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Final Report for the Joint Urban 2003 Atmospheric Dispersion Study in Oklahoma City: Lawrence Livermore National Laboratory participation

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Introduction

The Joint Urban 2003 (JU2003) field study was designed to collect meteorological and tracer data resolving atmospheric dispersion at scales-of-motion ranging from flows in and around a single city block, in and around several blocks in the downtown Central Business District (CBD), and into the suburban Oklahoma City area a few km from the CBD. Indoor tracer and flow measurements within four downtown study buildings were also made in conjunction with detailed outdoor measurements investigating the outdoor-indoor exchange rates and mechanisms. The movement of tracer within the study buildings was also studied.

The data from the field experiment is being used to evaluate models that are being developed for predicting dispersion of contaminants in urban areas. These models may be fast-response models based on semi-empirical algorithms that are used in real-time emergencies, or highly sophisticated computational fluid dynamics models that resolve individual building faces and crevices. The data from the field experiment, together with the models, can then be used to develop other advanced tools that are especially valuable in the efforts to thwart terrorists. These include tools for finding location and characteristics of a contaminant source; tools that can be used for real-time response or for forensic investigation. The tools will make use of monitoring networks for biological agents that are being established in several sensitive cities throughout the nation.

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

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

measurements of tracer were made by placing samplers on the tops of nearly 20 buildings and by sampling tracer at 7 levels on a 90 m crane.

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

Samplers to collect tracer data were located at various distances from the release locations for collecting data for validating urban dispersion models. At the same time, a dense network of meteorological instruments was deployed including in-situ anemometers and profiling platforms such as lidars, sodars and radars. The meteorological instruments were state of the art and were strategically placed to document the inflow and outflow boundary conditions from the CBD, as well as the evolution of the atmospheric boundary layer structure as the air circulated through and over the CBD. A high density network of atmospheric micrometeorological instruments was placed in one particular urban canyon to investigate circulation within the urban canyon and investigate the interaction of circulation within the canyon with that of the overall circulation.

Logistics

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

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

A command center and a forecast center were set up in the Oklahoma University Health Sciences Center (HSC). Daily weather briefings were presented to the principal investigators, using a classroom in the HSC. When a consensus was reached that an IOP would be conducted the following day, preparations would begin immediately. For the daytime IOPs, the far-field samplers were deployed later on the day of the briefing in preparation for tracer releases and operations the following day. The forecast team tracked the weather and forecasts throughout the day, keeping the test director informed of any changes or unusual occurrences. The near-field samplers and portable

meteorological instruments were deployed early in the morning of the IOP. Once the releases started, personnel in the command center maintained communications with the sampling teams in the field, getting observations from the real-time instruments and disseminating information about current wind conditions and where the plume appeared to be heading. A similar time schedule for the nighttime IOPs was adhered to, with weather briefings at night, for example, but with allowances to allow for most of the deployment of samplers during daylight hours.

The sampling equipment was staged out of two areas. The NOAA/FRD personnel used a city owned shipping and maintenance yard with a warehouse type building that became to be known as the "pink palace". This yard was just to the east of the south edge of the CBD and provided convenient access to major thoroughfares for the vans to transport to the north and west of the city. The LLNL equipment was staged from the Oklahoma State Department of Environmental Quality Building, which was located just north of the CBD.

Site Description

Several factors led to the selection of Oklahoma City for the JU2003 field study, including the cooperation of the local government and city offices as well as the existence of a host university and other institution that could provide infrastructure facilities such as laboratory space, a command center and meteorological forecasting capability. The size and layout of the central business district (CBD) and the availability of supporting meteorological data from the several meteorological entities within the state of Oklahoma are other factors that made Oklahoma City an attractive choice for the study.

Oklahoma City is a moderately sized city with a population of approximately 500,000 people (2000 census) living within the city and about 1 Million people in the metropolitan area.. There is a well-defined CBD with buildings as high as 150 meters, several ground-level and elevated parking facilities, and some open green space. The CBD is mostly confined north of Interstate-40 and extends about 0.5 kilometer. Beyond that point, few buildings are taller than two stories for several km. However, about 1.5 km to the northwest, there is a hospital high-rise building that is 42 meters high and several other high-rise buildings farther to the northwest in the vicinity of Oklahoma City University. The existence of this well-defined CBD made Oklahoma City an attractive location for the field study and contributed to the final selection.

Weather is of great interest to the people of Oklahoma, which has lead to the existence of high-quality, high-density meteorological observations. The Oklahoma Climatalogical Survey (OCS) has deployed the Oklahoma Mesonet (www.ocs.ou.edu) with stations in every county throughout the state, while the National Severe Storms Laboratory (www.nssl.noaa.gov) deploys specialized radar and other observation platforms. The existence and availability of these data for supporting the field study were attractive features in selecting Oklahoma City for the experiments. The University of Oklahoma Meteorology Department graduate students and the OCS provided forecast support throughout the duration of the field experiments. Their expertise and knowledge of the local conditions contributed greatly to the success of the experiment.

Summer was chosen for the experiment to avoid the maximum of severe storm activity that occurs earlier in the spring. A persistent anticyclone (often referred to as a Bermuda High) sets over the southeastern US or off of the coast in the western Atlantic. Along the western edge of this anticyclone, summers in Oklahoma City tend to be hot and relatively humid with the surface and boundary layer winds flowing preferentially from the south at moderate speeds. Occasionally weak cold fronts push down over the state, possibly triggering convection and rain showers. The high probability of southerly winds enabled the design of tracer experiments with releases along the southern edge and sampling instruments throughout and beyond the CBD.

However, the weak synoptic scale forcing in Oklahoma in the summer creates somewhat of a forecasting dilemma. Because the synoptic scale forcing is weak, local influences and weak mesoscale disturbances tend to force the winds to veer and back slightly around the preferred southerly direction. The result is that winds can be southeasterly to southwesterly at any particular time. The experiment was designed for this, with release points from the east or west sides of the planned sampler network. However, determining the release location due to winds with an easterly or westerly component became the forecast problem. The forecasters from the OU meteorology department did a great job, using their local knowledge to assist in determining the release location.

The Health Sciences Center at the University of Oklahoma provided laboratory space for analyzing the SF6 tracer samples, rooms for use as a forecast center and command center, and a moderately sized classroom for briefing and debriefing. The HSC is just northeast of the CBD, and was conveniently accessed by the researchers as they collected samples or gathered for discussion of past and present activity or future plans. Oklahoma City provided use of a shipping yard as a staging facility with a warehouse type structure, which affectionately came to be known as the “pink palace”, which was used for storage.

Meteorological Measurements

Meteorological measurements were made during the experiment to characterize the wind flow in and around the urban area. In particular, the instruments were deployed to characterize the urban boundary layer, the inflow conditions to the urban area, the downwind effect on the mean wind and turbulence, the building and the urban canyon influences on the mean wind and turbulence energy budget.

Several different types of instruments were deployed with a strategy of maximizing the utility of all of the instruments. The upwind or inflow conditions were characterized by deploying two CTI Wind-tracer lidars, one to the south-southeast and one directly east of the CBD. The scan strategies for the lidars were coordinated to scan the volume that is south of the CBD, creating three-dimensional wind vectors of the inflow air. A wind profiler, a sodar and the capability to release radiosondes were deployed at a site to the southwest, at a city maintenance facility. The data from these sites give a good characterization of the upwind conditions, providing boundary conditions and wind profiles for use in urban dispersion models, including simple to CFD models.

A similar site to the upwind site at the city maintenance facility was instrumented at the First Christian Church site at 14th and Harvey. This site was approximately 4 km downwind from the tracer release locations, about the same distance as the outermost tracer sampling arc. A wind profiler, a sodar and a radiosonde capability were deployed to characterize the boundary layer after being modified by the CBD. As at the upwind site at the maintenance facility, the wind profiler and sodar were operated continuously throughout the month, while radiosondes were released only during IOPs.

In addition to the profiling instruments described above, several sodars and mini-sodars were deployed within or just downwind of the CBD. These instruments were deployed to characterize the vertical structure of the lower part of the boundary layer as the air moved through and over the city. The strategy was to deploy these instruments in a roughly south-to-north line, to observe the evolution in the wind field as the structures in the CBD modify the wind field in the volume just above the structures.

Approximately 140 sonic anemometers were deployed within the CBD, just upwind or just downwind. Most of these sonic anemometers operated at 10Hz continuously throughout the experimental period and were located at street intersections, on rooftops and on small towers in the CBD. In particular, an individual block along Park Avenue well within the CBD was heavily instrumented with sonic anemometers and other instruments typical of a micrometeorological experiment. Collecting high frequency data from sonic anemometers allows researchers to calculate the mean wind vectors and turbulence spectral quantities. Researchers use the wind vectors and spectral quantities as input to exiting models to estimate the atmospheric dispersion, and are also used to formulate new parameterizations, refine existing parameterizations and develop new tools and models.

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

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

Table 1. Summary of IOPs.

IOP #	Begin Date 2003	Beg / End Time (CST)	Day/ Night	In-door	Release Location	# Releases; Puff (P)/ Continuous (C)
1	6/29 - Sun	08 / 14*	D		Westin (E side of St.)	8; P,P,P,P,P,P,C,C
2	7/02 - Wed	08 / 16	D		Westin	7; P,P,P,P,C,C,C

3	7/07 - Mon	08 / 16	D		Botanical	7; P,P,P,P,C,C,C
4	7/09 - Wed	08 / 16	D	I	Botanical	6; P,P,P,C,C,C
5	7/13 - Sun	08 / 16	D	I	Botanical	7; C,C,C,P,P,P,P
5a	7/15 - Tue	11 / 13	D		N 4th b. Hudson-Walker	3; C,C,C
6	7/16 - Wed	08 / 16	D	I	Botanical	7; C,C,C,P,P,P,P
7	7/18 - Fri	22 / 06	N	I	Botanical	7; C,C,C,P,P,P,P
8	7/24 - Thu	22 / 06	N		Westin	7; C,C,C,P,P,P,P
9	7/26 - Sat	22 / 06	N		Park	7; C,C,C,P,P,P,P
10	7/28 - Mon	20 / 03*	N		Park	6; C,C,C,P,P,P

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

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

Tracer Measurements

The purpose of the tracer measurements was to collect data to evaluate atmospheric dispersion models in and around urban areas, indoor dispersion and interior/exterior exchange rates. Traditional dispersion experiments (e.g Allwine et al., 2002) typically deployed samplers in arcs at fixed distances downwind from a release point, where the models being evaluated were Lagrangian particle models or Gaussian based plume or puff models,. However, as using computational fluid dynamics (CFD) models for urban dispersion becomes feasible, the need for a more grid-oriented deployment became apparent. Our approach was a hybrid deployment strategy, using a trapezoidal grid within the CBD, with arcs 1, 2 and 4 km downwind from the tracer release point (See Figure xx).

The SF6 tracer was sampled using 215 tracer bag samplers, 25 fast-response tracer analyzers, and one 5-level tracer profiling system. The bag samplers consisted of 12 to 15 bags per sampler, where the beginning and ending time of each bag was programmable for sampling periods of 5 to 15 minutes. The samplers were deployed at predetermined

locations prior to the release and collected after the last release. Once the samplers were collected, they were transported to the laboratory for analysis. After the analysis, the bags were purged and filled with "zero" air (pure oxygen) up to 3 times before redeployment.

Two types of fast-response tracer analyzers were deployed during the IOPs. Infrared spectrometers, which measure the SF6 infrared absorption as air is pumped through the unit, were used in the near-field (less than 100m) to the release point. Electron Capture Devices (ECD) have a lower limit of detection than IR spectrometers, making them more useful farther from the source. The NOAA/FRD deployed 15 ECDs at distances of 100-500 meters from the release location.

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

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

The data from the field experiment are archived at the Dugway Proving Grounds. Access to the data archive is open for general use. To establish permission for access, go to https://ju2003-dpg.dpg.army.mil.

The meteorological conditions during the July 2003 study period are briefly summarized in Table 3. The period of each IOP is identified showing the wind directions from primarily the SSW through SSE directions during the IOPs. The release locations and "indoor study" IOPs are also identified in Figure 4. The four buildings studied as part of the indoor component of Joint Urban 2003 were located near the intersections of Park & Broadway and McGee & Harvey. During indoor IOPs the release location was chosen such that the tracer plume would move in the direction of the indoor study buildings based on the forecast wind directions.

Table 3: A brief summary of the IOPs during JU2003

IOP	Date (2003), Time (CST)	Release	Comments	Meteorology
1	6/29 0800-1400	Day, Westin	Aborted before last release due to wind shift.	Convection to the north early, stationary front in KS

				Wind more SW than forecast
2	7/02 0800-1600	Day, Westin		Hurricane Bill, Wind more SW than forecast, weak PGF, with confluence zone over OK
3	7/07 0800-1600	Day, Botanical		CF along the NE, KS border, SW winds forecast and observed
4	7/09 0800-1600	Day, Botanical	Indoor sampling	Low in east NE with weak CF to eastern CO. Cold front approaching SW winds forecast and observed.
5	7/13 0800-1600	Day, Botanical	Indoor sampling	Stationary front along KS, OK border, some convection in west Ok. Weaker winds, SSE to SW
6	7/16 0800-1600	Day, Botanical	Indoor sampling	Stationary front in KS, S flow over OK
7	7/18-7/19 2200-0600	Night, Botanical	Indoor sampling	Stationary front in NE, Mesoscale low appears to be forming on NE OK. S winds forecast and observed
8	7/24 2200-0600	Night, Westin		Lee trough developing to W. Winds shifted SW to SE in time for IOP, as forecast
9	7/26 2200-0600	Night, Park	Urban Canyon experiment	Continued lee troughing, Forecast winds from S, observed varying SSE to SSW
10	7/28 2000-0300	Night, Park	Urban Canyon experiment Aborted before last release due to wind shift.	Cold Front E-W through KS approaching, S winds during IOP.

Lawrence Livermore National Laboratory operations

During the outdoor IOPs, LLNL deployed integrated SF6 samplers, knows as the blue boxes, as well as real-time analyzers that detected the presence of SF6 by analyzing

infrared absorption. In addition, meteorological instruments were deployed continuously during the entire month. Most notable, a "tower crane" was constructed at the northwestern edge of the CBD, with 8 levels where sonic anemometers were deployed to observe the ambient wind at 10Hz. Sampling at 10Hz allows calculation of the mean wind, but also the turbulent intensity of the wind. LLNL also deployed surface energy balance equipment on the University of Oklahoma tower on the north side of Park Avenue, about mid-block between Broadway and Robinson.

The blue boxes were deployed by LLNL personnel in the hours immediately preceding a release of SF6. Between IOPs the blue boxes were serviced and stored at the DEC building. Servicing included programming the microprocessors that control the valves, charging batteries, and general maintenance. During deployment the boxes were placed at street level and on rooftops, generally in pairs. After the releases and the termination of the IOPs, the bags were collected and taken to the laboratory in the University's Health Science Center. The gas chromatograph was used to measure the concentration of SF6. The GC was calibrated using industry standards.

The following contains the information needed to read the Blue-box files that can be retrieved from the https://ju2003-dpg.dpg.mil website

Variables :

Column 1 - Julian Date - The number of days since the beginning of the year. The first four digits represent the year, with the last three digits representing the number of days since the start of the year. (ex. 1st January 2002 has a Julian Data of 2002001)
Column 2 - The time in UTC displayed as hours:minutes:seconds.csec
Column 3 - Location of sample
Column 4 - UTM Northing in meters
Column 5 - UTM Easting in meters
Column 6 - Elevation in meters above the street level
Column 7 - Length of sample collection (s)
Column 8 - Average SF6 concentration in parts per billion by volume
Column 9 - QC Flag

QC Flags :

0 – Good Data
1 – Timing Problem

The MIRAN IR spectrometers were deployed in the near-field of the release to measure the concentration, including fluctuations, at rates approaching 1Hz. The technique is to measure the IR absorption as the ambient air is pulled through a mirrored chamber inside the instrument. For the outdoors deployment external pumps powered by car batteries were used to force air through the instrument, effectively increasing the sampling rate. Grab samples of the exhaust air were taken and analyzed in the laboratory for QC purposes and for adjusting the zero drift in the instrument.

The following contains the information needed to read the Miran files that can be retrieved from the https://ju2003-dpg.dpg.mil website

Variables :

Column 1 - Julian Date - The number of days since the beginning of the year. The first four digits represent the year, with the last three digits representing the number of days since the start of the year. (ex. 1st January 2002 has a Julian Data of 2002001)
Column 2 - Time - The UTC displayed as hours:minutes:seconds.csec
Column 3 - SF6 Concentration (ppb)
Column 4 - QC Flag

QC Flags :

0 = Valid Data
5 = Missing data; data fields are represented by a blank space
6 = Out of range; data fields are represented by -6999

A construction crane was leased as a portable tower for deploying sonic anemometers. The boom of the crane was 100 meters long and was deployed at an angle of 70 degrees, leaving a 94 meter vertical stretch to the ground. Two half-inch cables, separated at top and bottom hung from the top of the crane and were kept under 5000 lbs of tension. Unistrut rungs were hung from cable to cable at 7 to 14 meters spacing, presenting a ladder like structure. Sonic anemometers were positioned on the unistrut rungs at the levels 7.8, 14.6, 21.5, 28.3, 42.5, 55.8, 69.7 and 83.2 meters above ground.

The following contains the information needed to read the 10-minute average files that can be retrieved from the https://ju2003-dpg.dpg.mil website. The 10Hz data is also available.

Variables :

Column 1 - Julian Date - The number of days since the beginning of the year. The first four digits represent the year, with the last three digits representing the number of days since the start of the year. (ex. 1st January 2002 has a Julian Data of 2002001)
Column 2 - The time in UTC displayed as hours:minutes:seconds.csec
Column 3 - Num
Column 4 - Mean U component of wind velocity [m/s]
Column 5 - Mean V component of wind velocity [m/s]
Column 6 - Mean W component of wind velocity [m/s]
Column 7 - Temperature [deg C]
Column 8 - WSS
Column 9 - WSC
Column 10 - Wind direction
Column 11 - ST
Column 12 - u'u'
Column 13 - u'v'
Column 14 - u'w'
Column 15 - u'T'
Column 16 - v'v'
Column 17 - v'w'

Column 18 - v'T'
Column 19 - w'w'

QC Flags :
8 - data not quality controlled

The locations of blue boxes and missing data information from the blue boxes are included in the following tables. Each table contains a descriptor of the site location, which boxes were deployed at each site, the number of sample that are missing at each site (30 total expected, except for IOP01 and IOP10, where 21 and 20 were expected), the (x,y) coordinates of samplers and the height AGL.

	Descriptor	A-Box	B-Box	Number missing	X	Y	Height (AGL)
IOP01	Convention Center Ground	8	36	0	781	777	1
	Convention Center 2nd Level	13	30	0	781	777	6
	Sheridan& Broadway NW	19	32	0	767.4	799.4	1
	Rennaissance NW	10	35	0	795.6	863.6	1
	Westin Ground	21	25	0	766	860	1
	Westin Roof	15	38	0	766	860	14
	Broadway & Main SE	7	39	0	795	913	1
	Broadway & Main SW	1	41	0	773.1	909.1	1
	Main ST Median	23	24	0	738	921.8	1
	Broadway & Main NE	20	46	0	803.8	946.5	1
	Broadway & Park, SW	17	37	12	766.9	1024.8	1
	100 Park Ave, Roof	12	34	0	766.9	1024.8	48
	Bank One Building Ground	14	40	0	805	965	1
	Main Street Parking Ground	22	44	0	730.1	940	1
	Main St Parking Roof	6	45	0	730.1	940	26
	Century Center Parking Ground	4	43	4	689.8	913.6	1
	Century Center Parking Roof	11	26	0	689.8	913.6	18
	Robinson & Main SE	9	28	0	635.9	904.4	1
	Corporate Towers Ground	5	42	6	593.7	941.8	1
	Corporate Towers Roof	16	27	0	593.7	941.8	54
	Okland Building Ground	2	33	0	629.3	938.5	1
	Okland Building Roof	3	29	0	629.3	939.5	18

Table that specifies the location and sampler information for IOP01. The (x,y) coordinates are relative to UTM coordinates. To get to the UTM coordinate, add (634000,3925000) to the (x,y). All distances are in meters.

	Descriptor	A-Box	B-Box	Number missing	X	Y	Height (AGL)
IOP02	Convention Center Ground	8	36	5	781	777	1
	Convention Center 2nd Level	13	30	0	781	777	6
	Sheridan& Broadway NW	19	32	0	767.4	799.4	1
	Rennaissance NW	10	35	1	795.6	863.6	1
	Westin Ground	21	25	0	766	860	1
	Westin Roof	15	38	20	766	860	14
	Broadway & Main SE	7	39	0	795	913	1
	Broadway & Main SW	1	41	0	773.1	909.1	1
	Main ST Median	23	24	0	738	921.8	1
	Broadway & Main NE	20	46	12	803.8	946.5	1
	Broadway & Park, SW	17	37	0	766.9	1024.8	1
	100 Park Ave, Roof	12	34	0	766.9	1024.8	48
	Bank One Building Ground	14	40	0	805	965	1
	Main Street Parking Ground	22	44	13	730.1	940	1
	Main St Parking Roof	6	45	0	730.1	940	26
	Century Center Parking Ground	4	43	0	689.8	913.6	1
	Century Center Parking Roof	11	26	0	689.8	913.6	18
	Robinson & Main SE	9	28	0	635.9	904.4	1
	Corporate Towers Ground	5	42	15	593.7	941.8	1
	Corporate Towers Roof	16	27	0	593.7	941.8	54
	Okland Building Ground	2	33	12	629.3	938.5	1
	Okland Building Roof	3	29	1	629.3	939.5	18

Table that specifies the location and sampler information for IOP02. The (x,y) coordinates are relative to UTM coordinates. To get to the UTM coordinate, add (634000,3925000) to the (x,y). All distances are in meters.

	Descriptor	A-Box	B-Box	Number missing	X	Y	Height (AGL)
IOP03	Convention Center Ground	2	44	1	781	777	1
	Convention Center 2nd Level	22	25	24	781	777	12
	Sheridan& Broadway NW	21	30	0	767.4	799.4	1
	Sheridan&Robinson SE	16	45	0	643.8	775.7	1
	Westin Lobby Ground	13	27	0	766	860	1
	Corporate Towers Roof	20	37	9	593.7	941.8	60
	Corporate Towers Ground	14	24	0	593.7	941.8	1
	Colcord Roof	15	41	0	598.2	795	43
	Colcord Ground	23	40	0	598.2	795	1
	Broadway & Main SW	8	36	8	789.7	899	1
	Century Center Parking W-Roof	7	39	0	627.2	868.2	17
	Century Center Parking W-Ground	5	32	0	627.2	868.2	1
	Century Center Parking S-Roof	1	28	0	659.2	804.5	17
	Century Center Parking S-Ground	9	29	0	659.2	804.5	1
	Main St Parking Roof	10	26	0	730.1	940	37
	Main Street Parking Ground	6	34	0	730.1	940	1
	Robinson Plaza NE	4	33	9	595.7	919.7	1
	Robinson Plaza NW	11	35	0	553.6	913.1	1
	Robinson Plaza SE	19	42	15	592.1	858.3	1
	Robinson Plaza SW	3	43	0	547.7	852.1	1
	Robinson& Main NE	17	38	9	629.3	939.5	30
	Okland Building Roof	12	31	1	629.3	939.5	1

Table that specifies the location and sampler information for IOP03. The (x,y) coordinates are relative to UTM coordinates. To get to the UTM coordinate, add (634000,3925000) to the (x,y). All distances are in meters.

	Descriptor	A-Box	B-Box	Number missing	X	Y	Height (AGL)	
IOP08	101 Park S Street		15	33	11	731	1053	1
	101 Park S-3		20	38	0	731	1053	34
	101 Park S-4		2	26	0	731	1053	12
	101 Park S-Roof		14	25	0	731	1053	47
	Bank One Roof		11	40	1	810	965	148
	Bank One Street		7	43	0	805	965	1
	Broadway&Main NE		19	45	0	804	933	1
	Broadway&Main NW		23	32	3	768	936	1
	Broadway&Main SE		12	41	0	795	913	1
	Broadway&Main SW		10	39	3	773	909	1
	Century Parking Street		1	36	15	690	914	1
	Century Parking Top		3	30	0	690	914	18
	Coporate Tower Roof		22	27	0	594	942	54
	Corporate Tower Street		21	37	8	594	942	54
	Main Street Parking Top		4	29	0	730	940	26
	Main Street Parking Street		13	31	0	730	940	26
	Main Street Median		6	24	0	738	922	1
	OKLand Building Roof		16	44	1	629	940	18
	OKLand Building Street		5	42	2	629	940	1
	Renaissance, NW Corner		17	28	0	796	864	1
	Westin Hotel Roof		35	9	0	766	860	14
	Westin Hotel Street		8	34	0	766	860	1

Table that specifies the location and sampler information for IOP08. The (x,y) coordinates are relative to UTM coordinates. To get to the UTM coordinate, add (634000,3925000) to the (x,y). All distances are in meters.

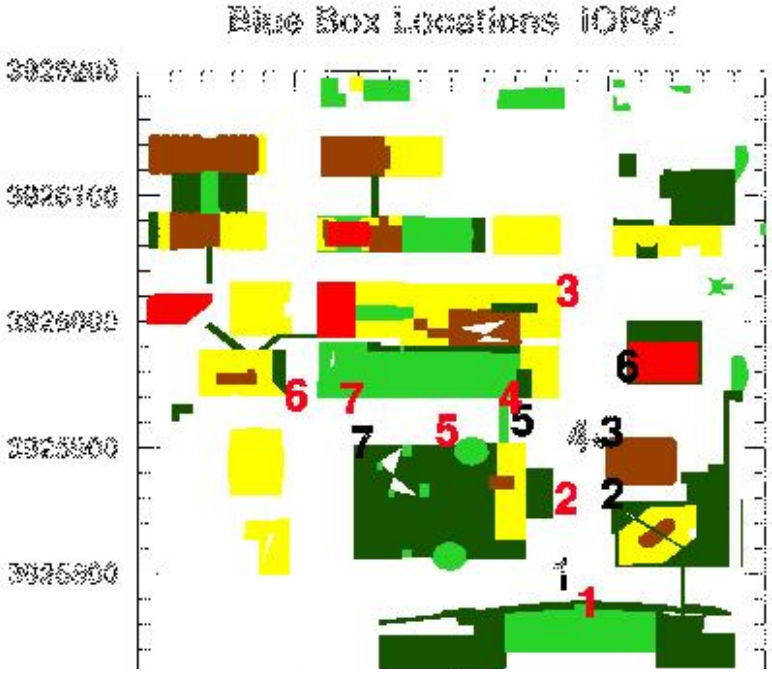
	Descriptor	A-Box	B-Box	Number missing	X	Y	Height (AGL)	
IOP09	100 Park N Roof		11	29	0	767	1025	48
	101 Park E Street		22	45	0	768	1072	1
	101 Park N Street		8	24	1	734	1088	1
	101 Park S Street		10	33	13	739	1053	1
	101 Park W Street		12	27	0	726	1072	1
	101 Park E-1		9	44	1	768	1072	35
	101 Park E-2		15	43	12	768	1072	12
	101 Park S-3		3	38	0	739	1053	34
	101 Park S-4		19	35	0	739	1053	11
	101 Park W-5		7	32	0	726	1072	34
	101 Park W-6		4	25	0	726	1072	11
	101 Park N-7		20	30	0	734	1088	11
	101 Park N-8		14	26	0	734	1088	34
	101 Park E Roof		5	41	24	768	1072	47
	101 Park N Roof		1	28	0	734	1088	47
	101 Park S Roof		21	39	0	739	1053	47
	101 Park W Roof		16	40	0	726	1072	47
	Leaderhip Square		17	37	0	588	1103	1
	Oklahoma Bank N		6	31	0	560	1170	1
	UMB Bank N		13	34	8	632	1083	1
	UMB Bank S		2	42	1	637	1055	1
	Robinson&Kerr SE		23	23	14	625	1148	1

Table that specifies the location and sampler information for IOP09. The (x,y) coordinates are relative to UTM coordinates. To get to the UTM coordinate, add (634000,3925000) to the (x,y). All distances are in meters.

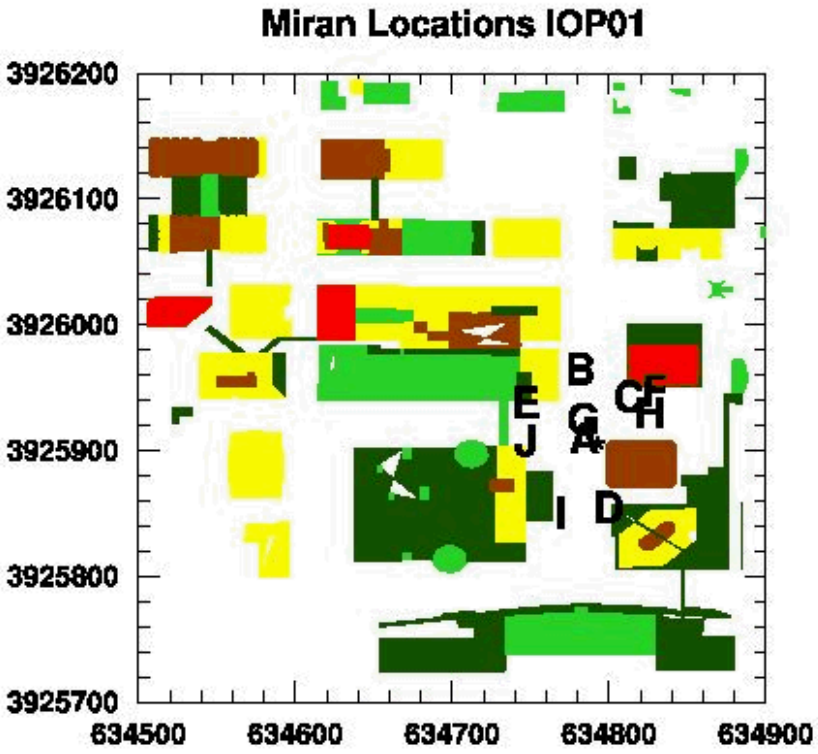
	Descriptor	A-Box	B-Box	Number missing	X	Y	Height (AGL)	
IOP10	100 Park Roof		11	29	0	767	1025	48
	100 Park N Street		22	45	0	740	1045	1
	101 Park E Street		6	31	0	768	1072	1
	101 Park N Street		17	24	0	734	1088	1
	101 Park S Street		10	37	0	739	1053	1
	101 Park W Street		8	27	0	726	1072	1
	B of A Plaza		12	34	0	726	1072	1
	Robinson & Couch SE		2	33	0	726	1072	1
	Robinson & Park NE		23	42	0	734	1088	1
	101 Park E-1		20	35	0	768	1072	35
	101 Park E-2		21	26	0	768	1072	12
	101 Park S-3		9	38	0	739	1053	34
	101 Park S-4		3	44	0	739	1053	11
	101 Park W-5		19	30	0	726	1072	34
	101 Park W-6		7	32	0	726	1072	11
	101 Park N-7		14	28	0	734	1088	11
	101 Park N-8		5	39	0	734	1088	34
	101 Park Roof-E		4	43	0	768	1072	47
	101 Park Roof-N		1	25	0	734	1088	47
	101 Park Roof-S		16	41	0	739	1053	47
	101 Park Roof-W		15	40	0	726	1072	47

Table that specifies the location and sampler information for IOP10. The (x,y) coordinates are relative to UTM coordinates. To get to the UTM coordinate, add (634000,3925000) to the (x,y). All distances are in meters.

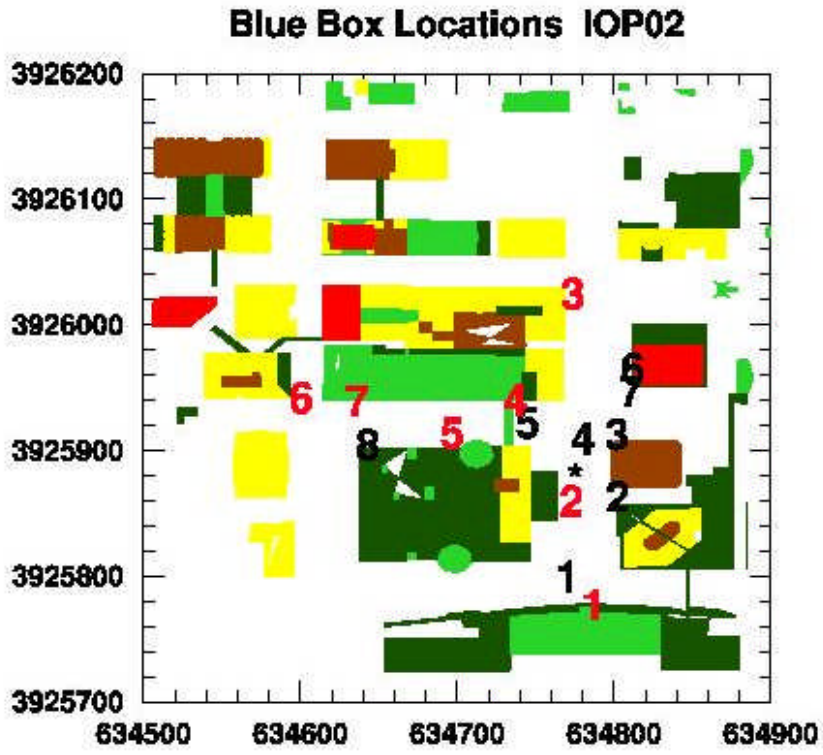
The following maps show the blue box and Miran locations for each of the IOPs. The coordinates referenced are UTM. The Miran letters refer to which unit was deployed at that location. The numbers in the Blue Box maps are arbitrary. The exact locations can be determined from the tables above.



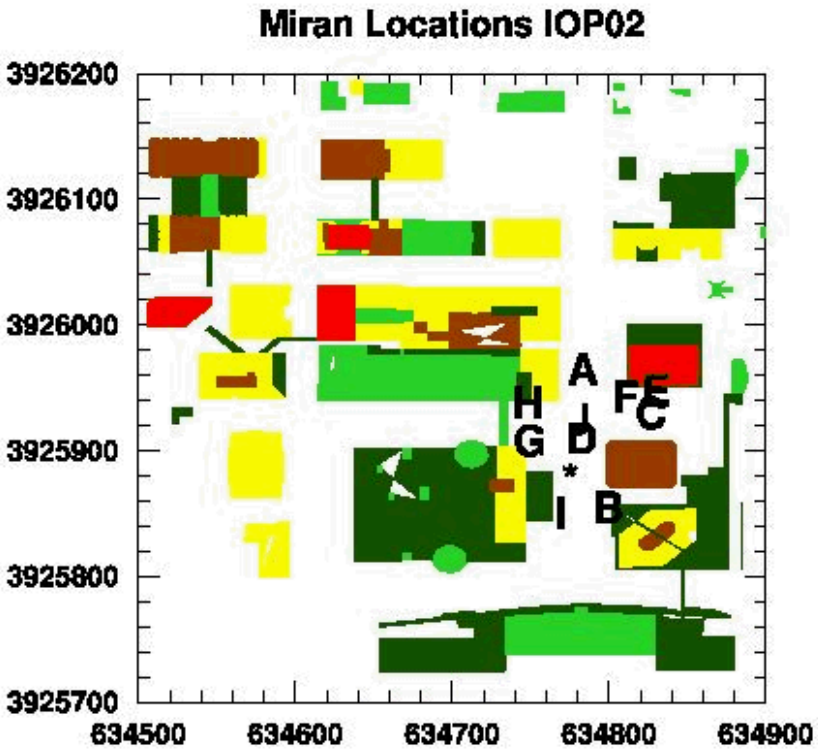
Blue Box Locations for IOP01. Black numbers are locations where ground level samplers were deployed, red numbers are where rooftop samplers were deployed along with a ground level sampler. The SF6 release point is indicated by the *.



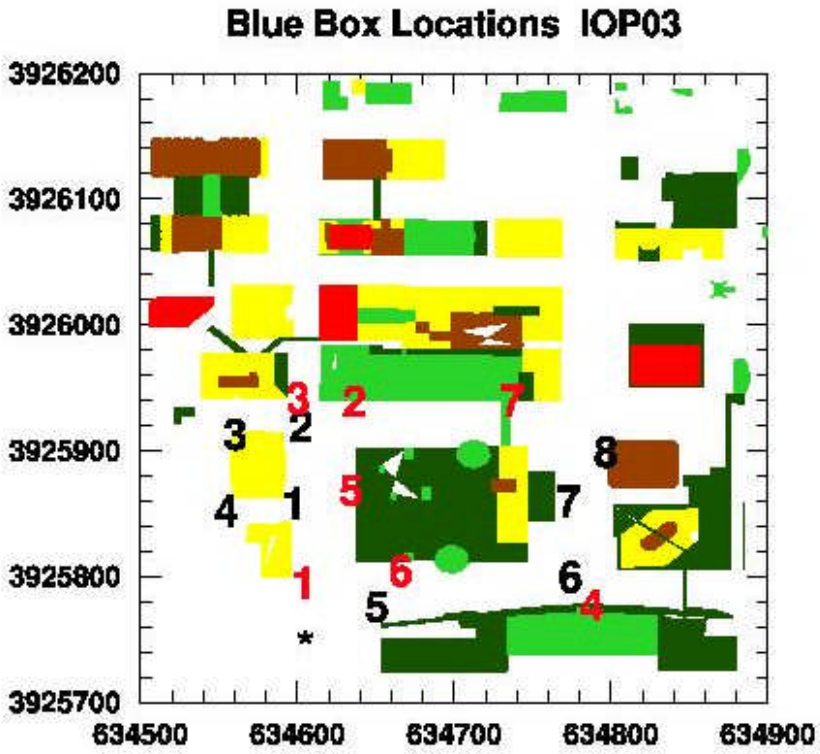
Miran locations for IOP01. The letters refer to the Miran unit at that location. The SF6 release point is indicated by the *.



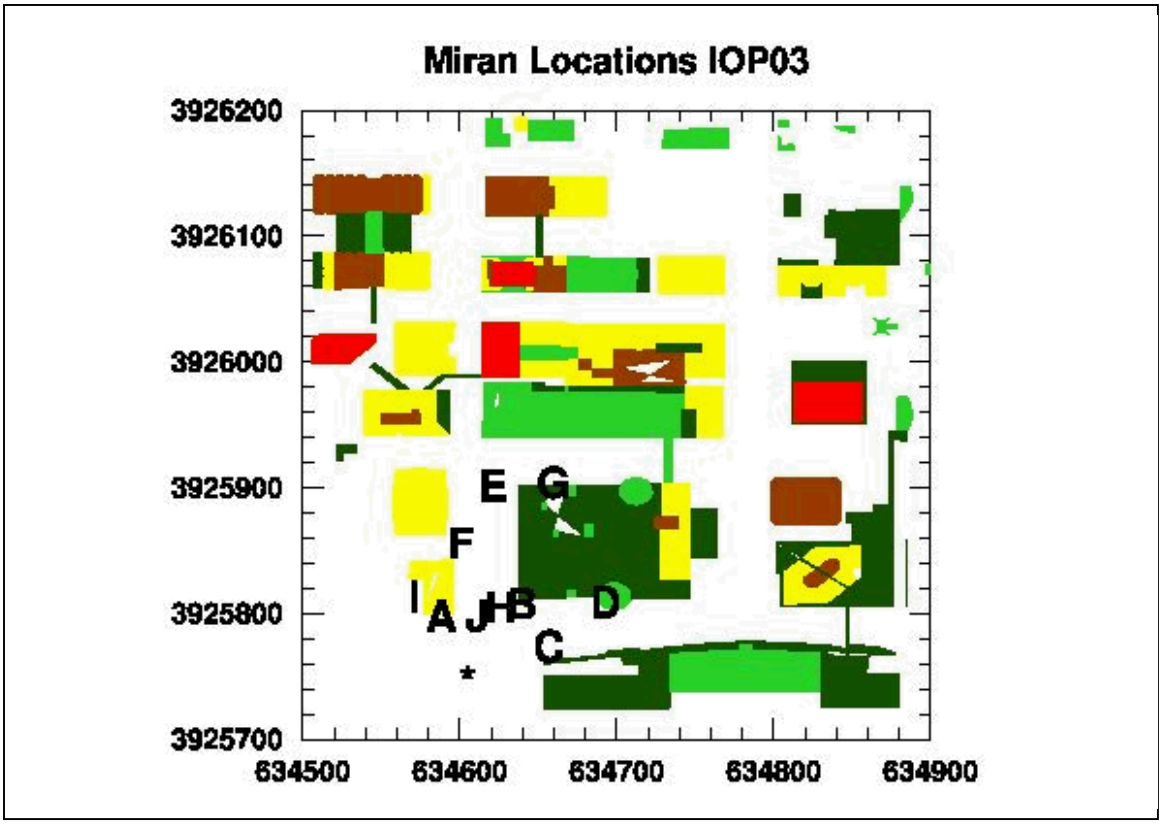
Blue Box Locations for IOP02. Black numbers are locations where ground level samplers were deployed, red numbers are where rooftop samplers were deployed along with a ground level sampler. The SF6 release point is indicated by the *.



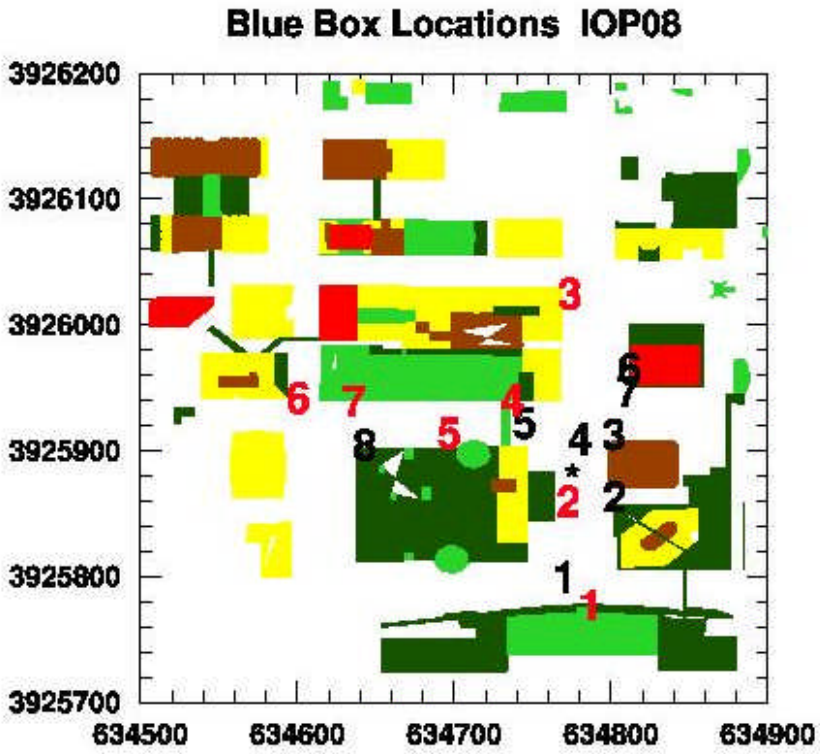
Miran locations for IOP02. The letters refer to the Miran unit at that location. The SF6 release point is indicated by the *.



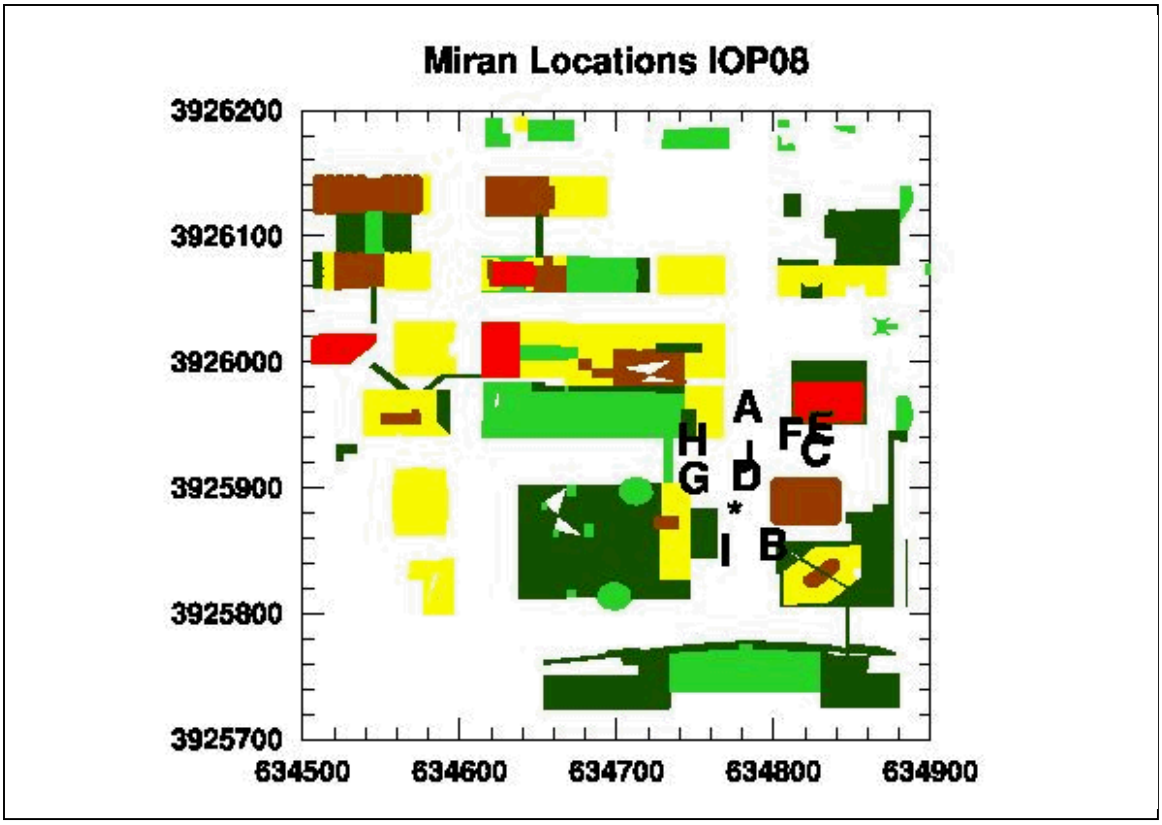
Blue Box Locations for IOP03. Black numbers are locations where ground level samplers were deployed, red numbers are where rooftop samplers were deployed along with a ground level sampler. The SF6 release point is indicated by the *.



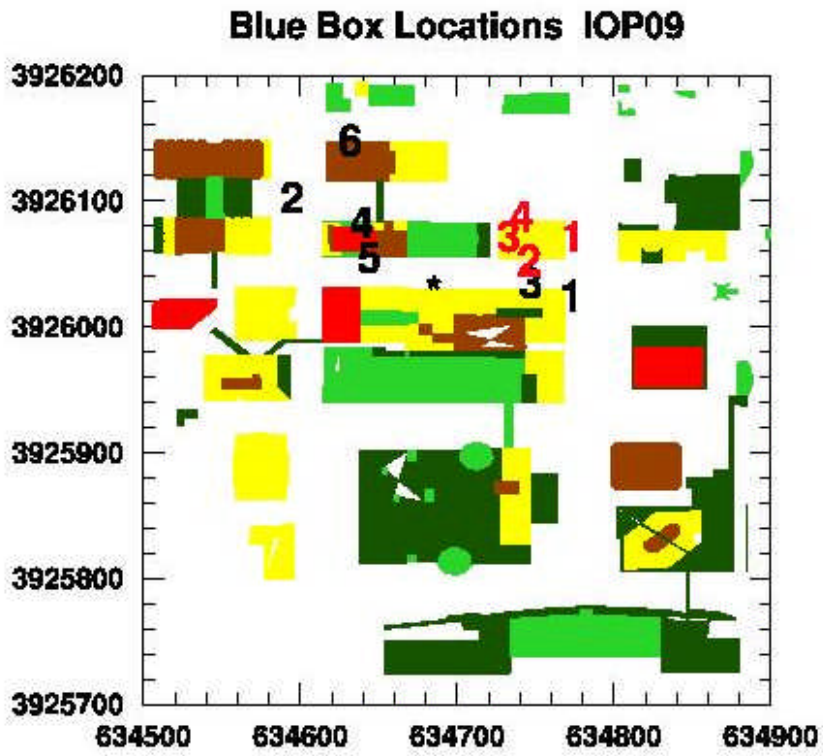
Miran locations for IOP03. The letters refer to the Miran unit at that location. The SF6 release point is indicated by the *.



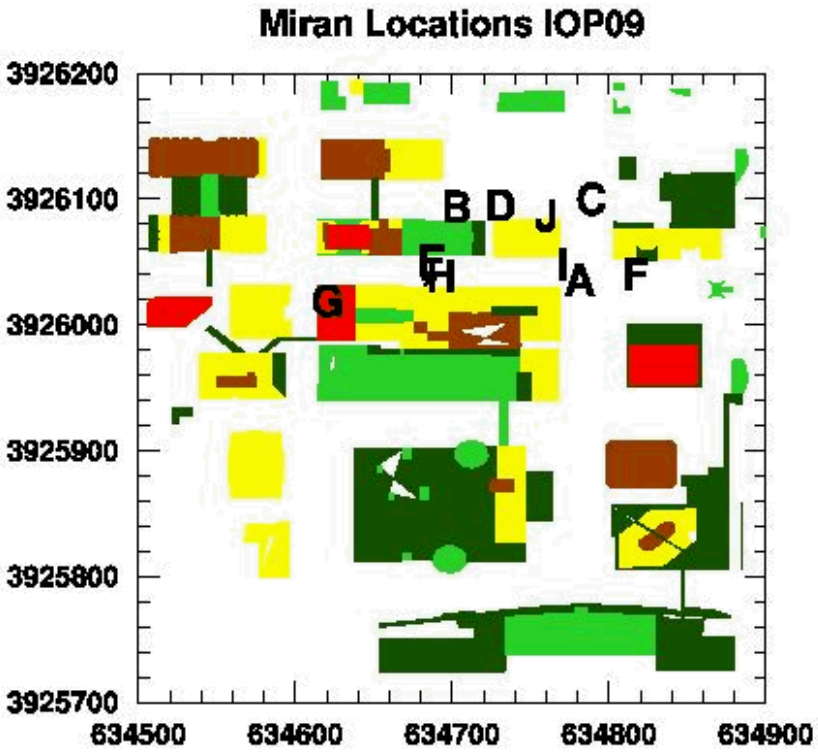
Blue Box Locations for IOP08. Black numbers are locations where ground level samplers were deployed, red numbers are where rooftop samplers were deployed along with a ground level sampler. The SF6 release point is indicated by the *.



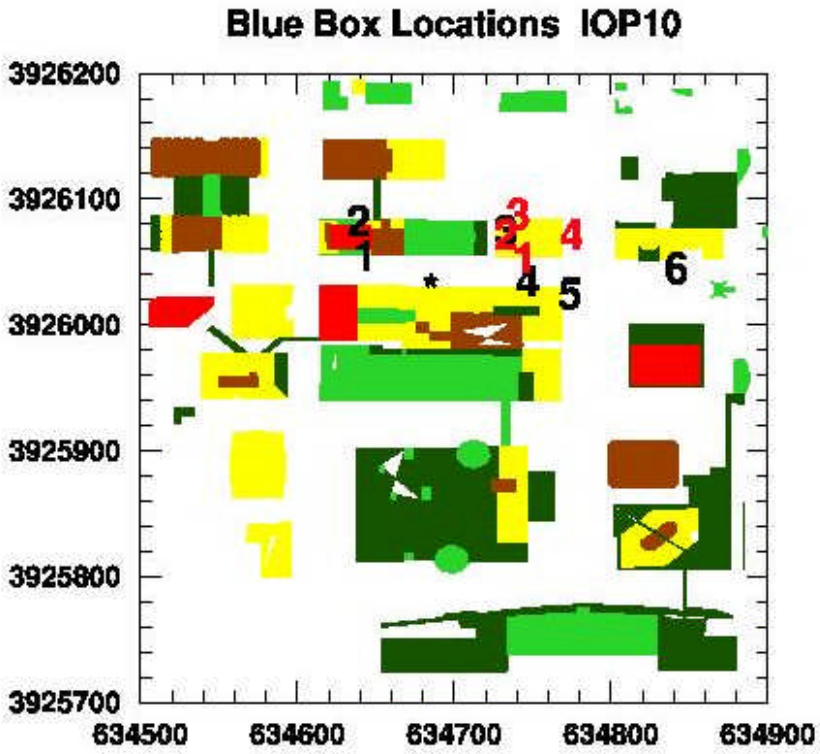
Miran locations for IOP08. The letters refer to the Miran unit at that location. The SF6 release point is indicated by the *.



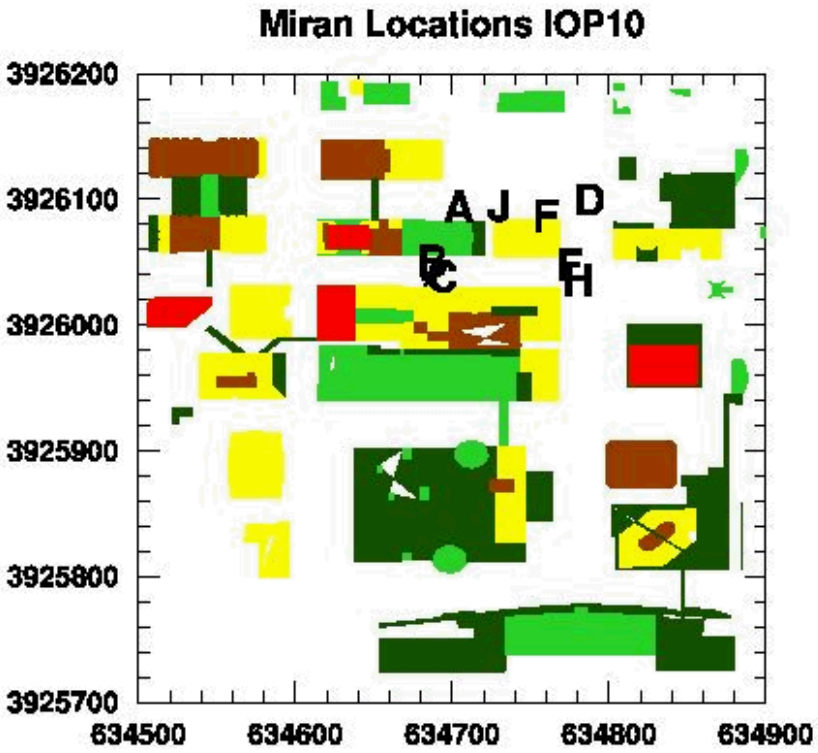
Blue Box Locations for IOP09. Black numbers are locations where ground level samplers were deployed, red numbers are where samplers were deployed in a profile along a building. The SF6 release point is indicated by the *.



Miran locations for IOP09. The letters refer to the Miran unit at that location. The SF6 release point is indicated by the *.

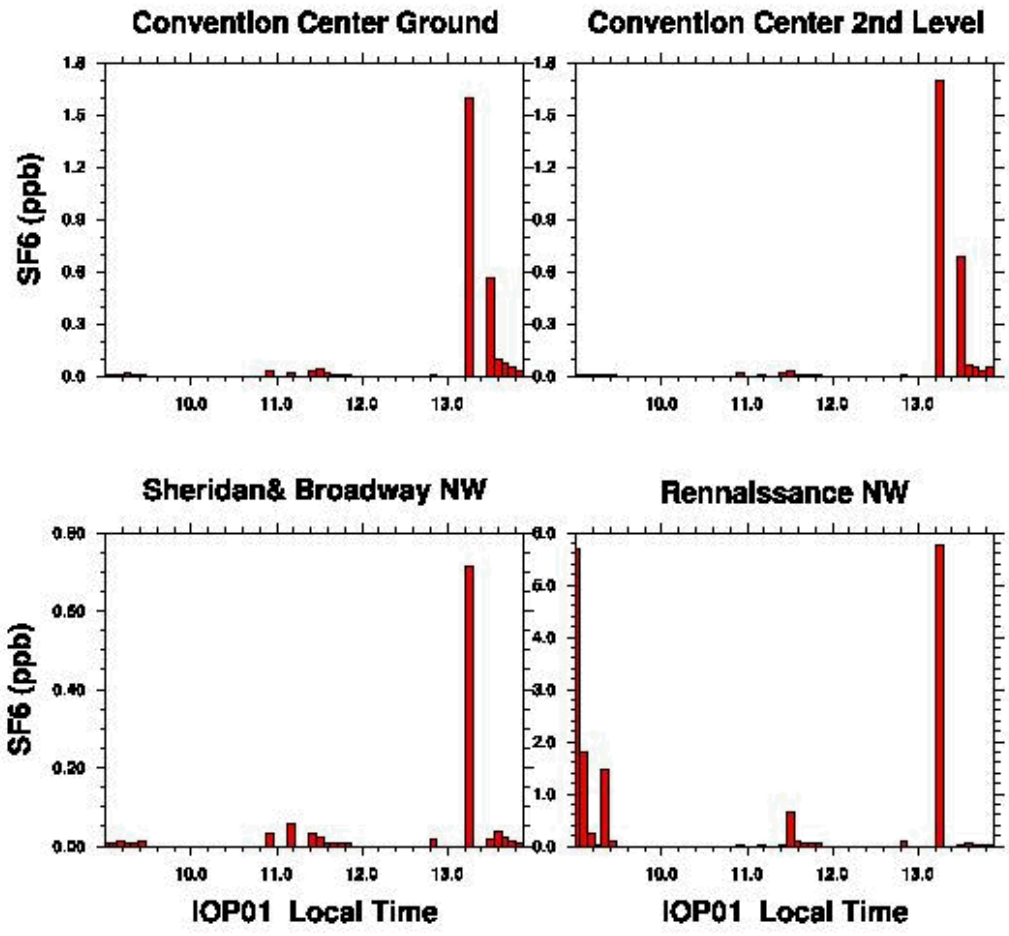


Blue Box Locations for IOP10. Black numbers are locations where ground level samplers were deployed, red numbers are where samplers were deployed in a profile along a building. The SF6 release point is indicated by the *.

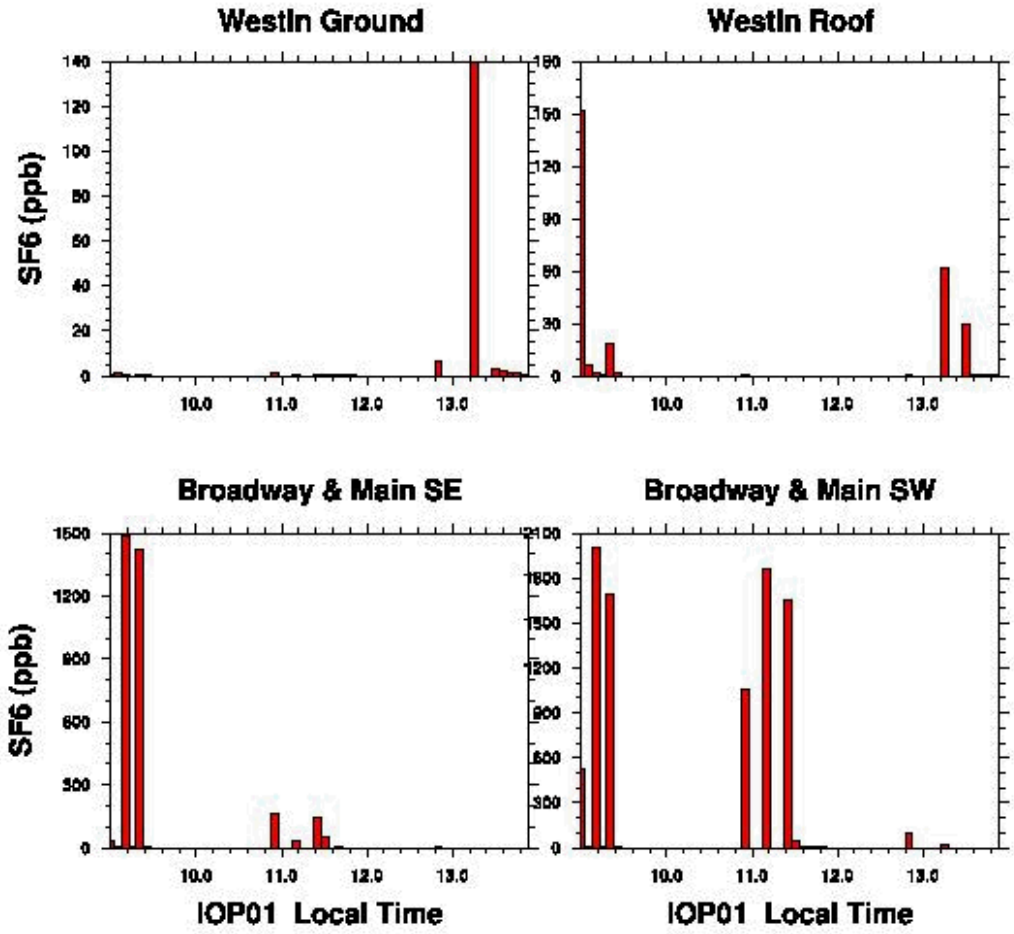


Miran locations for IOP10. The letters refer to the Miran unit at that location. The SF6 release point is indicated by the *.

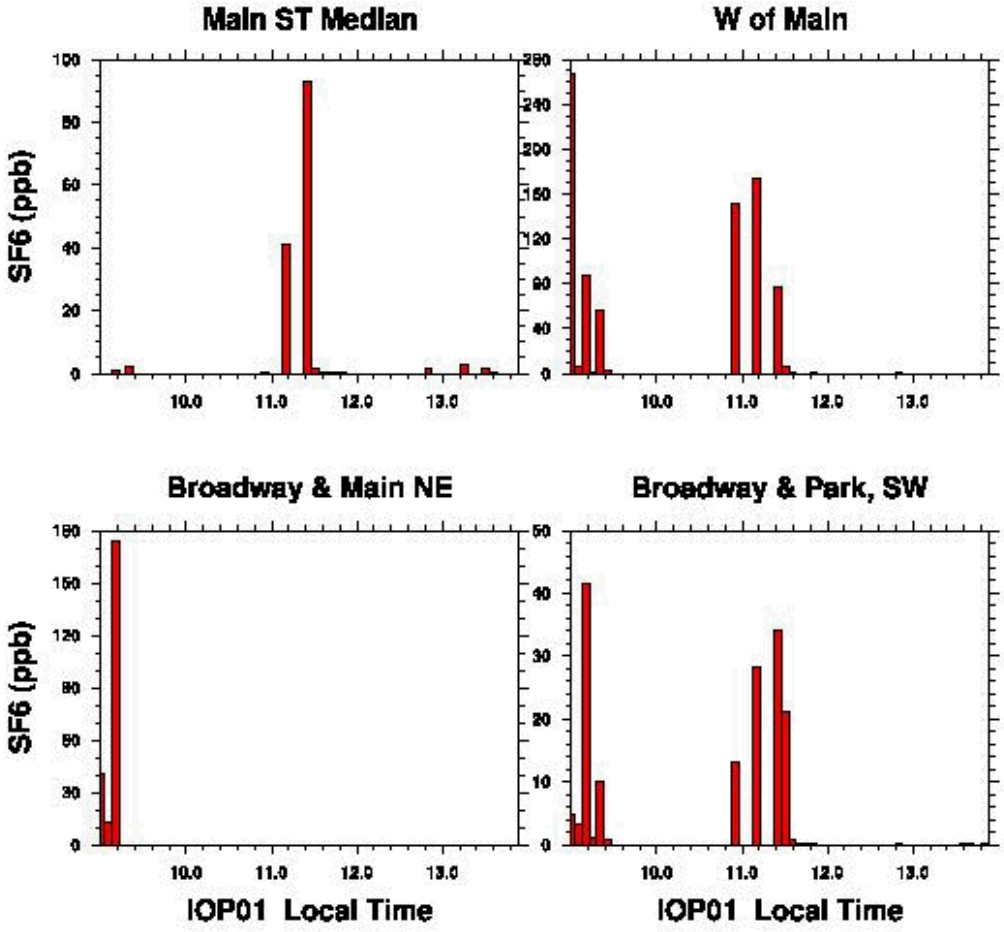
The following plots are the SF6 concentrations (ppbv) from the Blue Boxes and the Mirans for each IOP. Note the continuously changing scales.



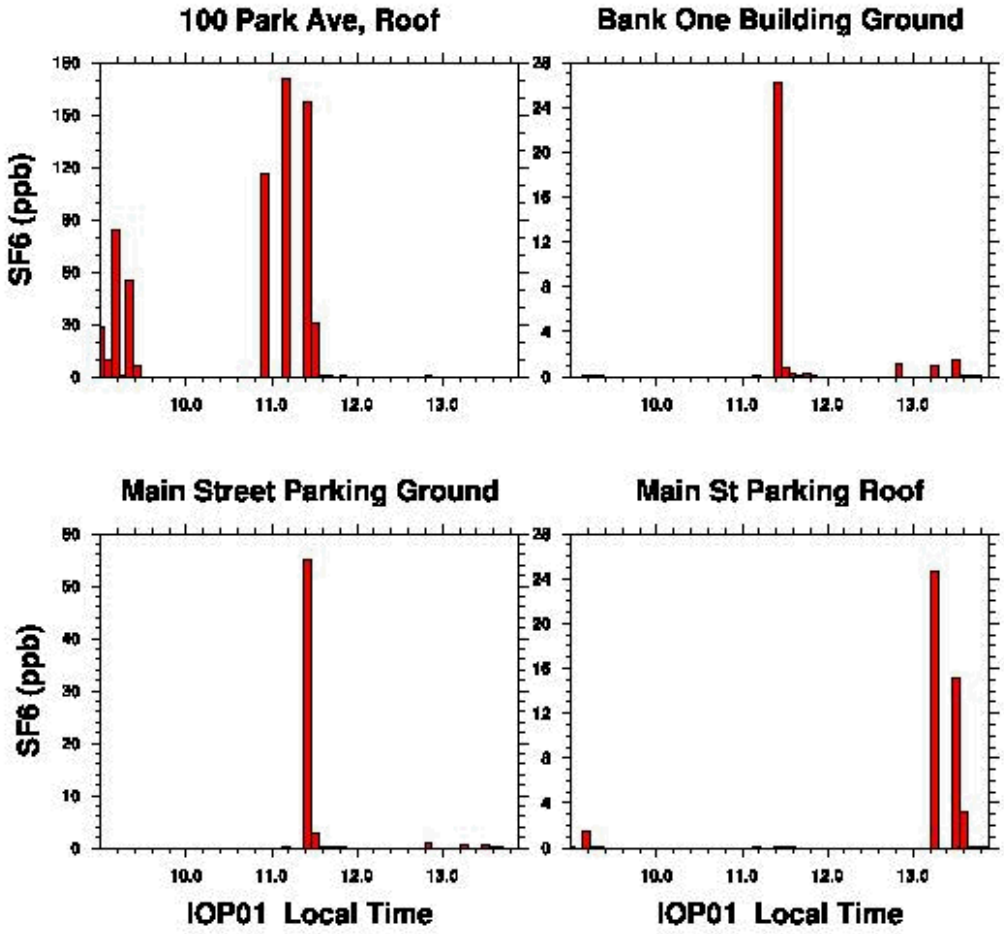
SF6 Concentration (ppbv) observed at the indicated sites during IOP01. Refer to the tables and maps for the exact locations



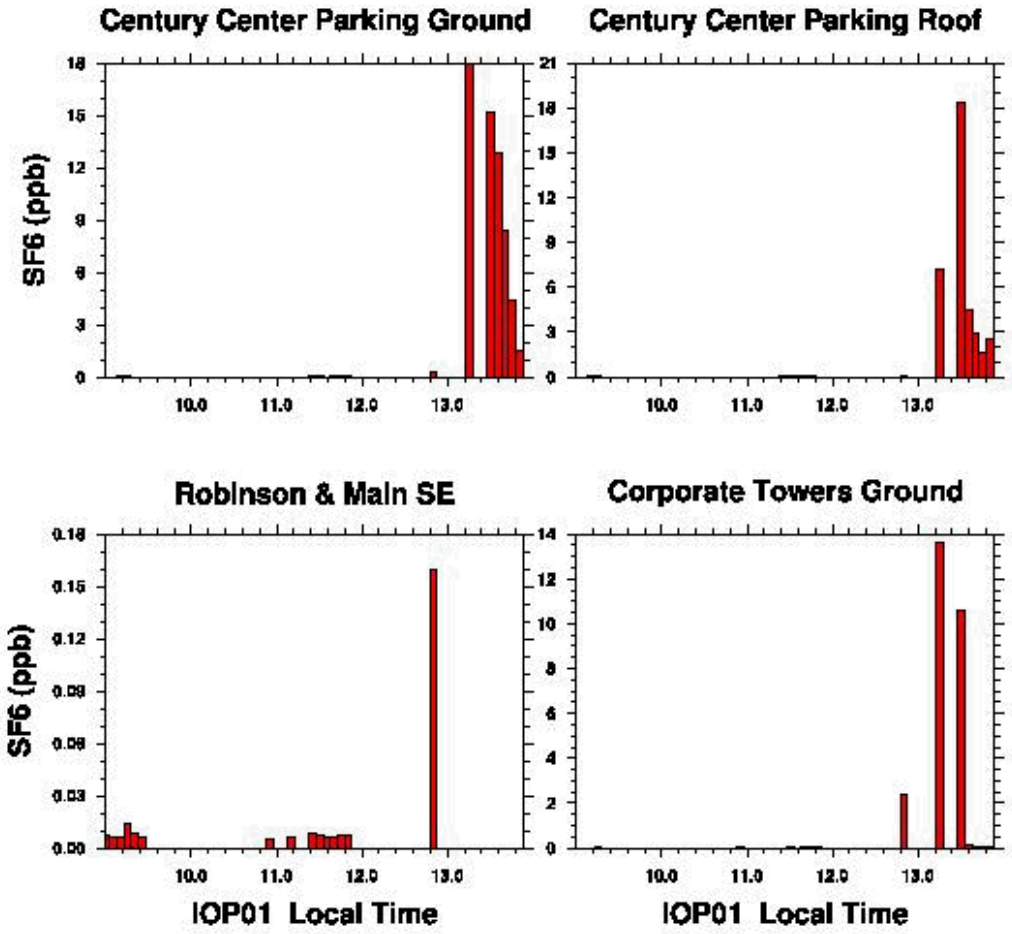
SF6 Concentration (ppbv) observed at the indicated sites during IOP01. Refer to the tables and maps for the exact locations



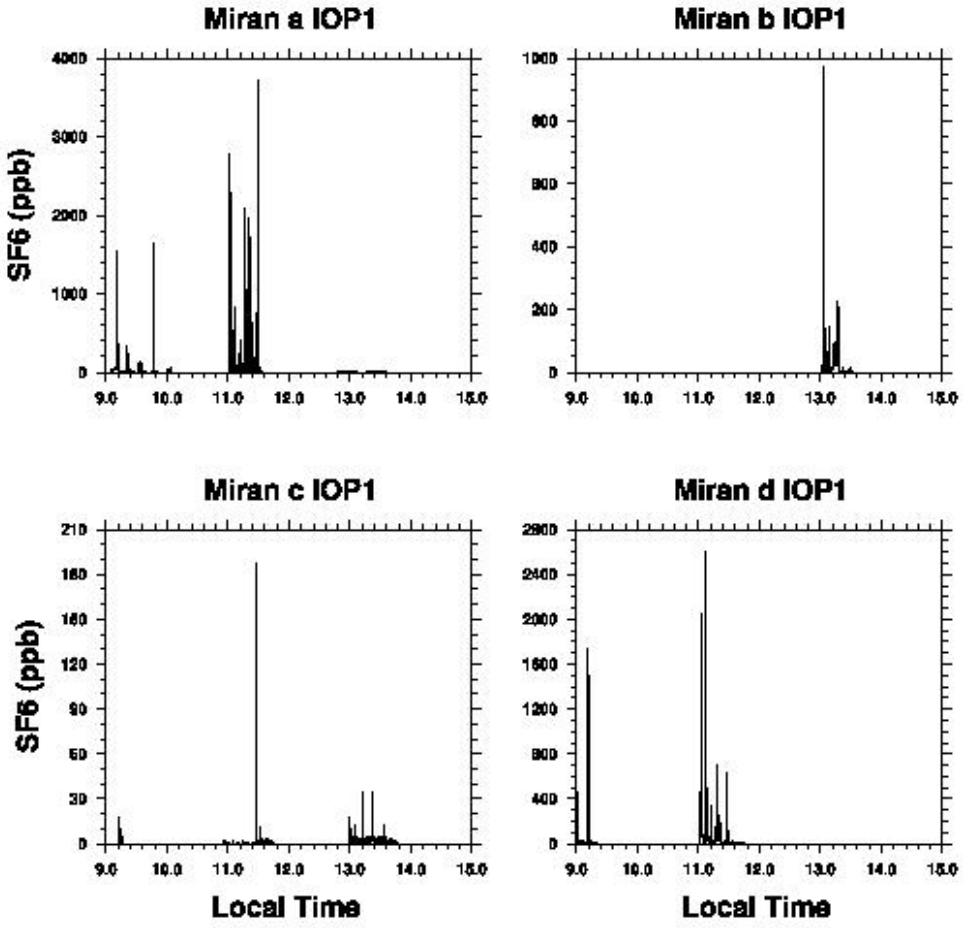
SF6 Concentration (ppbv) observed at the indicated sites during IOP01. Refer to the tables and maps for the exact locations



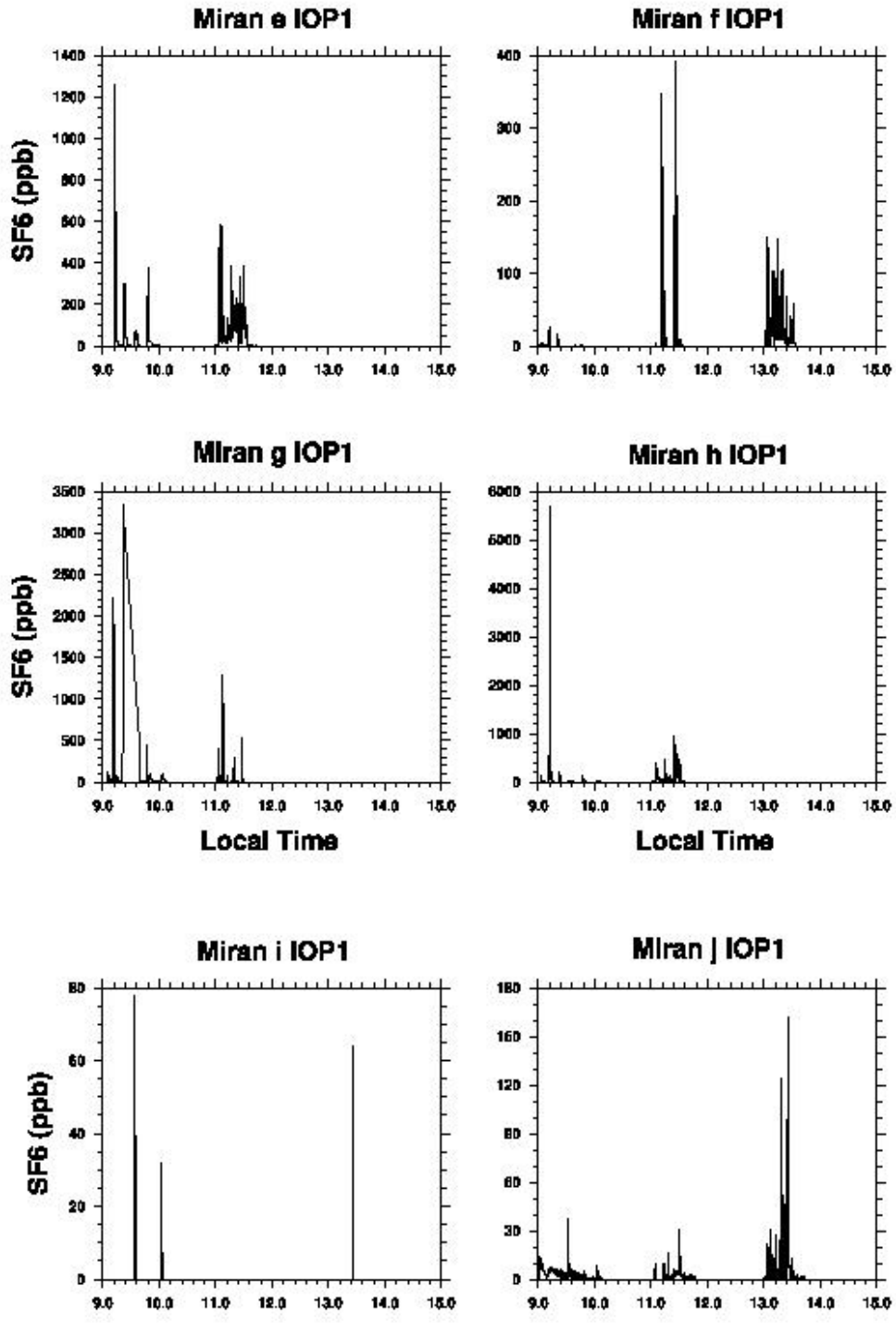
SF6 Concentration (ppbv) observed at the indicated sites during IOP01. Refer to the tables and maps for the exact locations



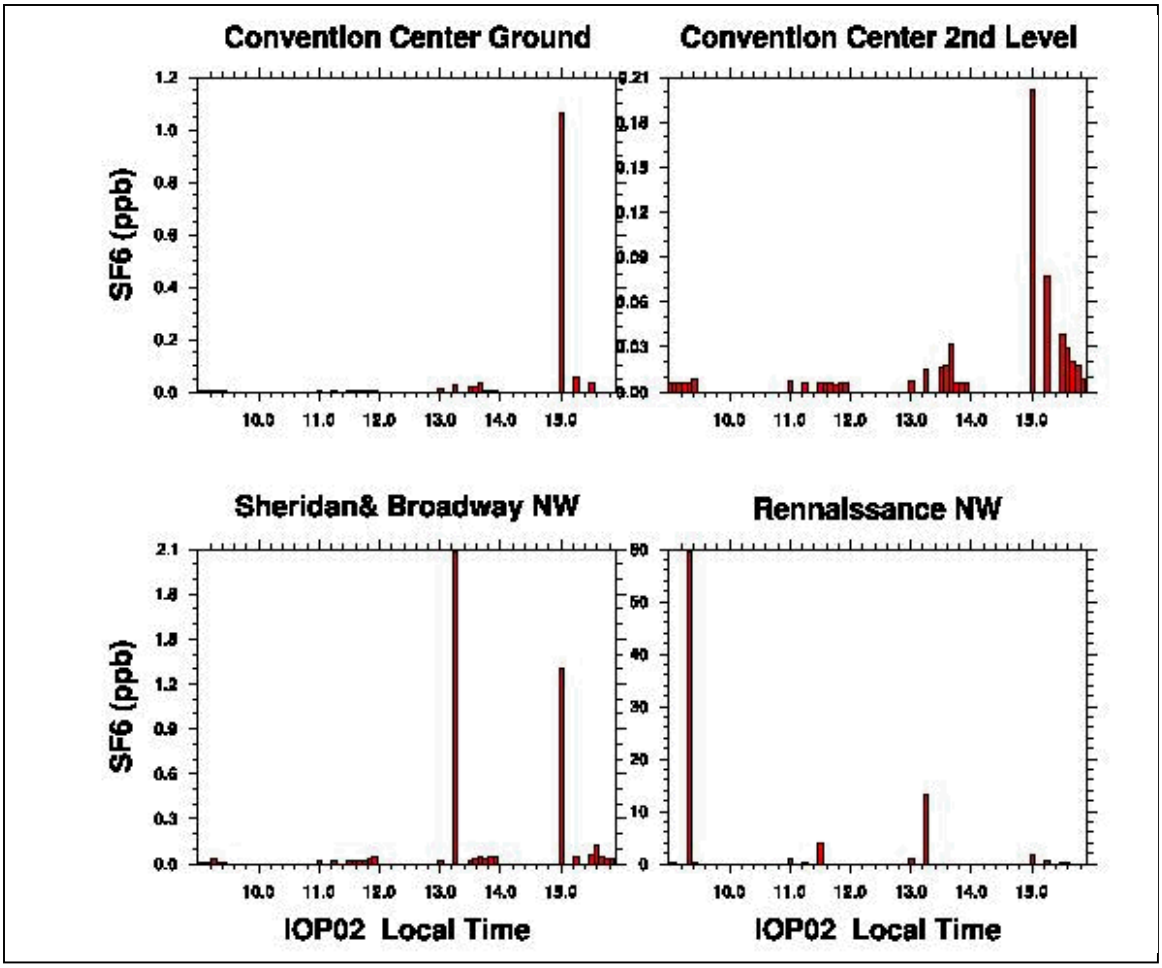
SF6 Concentration (ppbv) observed at the indicated sites during IOP01. Refer to the tables and maps for the exact locations



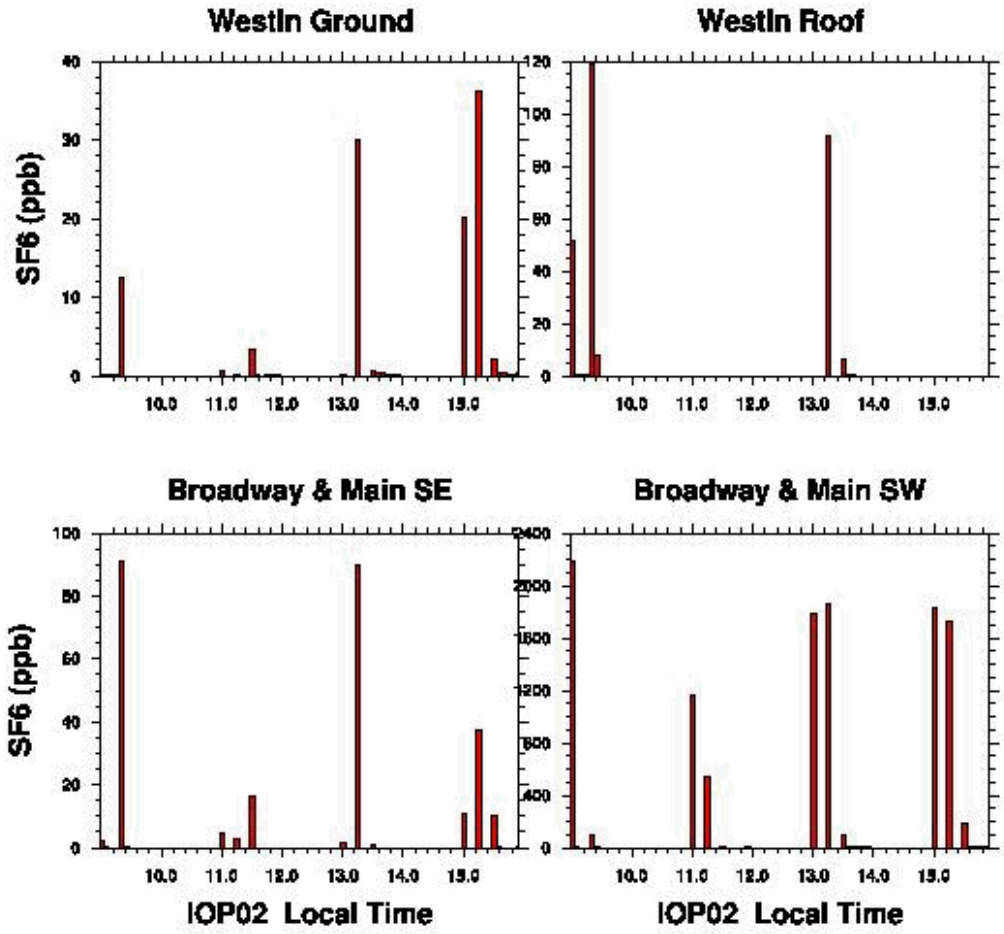
SF6 concentration for IOP01 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



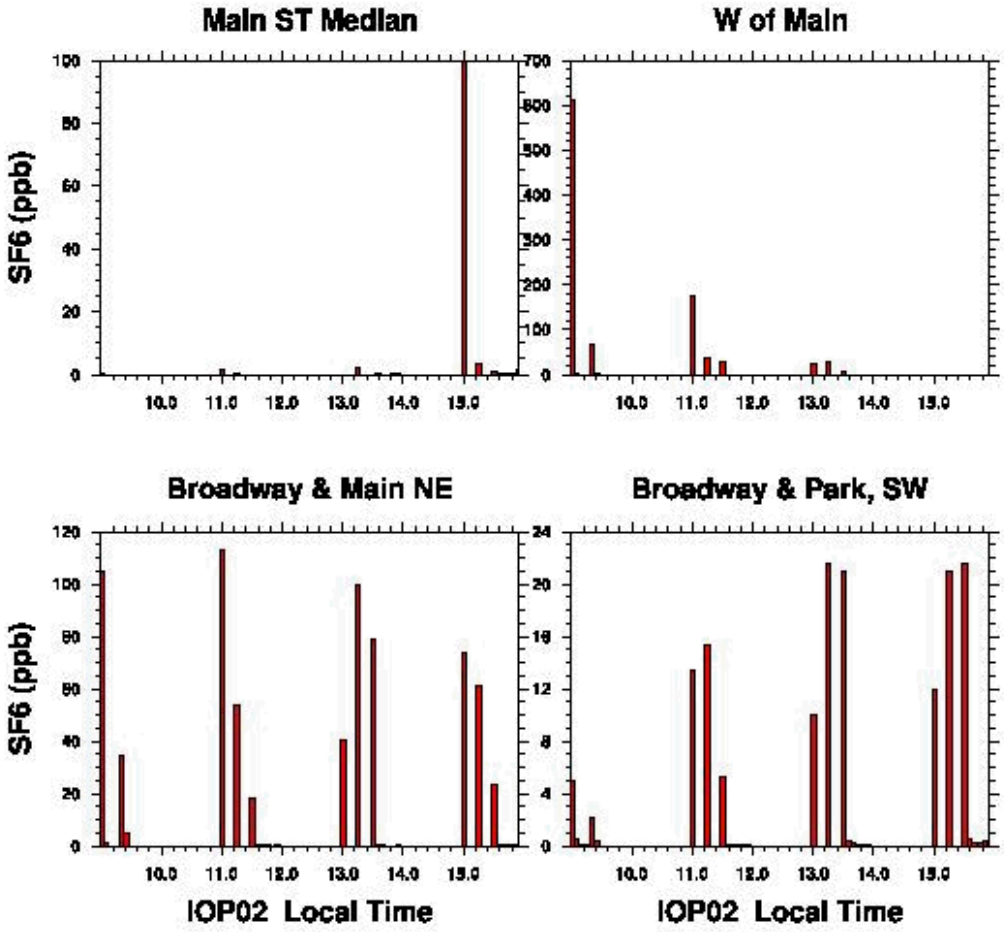
SF6 concentration for IOP01 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



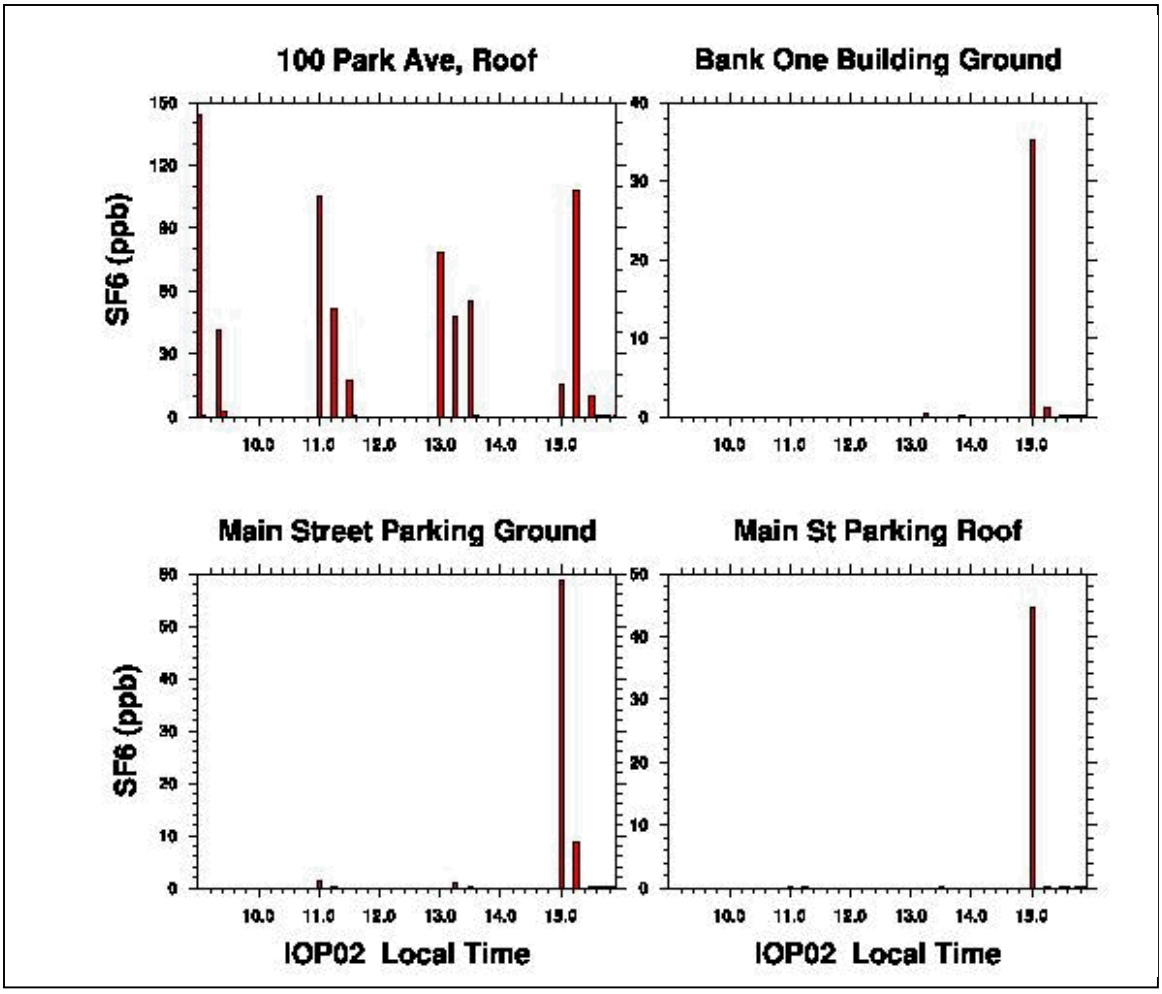
SF6 Concentration (ppbv) observed at the indicated sites during IOP02. Refer to the tables and maps for the exact locations



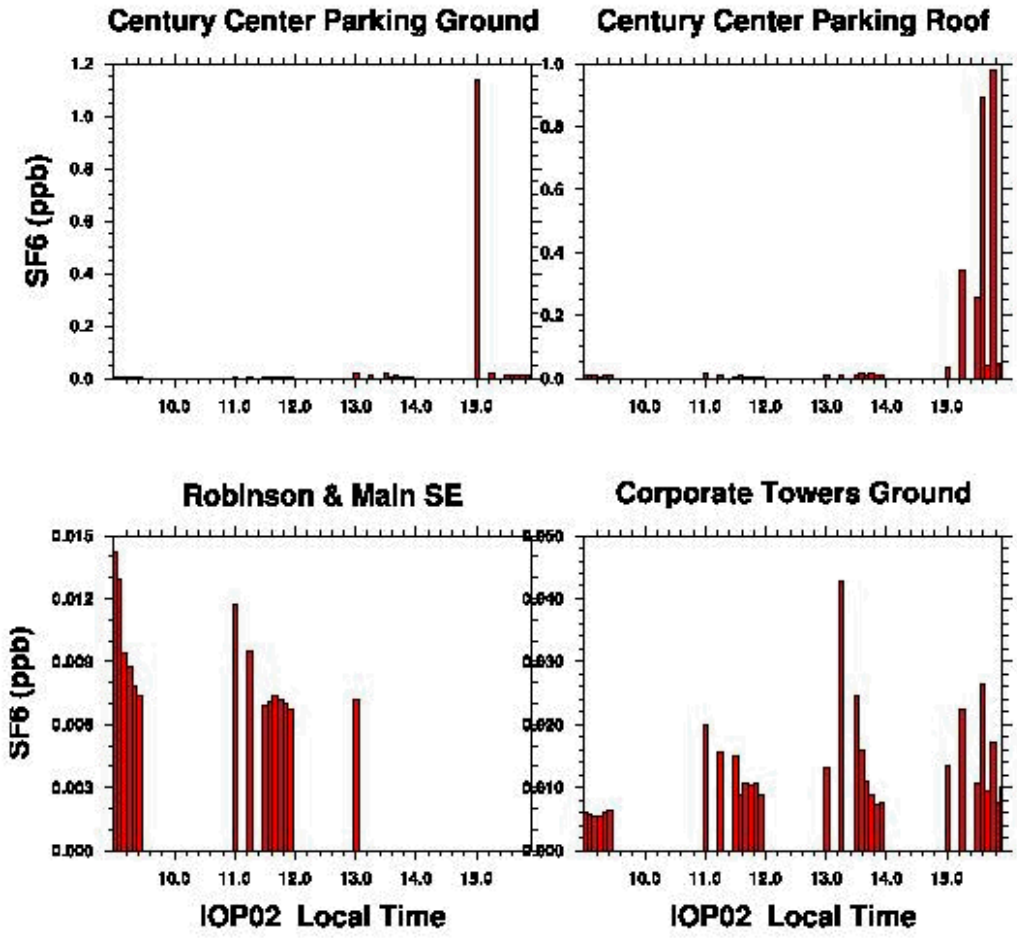
SF6 Concentration (ppbv) observed at the indicated sites during IOP02. Refer to the tables and maps for the exact locations



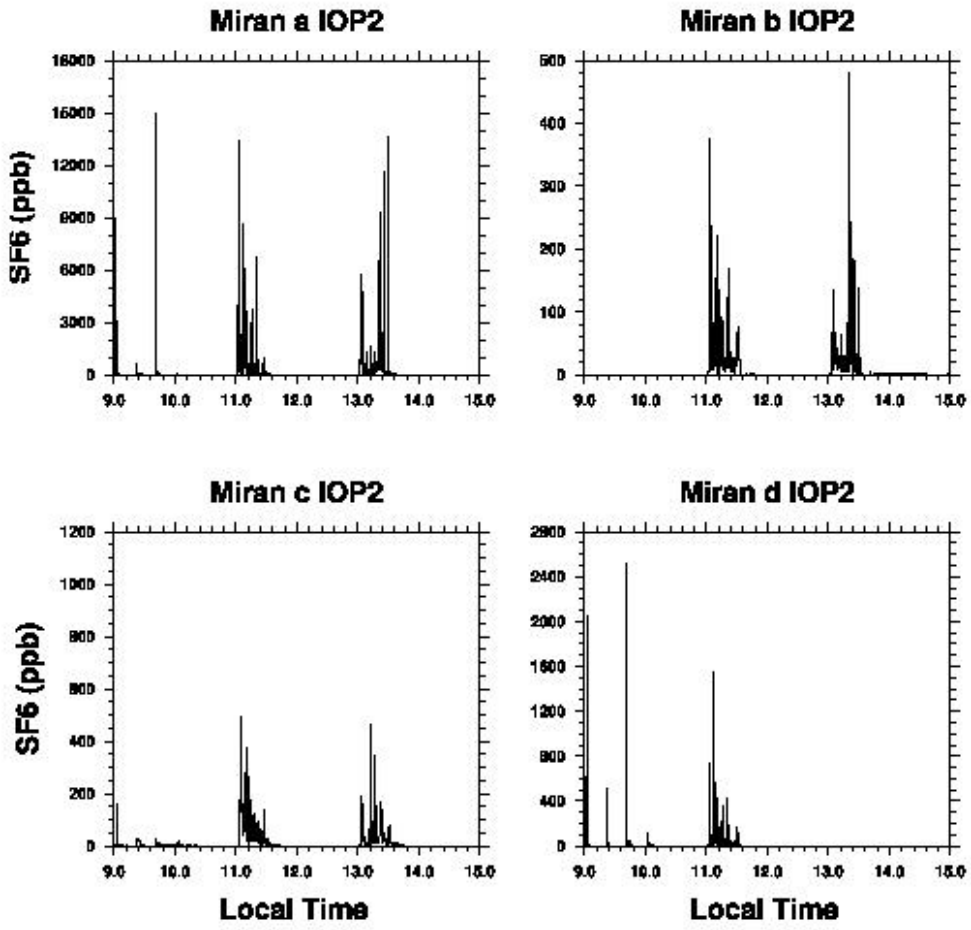
SF6 Concentration (ppbv) observed at the indicated sites during IOP02. Refer to the tables and maps for the exact locations



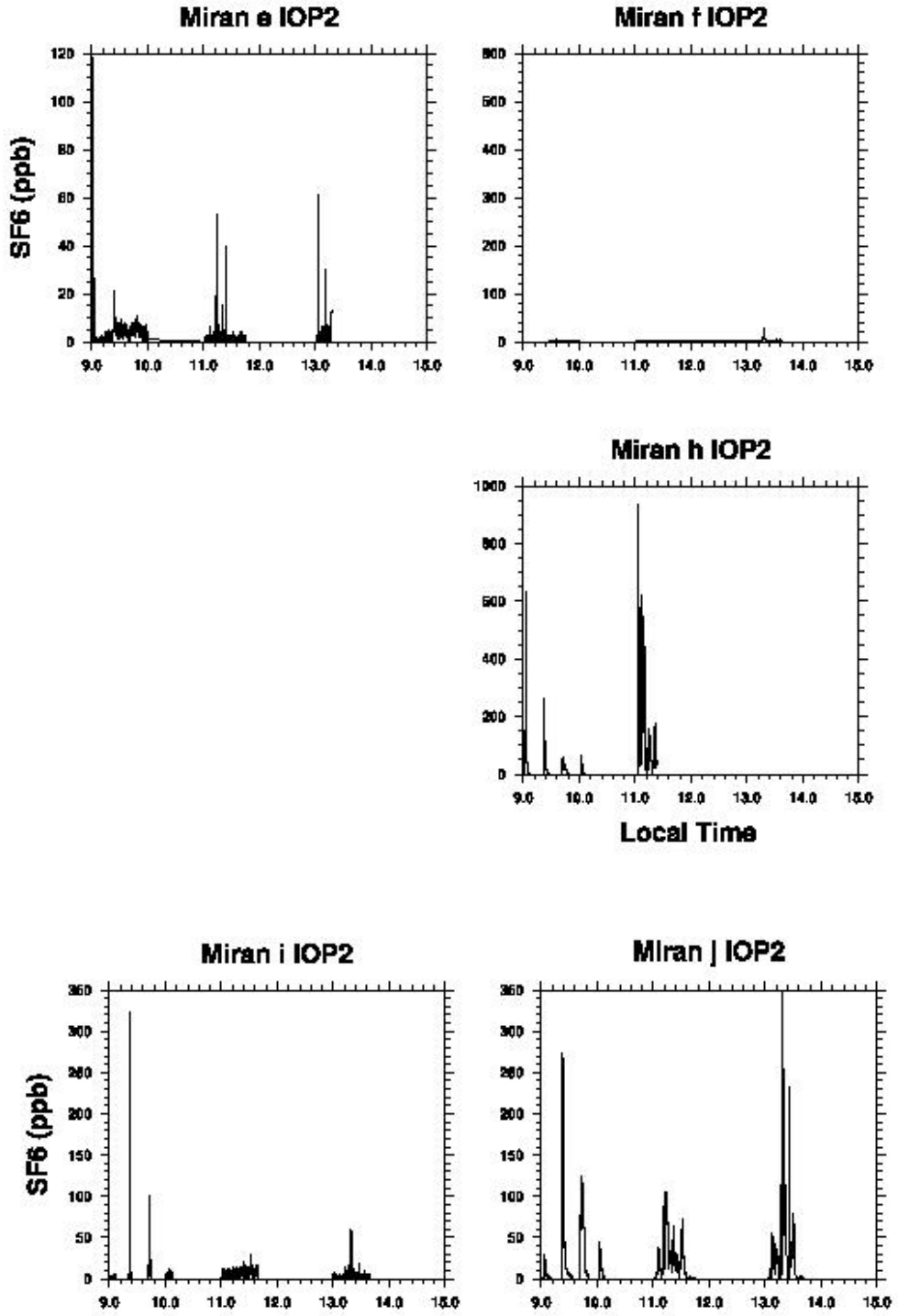
SF6 Concentration (ppbv) observed at the indicated sites during IOP02. Refer to the tables and maps for the exact locations



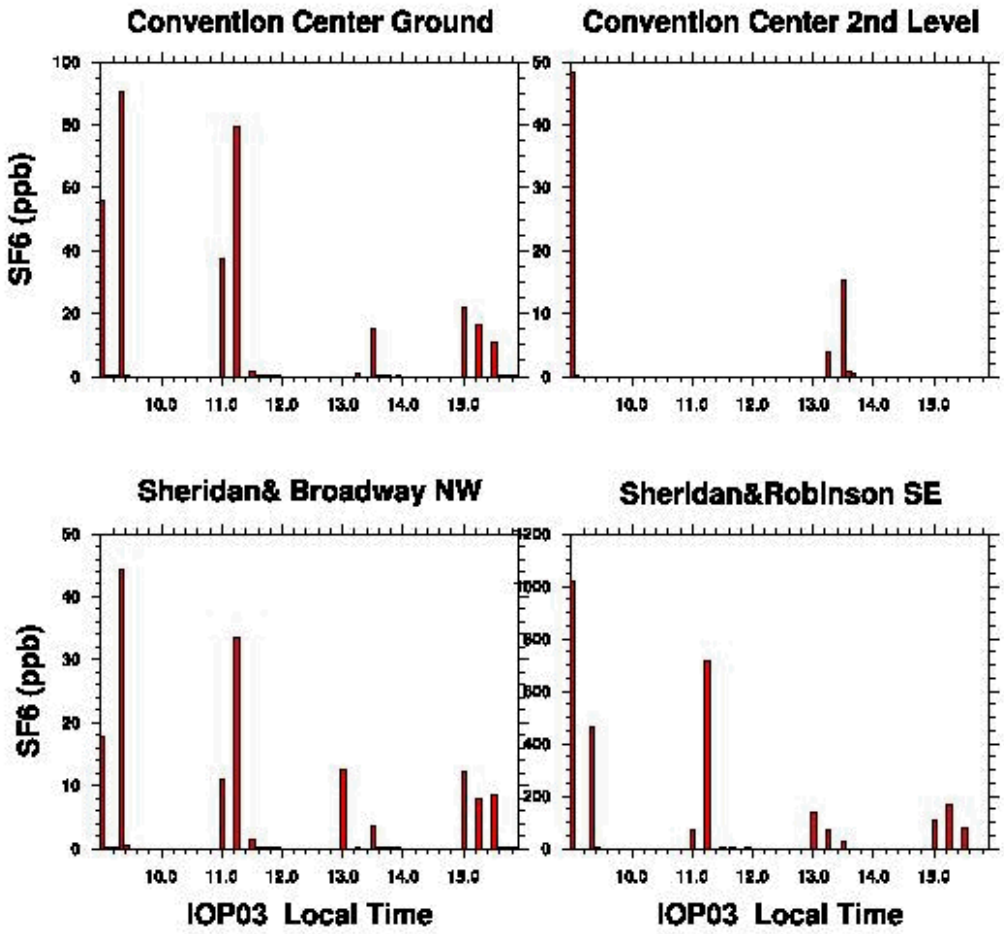
SF6 Concentration (ppbv) observed at the indicated sites during IOP02. Refer to the tables and maps for the exact locations



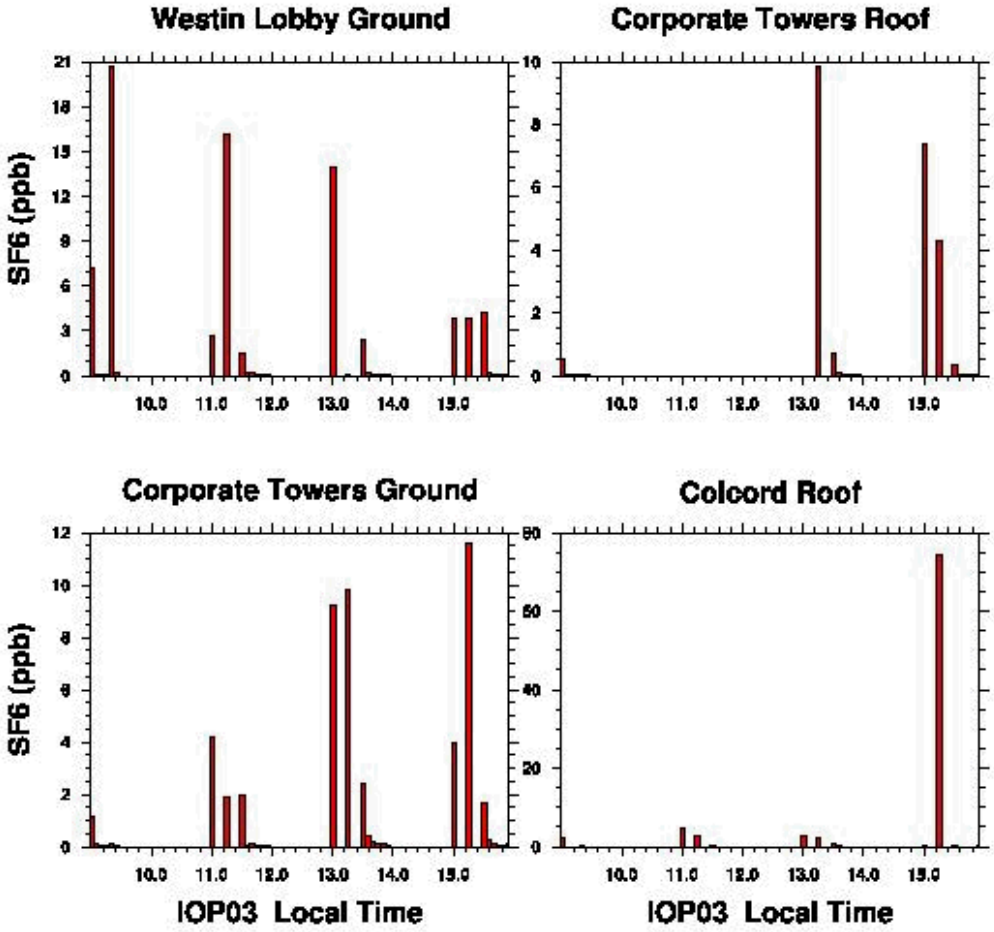
SF6 concentration for IOP02 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



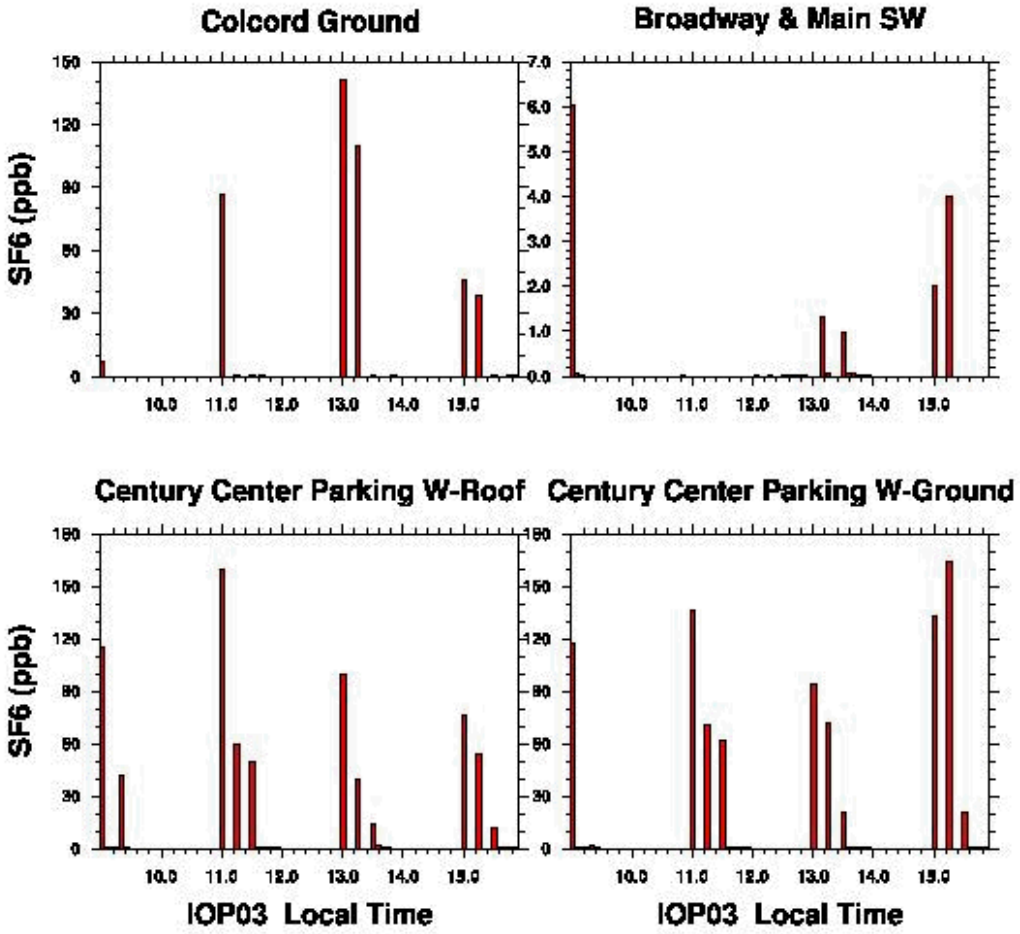
SF6 concentration for IOP02 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables.



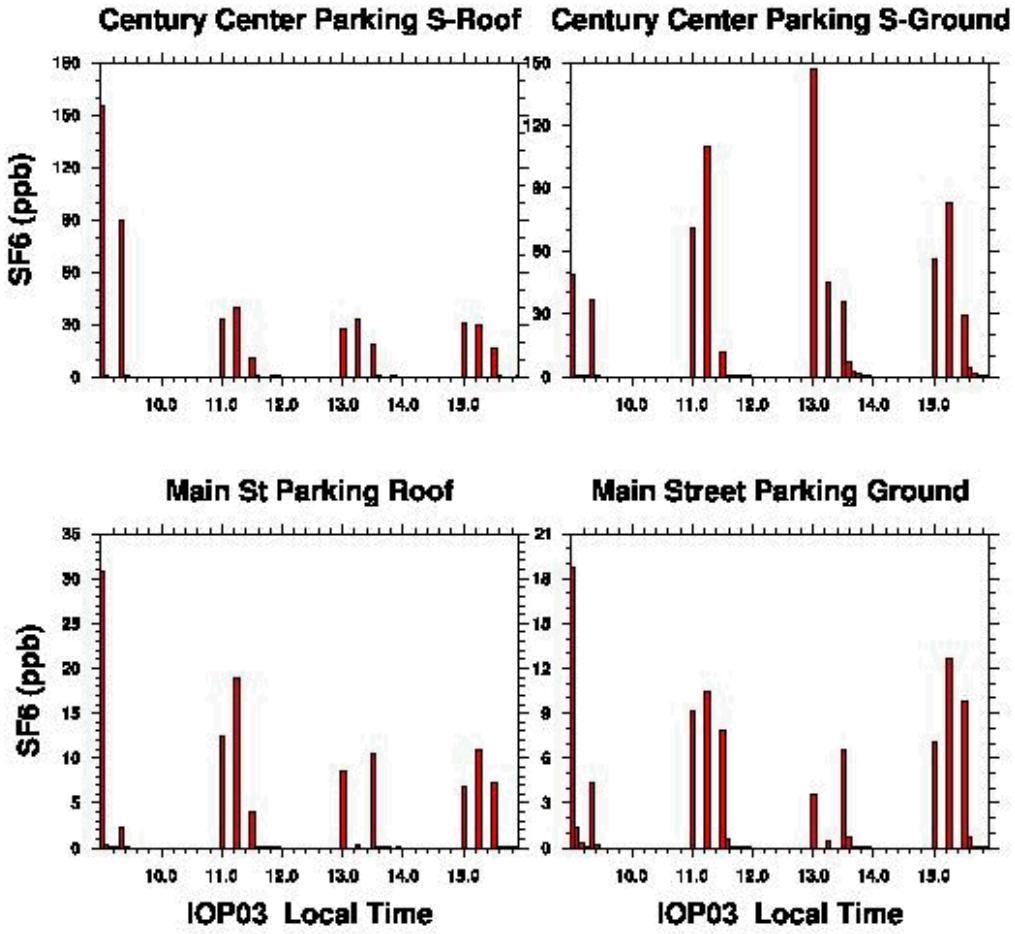
SF6 Concentration (ppbv) observed at the indicated sites during IOP03.
Refer to the tables and maps for the exact locations



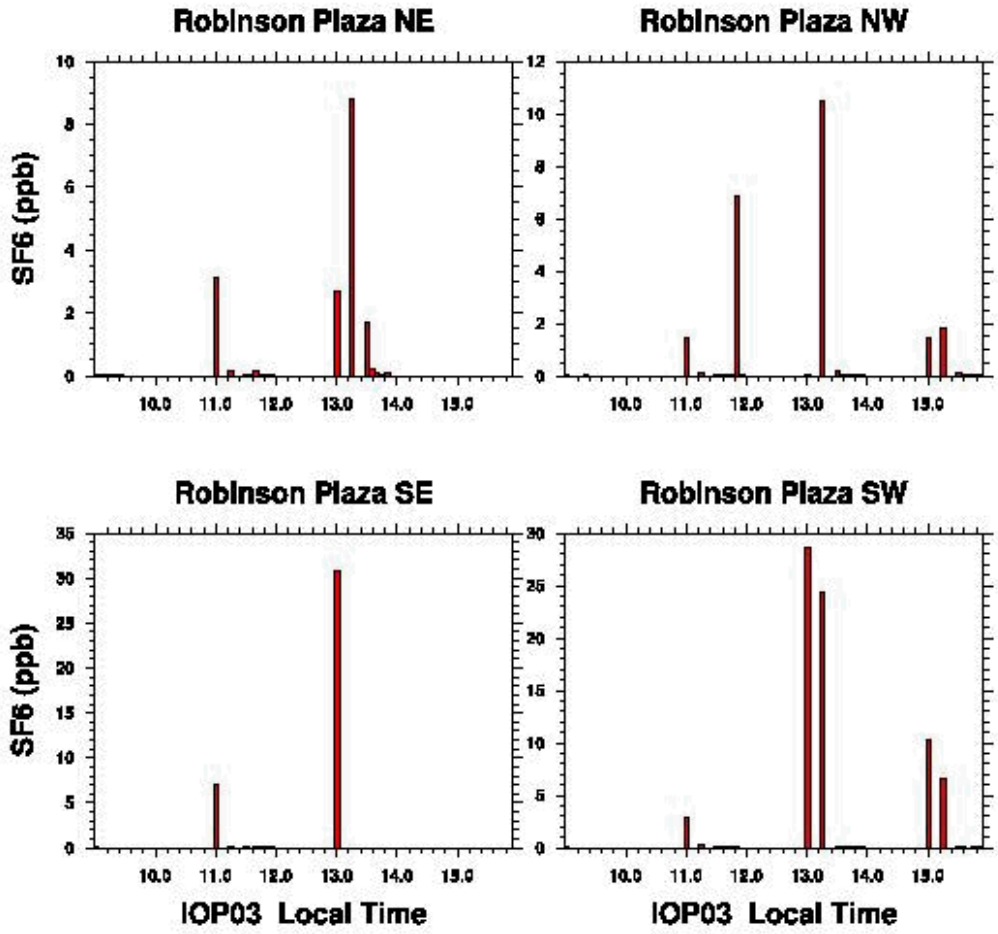
SF6 Concentration (ppbv) observed at the indicated sites during IOP03. Refer to the tables and maps for the exact locations



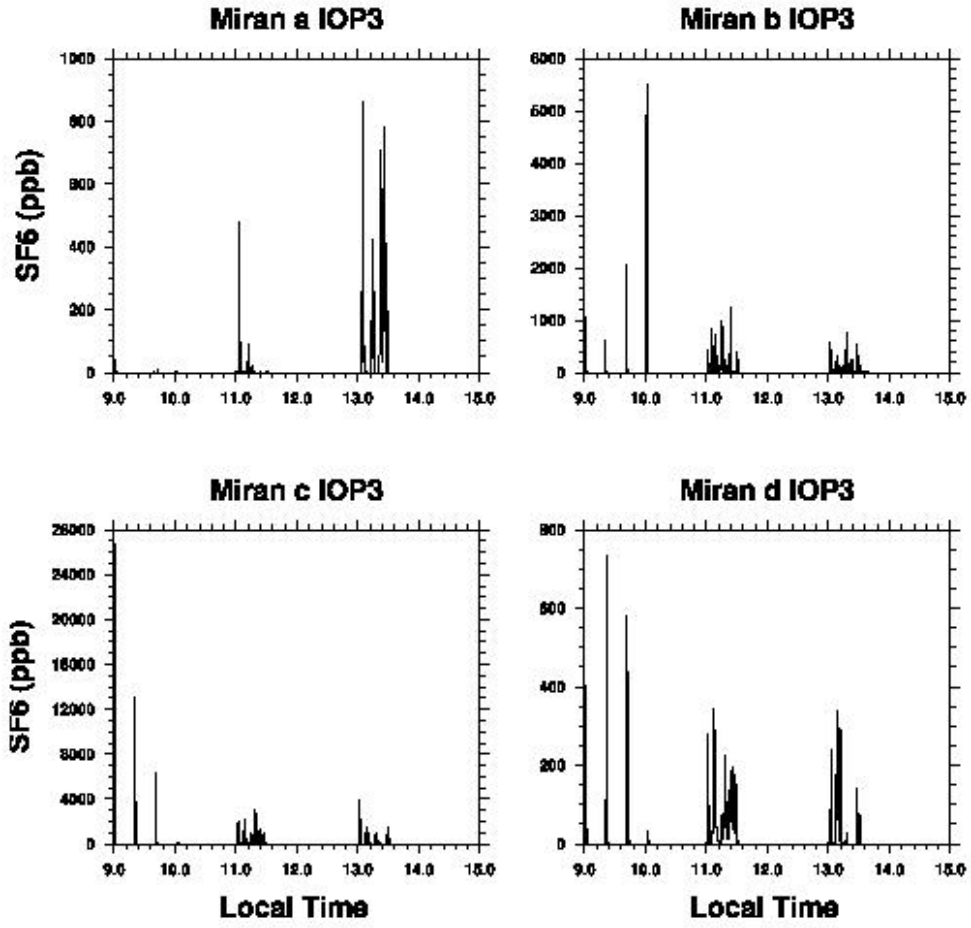
SF6 Concentration (ppbv) observed at the indicated sites during IOP03. Refer to the tables and maps for the exact locations



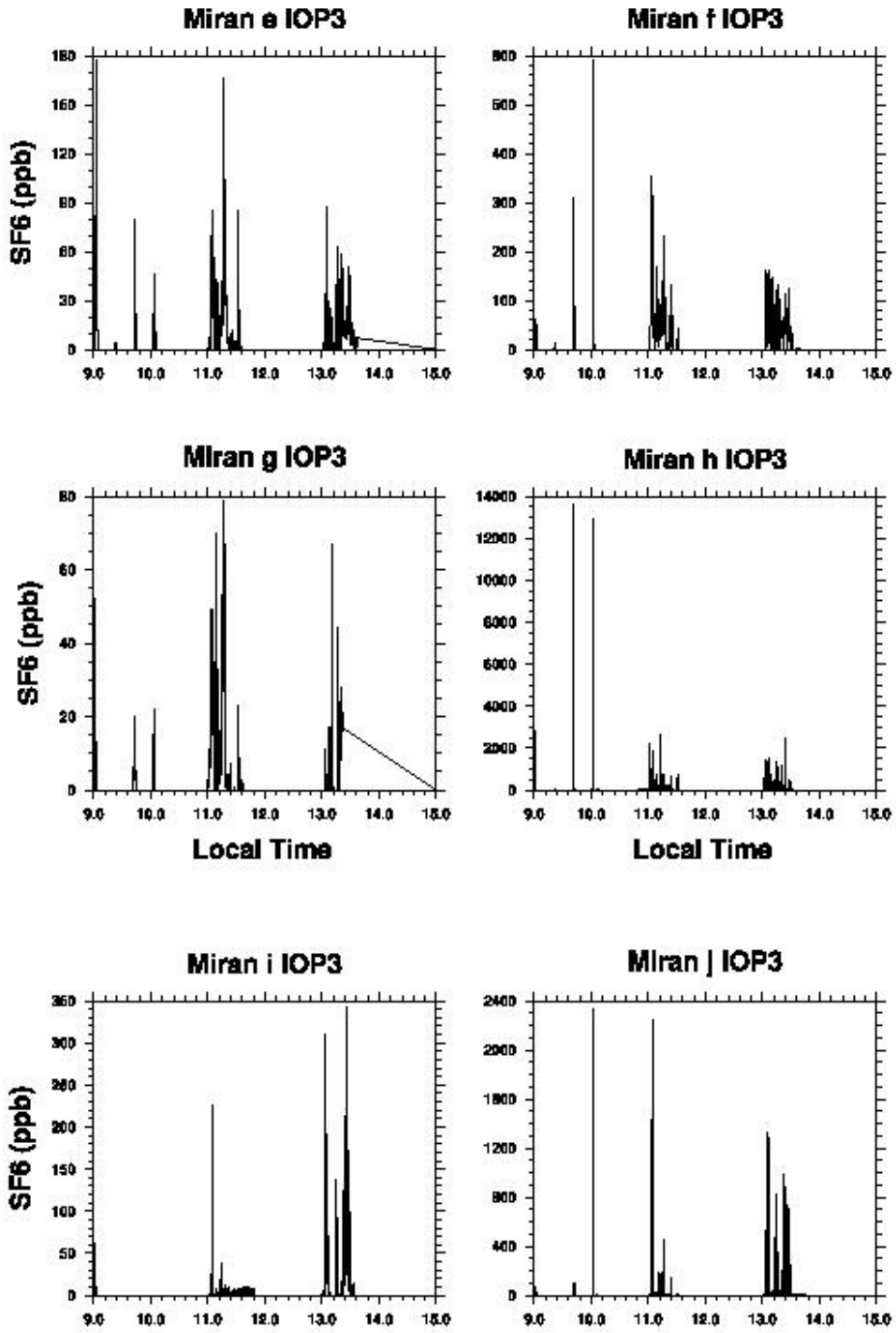
SF6 Concentration (ppbv) observed at the indicated sites during IOP03. Refer to the tables and maps for the exact locations



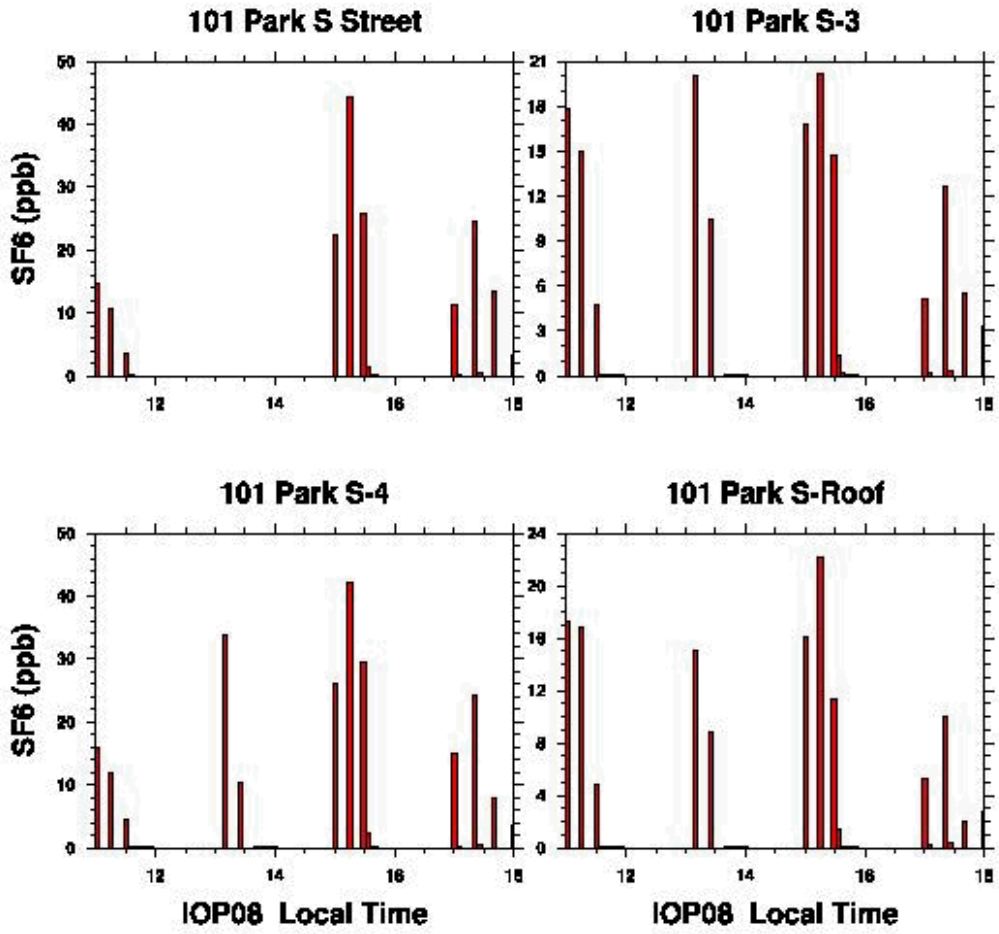
SF6 Concentration (ppbv) observed at the indicated sites during IOP03. Refer to the tables and maps for the exact locations



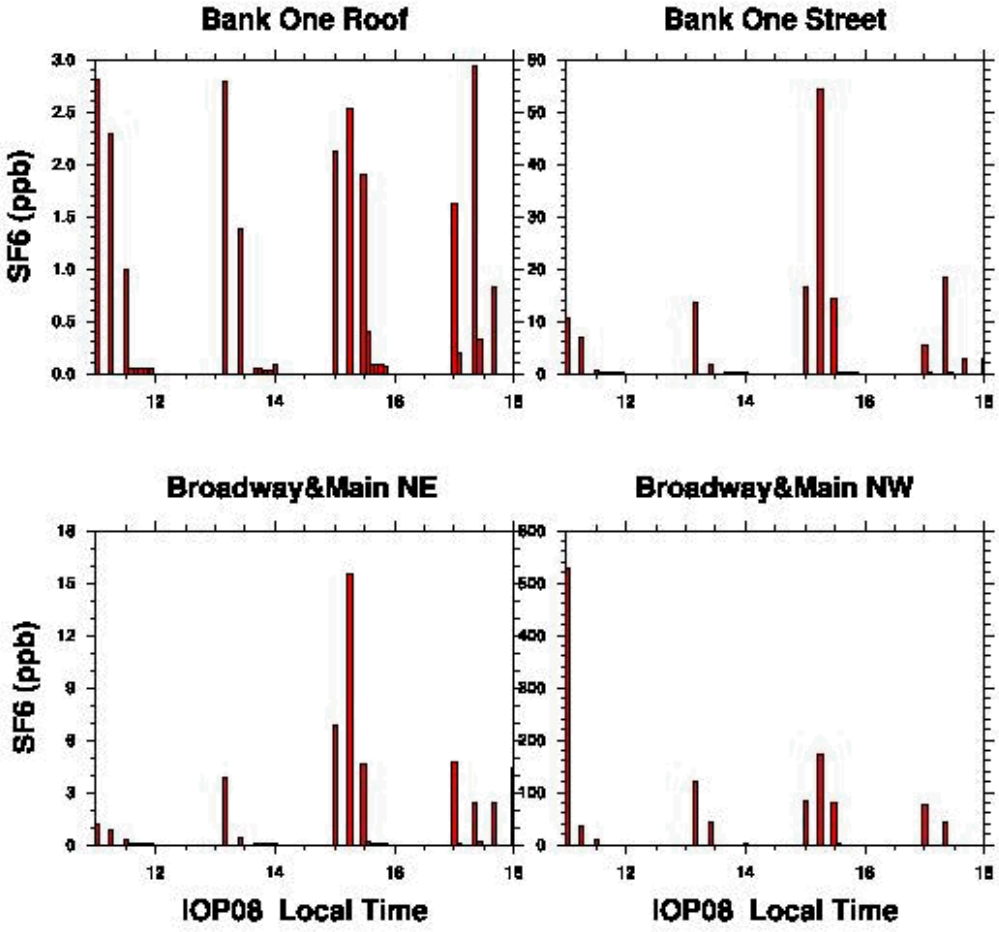
SF6 concentration for IOP03 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



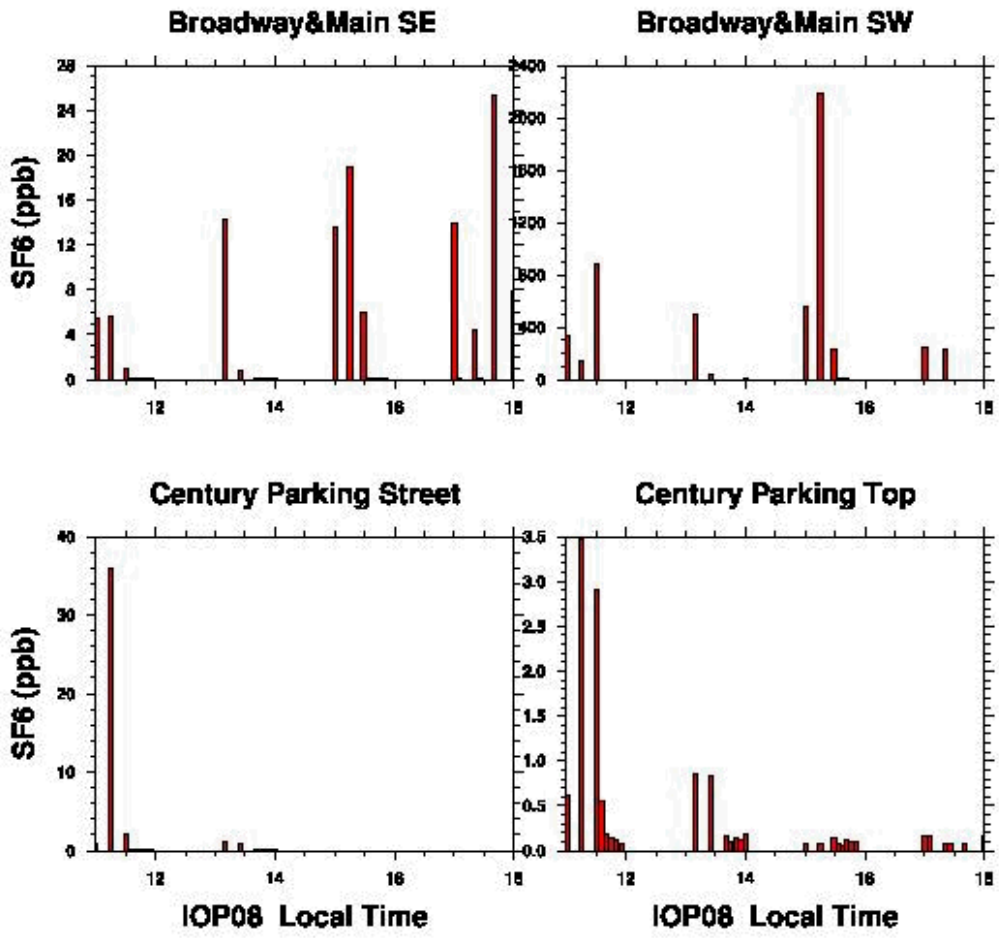
SF6 concentration for IOP03 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



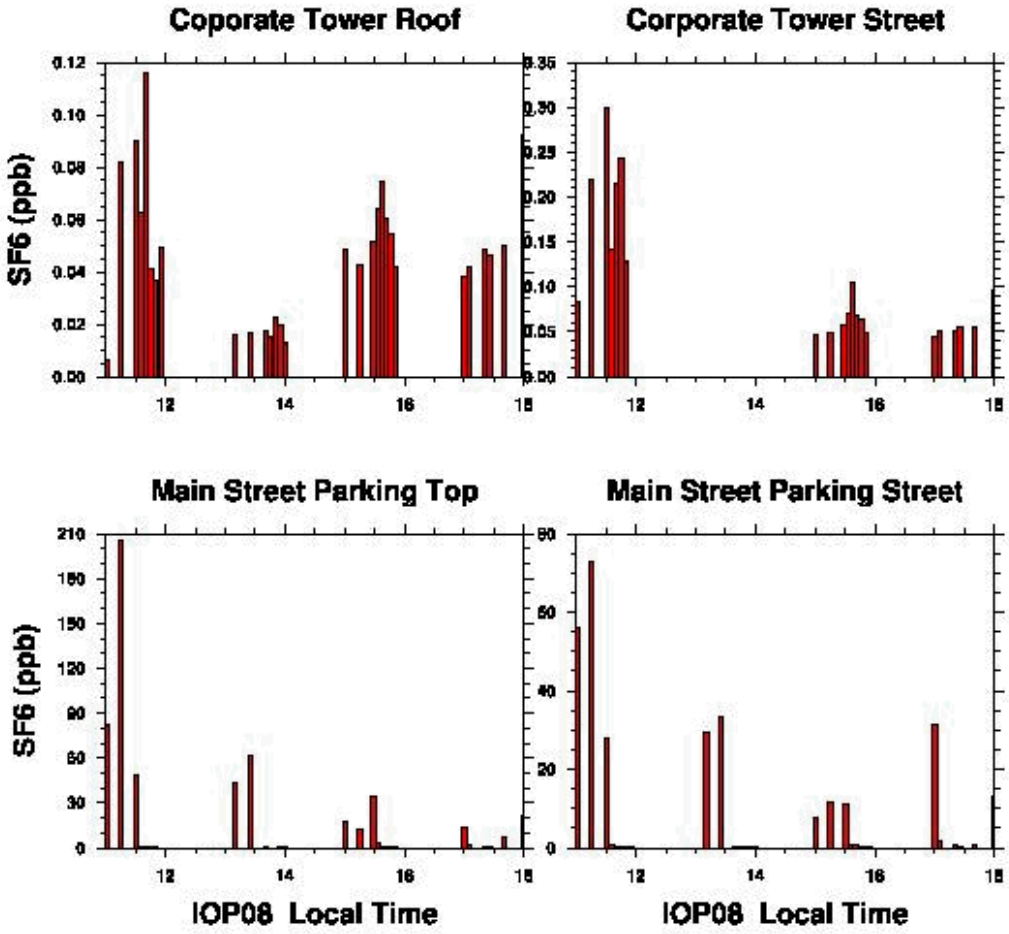
SF6 Concentration (ppbv) observed at the indicated sites during IOP08. Refer to the tables and maps for the exact locations



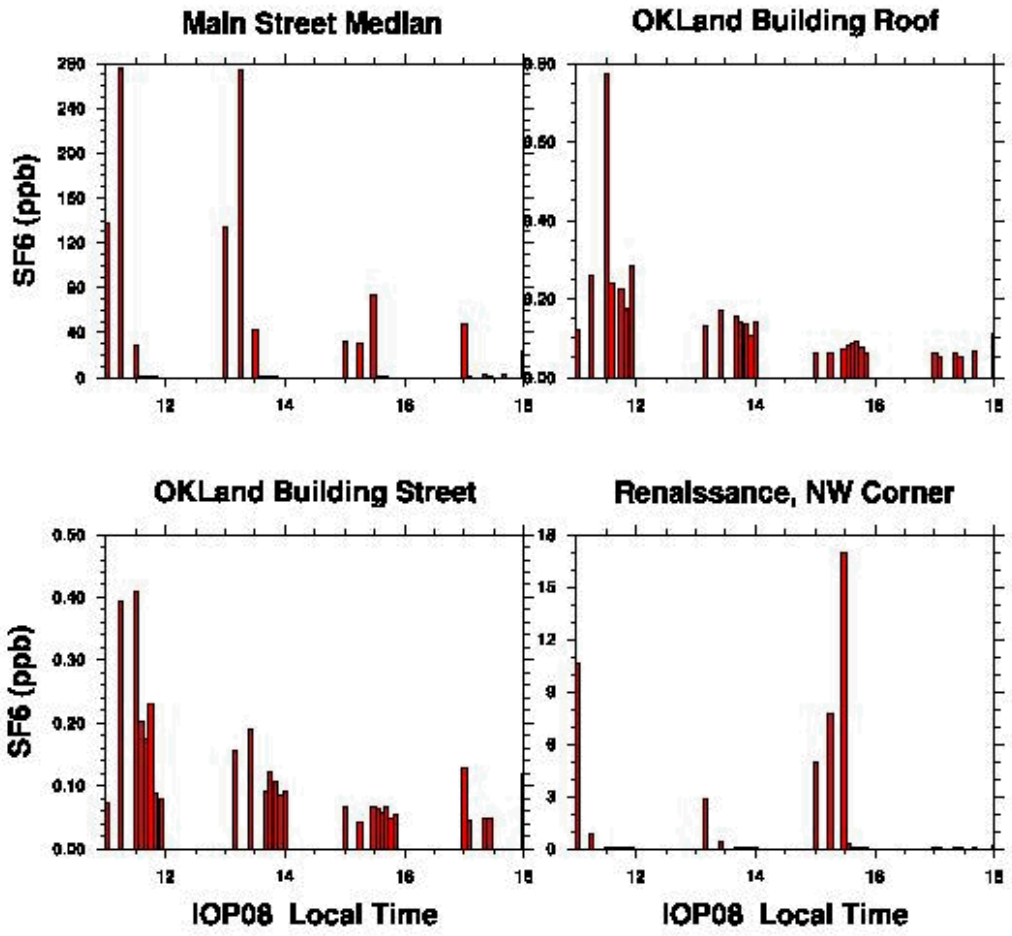
SF6 Concentration (ppbv) observed at the indicated sites during IOP08. Refer to the tables and maps for the exact locations



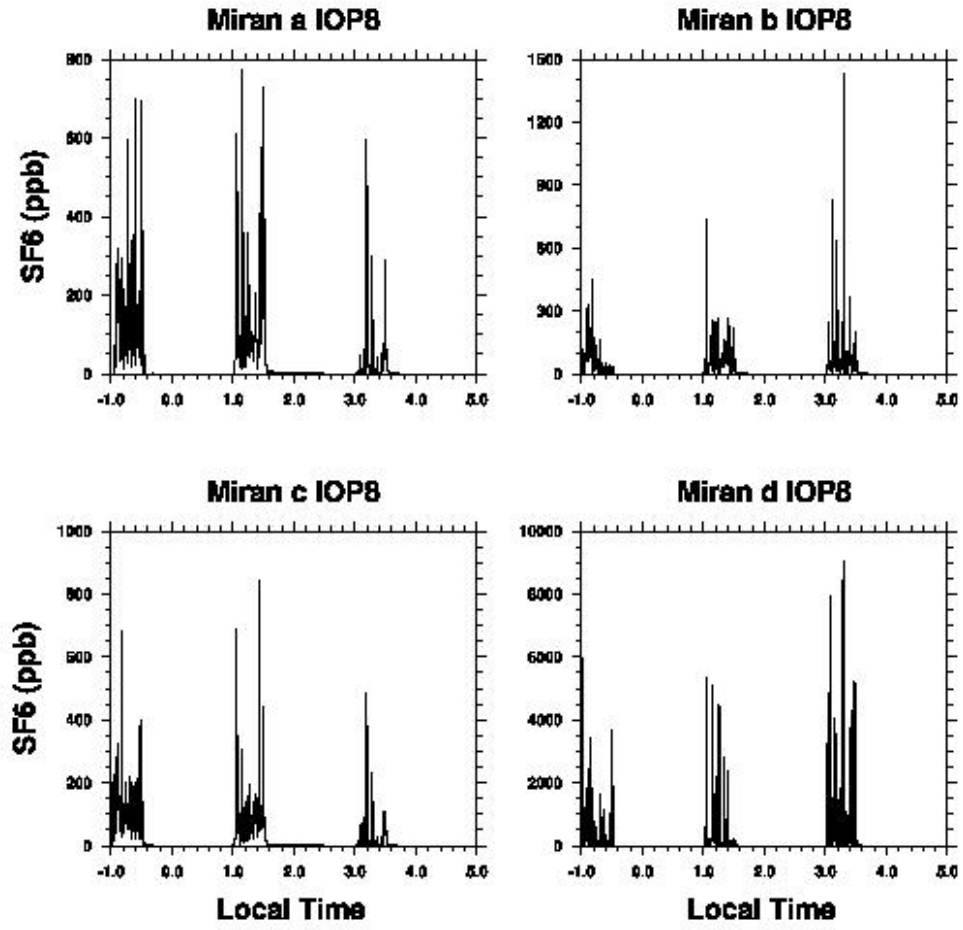
SF6 Concentration (ppbv) observed at the indicated sites during IOP08. Refer to the tables and maps for the exact locations



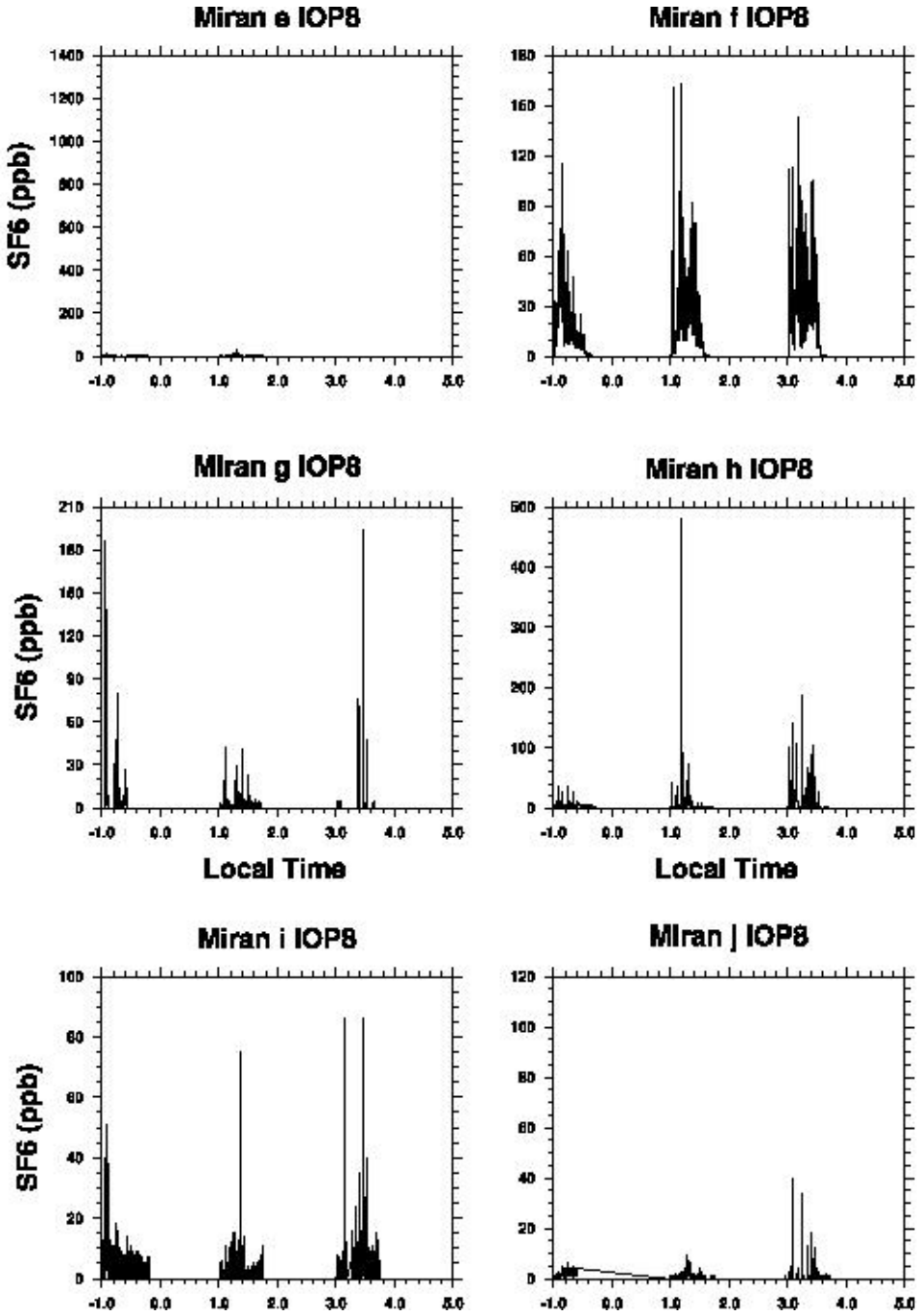
SF6 Concentration (ppbv) observed at the indicated sites during IOP08. Refer to the tables and maps for the exact locations



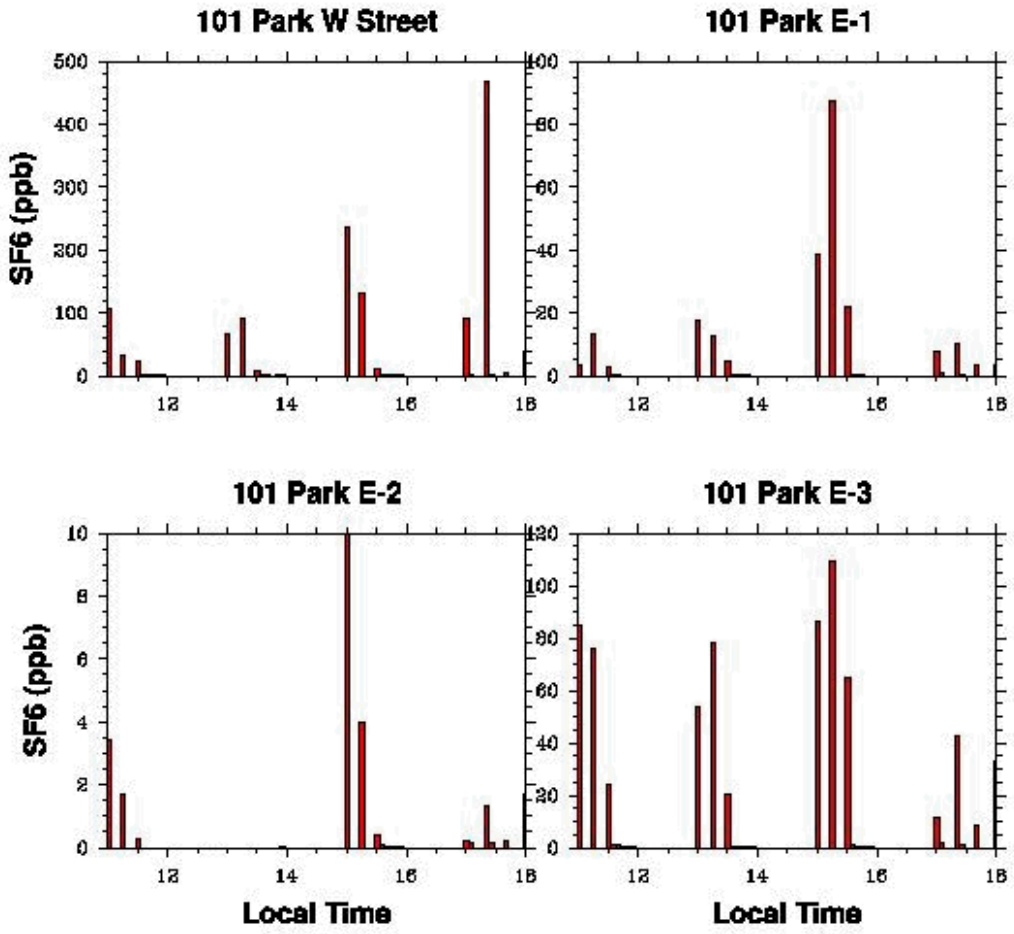
SF6 Concentration (ppbv) observed at the indicated sites during IOP08. Refer to the tables and maps for the exact locations



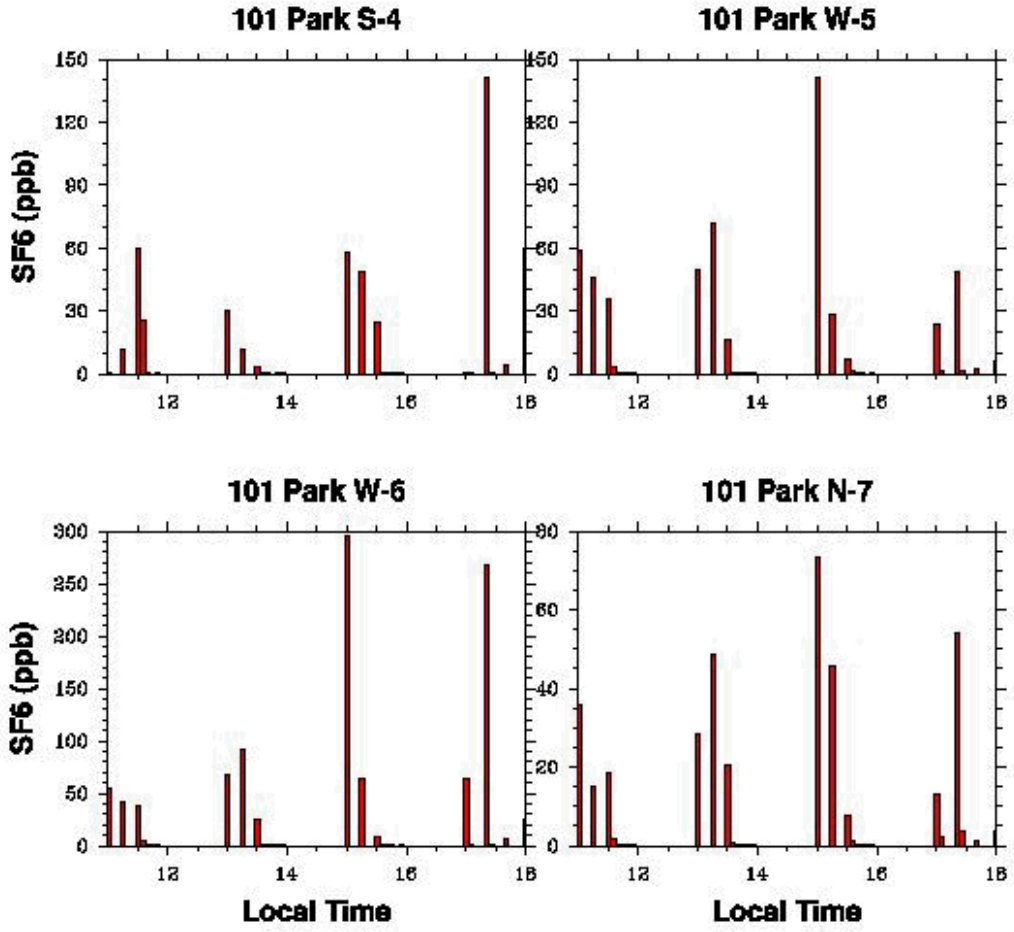
SF6 concentration for IOP08 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



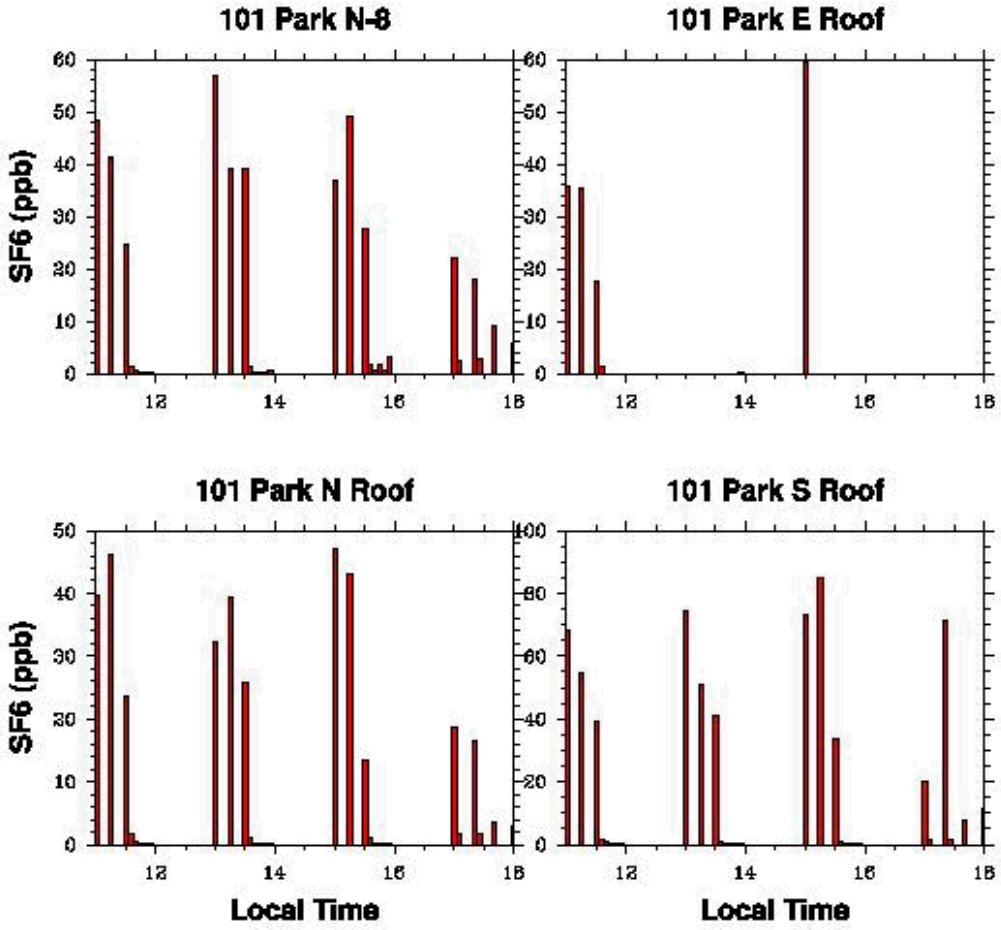
SF6 concentration for IOP08 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



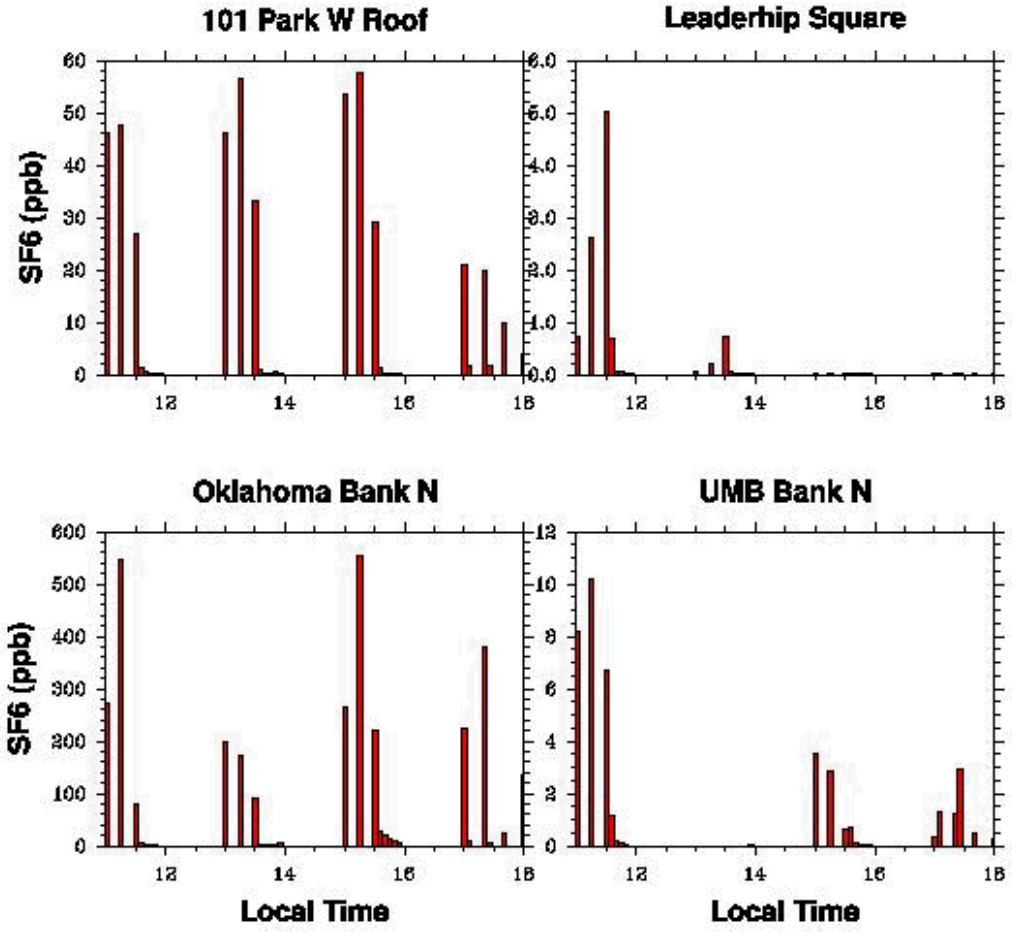
SF6 Concentration (ppbv) observed at the indicated sites during IOP09. Refer to the tables and maps for the exact locations



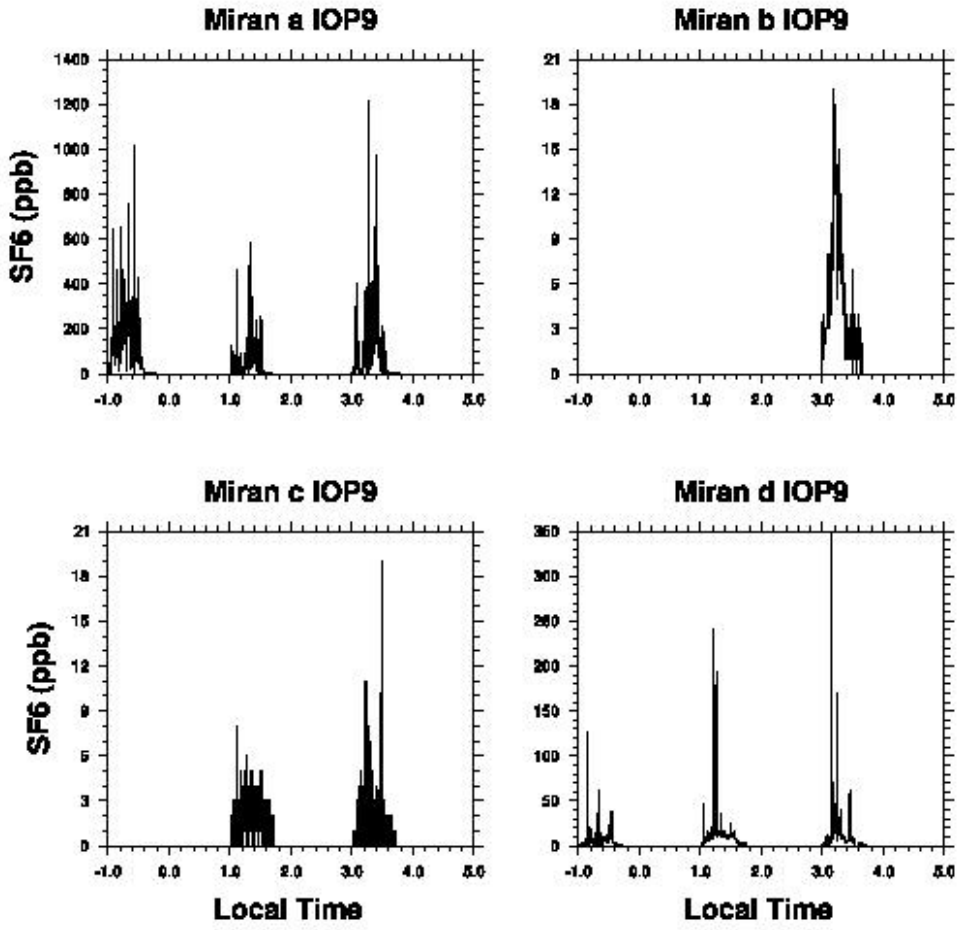
SF6 Concentration (ppbv) observed at the indicated sites during IOP09. Refer to the tables and maps for the exact locations



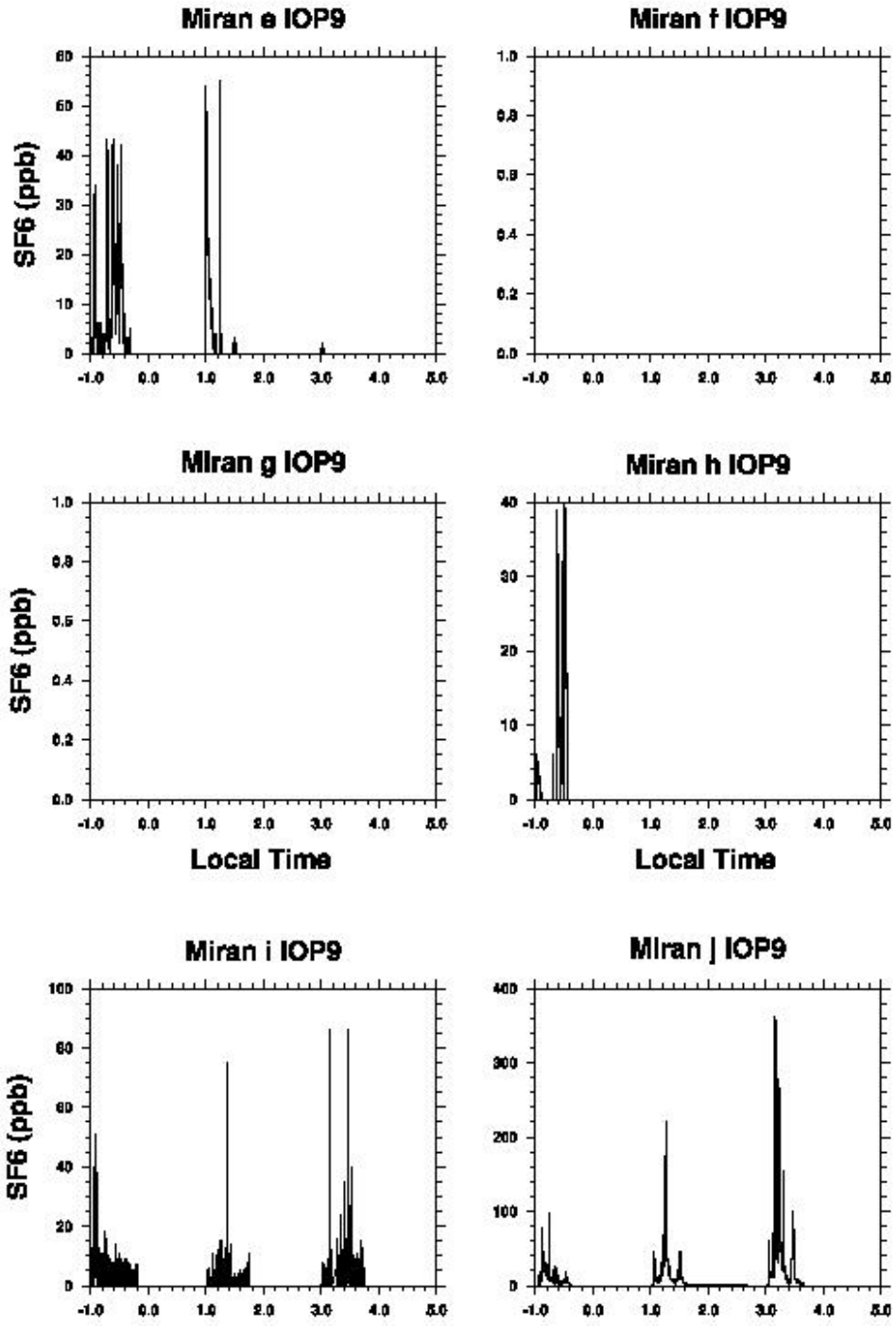
SF6 Concentration (ppbv) observed at the indicated sites during IOP09. Refer to the tables and maps for the exact locations



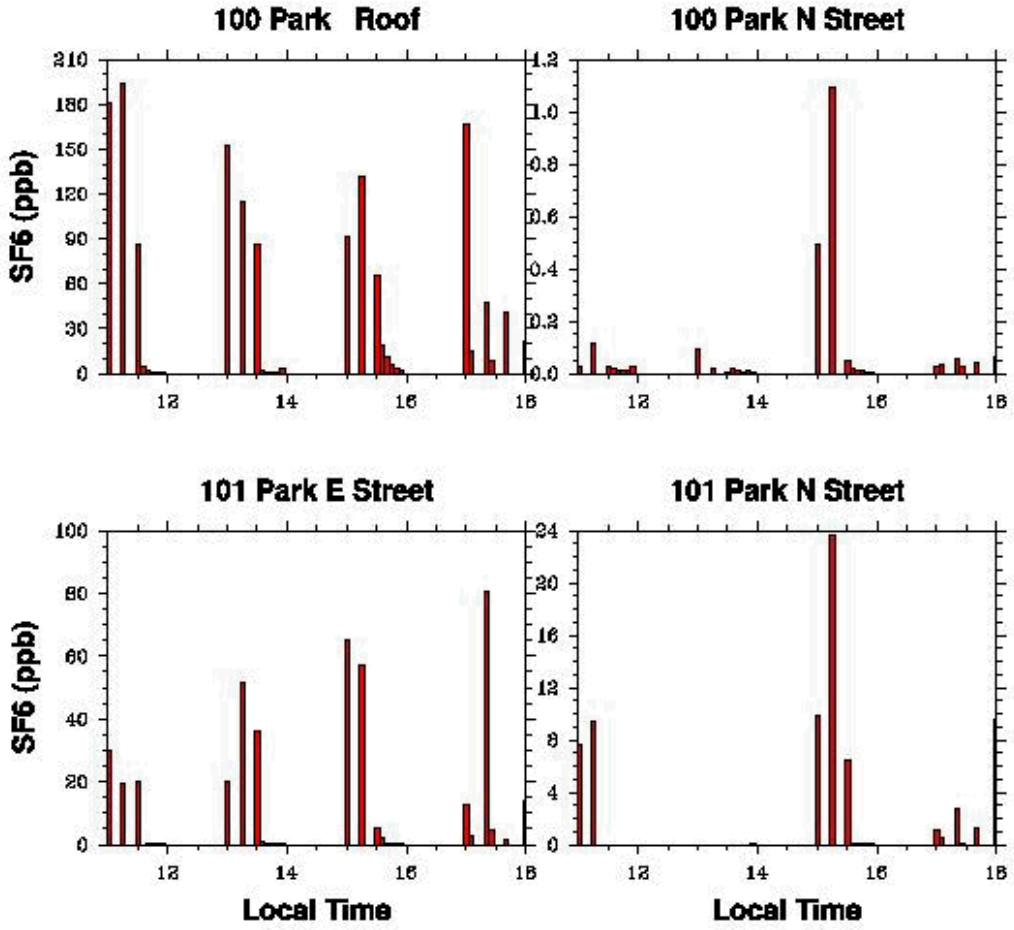
SF6 Concentration (ppbv) observed at the indicated sites during IOP09. Refer to the tables and maps for the exact locations



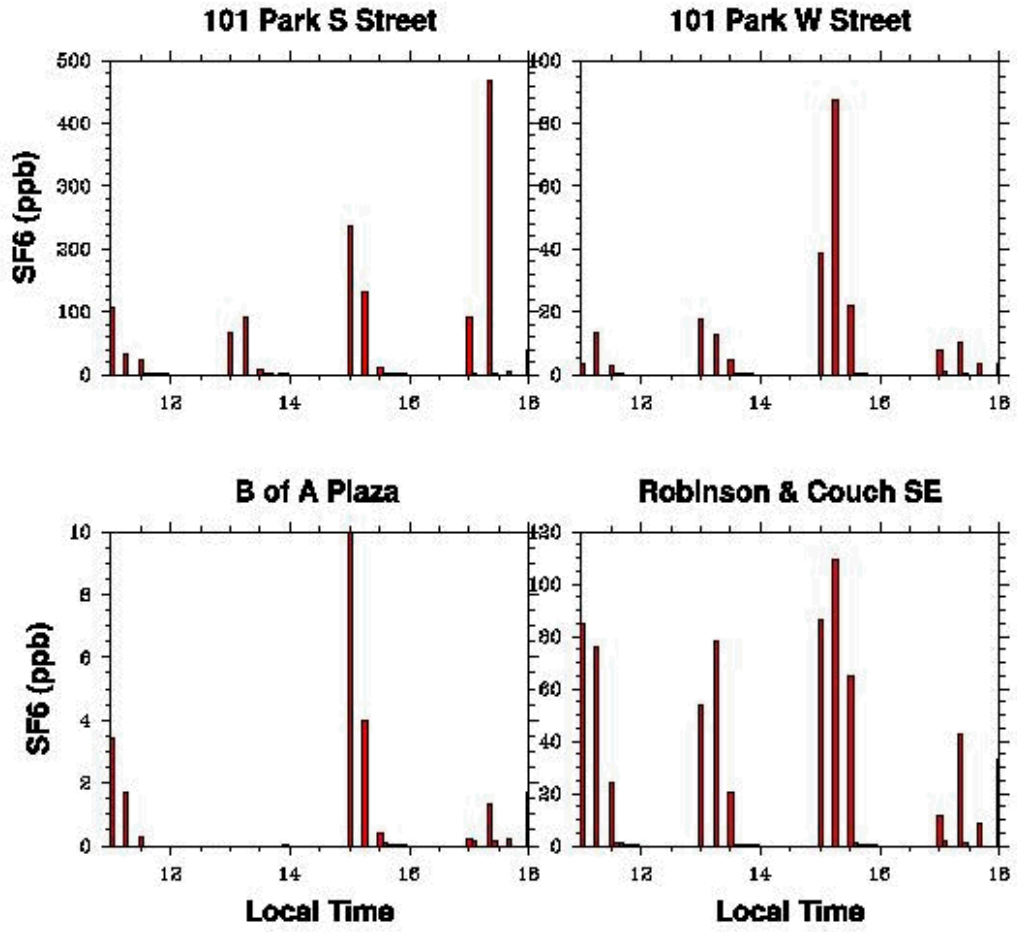
SF6 concentration for IOP09 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables



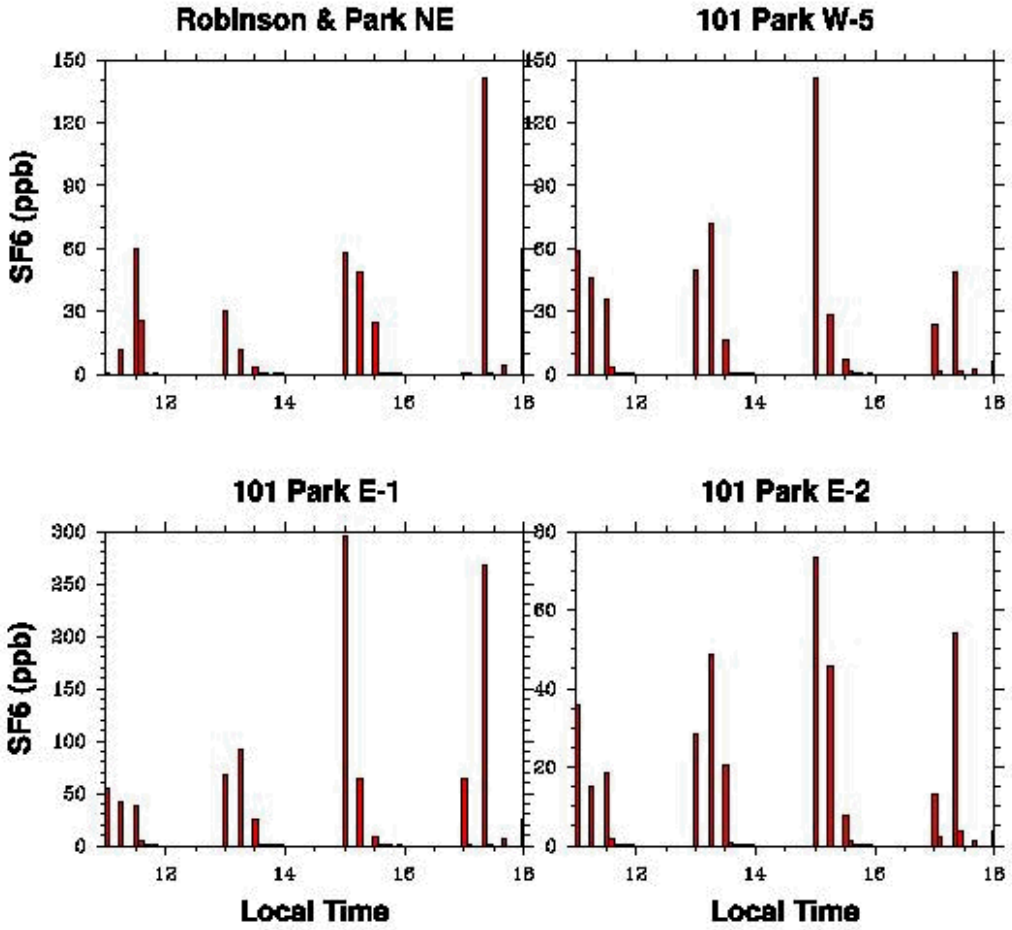
SF6 concentration for IOP09 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables.



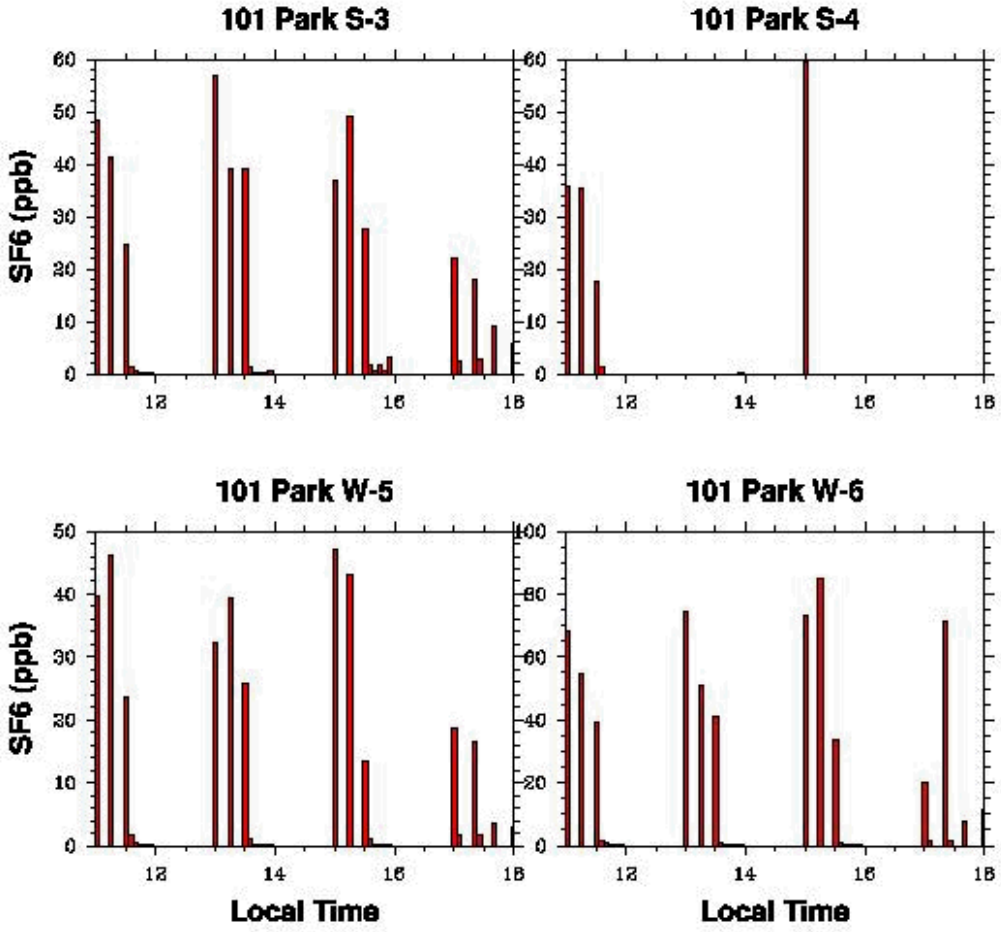
SF6 Concentration (ppbv) observed at the indicated sites during IOP10.
Refer to the tables and maps for the exact locations



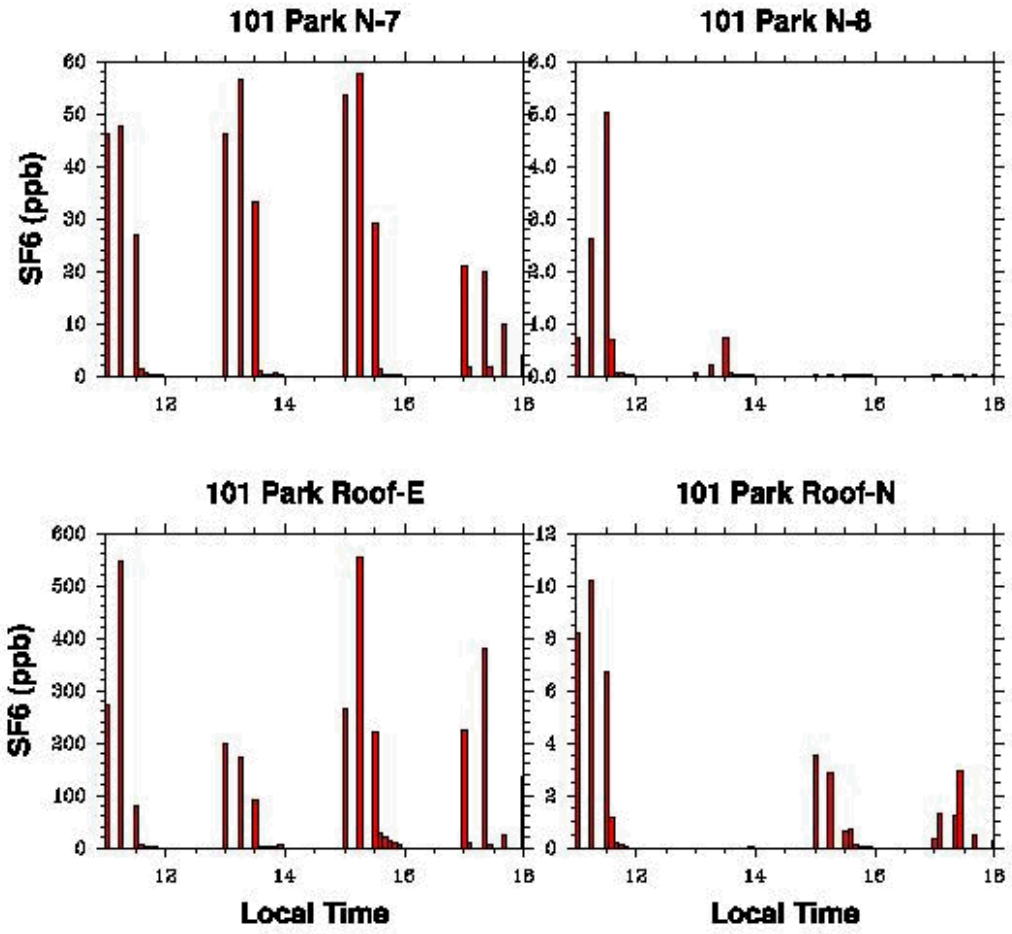
SF6 Concentration (ppbv) observed at the indicated sites during IOP10.
Refer to the tables and maps for the exact locations.



SF6 Concentration (ppbv) observed at the indicated sites during IOP10. Refer to the tables and maps for the exact locations.



SF6 Concentration (ppbv) observed at the indicated sites during IOP10. Refer to the tables and maps for the exact locations.



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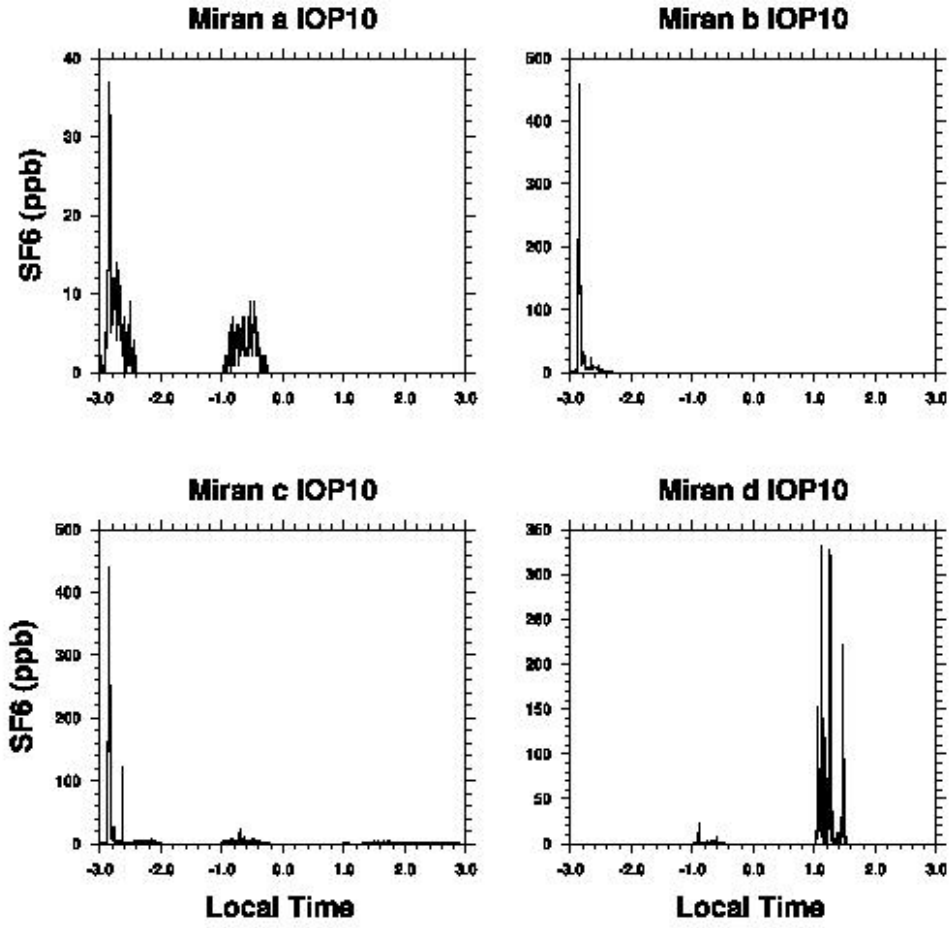
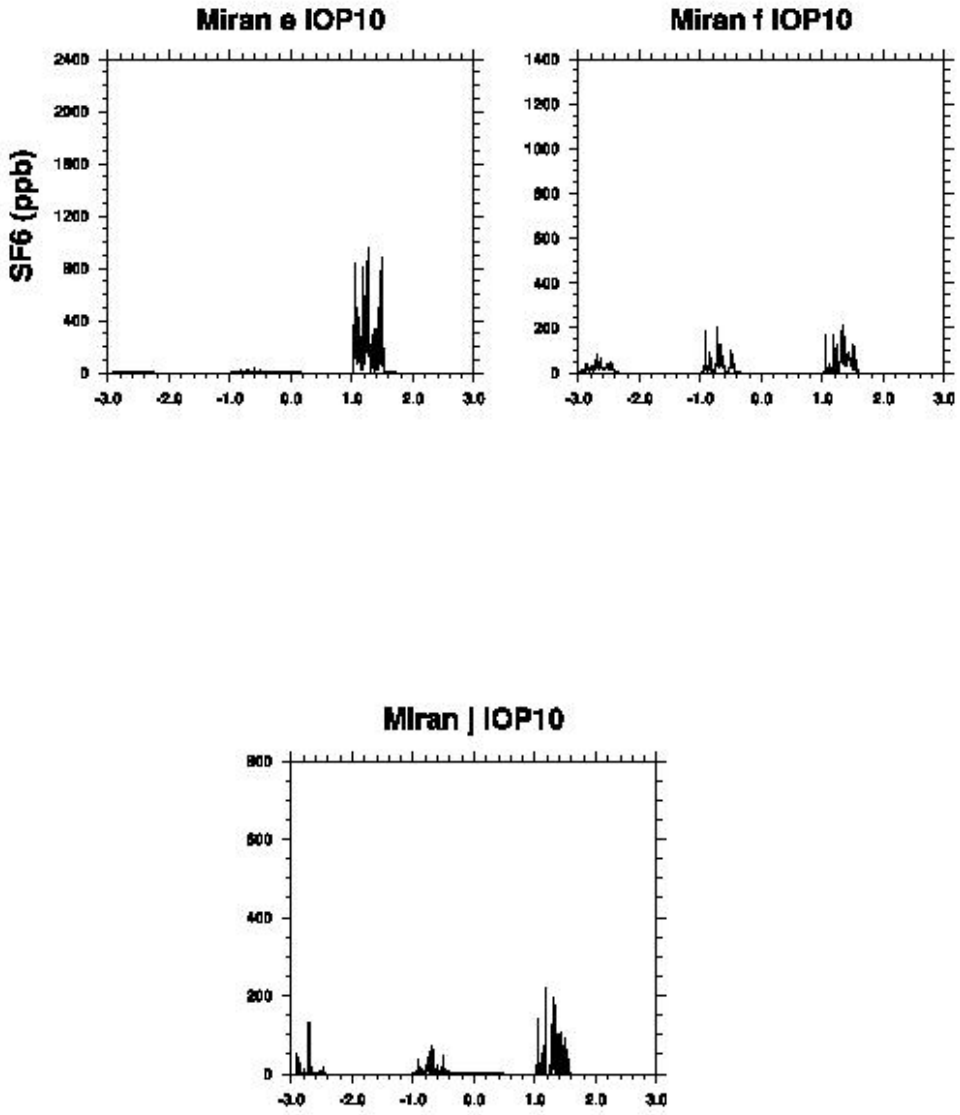
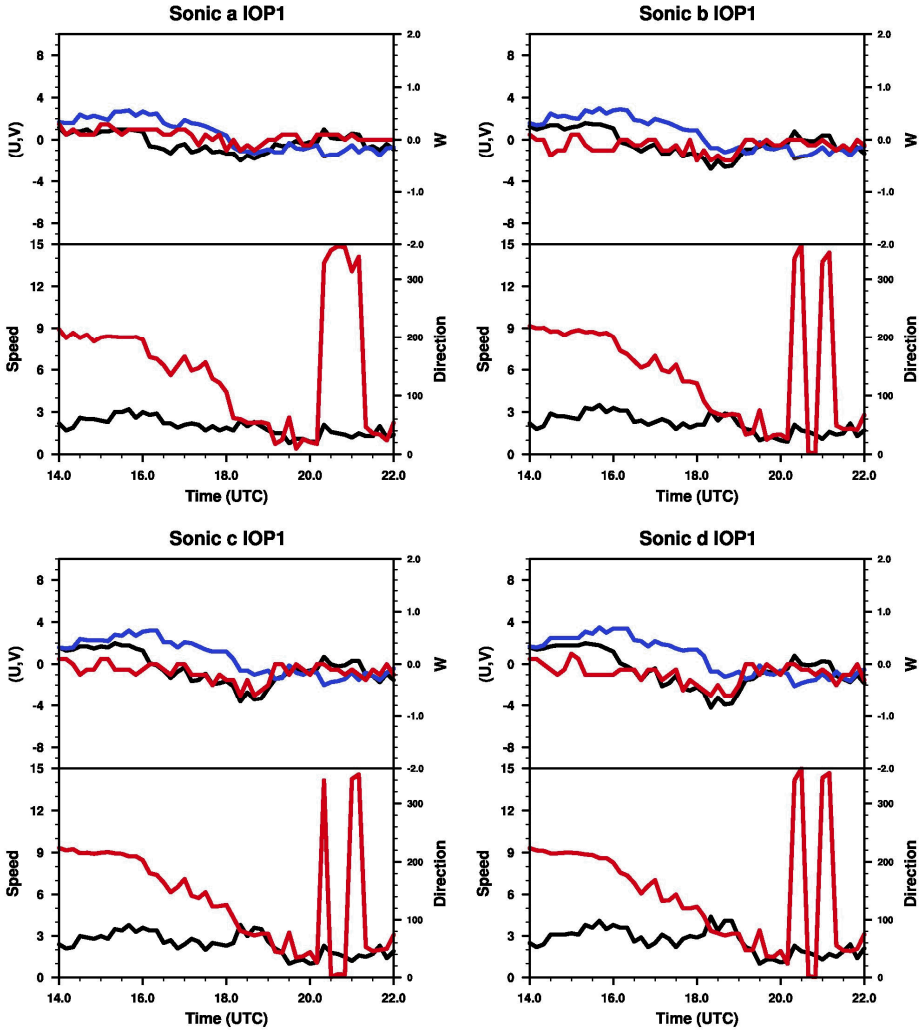


SF6 concentration for IOP10 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables

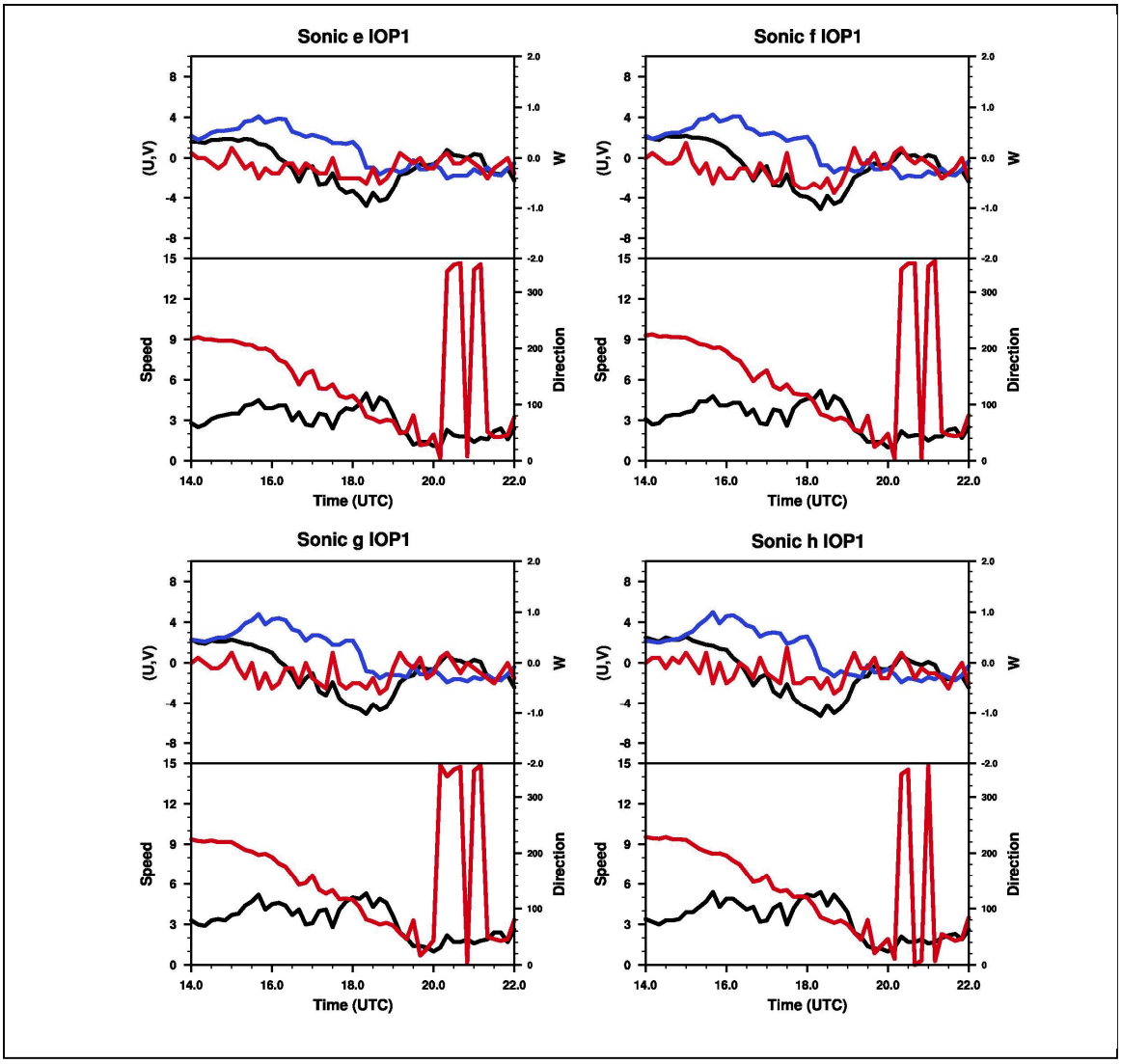


SF6 concentration for IOP10 as measured by the Miran real-time analyzers. The locations of each Miran is documented in the tables

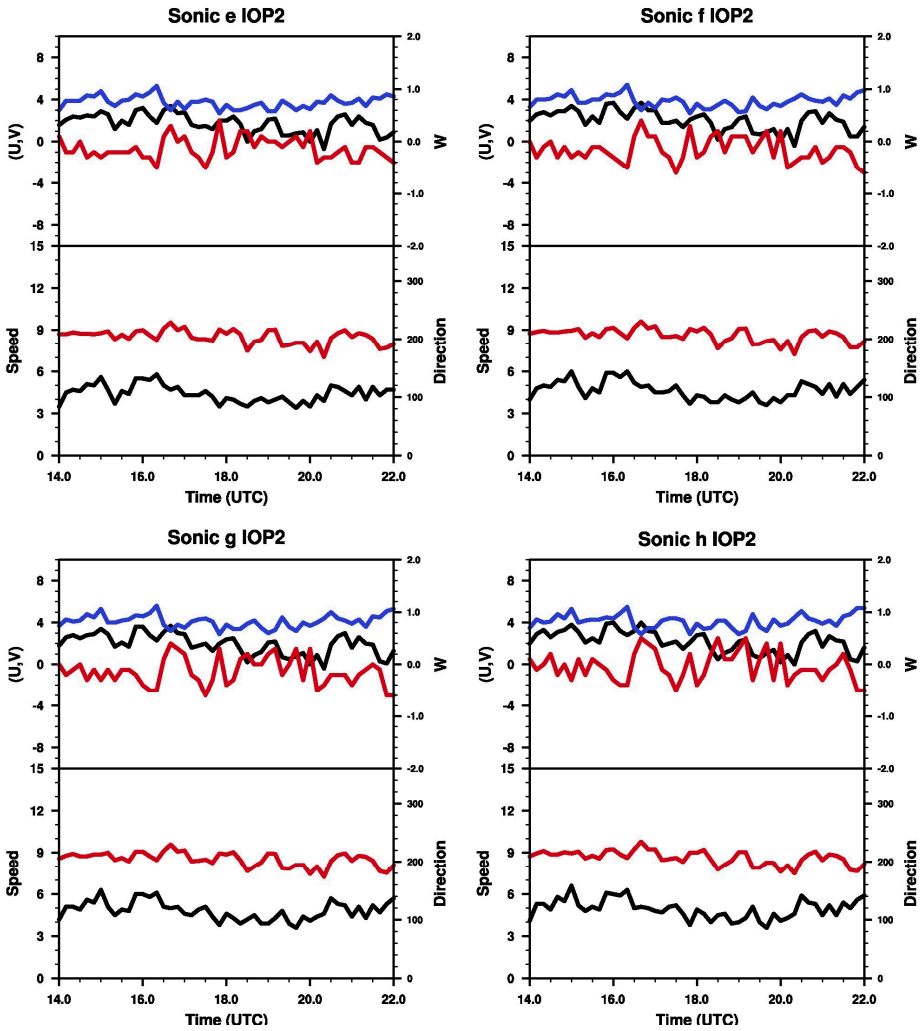
The following plots are the 10-minute averages for each IOP from the sonic anemometers on the crane, which was located at UTM coordinates (634467,3926810).



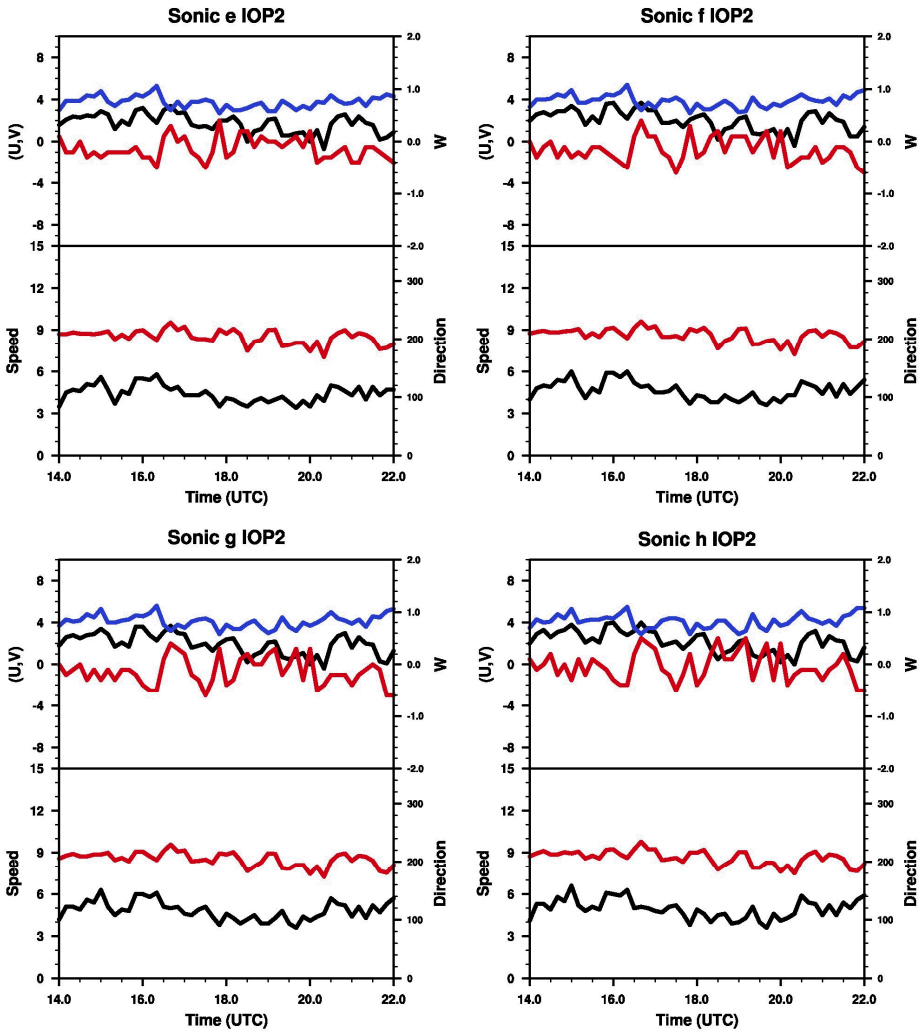
Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



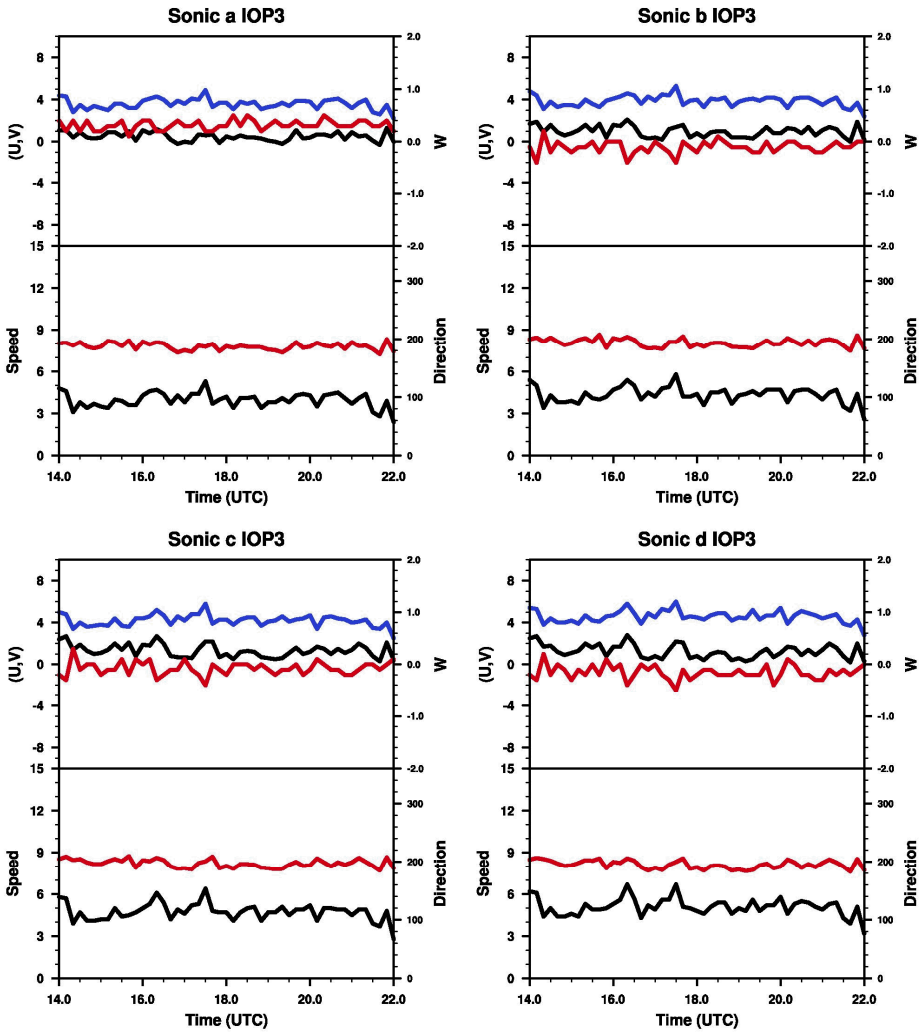
Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



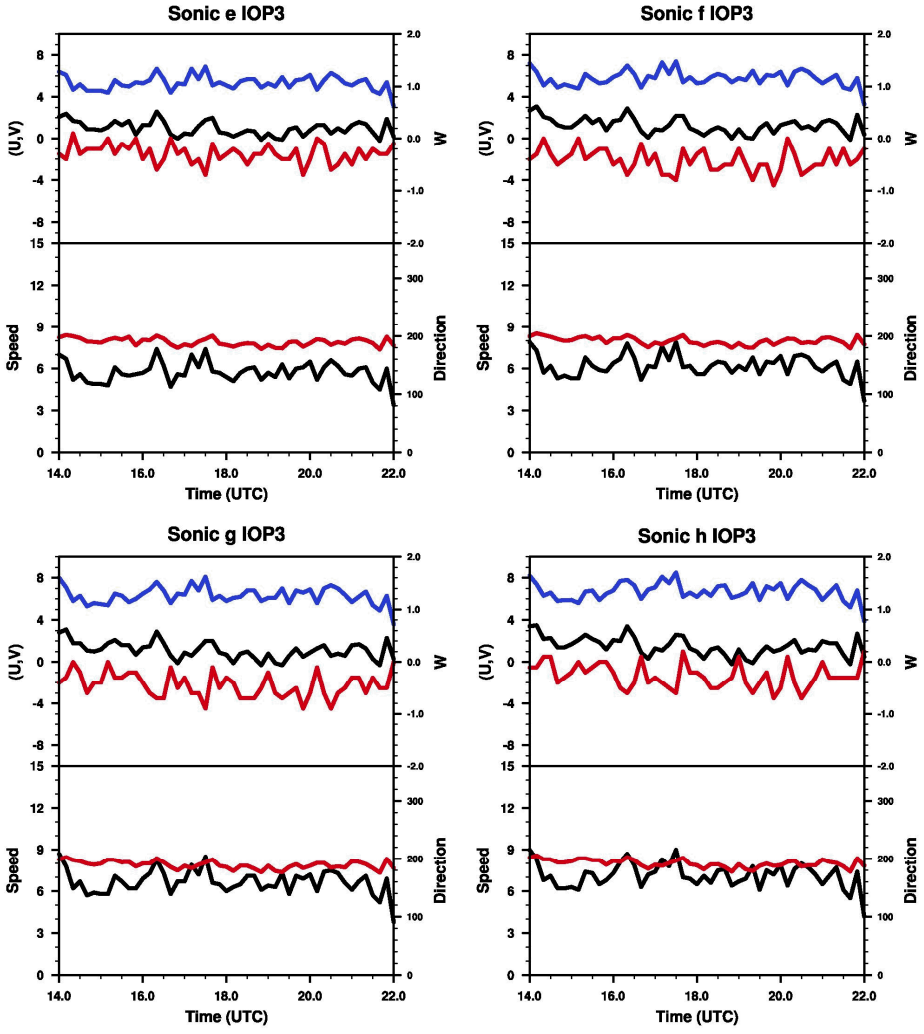
Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



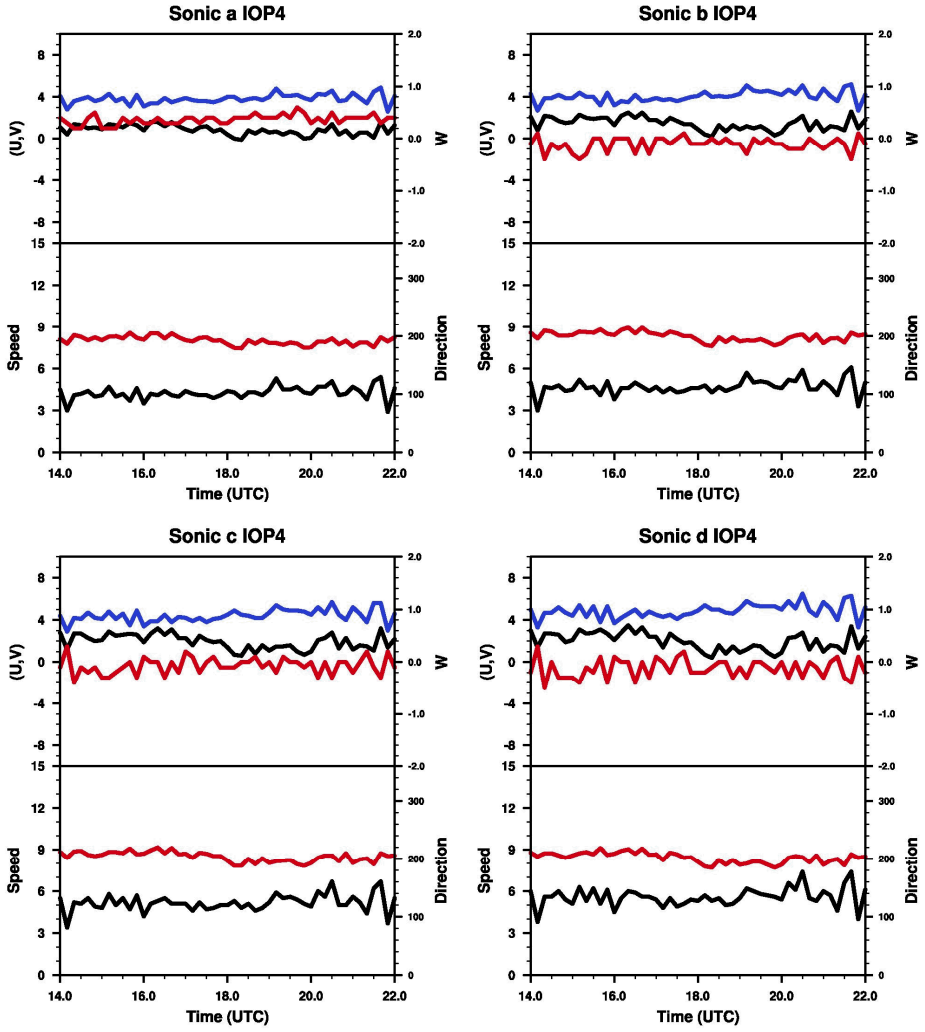
Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



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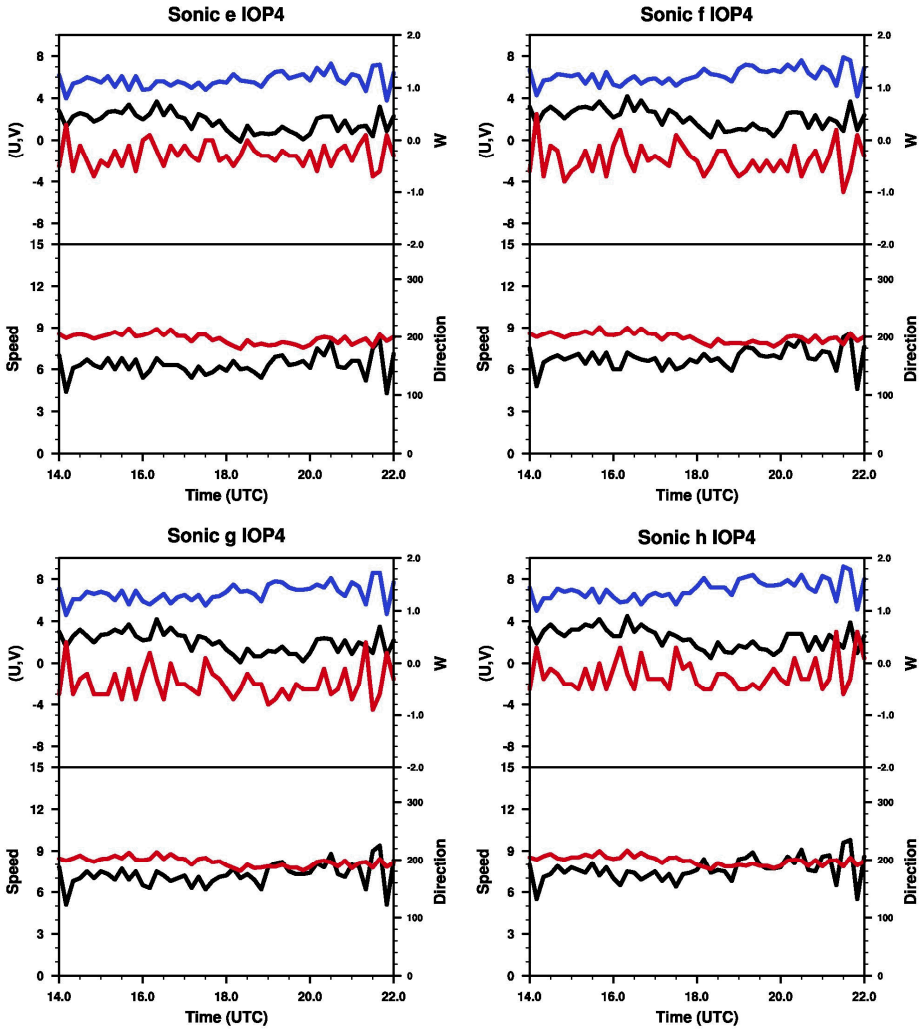

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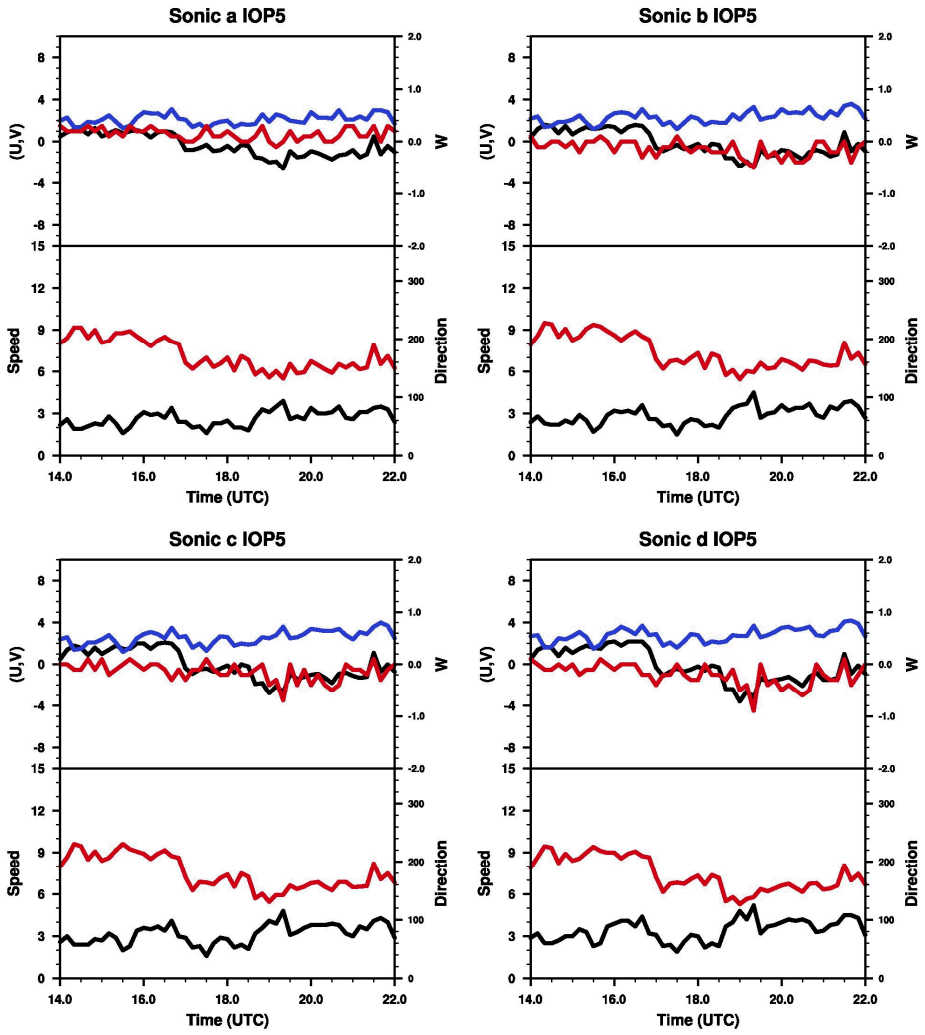

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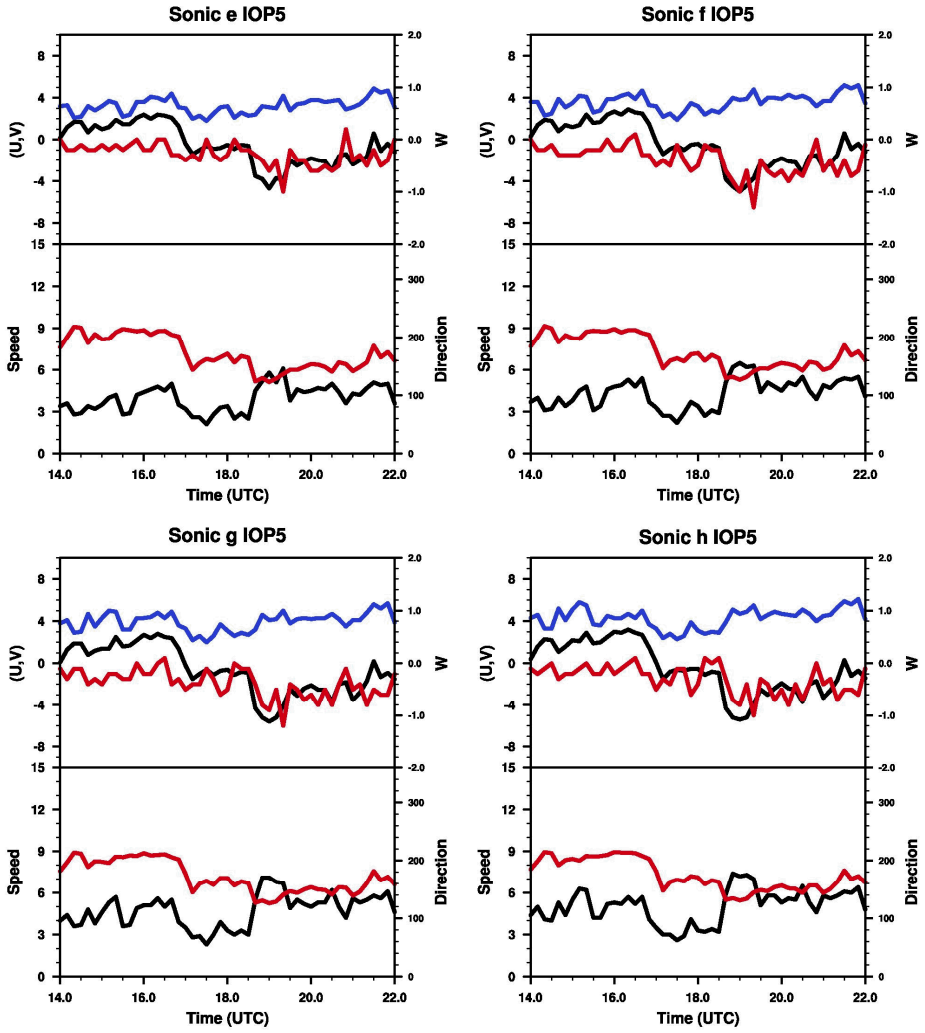

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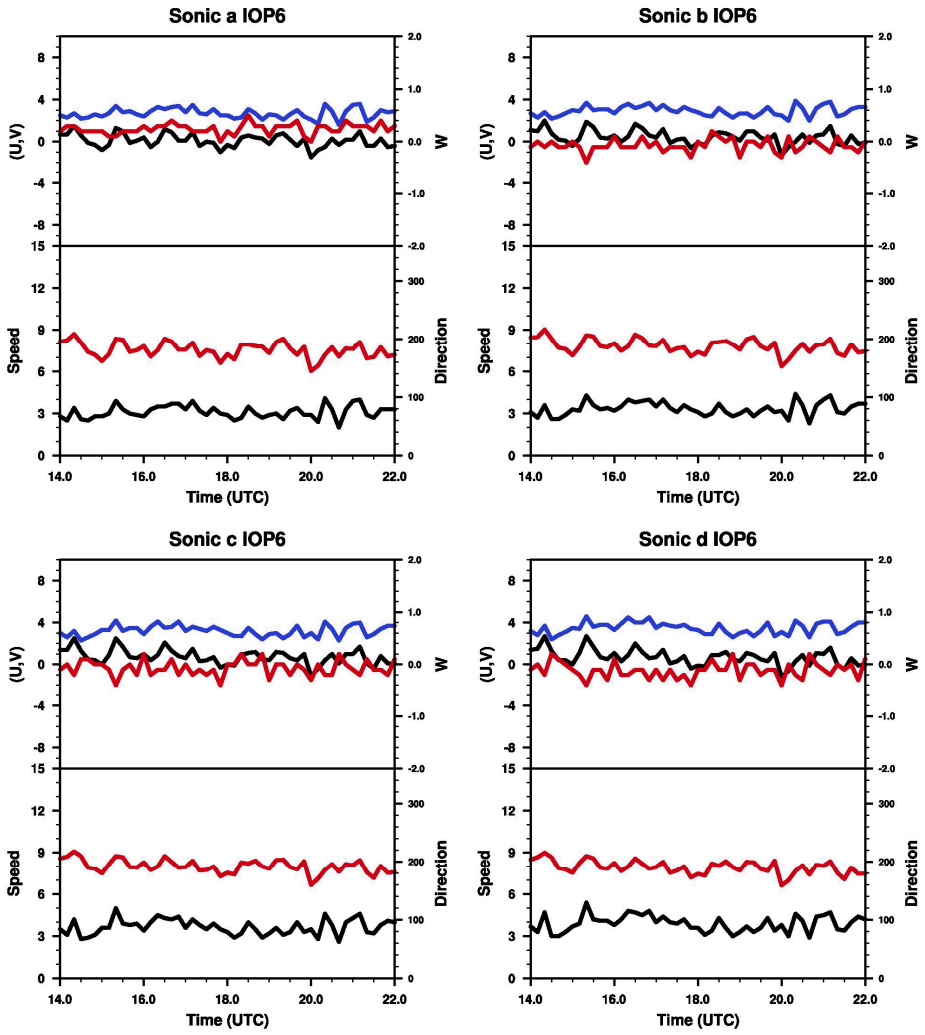

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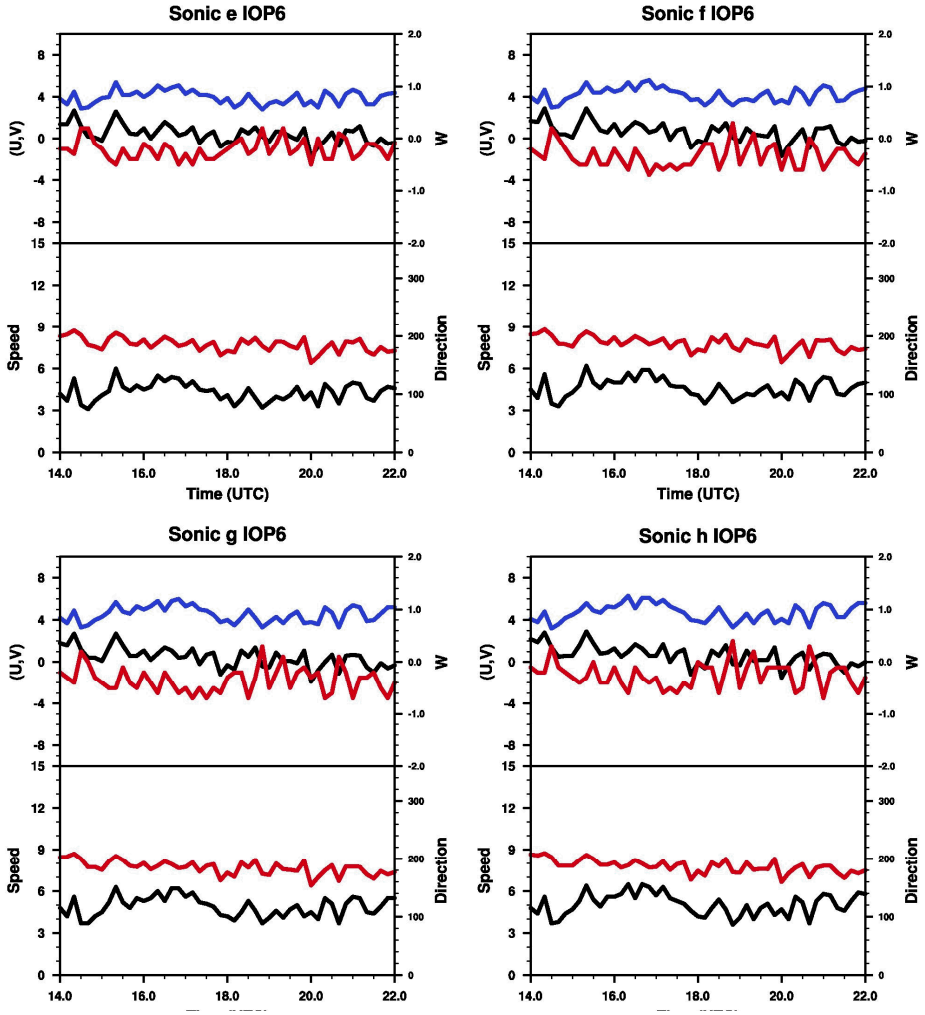
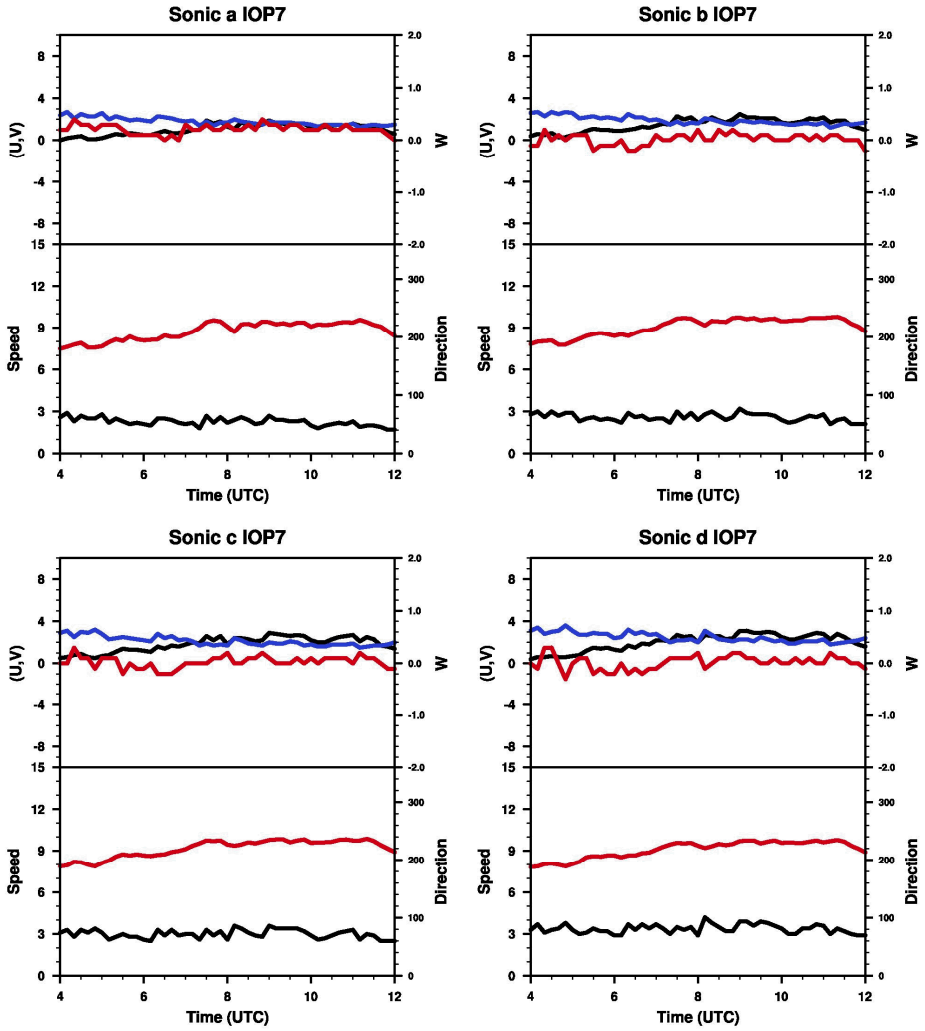
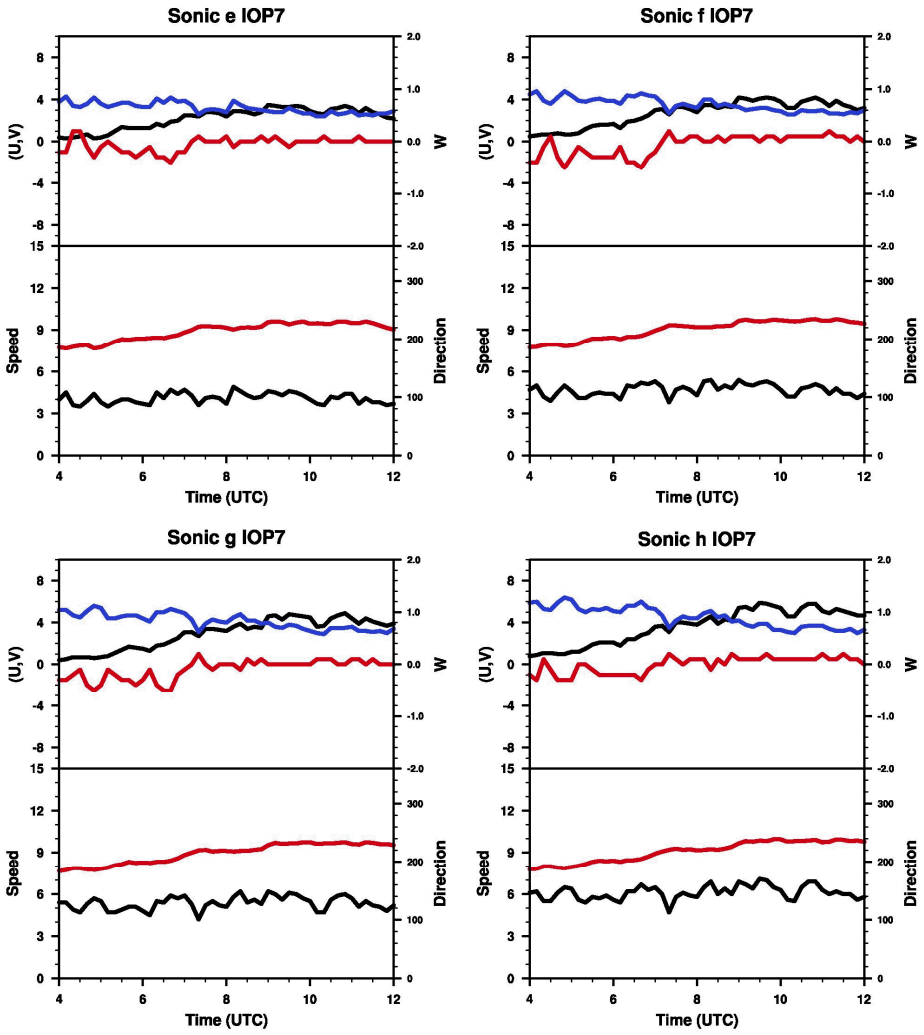


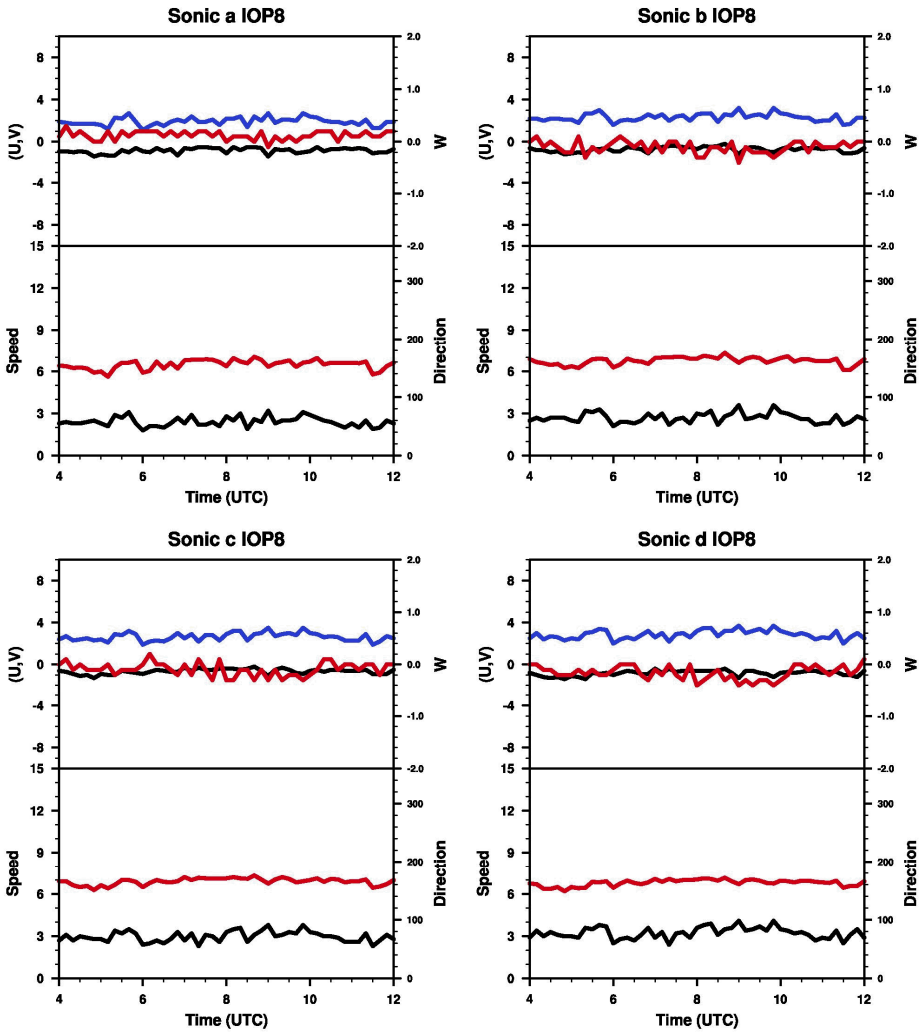
Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



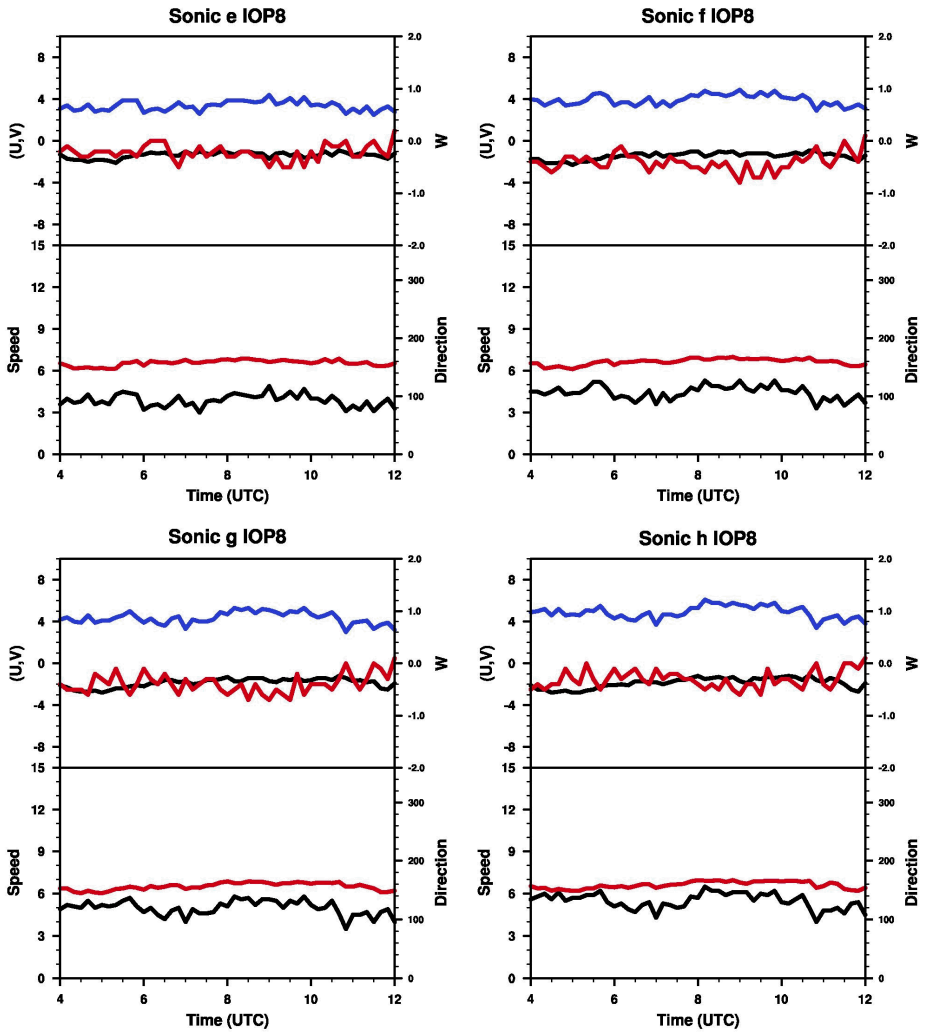
Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



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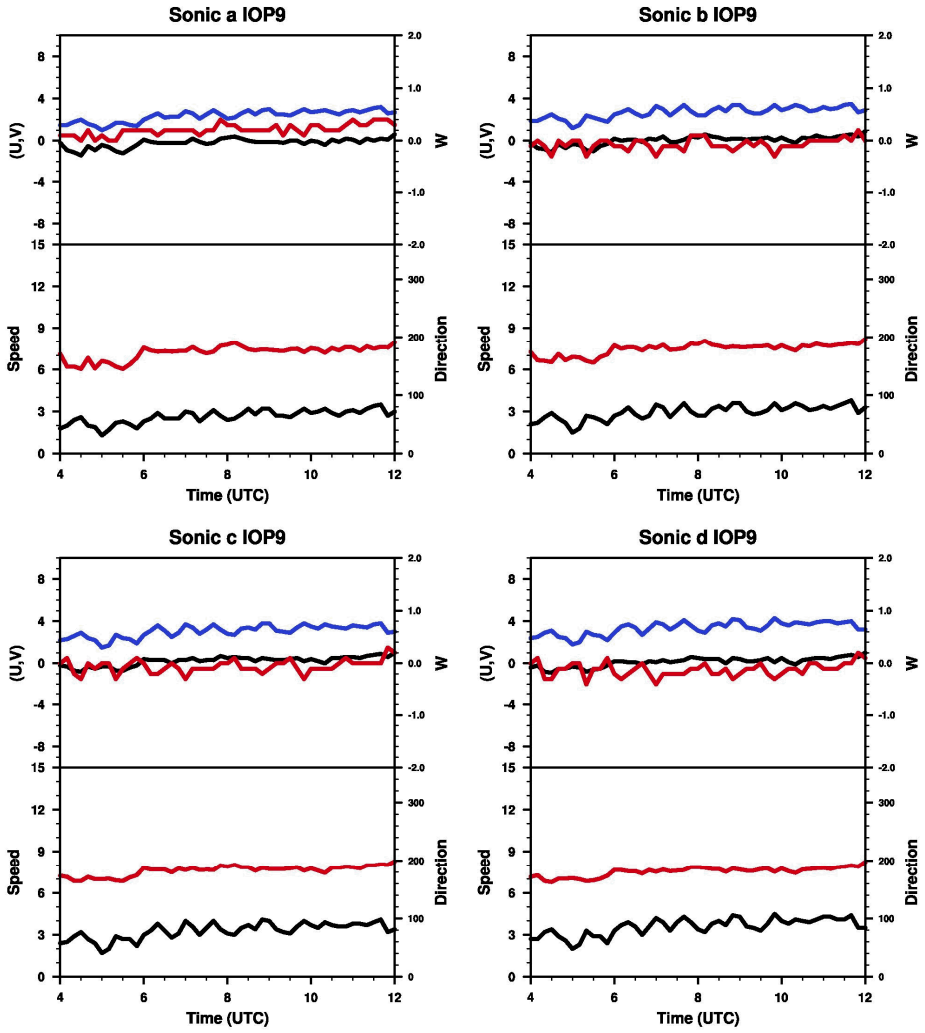
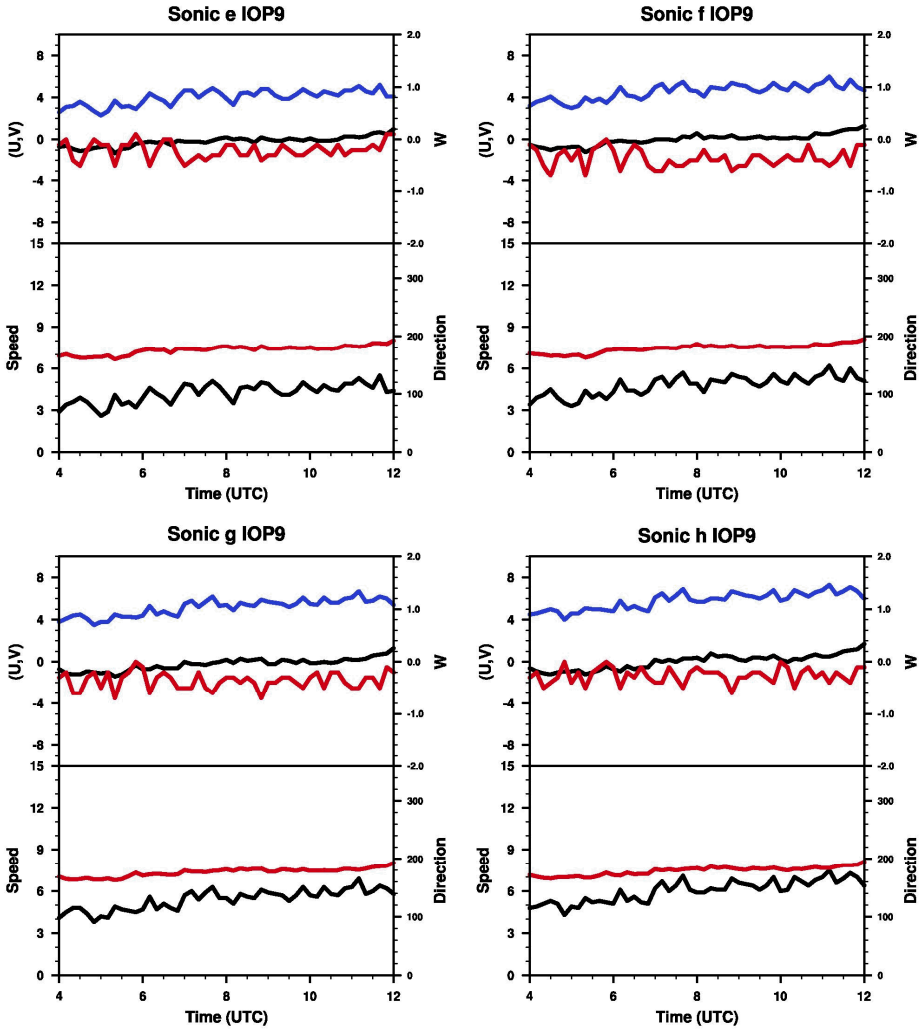


Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.



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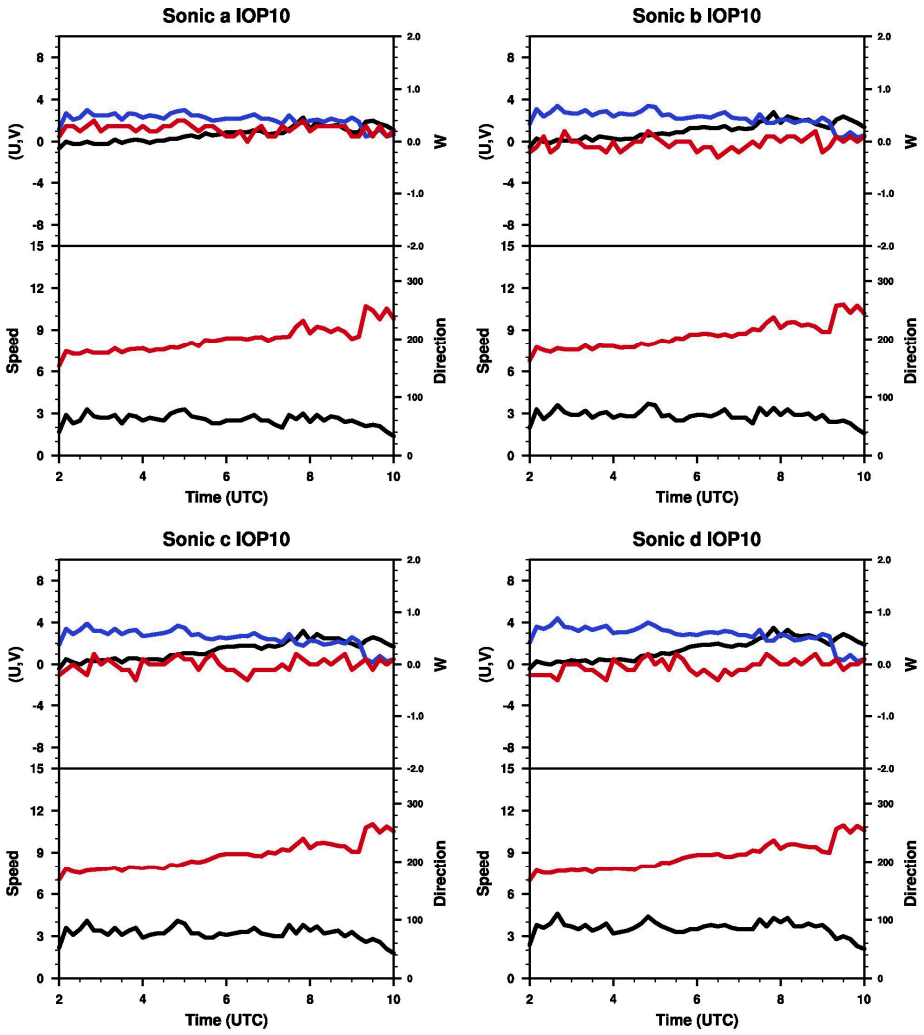

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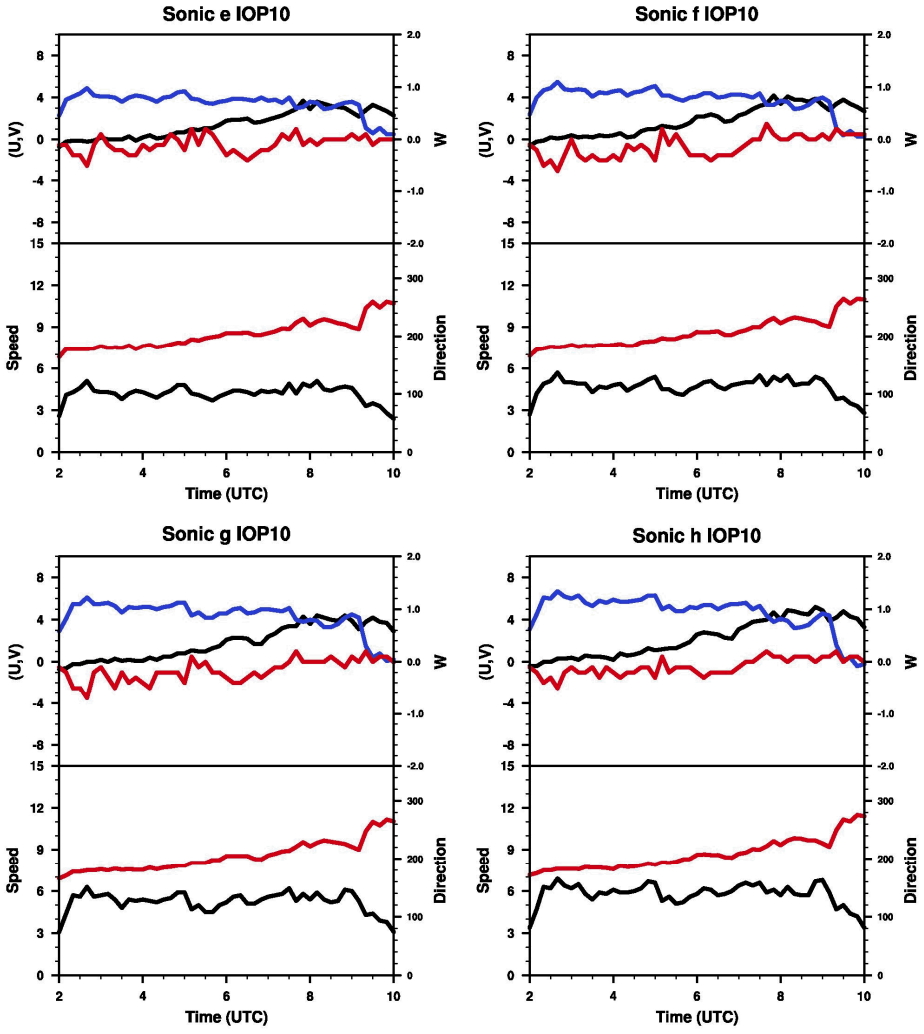
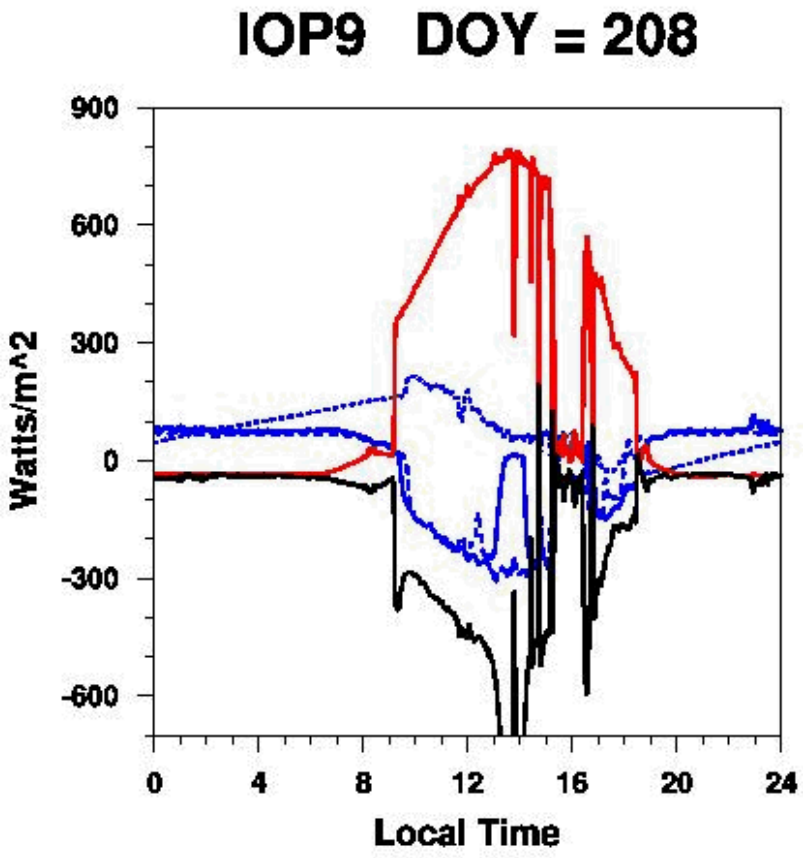


Ten-minute average winds from the sonic anemometers on the crane. The upper panels are the (u,v,w) components in black, blue and red respectively. The lower panels are the speed and direction in black and red.

Components to calculate a surface energy budget were installed on the University of Oklahoma's tower, which was erected in Park Avenue. The data is available at the JU2003 archive, however the reliability of the system was low and therefore much data is missing. An example of the SEB data is plotted below.



Acknowledgements

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