian tunnel tracer concentration vs. sampling time (CDT) for IOP 10. Note: The time scale (CDT) is greater than 24 because the IOP spanned for 2 days.

Without additional information on the characteristics of the sampling sites in the pedestrian underground, it is not possible to draw definite conclusions about these tracer concentration results. However, it is readily apparent that the tracer material entered the pedestrian tunnel and accumulated to levels nearly 4 fold above background levels. It is also interesting to note that the Kerr Park site (location 403) responded with a distinct peak following each daytime dissemination, while the Bank One site (location 402) responded similarly at night. It is possible that these results indicate differences in pedestrian traffic patterns or air circulation. Few of the tunnel data are suitable for computing dissipation coefficients, but from a limited number of cases it appears that k’s are an order of magnitude or more smaller in the tunnels than in the open air.

SUMMARY AND CONCLUSIONS

The Joint Urban 2003 atmospheric dispersion experiment conducted during July 2003 in and around Oklahoma City's central business district was successful due to the coordinated contributions of many organizations, and the enthusiastic cooperation of local officials. Data obtained from JU03 participants are archived with a common time base and format at the U.S. Army Dugway Proving Ground. The NOAA Air Resources Laboratory Field Research Division was a key participant in JU03. This group disseminated the sulfur hexafluoride tracer, sampled the tracer as it dispersed through Oklahoma City, and provided crucial wind and turbulence measurements. Other organizations provided weather analyses and forecasts, detailed site meteorological characterization, and additional tracer measurements. On-site sample analysis as part of ARLFRD's detailed quality assurance program provided feedback needed to correct deficiencies and ensure data quality. This quality assurance program identified some sampling problems with the Super PIGS. These were partially rectified during the experiment. The JU03 data set is unique due to the quantity and quality of tracer measurements taken at diverse urban locations that included street-level sites, building rooftops and interiors, and within a network of underground pedestrian tunnels.

The core JU03 data sets are those obtained during ten intensive operating periods. ARLFRD's principal contributions to the IOP data sets included time integrated tracer samples taken within the central business district, along sampling arcs 1-, 2-, and 4-km from the tracer release sites, and by mobile fast-response tracer analyzers. The ten IOPs produced a unique set of tracer puff and continuous point source measurements. Data collected during the IOPs illustrate how readily disseminated material is transported through street canyons and to rooftop levels in an urban environment. Railing, the exposure of a TGA to tracer concentrations in excess of its measurement limits, occurred during every IOP. This problem was particularly prevalent at TGAs stationed within 300 m of the dissemination point. Quantitative information about the true peak concentration at a measurement location is lost as a consequence of railing. Otherwise, JU03 can provide a great deal of useful information on urban plume dimensions, concentration maxima, and dispersion rates suitable for evaluating the performance of urban dispersion models.

Analysis of the tracer data combined with meteorological statistics provided by the ARLFRD sodar and dissemination site sonic anemometer provided useful insights into tracer dissipation. Tracer dissipation occured significantly more rapidly during the day than at night at both the street and rooftop levels. However, street vs. roof dissipation rate differences were not statistically significant at night or during the day. Rooftop-level wind speeds did not correlate well with dissipation rates during the day, but did show an influence at night. Street-level wind measurements near the dissemination site were not correlated with dissipation rates at any time. However, street-level turbulence statistics correlated well with dissipation rates at both rooftop and street levels. It is premature to draw firm conclusions from this limited analysis, but these results suggest that further analyses of wind and turbulence effects on dissipation in an urban environment are warranted.

Tracer sampling in pedestrian tunnels under the CBD showed tracer accumulation and dissipation rates of at least an order of magnitude longer than those in the free air. There were substantial day/night differences at several of these sites, perhaps due to differences in pedestrian traffic and/or ventilation rates. More detailed analysis of tracer samples in underground settings requires traffic and ventilation rate information that is not available within the JU03 data set.

ACKNOWLEDGMENTS

ARLFRD participation in the Joint Urban Test of 2003 was sponsored by NOAA and by the Defense Threat Reduction Agency, project number MIPR3FDPG87074 administered by John Pace. The authors acknowledge Jerry Allwine of Pacific Northwest National Laboratory for his project leadership role in JU03. We also appreciate the support of John Snow and Jeff Basara of the Oklahoma University and their team of graduate student forecasters. Their enthusiastic cooperation and assistance helped make this project a success. We would also like to thank the State of Oklahoma and the Oklahoma City officials, including JC Reiss, who provided storage facilities at the "Pink Palace" without charge, free parking, blocked roads, and allowed us to place sampler hangers on city property. In addition, we would also like to thank the Oklahoma City citizens who were very accommodating. We particularly like to thank OU Health Sciences Center director David Johnson for their help and cooperation during the planning and execution of this project. Robert Lynch, Associate Professor of Occupational and Environmental Health at the OU Health Sciences Center, is due a special note of appreciation for making his laboratories available for TAF operations and temporary cartridge storage. Also, we would like to thank the Oklahoma School of Science and Mathematics for letting us setup the sodar on their property without charge. ARLFRD participation in JU03 was successful due to the hard work and dedication of the ARLFRD on-site team. In particular, we thank Mark and Dianne Hoover, Camille Irwin, Sean Eldredge, Dave George, Tom Watson, and Ryan Walker for their help with the installation and operation of various samplers during the IOPs. Richard Eckman worked in the background on engineering and scientific aspects of the project.

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APPENDIX A. PIGS AND SUPER PIGS QA/QC

The following are detailed descriptions of the quality control and quality assurance methods followed for the sampling, analysis, and reporting of the JU03 time-integrated sampler tracer data. Protocols established in the Environmental Protection Agency's (EPA) Guidance for Data Quality Assessment (U.S. EPA, 2000a), the general requirements for the competence of calibration and testing laboratories of International Standards Organization/IEC Guide 25 (ISO, 1990), the quality systems established by the National Environmental Laboratory Accreditation Conference (U.S. EPA, 2000b), and the Department of Defense Quality Systems Manual for Environmental Laboratories (U.S. Department of Defense, 2002) provided a basis for quality assurance and quality control procedures followed during analysis. Instrument and method limits of detection (ILOD/MLOD) were calculated based upon 40 CFR Part 136, Appendix B and the American Chemical Society Committee on Environmental Improvement's paper titled, "Principles of Environmental Analysis" (Keith, et al., 1983). ACS principles relative to detection limit calculations in 40 CFR Part 136, Appendix B are documented in "Revised assessment of Detection and Quantitation Approaches" (U.S. EPA, 2004). Although our research-based automated analysis of tracer gases has no specified method performance or regulatory criteria, compliance to the established quality control procedures stated above were followed, where applicable, to provide high quality data that is both accurate and reliable.

1. Pre-project maintenance of PIGS.

Prior to deployment to the field, each PIGS was extensively tested for proper operation in the field and to ensure the collection of an adequate sample volume.

2. Re-tubing of all PIGS cartridges.

Prior to deployment to the field, all latex rubber tubing was replaced in each PIGS cartridge to ensure there were no pinholes, cracks, or other leaks within the tubing that might have developed over time.

3. Re-bagging of cartridges.

Prior to deployment to the field, new Tedlar® sample bags were added to each PIGS cartridge to replace older Tedlar® bags that were worn from extensive use. New Super PIGS cartidges, which were manufactured specifically just for JU03, received new Tedlar bags.

4. Testing of all sample bags.

Each bag was checked for leakage after installation to each PIGS and Super PIGS cartridge to ensure there could be no mixing of outside air with the bag contents. All air was evacuated, the tubing was closed tightly and the bags were watched for slight re-inflation, which was the indicator of some kind of leak in the bag. Those found to leak were replaced and the new bag was re-tested.

5. Pre-project cleaning and analysis checks of all PIGS and Super PIGS cartridge sample bags.

Prior to deployment to the field, all bags in approximately 700 PIGS cartridges and 300 Super PIGS cartridges were cleaned. The bags were cleaned by repeatedly filling them with UHP nitrogen and then evacuating on the cartridge cleaning apparatus seen in Fig. A-1. The apparatus consisted of a nitrogen tank and vacuum connected to a system that fills and evacuates the sample bags by the movement of a lever. Six cartridges were cleaned at one time. One side of the cleaning apparatus was used for the PIGS cartridges and the other was used for the Super PIGS cartridges. The computer mounted underneath the cleaning apparatus was used to create cartridge-cleaning records. This information was then uploaded to the ATGASs. The cleaning protocols (Fig. A-2) were developed after significant testing to ensure that bags containing concentrations in the expected high range of over 150,000 pptv could be cleaned to less than background levels. After cleaning, the bags were filled with UHP nitrogen and analyzed on the ATGAS to ensure there was no contamination from previous tests or from long-term storage. Any bags with a concentration greater than 2 pptv were re-cleaned and re-analyzed. All bags were stored evacuated until their use.

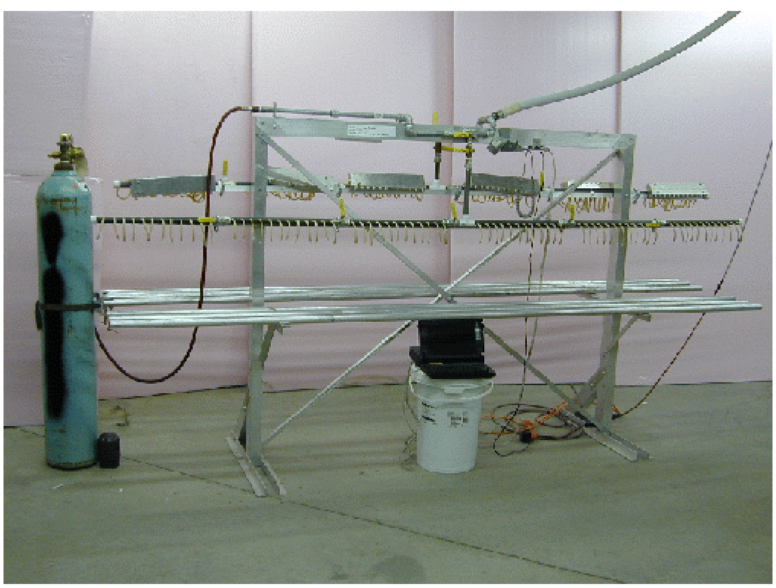

Figure A-1. Cartridge cleaning apparatus.

Cardboard Cartridge Cleaning Procedure

1. Connect all tubes to the cleaning machine.
2. Open all clips.
3. Make sure the cleaning machine valves are set so that nitrogen can flow into all connect cartridges.
4. Evacuate bags.
5. Fill all bags with nitrogen and then evacuate. Repeat until all bags have been evacuated 5 times.
6. Fill 1 box with nitrogen for analysis.
7. Scan all cartridge bar codes with the bar code scanner.
8. Close all clips and remove cartridges.

Plastic Cartridge Cleaning Procedure

1. Connect all cartridges to the cleaning machine.
2. Make sure the cleaning machine valves are set so that nitrogen can flow into all connect cartridges.
3. Evacuate bags.
4. Fill all bags with nitrogen and then evacuate. Repeat until all bags have been evacuated 3 times.
5. Fill all bags with nitrogen and disconnect from the cleaning machine.
6. Allow cartridges to stand for **AT LEAST 15 MINUTES.**
7. Connect cartridges to the cleaning machine again.
8. Evacuate bags.
9. Fill all bags with nitrogen and then evacuate. Repeat until all bags have been evacuated 3 times.
10. Fill 1 box with nitrogen for analysis.
11. Scan all cartridge bar codes with the bar code scanner.
12. Disconnect cartridges from the cleaning machine and remove them.

Figure A-2. PIGS (cardboard) and Super PIGS (plastic) cartridge cleaning protocols.

6. Development of analysis protocols for the expected sample concentration ranges.

Analysis protocols were developed to optimize instrument performance, accuracy and efficiency during the project. Due to the magnitude of concentration ranges that were expected, and the complexity and carry-over issues resulting from measuring extremely low concentration samples immediately following extremely high concentration samples on the ATGASs, analysis parameters such as between bag purge times, injection length, and between cartridge purge times were tested and adjusted for the worst case scenario of analysis of the highest expected concentration followed by the analysis of the lowest expected concentration. Sample column volume and electron capture detector attenuation adjustments were also tested at different concentration levels to provide quick adjustments to the instruments in the case of unexpected concentration ranges.

7. Pre-project calculation of instrument limit of detection (ILOD) and instrument limit of quantitation (ILOQ).

Prior to packing the ATGASs for transportation to Oklahoma City, the ILOD and ILOQ were established for each ATGAS to provide information on instrument performance. The ILOD is the instrument's limit of detection and is defined as the lowest concentration that can be determined to be statistically different from zero. It is based upon the specific instrument's ability to differentiate a low level concentration standard from instrument noise. The ILOD was calculated as three times the standard deviation of a low level standard that was analyzed twelve times (one bag per cartridge). The ILOQ is the instrument's limit of quantitation and is defined as the lowest concentration that can be determined within 30% of the actual concentration. The ILOQ was calculated as ten times the standard deviation of the same low level standard analyzed 12 times. Since using different concentrations will yield different ILOD and ILOQs, the analyst selected the lowest concentration standard to meet as many of the following criteria as possible:

- Has a relative standard deviation (RSD) (the standard deviation divided by the mean multiplied by 100) of less than 15%.

- Has a signal to noise (the mean divided by the standard deviation) between 3 and 10 (a higher value does not invalidate the result; rather it indicates that a lower concentration standard should be used).

- Has a percent recovery (analyzed value divided by the certified value multiplied by 100) between 90% and 110%.

Also, to include possible carry-over issues, a 50,500 pptv standard was analyzed just prior to the analysis of each low level standard on each valve location (1-12). The final percent recovery and mean concentration data were graphed and visually inspected to indicate any trends or biases that might not be easily detected by looking at the raw numbers. Even though the results met the above criteria, a consistently increasing concentration result could provide evidence of carry-over issues. The results were documented and used as a reference point for each ATGAS placed into the on-site laboratory facility (the TAF) in the Oklahoma University Health Sciences Building. Table A-1 shows the analyzed average, standard deviation, average recovery, signal to noise (S/N) ratio, RSD and the calculated ILOD and ILOQ. The average ILOD for all four ATGASs was 1 pptv while the average ILOQ was 3 pptv.

Table A-1. Pre-transport ILOD and ILOQ calculations for each ATGAS.

ATGAS Number	Certified Concentration (pptv)	Average (pptv)	Standard Deviation (pptv)	Average Recovery (%)	S/N Ratio	RSD (%)	ILOD (pptv)	ILOQ (pptv)
1	3.47	3.67	0.22	106	17	6	0.7	2.2
2	9.38	9.02	0.35	96	26	4	1.0	3.5
3	9.38	9.64	0.23	103	42	2	0.7	2.3
4	9.38	10.85	0.21	116	52	2	0.6	2.1
Avg.							1	3

8. Pre-project estimation of method limit of detection (MLOD) and method limit of quantitation (MLOQ).

Prior to deployment to Oklahoma City, the MLOD and MLOQ were estimated for the PIGS to provide information on method performance and an estimation of the lowest field concentration level that can be determined with some degree of certainty (Table A-2). When samples are left outside in the weather, transported to and from the laboratory facility, and the bags opened and closed, many more chances of variability are added. Determination of the MLOD and MLOQ for the Super PIGS could not be established before field deployment due to time constraints. The MLOD is defined as the lowest concentration that can be determined to be statistically different from zero. It is based upon the method's ability to differentiate a low-level concentration standard from instrument and method noise. The MLOD and MLOQ are calculated exactly the same as the ILOD and ILOQ except that method variability is factored into the equation by using results generated by samples that have been put through the rigors of field sampling. The MLOD was calculated as three times the standard deviation of a low level standard. The MLOQ is defined as the lowest concentration that can be determined within 30% of the actual concentration. The MLOQ was calculated as ten times the standard deviation of the same low level standard. Three sets of seven PIGS, 21 cartridges in all, were deployed in Idaho Falls to mimic sampler movement in Oklahoma City. All cartridges were analyzed and an MLOD and MLOQ were estimated using the same guidance criteria as for the ILOD and ILOQ. The estimated MLOD was 1 pptv while the estimated MLOQ was 5 pptv. The results were used as reference points for field analysis in Oklahoma City.

The MLOD and MLOQ tend to increase over time due to tubing and bag deterioration. It is very important to establish these limits prior to project commencement in order to know the method capabilities of the materials and equipment that are going to be used. Changes can then be made, if necessary, to achieve needed method performance. Without this knowledge, the data quality may suffer and project objectives may not be met.

Table A-2. Pre-project estimation of MLOD and MLOQ.

Certified Conc. (pptv)	Analyzed Average (pptv)	Average Recovery (%)	Standard Deviation (pptv)	RSD (%)	S/N Ratio	MLOD (pptv)	MLOQ (pptv)	Number of Points
3.84	3.62	94	0.46	13	8	1	5	21

9. ILOD and ILOQ re-determination after field deployment and prior to project initiation.

To verify that the ATGASs were functioning properly after being transported to and set up in a laboratory in Oklahoma City, the ILOD and ILOQ were once again determined just prior to initiation of the first IOP for each ATGAS (Table A-3). These results were compared to the results performed in the laboratory before transportation to the field (Table A-1). Any significant changes would require adjustments to the ATGASs to enhance their performance since all analysis protocols had been developed based upon results determined previously. No adjustments were needed since the results were consistent with those calculated prior to transport. The same certified standard could not be used to calculate the ILOD and ILOQ since the standard cylinder was empty upon arrival to Oklahoma City. The closest standard concentration was chosen to most closely mimic the prior analysis. The average ILOD was 1 pptv while the average ILOQ was 2 pptv.

Table A-3. Pre-project in-field calculation of ILOD and ILOQ.

ATGAS #	Certified Conc. (pptv)	Average (pptv)	Standard Deviation (pptv)	Average Recovery (%)	S/N Ratio	RSD (%)	ILOD (pptv)	ILOQ (pptv)
1	10.43	10.86	0.24	104	45	2	0.7	2.4
2	10.43	11.43	0.21	110	54	2	0.6	2.1
3	10.43	11.45	0.19	110	60	2	0.6	1.9
4	10.43	12.24	0.22	117	56	2	0.7	2.2
Avg.							1	2

10. Re-analysis of 17% of cleaned cartridges used in previous IOP.

After every bag in every cartridge for a given IOP had been analyzed for SF_6, all bags in each cartridge were cleaned with UHP nitrogen by following the cleaning protocols developed prior to the project (Fig. A-2). Personnel performing the cleaning had been trained on cleaning procedures prior to the field experiment. Seventeen percent (1of every 6) of those cartridges were filled with UHP nitrogen and analyzed on the ATGAS to ensure there was no carry-over contamination from the previous IOP. If contamination was found in any bag, all six cartridges from that group were analyzed to ensure no contamination and all “dirty” cartridges were re-cleaned and re-analyzed.

11. Sampler Servicing Procedure and Handwritten Sampler Servicing Records.

During sampler servicing, sampler deployers were required to follow written procedures (Figs. A-3 and A-4). These procedures were developed after years of prior field experience. The sampler deployers received classroom and hands-on training in Idaho Falls prior to the experiment.

Cardboard Sampler Deployment Procedure

Repeat all steps for each sampler serviced.

1. Record the location number and time on the Sampler Servicing Record Sheet.
2. Open the lid and record the sampler number on the Sampler Servicing Record Sheet.
3. Place the new cartridge in the sampler and write its number on the Sampler Servicing Record Sheet.
4. Connect the cartridge to the sampler, making sure that:
   a. The tubes are securely connected.
   b. The tubes are connected in the correct order.
5. Open the clips on the cartridge, making sure that:
   a. The clips are opened and move freely on the tubes.
   b. The tubing is fully opened. This may require you to push on the tube inside the clip with the blunt end of a pen.
6. Check the sampler inlet tubes to make sure they have not been pushed back into the sampler. Pull out on the tubes if necessary.
7. If needed, replace the battery in the sampler. Normally, the batteries will be replaced after about 5 tests. You will be notified when to replace batteries.
8. Plug the TimeWand II cord into the sampler. Verify that the right LED is blinking and the left LED is out. If the left LED is still on, remove the battery for at least 2 minutes and replace it. If the right LED is not blinking, check the cable connections and the battery.
9. With the TimeWand II, scan the sampler serial number, the cartridge serial number, and the location serial number. These may be scanned in any order. Make sure you use the correct location number for each sampler. The TimeWand II will now download the program into the sampler. The left LED will light to indicate a successful download. Make sure the left LED is on before removing the cable!

   NOTE: **In emergencies only**, the serial numbers may be entered with the keypad. (Type the 6-digit code and then press the "=" key.) Since this is very error prone, do not use this method unless there is absolutely no other way!
10. Disconnect the TimeWand II.
11. Record any problems on the Sampler Servicing Record Sheet. **If there are problems noted, place a mark on the metal bracket in the cartridge with a permanent marker** so that lab analyst will know to check the Sampler Servicing Record Sheet.

16. Place the lid on the sampler and put it on the hanger.

Cardboard Sampler Retrieval Procedure

Repeat all steps for each sampler serviced.

1. Record the location number on the Sampler Servicing Record Sheet.
2. Retrieve the sampler from the hanger and remove the lid.
3. Record the sampler number on the Sampler Servicing Record Sheet.
4. Record the cartridge number of the cartridge to be removed on the Sampler Servicing Record Sheet.
5. Record the time on the Sampler Servicing Record Sheet.
6. Verify that the cartridge was connected correctly and the bags were filled. Record any problems on the Sampler Servicing Record Sheet. **If there are problems noted, place a mark on the metal bracket in the cartridge with a permanent marker** so that lab analyst will know to check the Sampler Servicing Record Sheet.
7. Close the clips on the cartridge and remove it from the sampler.
8. Scan the number of the cartridge to be removed with the TimeWand II. Then scan the "Pick Up" tag on the cord. If the tag is missing or damaged, enter PX0000 followed by the "=" key on the TimeWand II's keyboard. (Operator's manual Section III.)

TimeWand II Data Retrieval Procedure

This procedure must be followed after completing each sampler servicing route. It loads information about the sampler servicing into the Gas Analysis System and insures the TimeWand II is charged. It also sets the clock in the TimeWand II.

1. Place the TimeWand II in the charger connected to the computer in the Tracer Analysis Lab.
2. Press any key on the TimeWand II. It will beep and display information about charge left and recharge time.
3. Double click the "Retrieve Data from TimeWands" icon on the computer and follow the instructions.
   NOTE: Data may be retrieved from several TimeWand II's at the same time. Place as many as you have in the charger before retrieving data.
4. The retrieve software searches for TimeWand II's until it has retrieved data from all of them. If some are not present, it will search for about 70 seconds. Wait for the search to complete.
5. You will be prompted to insert a floppy disk into a specific drive. A labeled floppy disk will be available with the computer.
6. Place the Sampler Servicing Record Sheets in the notebook provided.
7. Leave the TimeWand II's in the charger to re-charge the batteries.

Figure A-3. PIGS (cardboard sampler) deployment and retrieval procedures.

Plastic Sampler Deployment Procedure

Repeat all steps for each sampler serviced.

Open the cartridge lid. Place the sampler in the cartridge and press the wake up button on the sampler.

2. Turn on the downloader. **DO NOT CONNECT THE DOWNLOADER TO THE SAMPLER BEFORE IT SAYS "Ready"!**

3. Record the <u>installed cartridge</u> number on the Sampler Servicing Record Sheet.

4. Record the sampler number on the Sampler Servicing Record.

5. Record the location number on the Sampler Servicing Record Sheet.

6. Record time on the Sampler Servicing Record Sheet.

7. Move the locking handles into lock position. Verify that the sampler and cartridge connect properly and that the cartridge tubes open correctly.

8. When the sampler has stopped "buzzing" and the downloader says "Ready", connect the downloader to the sampler and the location box.

9. Perform download by pressing F1 on the downloader and following the instructions on the screen. Download will take about 30 seconds. Download is complete when the downloader says "SUCCESSFUL" on the screen.
   * If a battery error occurs, replace the sampler batteries and repeat the download by pressing F1 again.
   * If other errors occur, try repeating the download (press F1 at Ready). If the error persists, use a different sampler or cartridge.

Disconnect the downloader from the sampler and location box and turn it off.

11. Record any problems on the Sampler Servicing Record Sheet. If there are problems noted, place a mark on the metal locking handles in the cartridge with a permanent marker so that lab analyst will know to check the Sampler Servicing Record Sheet.

12. Close the lid on the cartridge and put it on the hanger.

Plastic Sampler Retrieval Procedure

Repeat all steps for each sampler serviced.

1. Record the location number on the Sampler Servicing Record Sheet.

2. Retrieve the cartridge from the hanger and open the lid.

3. Record the sampler number on the Sampler Servicing Record Sheet.

4. Record the cartridge number of the <u>cartridge to be removed</u> on the Sampler Servicing Record Sheet.

5. Record the time on the Sampler Servicing Record Sheet.

6. Verify that the cartridge was connected correctly and the bags were filled. Record any problems on the Sampler Servicing Record Sheet. If there are problems noted, place a mark on the metal locking handles in the cartridge with a permanent marker so that lab analyst will know to check the Sampler Servicing Record Sheet.

7. Open the metal locking handles and remove the sampler from the cartridge.

Figure A-4. Super PIGS (plastic sampler) deployment and retrieval procedures.

Hand written records for each removed or installed cartridge were entered on Sampler Servicing Record Sheets for every IOP. These records were created to provide the analyst with details pertaining to each cartridge and sample bag (Fig. A-5). These records were invaluable as a reference for sample check-in and later for QC flagging of data. These Sampler Servicing Records were filled out by field personnel and given to the laboratory analyst after sampler collection and delivery was performed. All record sheets were organized and placed in a binder for future reference. The metal plate of a cartridge was marked with a permanent marker if any problems were encountered during deployment or retrieval. If a mark was found, the analyst checked the sampler servicing record to determine the course of action for the analysis of that particular cartridge. The mark was then removed prior to the cartridge being used for the next IOP.

Sampler Servicing Record Sheet

Project: JU 2003 Route: CBD Paper Date: 7-19-03

IOP(s): #7 TimeWand: C Name: Hoover

Location	Sampler	Cartridge Removed	Time	Cartridge Installed	Comments or Problems
LC 0027	GF 0031	SN 1208	19:15	SN	
LC 0032	GF 0014	SN 0225	19:19	SN	
LC 0033	GF 0300	SN 0268	19:26	SN	
LC 0133	GF 0998	SN 0513	19:28	SN	
LC 0023	GF 0008	SN 0233	19:35	SN	
LC 0037	GF 0092	SN 1062	19:38	SN	
LC 0047	GF 0059	SN 4344	19:43	SN	
LC 0042	GF 0211	SN 1272	19:49	SN	
LC 0051	GF 0045	SN 0215	19:52	SN	
LC 0052	GF 0022	SN 1065	19:55	SN	
* LC 0057	GF 0212	SN 4368	20:01	SN	Clip Broken #11 bag
LC 0067	GF 0085	SN 4336	20:05	SN	
LC 0062	GF 0048	SN 0328	20:15	SN	
LC 0061	GF 0207	SN 4307	20:18	SN	
LC 0161	GF 0319	SN 0164	20:20	SN	
LC 0072	GF 0073	SN 0469	20:23	SN	
LC 0073	GF 0309	SN 1226	20:27	SN	
* LC 0074	GF 0210	SN 1106	20:30	SN	#6 bag Flat
LC 0076	GF 0056	SN 4372	20:34	SN	
LC 0176	GF 0049	SN 4345	20:36	SN	
LC 0077	GF 0069	SN 0131	20:40	SN	
LC 0082	GF 0062	SN 1266	20:50	SN	
LC 0087	GF 0202	SN 0242	20:53	SN	
LC	GF	SN		SN	
LC	GF	SN		SN	
LC	GF	SN		SN	
LC	GF	SN		SN	

Figure A-5. Example Sampler Servicing Record.

12. Chain of custody procedures.

Chain of custody procedures were followed to ensure that a history of every field sample was generated. The process of sampler operation provided a computer generated chain of custody of each sample as well as automatically associating each sample with a sampling time and location. This process minimized the possibility of errors caused by mistakes in manually recording, copying or entering location information.

13. Sample check-in procedures.

All cartridges were checked-in prior to analysis. During this process each bag was inspected and the following flags were entered for each bag:

B = Too big (overfilled)
G = Good
L = Low
F = Flat
D = Damaged clip or bag
I = Improper hookup (tubes crossed, clip open, etc.)

These flags were used later for querying, flagging, and final data QC purposes.

14. Daily calibration of the ATGAS.

In order to quantitate the concentration of the samples, each ATGAS was calibrated at the beginning of each analysis day using six to twenty-four NIST-traceable SF_6 standards. The calibration standards ranged from 1.97 pptv to 210,700 pptv and covered the entire range of field sample concentrations. The calibration ranges were modified occasionally to accommodate the concentration ranges of samples being analyzed. Concentrations of samples were calculated using a quadratic equation fit to groups of three points. The calibration curve was examined for "wild fits" and an error message was displayed if such an event occurred so that the analyst could more closely examine the curve and decide if it was appropriate to use.

15. Initial ATGAS calibration verification (ICV).

After each calibration was completed, the curve was validated by analyzing the same calibration standards as samples. This validation was used to provide evidence that sample concentrations within the calibration range could be quantitated correctly. The recoveries were required to be within ±10% of the certified value or the standards were re-analyzed. If the recoveries still did not meet the acceptance limits, the bags were refilled and analyzed again. If the recoveries were still not acceptable, the instrument was re-calibrated and ICV was attempted again.

16. Continuing ATGAS calibration verification (CCV).

Approximately every 3 hours, the validity of the ATGAS instrument calibration curves were checked by re-analyzing calibration standards as samples. This procedure, called continuing calibration verification (CCV), was performed to provide evidence that instrument drift had not caused the calibration to be unable to correctly quantitate sample results within a reasonable acceptance level. Standards were chosen to cover the concentration range of samples that had been analyzed since the last calibration verification. The standards were required to have a recovery of ±20% of the certified value for that section of the curve to be considered valid. If any of the standards were not within the acceptance window, the instrument was re-calibrated and the curves were re-validated. All data within the unacceptable concentration range, from the point of the last acceptable CCV, were flagged and re-analyzed.

17. Atmospheric background checks of SF_6 in the TAF.

A background atmospheric check of SF_6 consisted of analyzing three samples of the air in the TAF on each ATGAS every analysis day. This information was used to determine if there was any leakage in the analysis system when compared to the instrument blanks that were subsequently analyzed. The data was also used for inter-comparison between ATGASs that were being used on the same day to check the between instrument precision. The results were also used to reveal discrepancies between ATGASs to indicate a problem that otherwise might go undetected. The average concentration for all background checks was 7 pptv. The standard deviation and RSD between all four ATGASs was 0.64 pptv and 8%, respectively, with no RSD over 15%. This indicates extremely good precision between the ATGASs. Figure A-6 shows the concentrations of the TAF background checks for each ATGAS for each analysis. The agreement between ATGASs is readily apparent. Data are shown only on those days when more than one ATGAS was in use and the checks were analyzed at approximately the same time.

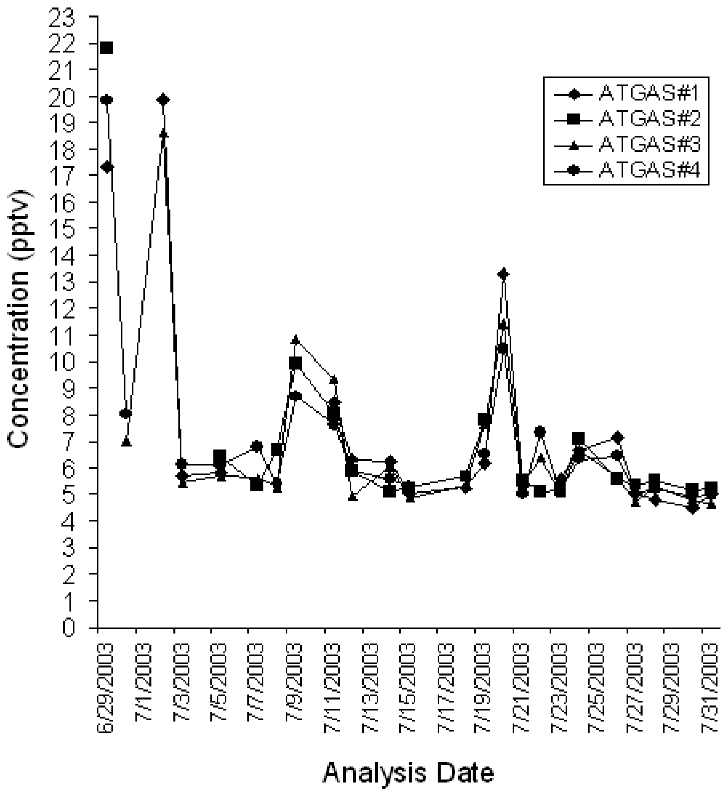

Figure A-6. Results of TAF background concentration checks on analysis days.

18. Analysis of laboratory blanks.

A laboratory or instrument blank was analyzed on each ATGAS each analysis day to verify that there was no contamination or leaks within the analysis system as compared to the background checks analyzed that day, that there was no carry-over from previously analyzed high concentration standards, and to ensure carrier gas purity. The blank sample consisted of a cartridge of twelve bags that were each filled with ultra high purity (UHP) nitrogen. The concentration results of all bags were required to be less than the lowest calibration standard and close to a concentration of 0 pptv. If the concentration of one or more of the bags was higher than the acceptable range, the bag was re-filled and re-analyzed. If the concentration still was not within acceptable limits, the instrument was re-calibrated and re-verified or the samples were flagged and re-analyzed. If there were still indications of contamination, the problem was identified and fixed before analysis continued.

Table A-4 shows the laboratory blank results for each ATGAS and its corresponding ILOD and ILOQ. The average ILOD and ILOQ of 1 pptv and 5 pptv respectively are comparable to the two previously established limits using low concentration standards (Tables A-1 and A-3). The average concentration results of 0.21 pptv ±0.47 pptv indicate no contamination or leakage problems within any of the ATGASs as well as no carry-over issues.

Table A-4. Laboratory blank sample results for each ATGAS.

ATGAS Number	Average Concentration (pptv)	Standard Deviation (pptv)	ILOD (pptv)	ILOQ (pptv)
1	0.25	0.36	1	4
2	0.29	0.47	1	5
3	0.28	0.44	1	4
4	0.00	0.60	2	6
Average	0.21	0.47	1	5

19. Analysis of laboratory duplicates.

Analyses of laboratory duplicates was performed each day to provide evidence of instrument precision. Each day at least one PIGS and one Super PIGS cartridge was analyzed in duplicate on each ATGAS. The sample and its duplicate were analyzed at least 1-3 hours apart in order to ensure an appropriate estimation of instrument precision over time. The duplicate cartridges chosen for this process contained the greatest number of bags with concentration ranges within the calibration curve for that particular ATGAS. Relative percent differences (RPD), i.e. the difference of the results of the two analyses divided by their average, were calculated and were required to be within 20%. Any result not within the acceptable limits was flagged and re-analyzed. If the result was still not within acceptable limits, the analysis was terminated until the ATGAS precision could be re-established. The RPDs and RSDs can be seen in Table A-5. All RPDs and RSDs were below 5% indicating good instrument precision over time.

Table A-5. Laboratory duplicate results for each ATGAS.

ATGAS Number	Average RPD (%)	Average RSD (%)
1	0.8	1
2	0.2	2
3	0.2	2
4	4.9	4
Average	1.5	2

20. Analysis of laboratory controls.

Laboratory controls were used to provide evidence of instrument precision and accuracy and were a product of all ICVs and CCVs. Table A-6 lists all ICVs and CCVs analyzed during the project along with their average results. All standards had less than 10% RSD except, understandably, for the 2.02 pptv standard which is at the ILOD. The average percent recoveries ranged from 98% to 101%. These two factors indicate extremely good instrument precision and accuracy. Again, the in-field calculated ILOD and ILOQ of 1 pptv and 4 pptv using the 3.48 pptv standard correspond well with the ILOD and ILOQs calculated previously (Tables A-1, A-3, and A-4).

Table A-6. Laboratory control results for all ATGASs.

Certified Concentration (pptv)	Average Concentration (pptv)	Average Recovery (%)	Standard Deviation (pptv)	RSD (%)	S/N Ratio	ILOD (pptv)	ILOQ (pptv)
2.02	2.00	99	0.30	16	7	1	3
3.48	3.41	98	0.35	10	10	1	4
9.00	8.81	98	0.55	6	16	2	6
10.43	10.53	100	0.57	5	18	2	6
20.18	19.97	99	1.2	6	17	4	12
38.7	38.5	99	2.0	5	19	6	20
77.4	75.9	98	4.5	6	17	14	45
82.9	82.1	99	3.9	5	21	12	39
284.6	280.0	98	17	6	17	51	170
291.4	289.6	99	17	6	17	51	170
514	506	98	23	5	22	69	230
779	767	98	48	6	16	144	480
796	790	99	45	6	18	135	450
1560	1542	99	96	6	16	288	960
3020	3003	99	178	6	17	534	1780
5100	5135	101	255	5	20	765	2550
5280	5212	99	453	9	12	1359	4530
7610	7572	100	365	5	21	1095	3650
8370	8374	100	313	4	27	939	3130
10120	10129	100	523	5	19	1569	5230
10440	10393	100	460	4	23	1380	4600
16310	16307	100	867	5	19	2601	8670
19430	19305	99	1035	5	19	3105	10350
21720	21681	100	771	4	28	2313	7710
36900	36662	99	1107	3	33	3321	11070
50500	50276	100	1568	3	32	4704	15680
75100	74932	100	2251	3	33	6753	22510
90000	89609	100	3059	3	29	9177	30590
103600	103506	100	2624	3	39	7872	26240
154900	154373	100	4315	3	36	12945	43150
179300	181594	101	2752	2	65	8256	27250
210700	211442	100	14582	7	14	43746	145820

21. Analysis of field blanks.

Field or method blanks were sampled and analyzed to indicate if there was any contamination or leakage within the entire sampling and analysis system. For example, isolated instances of high concentrations of SF_6 in the field blanks compared with acceptable results for the laboratory blanks indicate holes in the sampling bag, clips not properly closed, wrong location number, or other operational problems. Consistently high concentrations would indicate a sampling method that could not measure null concentrations accurately. The fifteen field blank samplers were set at 11 locations (Table A-7), several with two QC samplers, and each was used to check for any source of contamination or leaks within the sampler or in later handling of the cartridges. The PIGS blanks and controls were contained in one specially built sampler that housed two cartridges. One cartridge was the source cartridge and contained pre-filled bags of UHP nitrogen. The second cartridge was the receiver cartridge and captured the nitrogen that was transferred from the source cartridge via the pumping mechanisms during an IOP (Figs. A-7 and A-8). The total number of PIGS blanks analyzed for the entire project was 1200 with 1187 (99%) usable. The 13 unusable samples were either flat bags or did not meet all QC requirements.

Table A-7. Field locations of blank, control, and duplicate cartridges. Locations with an asterisk had two QC samplers stationed at that location.

Field Location	Cartridge Type	Position Number	Latitude deg. north	Longitude deg. west
CBD	blank	54	35.46974	97.5163
CBD	blank	056*	35.46969	97.5142
CBD	blank	57	35.46963	97.5129
CBD	blank	82	35.47293	97.5193
CBD	blank	086*	35.47279	97.5144
CBD	blank	87	35.47278	97.5128
CBD	control	23	35.46630	97.5178
CBD	control	42	35.46894	97.5197
CBD	control	043*	35.46890	97.5181
CBD	control	063*	35.47099	97.5180
CBD	control	65	35.47093	97.5154
CBD	control	72	35.47191	97.5193
CBD	duplicate	33	35.46742	97.5179
CBD	duplicate	053*	35.46977	97.5178
CBD	duplicate	61	35.47105	97.5210
CBD	duplicate	064*	35.47093	97.5165
CBD	duplicate	66	35.47072	97.5145
CBD	duplicate	76	35.47174	97.5142
1 km arc	blank	510	35.47512	97.5212
1 km arc	control	514	35.47667	97.5168
1 km arc	control	515*	35.47662	97.5158
1 km arc	duplicate	511*	35.47571	97.5204
1 km arc	duplicate	512	35.47630	97.5191
2 km arc	blank	537	35.47895	97.5319
2 km arc	blank	542*	35.48477	97.5207
2 km arc	control	540*	35.48373	97.5254
2 km arc	control	545	35.48598	97.5123
2 km arc	duplicate	543	35.48617	97.5180
4 km arc	blank	568*	35.49424	97.5456
4 km arc	blank	575	35.50328	97.5113
4 km arc	control	569	35.49760	97.5406
4 km arc	duplicate	567	35.49090	97.5492
4 km arc	duplicate	572*	35.50255	97.5254

Figure A-7. PIGS control or blank sampler showing source cartridge (right) and receiver cartridge (left).

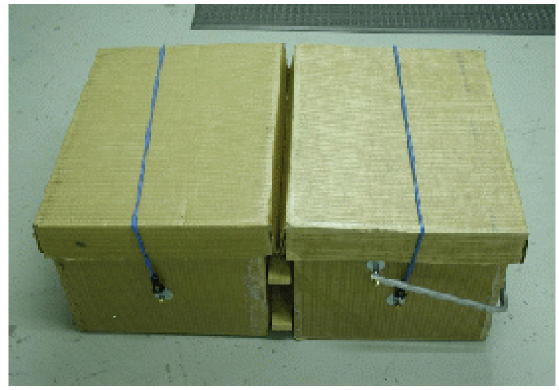

Figure A-8. PIGS control or blank sampler with the covers on and bungee cords in place.

The Super PIGS blanks and controls had two samplers contained in separate cartridges connected by a filling tube and a data information line. The two cartridges were held together by bungee cords. One cartridge was the source cartridge and contained pre-filled bags of UHP nitrogen. The second cartridge was the receiver cartridge and captured the nitrogen that was transferred from the source cartridge via the pumping mechanism during the IOP (Fig. A-9). The total number of Super PIGS blanks analyzed for the entire project was 600 with 461 (77%) usable.

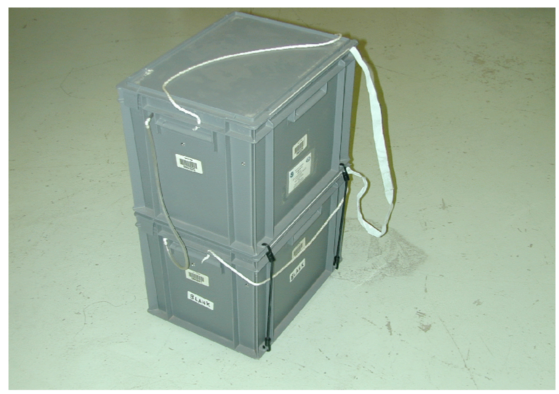

Figure A-9. Super PIGS control and blank cartridges.

Field blank results were visually scanned after completion of each IOP to ensure no obvious contamination or leakage problems. Every attempt was made to fix any problems before the initiation of the next IOP. Due to time constraints between IOPs, not every result could be reviewed closely or samples re-analyzed. After completion of the project, the blanks were graphed and scrutinized to determine if any flags should be added to the data.

Table A-8 below shows the PIGS average blank concentration result for each IOP. The average results of 1.1 pptv and standard deviation of 3.0 pptv indicate no evidence of contamination or leakage within the combined sampling and analysis system.

Table A-8. PIGS field blank results for each IOP.

IOP Number	Average Concentration (pptv)	Standard Deviation (pptv)
1	1.3	2.5
2	1.6	2.6
3	1.1	4.8
4	1.3	2.9
5	2.0	4.9
6	1.2	2.4
7	0.8	1.3
8	0.8	3.1
9	0.4	0.7
10	0.3	0.9
Average	1.1	3.0

Table A-9 shows the Super PIGS average concentration results for each IOP. The average results of 31 pptv and standard deviation of 46 pptv indicates evidence of contamination or leakage within the combined sampling and analysis system. Further discussion of this problem can be found in the Super PIGS QC Issues section of this report.

Table A-9. Super PIGS field blank results for each IOP.

IOP Number	Average Concentration (pptv)	Standard Deviation (pptv)
1	24	22
2	28	29
3	14	12
4	35	101
5	9	6
6	20	25
7	57	118
8	26	25
9	24	34
10	68	90
Average	31	46

22. Analysis of field duplicates.

Fifteen field duplicate samplers were placed at 11 locations, listed in Table A-7, in each IOP to check for imprecision and bias in the sampling, handling and storage of samples. These duplicate samplers were placed directly across from a regular field sampler on the same hanging structures so that each set of samplers would collect similar air samples. All samples and their duplicates were downloaded with the same information from the same Timewand or downloader. Field duplicate results were visually scanned after completion of each IOP to ensure there were no obvious indications of imprecision or bias. Every attempt was made to fix any problems before the initiation of the next IOP. Due to time constraints between IOPs, not every sample result could be reviewed closely and samples re-analyzed. After completion of the project, RPDs were calculated and sample results greater than the MLOQ were graphed against their corresponding duplicate to determine method performance (Figs. A-10 and A-11). A regression analysis of all data above the MLOQ was performed on each duplicate data set. The intercept and slope were used as an indicator of bias. The correlation coefficient was used as an indicator of precision. Both the PIGS and the Super PIGS showed no significant bias with similar slope results of 0.913 and 0.929 respectively. The Super PIGS indicated slightly more bias with an increased intercept of 64 pptv compared with the PIGS intercept of 6.6 pptv. A lower correlation coefficient of 0.929 compared with the PIGS correlation coefficient of 0.984 indicated good precision although not as good as the PIGS. The PIGS results indicate no significant bias. The total number of PIGS duplicates analyzed was 1200 with 86% usable. The total number of Super PIGS duplicates analyzed was 600 with 70% usable.

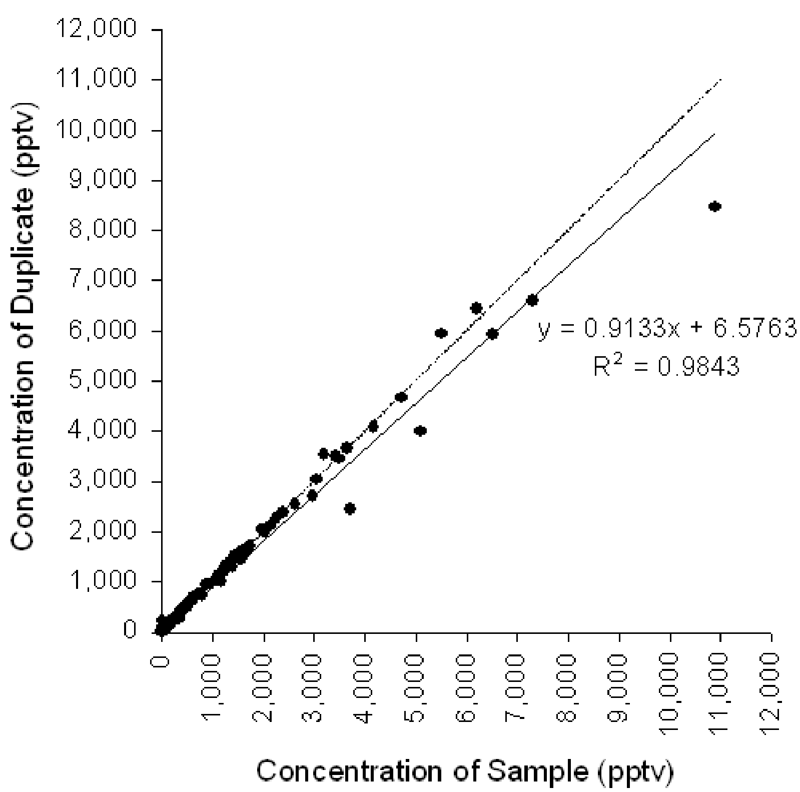

Figure A-10. Linear regression of PIGS field duplicates with concentrations greater than MLOQ (dashed line is 1:1).

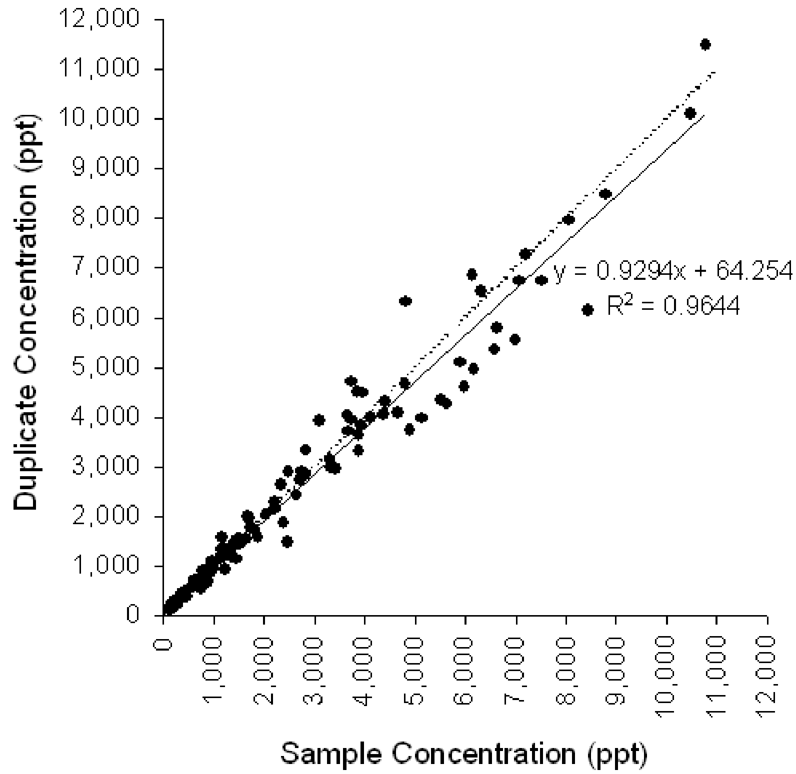

Figure A-11. Linear regression of Super PIGS field duplicates greater than the MLOQ (dashed line is 1:1).

The average duplicate RPD for the PIGS for each IOP was less than 15%. The average RSDs were all less than 10% (Table A-10). RPD and RSD less than 15% and 10%, respectively, indicate good precision and no bias.

Table A-10. PIGS field duplicate results.

IOP Number	Average RPD (%)	Average RSD (%)
1	7.4	5
2	6.5	5
3	6.7	5
4	9.5	7
5	12	8
6	12	8
7	5.9	4
8	6.6	5
9	6.9	5
10	4.7	3
Average	7.8	6

The average RPDs for the Super PIGS for each IOP were also less than 15% except for IOP 1 while the average RSDs were all less than 10%, except for IOP 1 (Table A-11). The PIGS average RPD was 7.8%, while the Super PIGS RPD was 9.3%. The PIGS average RSD was 6% while the Super PIGS average RSD was 7%. This indicates good precision with no bias and very comparable results with the PIGS.

Table A-11. Super PIGS field duplicate results.

IOP Number	Average RPD (%)	Average RSD (%)
1	17	12
2	9.6	7
3	12	8
4	2.6	2
5	9.4	7
6	5.0	4
7	8.0	6
8	8.6	6
9	13	9
10	8.2	6
Average	9.3	7

An insignificant number of samples, approximately 0.1%, had RPDs greater than 30% with either a sample or duplicate concentration of greater than four times the MLOQ. These results were closely investigated. If no problems could be found with the analysis, the sample and its duplicate were flagged as estimates and other samples within that batch were reviewed for trends.

23. Analysis of field controls.

Fifteen field control samplers were placed at 11 locations, listed in Table A-7, in each IOP to check for any bias and inaccuracy introduced during the sampling, handling, and storage of the samples. Each control sampler was placed alongside a regular field sampler. The controls were contained in specially built samplers that housed two cartridges and were identical in appearance to the field blank samplers (Figs. A-7 through A-9). One cartridge was the source cartridge and contained pre-filled bags of calibration gases. The second cartridge was the receiver cartridge and captured the calibration gas that was transferred from the source cartridge via the pumping mechanisms during the IOPs. Field control results were visually scanned after completion of each IOP to ensure there were no obvious recovery problems. Every attempt was made to fix any problems before the initiation of the next IOP. The estimated MLOD and MLOQ were calculated for each IOP and the flags for that IOP were set after each IOPs completion to give an indication of method performance. Due to time constraints between IOPs, these results could not be reviewed closely or samples re-analyzed. After completion of the project, the controls were graphed and scrutinized to determine if any flags should be added to the data and the final MLOD and MLOQ were calculated.

All PIGS controls had less than 15% RSD except, understandably, for the 2.02 pptv and 3.84 pptv standards which are at the MLOD and MLOQ, respectively, as seen in Table A-12. The average percent recoveries ranged from 89% to 108%. These two factors indicate good method precision and accuracy. The total number of PIGS controls was 1,200 with the percentage of usable data of 95%.

Table A-12. Field control results for the PIGS.

True Conc. (pptv)	Analyzed Conc. (pptv)	Recovery (%)	Standard Deviation (pptv)	RSD (%)	S/N Ratio	MLOD (pptv)	MLOQ (pptv)	Number of Points	Percent Usable
2.02	2.18	108	0.39	18	6	1	4	93	93
3.84	3.53	92	0.57	16	6	2	6	36	90
9.00	8.87	98	0.59	7	15	2	6	28	93
10.43	10.34	99	0.41	4	25	1	4	8	99
20.18	19.22	95	1.31	7	15	4	13	97	97
38.7	37.3	96	3.5	9	11	10	35	39	98
82.9	80.1	97	3.7	5	22	11	37	37	93
284.6	271.9	96	11.6	4	24	35	116	29	97
291.4	274.6	94	17.5	6	16	52	175	68	97
514	484	94	21.1	4	23	63	211	19	95
779	742	95	33	4	23	99	330	26	87
796	729	92	81	11	9	242	808	58	83
1560	1495	96	57	4	26	172	574	25	83
3020	2830	94	300	11	9	899	2995	95	95
5100	4978	98	122	2	41	366	1220	29	97
5280	4674	89	663	14	7	1990	6633	40	100
7610	7148	94	508	7	14	1525	5084	58	97
8370	8304	99	221	3	38	664	2212	10	100
10120	9723	96	551	6	18	1654	5513	26	87
16310	15049	92	1812	12	8	5438	18127	67	96
19430	18473	95	1006	5	18	3018	10059	70	100
21720	20850	96	878	4	24	2634	8779	29	97
36900	34181	93	3267	10	10	9800	32667	57	95
50500	47401	94	4436	9	11	13307	44357	57	95
75100	70826	94	3355	5	21	10065	33548	30	100

As seen in Table A-13, the Super PIGS controls had RSDs ranging from 2% to 91% with the highest results coming from standard concentrations near the MLOD and MLOQ. The average percent recoveries ranged from 77% to 629%. These two factors indicate method problems with precision and accuracy. Further discussion can be found in the Super PIGS QC Issues section of this report. The total number of Super PIGS controls analyzed was 600 with the average percentage of usable data of 60%.

Table A-13. Field control results for the Super PIGS.

True Conc. (pptv)	Analyzed Conc. (pptv)	Recovery (%)	Standard Deviation (pptv)	RSD (%)	S/N Ratio	MLOD (pptv)	MLOQ (pptv)	Number of Points	Percent Usable
2.02	12.7	629	12	91	1	34	115	32	64
3.84	5.95	155	2.9	49	2	9	29	10	50
9.00	16.9	187	83	49	2	25	83	10	67
20.18	28.3	140	13	47	2	40	132	32	64
38.7	40.2	104	9.6	24	4	29	96	11	55
82.9	77.6	94	6.8	9	11	20	68	10	50
284.6	250.8	88	15	6	17	45	151	11	73
291.4	273.0	94	32	12	8	97	323	23	66
514	457	89	47	10	10	142	472	6	60
779	666	86	82	12	8	247	822	10	67
796	713	90	79	11	9	237	789	18	51
1560	1454	93	85	6	17	255	851	9	60
3020	2543	84	494	19	5	1482	4939	33	66
5100	4486	88	156	3	29	469	1564	10	67
5280	4555	86	394	9	12	1183	3944	13	65
7610	6705	88	494	7	14	1482	4941	22	73
10120	9427	93	391	4	24	1172	3906	9	60
16310	13682	84	1883	14	7	5650	18835	21	60
19430	16993	87	1420	8	12	4259	14196	17	49
21720	15801	77	4752	28	4	14256	47521	8	53
36900	31855	86	1802	6	18	5406	18018	16	53
50500	40382	83	5394	13	8	16182	53941	21	70
75100	62803	84	1523	2	41	4572	15238	6	40

24. Software quality control checks.

Several important quality checks were built into the software to efficiently aid the TAF analyst in ensuring that the ATGAS instruments were functioning correctly during analysis.

- Since the concentration is dependent upon the temperature of the ATGAS ovens, it is critical that the temperatures do not fluctuate widely during analysis. Temperature acceptance limits were set and the software produced a pop-up window to alert the analyst in case of unacceptable temperature readings. All samples obtained using the incorrect temperature were re-analyzed.

- To check for instrument drift, the software alerted the analyst to validate the calibration curve when more than three hours had elapsed from the last CCV. The analyst had the option of overriding the alert or checking the calibration and re-starting the 3 hour clock.

- In order to verify the calibration curve in the area of interest and to save time, the software produced on the computer screen a record of the highest and lowest concentrations measured since the last CCV. The analyst had only to re-analyze calibration samples within that range.

- Several data flags were shown immediately on the computer screen to aid the analyst in deciding whether the data for each bag was "good" or re-analysis was necessary.

- The software kept track of which ATGAS field duplicate was analyzed on and directed the analyst to use the same GC for the duplicate cartridge. This helped to quantitate the variability of the field analysis without adding the extra variability of analyzing on a separate ATGAS.

- The software alerted the analyst if any calibration points did not meet pre-determined acceptance criteria. The analyst could then review the calibration curve to determine the acceptable course of action.

25. Data verification.

Data verification was performed to ensure that the samples met all QC acceptance limits and that all samples had been analyzed for that particular IOP. Transcription and calculation errors were reduced by automated data reduction techniques such as automated flagging of results outside acceptable limits, auto-generated quality control sheets (Fig. A-12 and A-13), auto generation of chromatogram plots including calibration curves (Fig. A-14) and electronic transfer of data from the ATGAS's to Excel spreadsheets. The analyst and at least one other person familiar with the data analysis process reviewed all data packages. All data packages were batch processed per run on each ATGAS. All data packages included the raw data, a copy of the logbook pages for that analysis, the quality control sheet that summarized the results of all QC data generated for that batch (Fig. A-12 and A-13), plots of all chromatograms and calibration curves (Fig. A-14), and a data verification sheet (Fig. A-15) to ensure the verifier checked all QC parameters. Software produced an Analysis Summary (Fig. A-16) that was utilized to ensure that there was at least one acceptable result for each bag for each location that was downloaded for each IOP. Any samples rejected by the software were re-analyzed and the Analysis Summary report was re-run until all samples had been analyzed or a justifiable reason had been determined for a missing sample. Cartridges were not cleaned until all available samples had been analyzed.

National Oceanic and Atmospheric Administration
Air Resources Laboratory Field Research Division
Quality Control Sheets

1

Analyst: Camille Erwin Debbie Lacroix Verified by: Roger Carter
Date: 07/11/2003
Project: JUT2003 Date: 13 July 03
GC# 3
Parameter SF6
Data file: G3030711.r01

Calibration Verification(+/-10%)

Bag	True Value	Result	%Recovery	area
#01	2.02	2.19	109	3445
#02	3.47	3.63	105	5290
#04	20.18	20.28	100	24616
#05	38.70	37.74	98	45170
#06	82.90	81.65	98	95773
#07	291.40	289.11	99	385102
#09	796.00	789.28	99	1017609
#10	1560.00	1552.75	100	1726576
#11	3020.00	3006.25	100	2684647
#12	5280.00	5340.60	101	3735608
#01	7610.00	7641.58	100	4634763
#02	10120.00	10288.29	102	5740551
#03	16310.00	16538.96	101	7562027
#04	19430.00	19825.96	102	8284330

Lab Blank
(<lowest cal)

Bag	Result
#01	.78
#02	.63
#03	.79
#04	.81
#05	.38
#06	.41
#07	.40
#08	.60
#09	.32
#10	.47
#11	.41
#12	.26

Calibration Check(+/-20%)

True Value	Result	%Recovery
3.47	4.05	117
20.18	21.30	106
796.00	842.05	106
5280.00	5705.80	108
7610.00	7965.19	105
16310.00	17390.03	107
19430.00	20835.45	107
2.02	2.27	112
20.18	20.76	103
291.40	306.29	105
1560.00	1665.03	107
5280.00	5685.96	108
2.02	1.88	93
7610.00	8027.12	105
19430.00	20753.54	107
2.02	2.05	101
20.18	20.98	104
291.40	304.83	105
796.00	846.22	106
3020.00	3260.31	108
5280.00	5626.54	107

Background Level

Bag	Result
#1	9.16
#2	9.45
#3	9.37
Average	9.33

Sample
Min= .26
Max= 19764.42

Temperature
Min= 64.8
Max= 66.4

Final Calibration Verification(+/-20%)

Bag	True Value	Result	%Recovery
#01	2.02	1.95	97
#02	3.47	3.67	106
#04	20.18	20.73	103
#05	38.70	39.95	103
#06	82.90	85.07	103

Comments/Corrective Actions

SN5366 #10 was low
SN0279, #10 clip broken, but tube still shut so data OK.

Figure A-12. Page 1 of a QC sheet.

#07	291.40	305.77	105
#09	796.00	832.54	105
#10	1560.00	1665.69	107
#11	3020.00	3274.43	108
#12	5280.00	5722.73	108
#01	7610.00	7927.68	104
#02	10120.00	10587.04	105
#03	16310.00	17351.48	106
#04	19430.00	20787.99	107

Duplicates

cart	Bag	Result 1	Result 2	RPD
SN0344	#01	19760.12	19558.48	1.0
SN0344	#02	10190.72	10126.44	.6
SN0344	#03	5508.78	5464.28	.8
SN0344	#04	3144.14	3129.20	.5
SN0344	#05	1613.81	1604.43	.6
SN0344	#06	808.41	792.72	2.0
SN0344	#07	287.27	282.09	1.8
SN0344	#08	82.29	81.69	.7
SN0344	#09	38.01	37.61	1.1
SN0344	#10	19.94	19.95	.0

Figure A-13. Page 2 of a QC sheet.

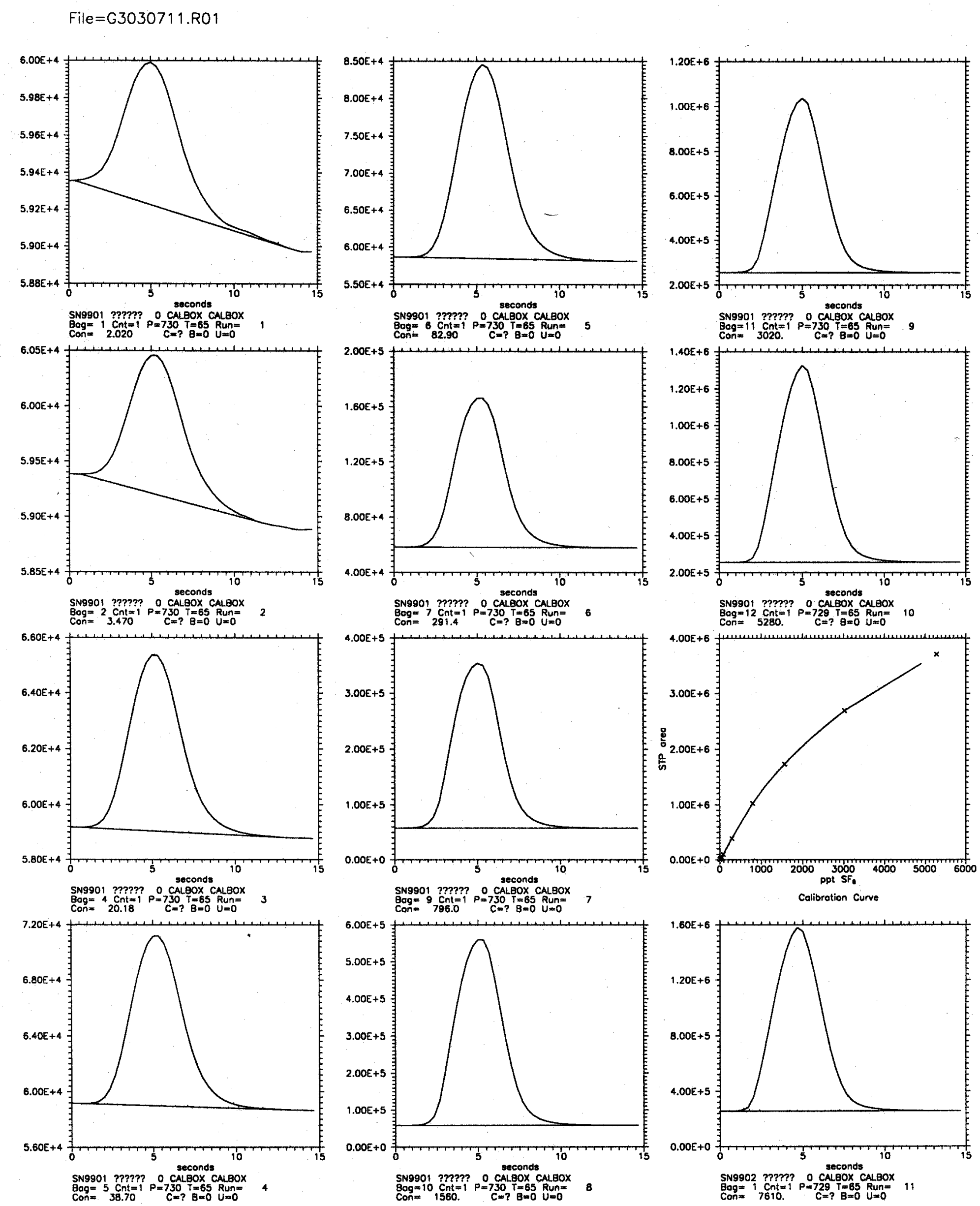

Figure A-14. Examples of chromatograms and calibration curve.

Quality Control Verification Sheet

Aired Woaset 11-19-03

Date: 13 July 03

Verifier: Roger Carter

Data File: G3030711.R01

Project: JUT203

	YES	NO	NA
Does the data package contain complete and legible:	☑	☐	☐
Raw data?	✓		
Logbookcopy?	✓		
Qcsheet?.	✓		
Chromatrograms?	✓		
Is the data file on the raw data sheet, logbook copy and QC sheet the same?	☑	☐	☐
Do the dates match on the raw data sheet, logbook copy and QC sheet?	☑	☐	☐
Is the same project and test number on the QC sheet and raw data?	☑	☐	☐
Have all samples noted as needing to be re-run, actually been re-analyzed?	☐	☐	☐
Are all pressures ok (>700) and the temperature 63-67°? Are any that are not within the acceptable limit flagged as unusable?	☑	☐	☐
Are all chromatogram integrations ok?	☑	☐	☐
Is the calibration curve acceptable?	☑	☐	☐
Do all samples have a project ID where needed?	☑	☐	☐
Do all samples have a check in flag associated with them?	☑	☐	☐
Has the background level been reported and is it greater than the lab blank indicating there is no leakage within the system?	☑	☐	☐
Are all calibration checks within the concentration range of the sample set previous to it?	☑	☐	☐
Has a final full set of calibration checks been analyzed or at least those covering the concentration range previous to it?	☑	☐	☐
Are all anomalies reported on the logbook copies also reported on the QC sheet?	☑	☐	☐
Has all the data been transferred correctly from the raw data to the QC sheet?	☑	☐	☐
Are all standards in the calibration curve verification within 10% of the true value and any anomalies noted?	☑	☐	☐
Are lab blanks analyzed and less than the lowest calibration standard?	☑	☐	☐
Are recoveries for the calibration checks within ± 20%?	☑	☐	☐
If recoveries for the calibration checks were not within ± 20%, were the samples previous to it re-analyzed?	☐	☐	☑
Were duplicates within ±20% RPD?	☑	☐	☐

Verifier Comments:

Figure A-15. Example of a data verification sheet.

Anlsum.out

Plastic IOP6

```
Analysis Summary for JUT203  test 12
  start year=2003  start month= 7
  estimated results accepted as good.
  21-JUL-03 23:27:18

 Cartridges downloaded, but analysis NOT complete

 Cartridges with complete analysis that were NOT downloaded
     SN1291  LC****  1  2  3  4  5  6  7  8  9 10 11 12
     SN5243  LC****  1  2  3  4  5  6  7  8  9 10 11 12

 Locations downloaded but NOT listed as project locations
     LC8043
     LC8044
     LC8045
     LC8046
     LC8053
     LC8055
     LC8056
     LC8063
     LC8064
     LC8065
     LC8066
     LC8083
     LC8084
     LC8086
     LC8153
     LC8164
     LC8166
     LC8254
     LC8256
     LC8286
     LC8343
     LC8363
     LC8365
     LC8940
     LC8945
     LC8946
     LC8950
     LC8954
     LC8956
     LC8963
     LC8964
     LC8965
     LC9043
     LC9044
     LC9045
     LC9046
     LC9053
     LC9054
     LC9055
     LC9056
```

ignore not download record

Page 1

Figure A-16. Example of an Analysis Summary sheet.

26. Post Determination of Method of Limit Detection.

Although the PIGS MLOD and MLOQ were estimated prior to deployment to Oklahoma City, the final MLOD and MLOQ for the PIGS and the Super PIGS was re-established after completion of the project. The MLOD and MLOQ were determined to provide a concentration result with a defined level of confidence to be statistically different from zero. All concentrations were compared with these values and QC flags were generated accordingly. All data were later flagged according to these values. The method limit is dependent upon method performance and should be established using the same variables such as location, time, and weather conditions as was used for the data collection. The PIGS MLOD and MLOQ were calculated based upon the analysis of field controls (Table A-12), the procedure stated in the pre-project MLOD and MLOQ determination section. Table A-14 shows the results from the 2.02 pptv field control used to calculate the final PIGS MLOD of 1 pptv and MLOQ of 4 pptv.

Table A-14. Post-project determination of PIGS MLOD and MLOQ.

Certified Conc. (pptv)	Analyzed Average (pptv)	Average Recovery (%)	Standard Deviation (pptv)	RSD (%)	S/N Ratio	MLOD (pptv)	MLOQ (pptv)	Number of Points
2.02	2.18	108	0.39	18	6	1	4	93

The Super PIGS MLOD and MLOQ however, could not be calculated in the same way as the PIGS using the field control results (Table A-13). The MLOD and MLOQ were calculated based upon testing that was done later at the FRD laboratory facility. A total of 97 points were used to calculate the final MLOD as 33 pptv and the final MLOQ as 111 pptv. The final MLOD and MLOQ values for both the PIGS and Super PIGS were used to set QC flags in the database.

27. Method verification.

All field data were verified to make sure there was a result for every location, cartridge and sample bag and that all results were flagged appropriately. Every quality control sheet (Figs. A-12 and A-13) for each data package was reviewed to ensure proper flagging of final data. Dot plots (Fig. A-17) were created and reviewed to ensure all data were reasonable with respect to each release. Any suspicious data point was traced back through the analysis and deployment records to determine if it was indeed a valid result. The sampler servicing record (Fig. A-5), which was used by all field deployers to note any problems was used to check any outliers or anomalies in the data. Time history plots (Fig. A-18) were also reviewed as well as chromatograms (Fig. A-14) to determine any suspicious data points. Any suspicious data point was traced back through the analysis and deployment records to determine if it was indeed a valid result. All field QC was scrutinized. All suspicious data were appropriately flagged.

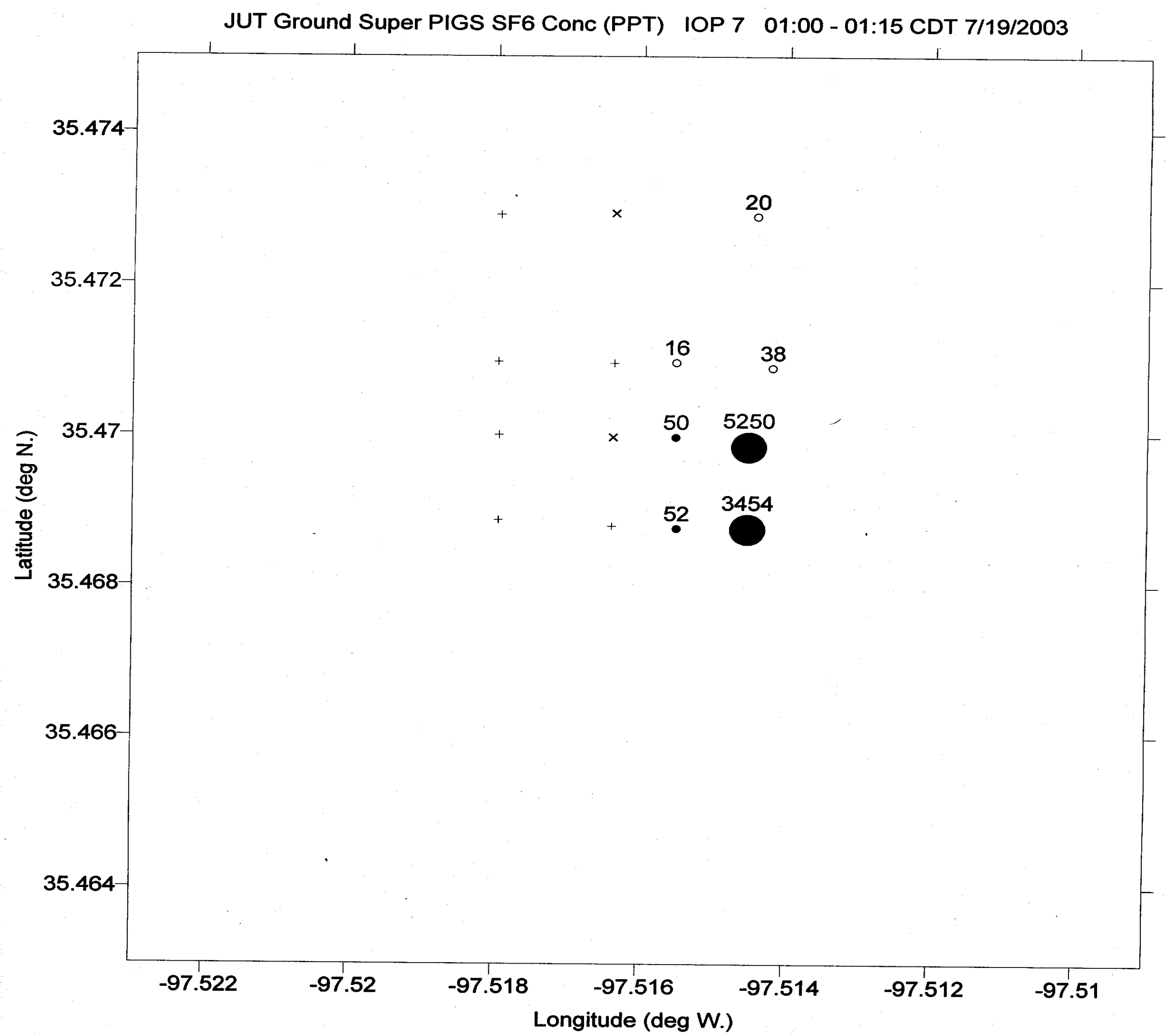

Figure A-17. An example of a dot plot where "+" means less than MLOQ, "x" indicates no data, and the dot size is proportional to bag concentration.

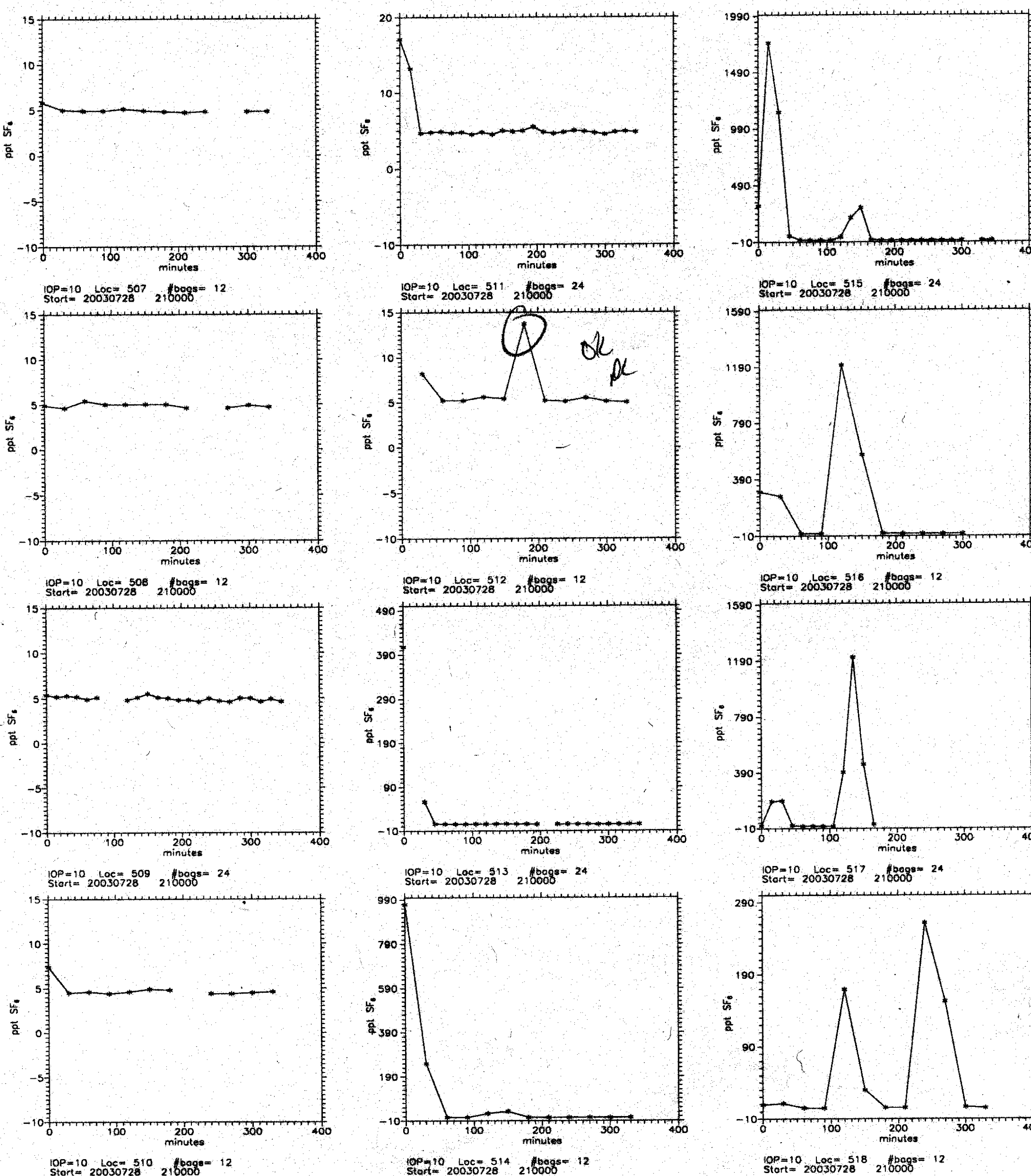

Figure A-18. Example of a tracer concentration time history plot for 12 selected locations in IOP 10, with each dot representing results from one sample bag.

28. Data handling.

All results were printed on hard copy as a backup in case of loss of the data files and to aid in the data verification process. The data packages were filed for future reference and to be readily available during the project for immediate review. Backup copies of the raw ATGAS data were made occasionally and at the end of the project to prevent total loss of data in the case of a computer failure. All final QC and sample results were printed on hard copy and placed in a binder to be stored with any reference materials for the project.

29. Holding time studies.

Holding time studies are determinations of the length of time a sample can be held in its container before the sample concentration changes appreciably. Holding time studies should be conducted whenever the method or sampling container is changed in any way prior to commencement of a project. These studies should be used to determine what effect degradation of the materials will have on sample results. Knowledge of the length of time the samples can be held will help in planning the analysis schedule for the samples in the field. Due to time constraints, holding time studies for the PIGS and the Super PIGS could not be performed prior to commencement of the project. Although holding time studies had been conducted on the PIGS previously, replacement of the tubing and new Tedlar® bags necessitated completion of new studies to determine the length of time that the samples could be held before degradation of the data results. These studies were performed upon return from the project and showed that holding the samples for 3-4 days, as was sometimes needed in the field, did not have any detrimental effect on sample results.

Super PIGS QC Issues

During field deployment, some of the results from the Super PIGS field control QC samplers were sub-standard compared with those collected using the PIGS. On the other hand, Super PIGS field sample results compared well to their neighboring PIGS samplers. Adding to the confusion was the observation that the results from duplicate or collocated Super PIGS samplers were very similar and exhibited none of the problems observed in the field blanks and field controls. The discrepancies surfaced immediately after the first IOP and the samplers were examined for mechanical problems. Operational tests were conducted periodically as time permitted throughout the rest of the study. Randy Johnson, the FRD engineer who designed the samplers, flew to Oklahoma City for several days to help with this process. Several defects were found and repaired, but these failed to completely solve the problem with the QC samples. Time constraints imposed by the Super PIGS construction schedule did not permit any pre-deployment sampler performance studies to be conducted. Additional time constraints imposed by the schedule of IOPs during the field study prevented more intensive testing required to fully identify the problems. To meet the schedule of the field study, there was no choice but to continue using the Super PIGS without complete confidence that all of the sampling problems were resolved.

A comparison of the blank, control, and duplicate results for the laboratory, PIGS, and Super PIGS are seen in Table A-15. As can be seen, all results increased slightly when the added variability of the sampling method is included. However, the large increase in the Super PIGS blank and control results along with only a slight increase in duplicate results make it apparent that more than just normal random variations occurred with the QC samplers.

Table A-15. Comparison of blanks, controls and duplicates.

Source Type	Blanks Average Concentration (pptv)	Control Average RSD (%)	Duplicates Average RSD (%)
Laboratory	0.21	5	2
PIGS	1.1	7	8
Super PIGS	31	14	9

As a result of the problems observed with the Super PIGS QC samplers, a sampler testing program was conducted at the FRD office in the months following the JU03 project. The testing entailed operating the samplers using the same control program as was used in the field. Several PIGS and Super PIGS were placed inside a large, insulated test box. A high concentration standard was injected into the test box containing the PIGS and Super PIGS samplers. The injection was timed to coincide with the sampling of the third bag with the final concentration calculated to mimic concentrations most seen in the field. Fourteen tests were conducted with the Super PIGS in the test box. These trials tested the QC sampler handling methods, the effect of elevated temperatures on the samplers, the effect of humidity on the samplers, the effect of sample holding times, the effect of high concentrations of SF_6 on field blanks, using direct comparisons of PIGS and Super PIGS in controlled concentration of SF_6.

During the testing, two of the Super PIGS samplers used for QC purposes during the field experiment were found to be assembled incorrectly. The inlet tubing to the sample pump inside the sampler was not connected. This was likely the result of a manufacturing process defect. Thus, these two samplers really did not sample from the source bags as intended. When the analyzed sample data from these two samplers were removed from the QC database, the overall results improved greatly and showed reasonable values of MLOD and MLOQ. However, MLOD and MLOQ were still much higher than those calculated for the PIGS. Following the discovery of the missing tubing in the two QC samplers, all remaining Super PIGS samplers were also inspected and none were found to have the manufacturing defect.

Although the missing inlet tubing was the major problem identified to have caused the poor Super PIGS field QC performance in two samplers, other minor problems were discovered with the Super PIGS during post deployment test box testing. For example, it was found that all Super PIGS samples tracked very well and were extremely comparable to their PIGS counterparts, but there was leakage into bags from the outside air when the cartridge was connected to the sampler. Test box studies showed that blanks operated in an atmosphere where SF_6 was present had higher levels of SF_6 in the sample bags. Consequently, the field blanks co-located with samplers showed blanks tracking the concentrations of samplers in some cases and verified the test box results (Fig. A-19). The field controls also showed high concentration levels in the low concentration bags and exhibited variability especially at the lower concentrations as seen in Fig. A-20.

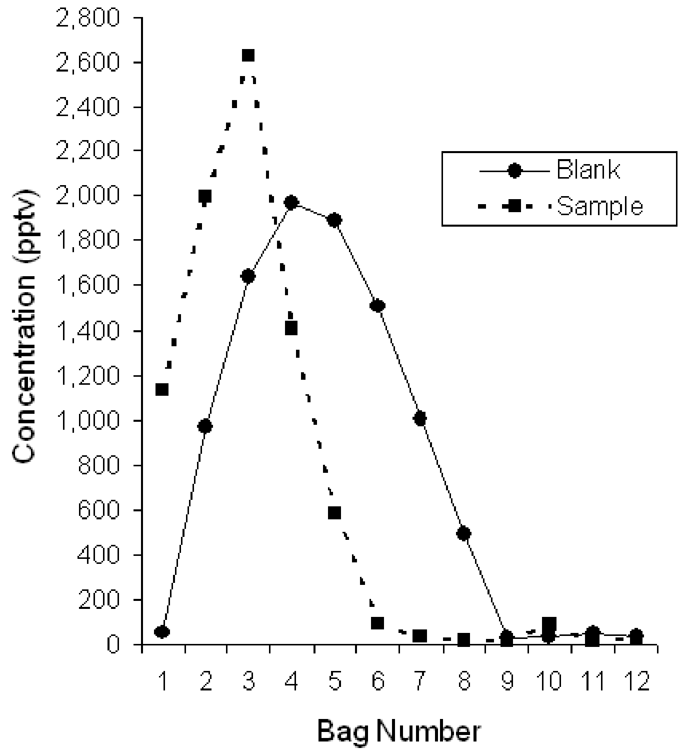

Figure A-19. Example of a Super PIGS field blank tracking the collocated sampler.

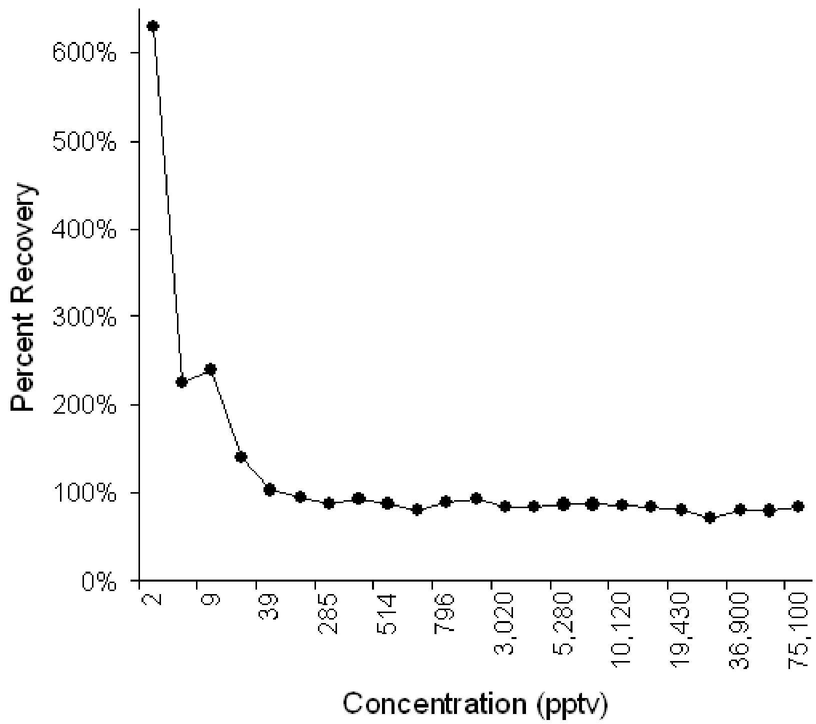

Figure A-20. Percent recoveries of Super PIGS field controls.

The test box and field results clearly indicated that the Super PIGS QC samplers were mixing air from the environment with the air being drawn into the sampler inlet tube as the sample bags were being filled. For a QC sampler which is pulling in air from source bags filled with known concentrations of SF_6, the environmental air usually contains a much different concentration of SF_6 than the intended sample in the source bag. Thus, mixing the two together significantly changes the results. For a regular Super PIGS that is filling the bags with environmental air, mixing additional environmental air with the incoming air does not change the concentration of the sample at all. Obviously, the Super PIGS QC samplers did not represent actual sampler performance and could not be used to subsequently calculate the MLOD and MLOQ. The MLOD and MLOQ were therefore calculated based on the results of the first two bags in each sampler used in the test box sampler tests at the FRD office. These should have had concentrations of 0 pptv. However, due to the leakage and diffusion issues, these bags always contained some concentration of SF_6 with an average concentration of 12 pptv. A total of 97 data points were used to calculate the final MLOD as 33 pptv and the final MLOQ as 111 pptv. These results also compared favorably to the results in Table A-13 where the 38.7 pptv standard exhibited an RSD of 24%, an MLOD of 29 pptv, and an MLOQ of 96 pptv.

None of these effects appear to be large enough to significantly reduce the usability of the JU03 field data. Still, the discrepancies were quantified so that the reported MLOD and

MLOQ values for the Super PIGS accurately reflected the true quality of the field data collected during JU03.

Summary

All calculations for the ILOD and ILOQ both before and during the field deployment, (shown in Table A-16) were comparable. The calculated ILOD for each determination was 1 pptv while the ILOQ ranged slightly from 2 to 4 pptv using low level standards and up to 5 pptv using laboratory blanks. The MLOD and the MLOQ estimated prior to the project and the final calculated results after the project for the PIGS and Super PIGS are shown in Table A-17. The estimated PIGS MLOD and MLOQ results calculated prior to the project were nearly identical to the final project calculation indicating good method performance (Table A-18). Super PIGS MLOD and MLOQ results were discussed in a previous section.

Table A-16. Instrument limit of detection (ILOD) and instrument limit of quantitation (ILOQ) calculations.

	ILOD (pptv)	ILOQ (pptv)
Pre transport (low level standard)	1	3
Pre project (low level standard)	1	2
Project laboratory (blanks)	1	5
Project laboratory (low level standard)	1	4

Table A-17. Method limit of detection (MLOD) and method limit of quantitation (MLOQ) calculations.

	MLOD (pptv)	MLOQ (pptv)
Pre-project estimation PIGS (field controls)	1	5
Post- project PIGS (field controls)	1	4
Post-project Super PIGS (laboratory studies)	33	111
Post-project Super PIGS (field controls)	29	96

Table A-18. Target QC limits and QC results for the ATGAS instrument, PIGS and Super PIGS samplers.

	Target Limits	Average Instrument Results	Average PIGS Results	Average Super PIGS Results
Between Instrument Precision (background checks)	<10% RSD	8% RSD ± 4%		
Instrument Bias (lab blanks)	< 1 pptv	0.21 pptv ± 0.49 pptv		
Instrument Precision (lab duplicates)	<5% RPD	2% RPD ± 2%		
Instrument Accuracy and Precision (Lab control)	<10% RSD	5% RSD ± 3%		
Method Bias (field blanks)	<5 pptv		1.1 pptv ± 3 pptv	31 pptv ± 46 pptv
Method Precision (field duplicates)	<15% RPD		8% RPD ± 11%	10% RPD ± 9%

A summary of the project statistics are shown in Table A-19. The average percentage of good data greater than the MLOQ was 71%, the percentage of good data less than the MLOD was 16%, and the percentage of good data greater than the MLOD but less than the MLOQ was 5.3%. The percentage of good data, that data with no known analytical or field sampling problems, is the sum of the percentage of good data greater than the MLOQ, data less than the MLOD and data greater than the MLOD but less than the MLOQ. This average percentage was 92%. The percentage of data with analysis QC problems was 0.23%, the percentage of data with field problems was 7.4%, and the percentage of data with analysis problems was 0.39%. The percentage of data with problems includes data with analysis QC problems, field problems, and analysis problems were 8% for the project.

Table A-19. Detailed summary statistics for PIGS and Super PIGS final data.

IOP	Good Data > MLOQ (%)	Good Data < MLOD (%)	Good Data > MLOD but < MLOQ (%)	Good Data (%)	Analysis/ QC Problems (%)	Field Problems (%)	Analysis Problems (%)	Data Problems (%)
1	54	12	4.3	70	0.06	29	0.06	30
2	69	17	4.0	90	2	7.7	0.06	10
3	72	13	4.8	90	0	10	0.17	10
4	71	16	5.0	92	0	6.3	1	8
5	69	19	4.4	92	0.11	7.3	0	8
6	76	14	5.4	95	0	4.1	0.67	5
7	71	22	4.6	97	0.06	2.6	0.28	3
8	77	10	9.9	97	0	3.3	0.06	3
9	76	15	6.9	98	0.11	1.7	0.72	2
10	73	20	3.7	97	0	2.2	0.89	3
Ave	71	16	5.3	92	0.23	7.4	0.39	8

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APPENDIX B. TGA QA/QC

Continuous SF_6 concentration measurements were made by ten van mounted, ARLFRD-built mobile tracer gas analyzers (TGA). The analyzer is based on a modified TGA–4000 (Scientech Inc. of Pullman, Washington) which has been integrated with a controlling computer, a GPS system, a dilution system, an automated cleaning system and a computer controlled calibration system. These analyzers measure atmospheric SF_6 concentrations with a response time of just under one second (Benner and Lamb, 1985).

The TGA tags each concentration measurement with sampling time and location from the GPS system. These were collected by the computer at the rate of 2 Hz, stored for later post-processing and simultaneously displayed for operator interpretation and control. Using this display, operators performed real-time monitoring of plume concentrations, and used software controls to mark the beginning and ending of the plume trace. The operator then communicated this information to personnel directing the test.

Calibration

Calibration of the TGA was accomplished by allowing it to sample calibration mixtures with known concentrations of SF_6 and recording the output corresponding to each concentration. SF_6 concentrations of sample air are then determined by linearly interpolating between the calibration concentrations whose output values bracket the sample output. The calibration functions are all controlled by the integrated computer when initiated by the operator.

The SF_6 calibration standards were stored in Tedlar® bags identical to those used in the PIGS, which are described in Appendix A. The bags were connected to the TGA sample stream by a series of electrically operated three-way valves. The computer switched the sample stream from outside air to a given calibration mixture by activating the corresponding valve. Eight calibration standards were used ranging in concentration from pure air (0 pptv) to over 10,000 pptv SF_6. The calibration standards were manufactured by Scott-Marrin, Inc. of Riverside CA and had a manufacturer listed concentration uncertainty of ±5% and were NIST traceable. A full set of eight calibrations was run on each analyzer both before the release began and after sampling was completed. Operators also ran calibration verification sets during the tests as needed. Usually, these were complete sets, but in some cases lack of time forced these to be partial sets.

Two quantities that are useful for evaluating instrument performance are the method limit of detection (MLOD) and the method limit of quantitation (MLOQ). The MLOD is the lowest concentration level that can be determined to be statistically different from a blank or a 0 pptv SF_6 sample (Keith et. al., 1983). The MLOQ is typically defined to be the level at which the concentration may be determined with an accuracy of ±30%. The recommended values for these are 3σ for MLOD and 10σ for MLOQ, where σ is the standard deviation for measurements made on blanks or low standards (Keith et. al., 1983). The MLOD differs from the instrument limit of detection (ILOD) in that it includes all variability introduced by the sampling method. MLOD/MLOQ are used in this report because they are based on the variability observed during sampling operations.

Since the TGA is measuring continuously, every point may be viewed as a measurement of a blank so long as it is sampling clean air. The standard deviation of the baseline signal then defines σ.

A second method of determining the MLOD and MLOQ is to calculate the standard deviation of the instrument's response to a calibration gas. This deviation may then be used as σ in the MLOD/MLOQ calculations.

Both methods were used for the real-time analyzers. After data collection for an IOP was completed, the data analyst followed a written procedure and calculated each instrument's MLOD and MLOQ from the baseline noise and from the variation of instrument response to each calibration gas used during the testing. The procedure called for comparing the MLOD from the lowest concentration calibration with a signal to noise ratio between 3 and 10 with the MLOD from the baseline calculation. The larger of these two values was generally selected as the instrument MLOD for that IOP. However, other factors such as number of calibrations available for the calibration variation calculation, consistency of the calculated numbers from different calibration concentrations and availability of good calibrations in the MLOD range were also considered. In some cases, adjustments were made or another value selected. Every effort was made to ensure that the selected MLOD accurately represented instrument performance or registered an error by being higher than necessary. Setting the MLOD too low allows some data to be flagged as valid when it should not be and is unacceptable by FRD standards.

The MLOD/MLOQs for each instrument and each IOP are listed in Table 6. The MLODs for this project were noticeably higher than the 10 pptv specification for the instrument. This was largely because the analyzers were adjusted to cover 0 to 10,000 pptv which was a much larger range than typically used. Some low-end sensitivity was sacrificed thereby making the MLODs higher. There were also some cases of exceptionally high MLODs. These were due to instrument problems. Often, operational problems first affect low-end sensitivity of the instrument which causes the calculated MLOD to be much higher. Generally speaking, an MLOD of 150 pptv or greater indicates that the analyzer was experiencing difficulties during that IOP.

Accuracy Verification Tests

To determine the overall accuracy and precision of the real-time analyzer measurements, calibrated analyzers were allowed to sample gas mixtures with known SF_6 concentration. The percent recovery (i.e., 100% multiplied by the measured concentration divided by the actual concentration) for each test was recorded. Ninety-seven tests were made and are summarized in Table B-1. These tests were made over a period of two months during the year 2000 on multiple analyzers. Most of these tests were made in the laboratory, but some were made with the analyzers mounted in minivans. The test conditions were designed to mimic the actual field operations as closely as possible. The calibration procedures were exactly the same as those used in the field and the times between calibration and test varied from a few minutes to several hours, just as they do in actual operations. Measurements were made both with and without the dilution system operating. The sampled mixtures were not the same as the calibration mixtures. A second set of tests was conducted during the summer of 2004. The measurements were made the same way except all instruments were in the laboratory and no dilution system was used.

Table B-1. Percent recovery of SF_6 concentrations by real-time analyzers sampling known mixtures as unknowns.

SF_6 Concentration (pptv)	Average Recovery (%)	Standard Deviation (%)	Number Of Trials
year 2000			
514	98	8.7	20
2065	110	4.1	17
2087	105	6.7	15
2065 and 2087 combined	107	5.9	32
4095	101	8.7	45
year 2004			
504	105	5.0	54
1593	105	7.3	46
8300	106	2.8	73

Since both the calibration mixtures and the sampled mixtures were listed by the manufacturer as ±5%, it is reasonable to expect accuracy variations up to ±10%. All of the average recovery values are within this range. The standard deviations for all of the groups reported were less than 8.7%, which should be a reasonable estimate of instrument precision.

Quality Control

The quality control (QC) procedure for the real-time analyzers included 12 steps that ensure the real-time analyzer data is as reliable as possible. During field operations, operators were required to follow written checklists that included all QC steps. A written procedure was also followed during post-test processing. The QC steps are:

1. Pre-project preparation.
2. Monitoring of key operational parameters during the study.
3. Daily instrument calibrations.
4. Real-time monitoring of QC parameters during testing.
5. Operator logging of all measurements.
6. Post-test screening of calibrations.
7. Post-test determination of MLOD/MLOQ.

8. Post-test screening of data.
9. Verification of all calculations and data by a second analyst.
10. Identification of data problems and setting of QC flags.
11. Identification of latitude/longitude for stationary analyzers.
12. Review of final data files.

1. Pre-project preparation.

Before the experiment, each analyzer was thoroughly tested to be sure that all systems were in good working order. Any necessary repairs were made. The analyzers were then conditioned by running them for several weeks, which was required for optimum performance. During this period, each one was adjusted to provide the best response to the range of concentrations expected during the study.

Operator training occurred several weeks before field deployment. Dedicated binders were prepared for each analyzer that contained all procedures, phone numbers, safety and Nuclear Regulatory Commission (NRC) requirements. All operators were trained on the operation of the TGAs, including troubleshooting and data handling. They were each required to complete at least one day of hands-on training plus attend one training class at the FRD office in Idaho Falls. In Oklahoma City, operators were expected to run the analyzers for several days prior to the first IOP as part of the required training.

2. Monitoring of key operational parameters.

Analyzer operators filled out a Settings Record as they ran the real-time analyzers (Fig. B-1). They recorded 17 instrument parameters at key times during the operation. These included gas pressures, flow rates, temperatures, electrometer settings, etc. The Settings Record, constructed in table form, contained several days of entries. These sheets were reviewed for any large changes in the parameters that could indicate a problem with the analyzer. Any changes were investigated and the required maintenance was performed. Each TGA operator also maintained a dedicated logbook during the experiment and recorded the measured SF_6, location of the analyzer, and any problems with the analyzer. Operators ran their analyzers between IOPs to ensure optimum instrument performance.

TGA-4000 Settings Record

TGA number: 3

Feb. 2001

date	time	N_2 primary	N_2 delivery	EX 1 flow	EX 2 flow	H_2 primary	H_2 delivery	sample controller	H_2 controller	zero	gain	period	RTEMP	cal slope	LUD	Air primary	Air delivery	dilution controller
6-26-03	14:00	2350	13	145	45	2070	20	188	~~40~~	328	3	1	198	3105	24			
6-26-03	8:30	1810	13			1870	23											
6/25/3	920	1810	13	150	49	1900	15	173	101	355	3	1	193	814	32			
6/25	1650	1100	20			1780	16									~~900~~	10	061
6-26	8:30	1010	13	144	44	1700	17	173	101	348	3	1	198	915	16	1900 ~~1600~~	10	063+
"	15:30	420				1600										1940		
6-27	8:00	400	13	142	45	1560	16	173	101	311	3	1	198	880	20	1930	10	062
"	10:30	200				1520					3	1				1930		
6-28	12:15	New N_2 1320	12	140	40	1550	15	173	101½	321	3	1	198	—	—			
"	15:00	1130				1510												
6-29	7:00	1100	12	140	42	1490	15	173	101½	296	3	1	197	934	18	1950		
"	14:50	420				1320										1950		
7-1	12:35	120	12	141	43	1340	15	173	101	—	3	1	199	—	—	—		
"	15:45	4200				1280												
7-2	6:50	New N_2 2300	12	141	43	1220	15	173	101	261	3	1	197	984	22	1960		
"	17:00	1370				1030												
7/3/03	1400	1370	11	145	50	1050	15	173										

Figure B-1. A TGA-4000 settings record.

3. Daily instrument calibrations.

All analyzers were calibrated at the beginning and end of each measurement period and between releases. Typically, there was ample time to run a complete set of calibrations between releases, but in a few instances, between release calibrations were limited to a few selected bags because of time constraints. This allowed a calibration curve to be generated using calibrations that bracketed the testing period. It also provided a check on analyzer sensitivity drift.

4. Real-time monitoring of QC parameters during testing.

Calibration verifications were performed throughout the IOP to monitor instrument drift. After the first set of calibrations was completed, the calibration curve was checked every time additional calibrations were performed. This was done by treating the new calibrations as unknowns and calculating their concentration based on the calibration curve generated from the first set of calibrations. Due to the nature of the instrument and the need for almost instantaneous measurements, when the calculated concentrations were more than 20% different than the actual concentrations, the operator first ensured that a complete set of calibrations was run then immediately continued with sampling. Appropriate calibrations for each measurement period were selected later during the post-test screening of calibrations. The analyzer also calculated and displayed an MLOD from the baseline noise. Operators were required to display and record this value after every set of calibrations. If large variations were observed, the cause was investigated and corrected.

5. Operator logging of all measurements.

To help ensure that noise spikes, analyzer adjustments, and extraneous features were not reported as valid measurements, operators were required to mark all SF_6 peaks on the computer using the software marking function. They also recorded details of each peak, e.g., time, concentration, latitude and longitude, together with other pertinent observations in a notebook. Any signals that could be mistaken for SF_6 were also recorded in the notebooks.

6. Post-test screening of calibrations.

After an IOP was completed, the TGA operators delivered a copy of their logbook entries as well as a disk containing all data for the IOP to the data analyst. The entire data file including the calibrations from each analyzer was then carefully reviewed by the data analyst on a laptop. To ensure that concentration calculations were as accurate as possible, any calibration points with problems such as significant baseline drift, contamination, accidental instrument adjustments, etc., were identified and eliminated. The recovery for each calibration was calculated and examined. This was done by treating the calibration as an unknown and calculating the concentration using the calibration curve. The recovery was defined as the calculated concentration divided by the actual concentration converted to a percent. The recoveries for all calibrations above the MLOQ were expected to be between 80% and 120%. If they were not, they were re-examined for problems and the logbook entries were reviewed. In cases where the calibrations showed evidence of significant sensitivity drift during the test, the calibrations could be divided into two groups, typically an "early" group and a "late" group. Each group was used to calculate concentrations for peaks within the time frame they encompassed. If the calibrations still failed to meet the recovery limits, all data in the concentration ranges that were out of limits were flagged as estimates.

7. Post-test determination of MLOD/MLOQ.

The MLOD and MLOQ were determined for each analyzer for each day's operation. These values define the lower limit of valid measurements. Concentrations below these levels are flagged with appropriate QC flags so users of the data are aware of its limitations. The MLOD and MLOQ were calculated by two methods: calculations based on the baseline noise and calculations based on the variation in response to calibrations of the same concentration. The data analyst then compared these two calculations and selected the instrument MLOD/MLOQ following the guidelines in a written FRD procedure. Typically, the value calculated from the lowest concentration calibration with a signal to noise ratio in the 3 to 10 range was compared to the value calculated from the baseline noise and the larger of the two selected. However, other factors such as number of calibrations available, instrument problems, behavior on other calibration levels, etc. were considered in the selection.

8. Post-test screening of data.

After a test, the data analyst reviewed the marked peaks and compared them with the notebook to ensure that marked peaks were above the MLOD and that they were not false peaks caused by extraneous factors such as altitude changes, bumps, interfering chemicals in the air, etc. The peaks were checked for correct identification of instrument baseline on leading and trailing sides of each peak. The entire data set was examined for possible peaks that may have been missed. Once necessary corrections were made, the peaks were converted to concentrations, plotted and reviewed.

9. Verification of all calculations and data by a second analyst.

During steps 5, 6, and 7, the data analyst generated a QC sheet (Figs. B-2 and B-3), plots of the calibrations curves, results from the MLOD/MLOQ calculations, and plots of all peaks. The QC sheet was annotated with notes explaining problems that were identified, corrective actions taken, and justification for all data processing decisions that were made by the analyst. A second person familiar with the data processing procedures reviewed and verified this entire data package. If any errors were discovered or if the verifier did not agree with the decisions made, the problems were discussed with the data analyst and a resolution agreed on and implemented.

Final sheet

NOAA ARLFRD TGA-4000 Quality Control Sheet

IOP #3
peak files: 003-2-*.PLM

file: .\T2030707.F00
TGA: 2
start time = 7-Jul-2003 07:00:39

operator: Neil Harkan

data analyst: Roger Carter   verified by: [illegible]

analysis date: 14 July '03   verify date: 10-21-03

	analyst	verifier
All calibration recoveries are within +/-20%	yes no	yes no
LOQ < 150 ppt	yes no	yes no
RMS error (as percent of range center) < 10%	yes no	yes no
Data is usable as is	yes no	yes no
IF data is not usable as is, it could be usable with corrective actions noted below	yes no	yes no

limit of detection (LOD) = 7.9 ppt
limit of quantitation (LOQ) = 26.2 ppt
(LOD/LOQ calculated from baseline variations.)

Calibrations recalculated as unknowns:

cal #	true value	result using 1st cal set	%recovery using 1st cal set	result using all cals ave.	%recovery using all cals ave.
0	0.0	-0.0		0.0	
1	38.7	38.7	100.0	35.7	92.2
2	82.9	82.9	100.0	76.2	91.9
3	291.4	291.4	100.0	274.4	94.2
4	796.0	796.0	100.0	749.1	94.1
5	1560.0	1560.0	100.0	1456.7	93.4
6	5280.0	5280.0	100.0	5142.5	97.4
7	10120.0	10120.0	100.0	9859.2	97.4
8	0.0	-0.0		0.0	
9	38.7	40.4	104.4	37.1	96.0
10	82.9	86.5	104.3	79.7	96.2
11	291.4	307.8	105.6	287.7	98.7
12	796.0	838.7	105.4	790.2	99.3
13	1560.0	1675.7	107.4	1548.4	99.3
14	5280.0	5889.2	111.5	5350.4	101.3
15	10120.0	10437.2	103.1	10197.3	100.8
16	0.0	-0.0		0.0	
17	38.7	41.4	107.0	38.0	98.2
18	82.9	88.4	106.6	81.6	98.4
19	291.4	317.1	108.8	295.9	101.5
20	796.0	853.2	107.2	803.7	101.0
21	1560.0	1716.9	110.1	1586.5	101.7
22	5280.0	5969.0	113.0	5435.4	102.9
23	10120.0	10443.0	103.2	10203.5	100.8
24	0.0	-0.0		0.0	
25	38.7	45.0	116.2	41.2	106.5
26	82.9	92.8	111.9	85.8	103.5

Figure B-2. Page 1 of a TGA-4000 QC sheet.

27	291.4	321.2	110.2	299.7	102.9
28	796.0	867.8	109.0	817.2	102.7
29	1560.0	1747.2	112.0	1616.8	103.6
30	5280.0	5941.0	112.5	5405.5	102.4
31	10120.0	10375.6	102.5	10131.6	100.1
32	0.0	-0.0		0.0	
33	38.7	45.6	117.9	41.8	108.1
34	82.9	98.1	118.4	90.9	109.6
35	291.4	324.4	111.3	302.8	103.9
36	796.0	868.4	109.1	817.8	102.7
37	1560.0	1751.8	112.3	1621.4	103.9
38	5280.0	6036.8	114.3	5507.6	104.3
39	10120.0	10447.6	103.2	10208.4	100.9

Calibration curve errors (for all calibrations averaged):

	RMS error	percent of range center
all cals	77.26 ppt	1.5%
< 544	6.13 ppt	2.3%
> 544	112.1 ppt	2.1%

comments/corrective actions:

all < 26 should be marked as estimates.
corrected positions should be added to file.

Figure B-3. Page 2 of a TGA-4000 QC sheet.

10. Identification of data problems and setting of QC flags.

The operator logbooks and concentration plots were carefully reviewed for any anomalies that required the QC flags to be set. The review focused specifically on instrument over range, dilution system usage that was not detected, starting or stopping of the dilution system during a peak, and van movements during a peak. Any other problems were also noted. From this review, a list of flags that needed to be set was generated and entered into the computer. These were combined with the data during the generation of final data files so that users would be aware of any questionable data. The flags values are defined as:

0 Good data.
1 Concentration less than MLOQ but greater than MLOD; treat as an estimate. (See note on dilution system below.)
2 Concentration less than MLOD; not statistically different than 0; treat as 0 or null value. (See note on dilution system below.)
3 Concentration is greater than 115% of the highest calibration; treat as an estimate.
4 Instrument over ranged its output; concentration is unusable.
5 Null values. Analyzer was in position and operating correctly and no SF_6 was found. Treating these concentrations as 0 is appropriate.
6 Analyzer was not in use. No data available. Do NOT treat these as 0. Flag 6 indicates a human decision to not operate. For example: leave and do calibrations, move to a new place, we don't need you this test, etc.
7 Analyzer was broken. No data available. Do NOT treat these as 0 values. Concentrations are unknown.
8 Analyzer was operating, but was experiencing problems. Treat all concentrations as estimates.
9 Concentrations are unusable because of instrument problems, but are included for qualitative indications only. In this case, the instrument was operating and collected data, but problems discovered later made it impossible to have any confidence at all in the concentrations. Since the data was available it was included and may be useful for some purposes such as determining arrival times, etc. Calculations should not be done with these concentrations.
10 Concentrations unusable because of external problems. For example: fugitive sources, noise caused by trucks passing, etc.
11 Concentrations are estimates because of external problems. This flag indicates that something external to the analyzer had a small effect on the data, making it less certain but not totally unreliable. For example: a passing truck creating a small amount of noise during a high concentration peak.

Comments on QC flags

In most cases, concentrations flagged as unusable were set to -999 in the data files. In some cases, data was included with a flag that indicates missing or unusable data, the most common example being instrument over range, (flag 4). In these cases, the data were there for qualitative indications only and should not be used for calculations.

In a few cases, the MLOD/MLOQ for an analyzer was calculated to be an abnormally high value. The indication was that the instrument was not measuring low concentrations correctly. Flags 8 and 9 were then used instead of 1 and 2 to indicate less than MLOD (flag 9) and less than MLOQ (flag 8) since these more accurately reflect what was happening.

Note on dilution system use: When the dilution system was used, the incoming sample stream was mixed in equal parts with ultra pure air. This reduced the concentration to half the actual concentration in the air. The concentrations measured by the analyzer are doubled before reporting to reflect the actual air concentration. However, the MLOD and MLOQ levels reflect instrument operation and must be based on instrument levels, which are 50% of reported concentrations. While the dilution system was in use, the levels at which flags 1 and 2 are set will be twice the reported MLOD/MLOQ values (i.e., 1 indicates a data value less than 2*MLOQ; 2 indicates a data value less than 2*MLOD).

11. Identification of latitude/longitude for stationary analyzers.

Each analyzer was equipped with a GPS unit and the attached computer automatically tagged each measurement with a time and position. However, close to the tall buildings in the central business district, the GPS signals were not reliable. For stationary vans, the positions included in the final data files were determined as follows:

For every SF_6 peak marked by the operator at a given location, the median latitude and longitude from the "good" GPS positions in the file was determined. "Good" GPS positions were defined to be all those with horizontal dilution of precision (HDOP) less than or equal to 3.0 and the number of satellites in use greater than or equal to 4.

The operator notebooks were then carefully reviewed to determine which peaks were measured at the same location. Once a group of peaks was identified with a particular location, the median values of latitude and longitude were plotted on a map. If the medians appeared to make a tight group at the appropriate location, it was assumed that the GPS worked reasonably well and the reported position was the average of these medians. If the medians exhibited significant scatter (more than a few car lengths), appeared to be in the wrong location or there were too few to determine if the grouping was good, it was assumed that the GPS did not work well in that location and the GPS locations were not used. In these cases, the positions were read off of high-resolution satellite photos available from Terraserver.com. These photos had resolutions of about 6 inches per pixel and readily showed sidewalks, crosswalks, parking spaces, vehicles on the roads, etc. The positions read off of Terraserver.com did not include altitudes, so the altitude was reported as -999 in the data files while those taken from GPS positions have an altitude reported in meters. If the altitude is -999, it should be assumed that the analyzer van was at street level. (All vans were at street level except when analyzer 7 was parked on the top of the Main Street Parking Garage. A GPS position was reported in this case.)

When the analyzer vans were mobile, the GPS positions read by the van were reported in the data files. Some caution is advised when using the data since they will contain some spikes and erroneous readings. There are also a few instances where the GPS lost its position and took several minutes to regain it. These are most easily detected by looking at the HDOP (horizontal dilution of precision) and the number of satellites the GPS used. Both of these values are included in the data files. HDOP decreases as the reliability of the position value improves. Typically, reliable readings will have HDOP values of 4 or less. Higher HDOP values indicate that the position is questionable and anything with an HDOP over 10 is generally very bad. The reliability of the position values also improve as the number of satellites increases. At least 4 satellites are required for a good GPS position and more are better. Any position with less than 4 satellites should be regarded as unreliable. These rules of thumb apply only to the mobile vans. Stationary vans that have averaged GPS positions or positions read off of Terraserver.com have HDOP=0 and number of satellites= -1 in the data files.

Van 5 was always mobile. Other vans were inadvertently mobile for one peak measurement on three occasions: van 3 in IOP 4, van 2 in IOP 5, and van 8 in IOP 5. These occurred when the analyzer unexpectedly encountered an SF_6 plume while driving to or leaving a stationary position.

12. Review of final data files.

After the final data files were created, they were carefully reviewed for any problems. Each of the 390 data files were read into Excel and each column plotted versus time. The concentrations were compared to the earlier peak plots to verify that all the peaks were included at the correct time. The position variables (longitude, latitude, altitude, HDOP, number of satellites) were plotted and reviewed to verify that van movements were accurately reflected in the data files. Longitudes and latitudes were checked to verify that the correct ones were being included. The QC flags were checked visually by plotting and by computer programs that listed start and stop times for each flag and the range of concentrations flagged with a 1 or 2. These lists were then compared with the lists generated earlier in the QC process. Any problems were fixed and the files regenerated using the updated information. The process was repeated until no discrepancies were found.

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APPENDIX C. LIST OF ACRONYMS

ACS – American Chemical Society
AGL -- above ground level
ARO – Army Research Office
ARL – Air Resources Laboratory
ARLFRD – Air Resources Laboratory Field Research Division
ASCII – American standard code for information interchange
ASU – Arizona State University
ATDD – Atmospheric Turbulence and Dispersion Division
ATGAS – Automated Tracer Gas Analysis System
CBD – central business district
CBRD – Chemical, Biological and Radiological Defense
CCV – continuing ATGAS calibration verification
CD – compact disk
CDT – Central Daylight Time
CFR – Code of Federal Regulations
DHS – Department of Homeland Security
DOT – Department of Transportation
DPG – Dugway Proving Ground
DRDC – Defence Research and Development Canada
DSTL – Defence Science and Technology Laboratory
DTRA – Defense Threat Reduction Agency
ECD – electron capture detector
EPA – Environmental Protection Agency
FRD – Field Research Division
GC – gas chromatograph
GPS – global positioning system
HDOP – horizontal dilution of precision
ICV – initial ATGAS calibration verification
ILOD – instrument limit of detection
ILOQ – instrument limit of quantitation
IOP – intensive operating period
ISO – International Standards Organization
IU – Indiana University
JU03 – Joint Urban 2003 Experiment
LLNL – Lawrence Livermore National Laboratories
LOD – limit of detection
LOQ – limit of quantitation
MLOD – method limit of detection
MLOQ – method limit of quantitation
MSL – (above) mean sea level
NELAC – National Environmental Laboratory Accreditation Conference

NOAA – National Oceanic and Atmospheric Administration
NRC – Nuclear Regulatory Commission
OCS – Oklahoma Climatological Survey
OU – Oklahoma University
PIGS – programmable integrating gas samplers
pptv – parts per trillion by volume
ppt - parts per trillion by volume
PVC – polyvinyl chloride
QC – quality control
RPD – relative percent differences
RSD – relative standard deviation
SF_6 – sulfur hexafluoride
S/N – signal to noise (ratio)
sodar – sound direction and ranging
SUV – sports utility vehicle
TAF – tracer analysis facility
TGA – trace gas analyzer
TKE – turbulent kinetic energy
TP9 – Technical Panel 9
TTCP – The Technical Cooperation Program
UHP – ultra high purity
UTC – coordinated universal time
UU – University of Utah
PA – public affairs
PNNL – Pacific Northwest National Laboratory
WS – wind speed

Keywords

ARLFRD, joint urban, sulfur hexafluoride sampling, Oklahoma City, atmospheric tracer, Field Research Division, total gas analyzer, TGA, PIGS, Super PIGS, SF_6 dissemination, SF_6 sampling, programmable integrating gas samplers, urban dispersion.

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