STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV 10/98)

1. REPORT NUMBER

2. GOVERNMENT ASSOCIATION NUMBER

3. RECIPIENT'S CATALOG NUMBER

4. TITLE AND SUBTITLE

Quantify the Effect of Roadside Barrier on Near Road Air Pollutant Dispersion and Concentration

5. REPORT DATE

April 2023

6. PERFORMING ORGANIZATION CODE

N/A

7. AUTHOR

Javier González-Rocha Ranga, Yifan Ding, David Pankratz, Akula Venkatram

8. PERFORMING ORGANIZATION REPORT NO.

N/A

9. PERFORMING ORGANIZATION NAME AND ADDRESS

University of California, Riverside
Department of Mechanical Engineering
900 University Avenue
Riverside, CA 92521

10. WORK UNIT NUMBER

N/A

11. CONTRACT OR GRANT NUMBER

N/A

12. SPONSORING AGENCY AND ADDRESS

California Department of Transportation (Caltrans)
Division of Research, Innovation and System Information, MS-83
1727 30th Street Sacramento, CA 95816

13. TYPE OF REPORT AND PERIOD COVERED

Final Report

14. SPONSORING AGENCY CODE

N/A

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Roadside barriers, which are common in California, are designed to reduce the impact of highway noise on people living close to highways. Studies indicate that these noise barriers can also reduce near-source pollutant concentrations by as much as 20-40% within 180 m from the source relative to those in the absence of the barrier. This has motivated the development of algorithms that account for the mitigating impact of roadside barriers on near-road air quality. The US EPA recommended model, AERMOD, for regulatory applications includes a research version of an algorithm for barrier effects. Before this algorithm, based on results from wind tunnel and tracer studies, can be used for regulatory applications that involve the impact of vehicular emissions, it must be evaluated with data from real-world highways.

Once an acceptable algorithm is developed, transportation projects will be able to quantify the mitigation offered by roadside barriers for conformity determination. It will also enable estimating the air quality benefit that barriers currently provide to near-road residents. The overall objective of this project was to construct the data set required to evaluate the roadside barrier algorithm. This objective was achieved by conducting field studies in the vicinity of roads with noise barriers to collect the data and then processing the data to a form that can be used to evaluate the algorithm. Three field studies (one barrier study, two barrier study, and no barrier study) at three near-road sites located in the greater Riverside/San Bernardino area were conducted. The field studies have provided data sets that can be used to evaluate the performance of AERMOD in estimating the air quality impact of emissions from vehicles traveling on roads with noise barriers.

17. KEY WORDS

roadside barrier, soundwall, noise barrier, air quality, pollutants, AERMOD, tracer study,

18. DISTRIBUTION STATEMENT

No Restriction.

19. SECURITY CLASSIFICATION *(of this report)*

Unclassified

20. NUMBER OF PAGES

47

21. COST OF REPORT CHARGED

Measurement Report for Quantifying the Effects of Roadside Barriers on Near Road Air Pollutant Dispersion and Concentration: No-Barrier and Two-Barrier Sites

Prepared for:

California Department of Transportation Division of Research, Innovation and System Information
1120 N Street
MS49
Sacramento, CA 95814

Contract No. 65A0707

March 6, 2023

Principal Investigators:
Javier González-Rocha
Ranga Rajan Thiruvenkatachari
Yifan Ding
David Pankratz
Akula Venkatram
Department of Mechanical Engineering
University of California, Riverside
Riverside, CA 92521
(951) 827-2105

UC RIVERSIDE Caltrans CALIFORNIA DEPARTMENT OF TRANSPORTATION

DISCLAIMER

EXECUTIVE SUMMARY

Roadside barriers, which are common in California, are designed to reduce the impact of highway noise on people living close to highways. Field (Finn et al., 2010) and wind tunnel (Heist et al., 2009) studies, using line sources of tracers to simulate roads, indicate that these noise barriers can also reduce near-source tracer concentrations by as much as 20-40% within 180 m from the tracer source relative to those in the absence of the barrier. This has motivated the development of algorithms that account for the mitigating impact of roadside barriers on near-road air quality.

The US EPA recommended model, AERMOD (Cimorelli et al., 2005), for regulatory applications includes a research version of a algorithm for barrier effects. Before this algorithm, based on results from wind tunnel and tracer studies, can be used for regulatory applications that involve the impact of vehicular emissions, it must be evaluated with data from real-world highways. Once an acceptable algorithm is developed, transportation projects will be able to quantify the mitigation offered by roadside barriers for conformity determination. It will also enable estimating the air quality benefit that barriers currently provide to near-road residents.

The overall objective of this project is to construct the data set required to evaluate the roadside barrier algorithm. This objective was achieved by conducting field studies in the vicinity of roads with noise barriers to collect the data and then processing the data to a form that can be used to evaluate the algorithm.

Researchers from the University of California, Riverside (UCR) Mechanical Engineering Department conducted field studies at three near-road sites located in the greater Riverside/San Bernardino area. The first study was conducted in July/August 2019, and the second and third studies were conducted in the summer of 2022 after a two-year hiatus caused by the pandemic. The tracer measurements were supplemented with selected meteorological parameters and traffic counts. Data from the no-barrier site will be compared with those from the barrier sites to quantify the effects of barriers on near-road air quality. This report presents the results from tracer measurements conducted during the summer of 2022 at near-road sites with no-barrier and double-barriers. A separate report (Pankratz and Venkatram, 2020) presented the results for these measurements performed at the single barrier location.

The first study at a site with a single downwind barrier was conducted during a two-week period in July/August 2019 along a 2 km section of Interstate 215 (I-215) running through the UCR campus. Measurements were performed on four consecutive Tuesdays: 1300-1630 PDT 7/30/2019, 1500-1830 PDT 8/62019, 2000-2330 PDT 8/13/2019 and 1800-2130 PDT 8/20/2019. Eight vehicles were outfitted and used to release sulfur hexafluoride, the tracer gas, as the vehicles traveled in a loop that included the northbound and southbound lanes of I-215. Samples were collected at one upwind location and 39-46 downwind locations. The downwind samplers were located 3 to 200 meters downwind of the freeway with sample inlet heights between 1 and 5 meters. Other data required to evaluate the barrier algorithm included meteorological variables measured with sonic anemometers and traffic count. The tracer measurements were supplemented with concentration measurements of carbon monoxide (CO), carbon dioxide (CO_2), and black carbon (BC).

The second tracer study was conducted over a 3.5-hour periods on three days at a no-barrier site in Riverside, California along the section of Chicago Avenue running between Martin Luther King Boulevard and Le Conte Drive. The tracer release system consisted of four vehicles fitted with SSFF 6 release systems that were driven in loops in the study area. The sampling system consisted of six samplers collecting 30- minute integrated air samples. The sampling systems were placed from 3 m downwind of the edge of the road to 200 m. Sampling towers were placed 10 m from the edge of the road collecting samples at different heights (1.5 m, 5 m, and 10 m). The air samples collected from the field experiment were analyzed at the

UCR College of Engineering Center for Environmental Research and Technology using three gas chromatographs fitted with electron capture detectors.

The double-barrier study was conducted next to a section of SR-71 in Corona. The section, which was 700 m long, had an upwind and downwind barrier. Samplers were placed between 3 m and 322 m from the downwind barrier at the double-barrier site. Three 3-D sonic anemometers were used to measure meteorological variables at the double barrier site.

A total of 798 30-minute average samples was collected at the no-barrier site and analyzed. A total of 508 30-minute average samples was collected at the double-barrier site. The precision of the SSFF measurements collected from the no-barrier and double-barrier sites met pre-determined quality metrics. A system audit, performed on 08/05/2022, found the project sample handling, data processing and recording keeping met specifications. Precision of the integrated bag samplers were assessed using two methods. The first was by collocating samplers at two locations and the second was by replicate analysis. The precision of the measurements met specified metrics. All tracer gas, meteorological, and vehicle count data were subjected through zeroth- and first-level data quality checks and controls. A total of 1312 primary samples were analyzed out of which 104 samples were invalidated. Reasons for invalid samples included flat bags, GCs going full scale, and other instrument analysis anomalies.

The field experiments performed during the summers of 2019 and 2022 have provided data sets that can be used to evaluate the performance of AERMOD in estimating the air quality impact of emissions from vehicles traveling on roads with noise barriers, which are common in California. These results will greatly extend the ability of Caltrans and other regulatory agencies in assessing the air quality impact of highway projects.

ACKNOWLDEDGEMENTS
The field measurements were made possible by a group of individuals and organizations whose valuable contributions are greatly appreciated. We wish to thank the following organizations and individuals for their time and resources in contributing to the success of the measurement program:

1. **Caltrans District 8** for allowing the use of the land near the roadside barrier and for use of approximately 200 traffic cones.

2. **Google™** for their permission to use the maps presented in the figures of this document.

3. **UCR Graduate and Undergraduate Students** for their dedication to learning new tasks, working as a team, putting in long hours and working both late nights and early mornings.

The following undergraduate students contributed to the success of the field study:

Ms. Chloe Au, Ms. Angela Calderon, Mr. Nathaniel Bernal, Mr. Kenneth Chew, Mr. Jason Chu, Mr. Kenneth Chung, Ms. Khan H. Duong, Mr. Bryan Flores, Mr. Nathan Gee, Ms. Rajbir Kaur, Mr. Zain Khan, Mr. Harrison Kong, Mr. Braxton Mott, Mr. José Rocha-Rocha, and Ms. Grace Vu.

5. **UCR Fleet Services and Mr. Kyle Walker** for providing the vehicles that we equipped for the tracer gas release study.

6. **The following project advisory group team members from the EPA** for their inputs into the execution of the measurement program and their technical and editorial review of project reports: Mr. Chad Bailey, Dr. Richard Baldauf, Ms. Laura Berry, Dr. David Heist, Ms. Karina O'Connor, and Dr. Chris Owens.

7. **Professor Jay Gan Jay** in the UCR Environmental Sciences Department for the loan of five GC/ECDs for the tracer gas measurements.

Table of Contents

List of Figures

List of Tables

1 Roadside Barriers

"Highway traffic noise has been a Federal, State, and local concern since the first noise barrier was built in 1963" (FHA, 2020a). These barriers, referred to as "sound walls," "noise barriers" or "roadside barriers" vary in height from approximately 2 meters to 5 meters or more (FHA 2020b). In addition to affecting the amount of highway noise reaching adjacent property, these roadside barriers also affect the transport of vehicle emissions from the highway (Finn et al., 2010). This report presents the findings from air quality transport and dispersion measurements made along roadways with no barriers and also along roadways with barriers on both sides of the roadway.

1.1 Introduction

The US EPA recommends AERMOD (Cimorelli et al., 2005) for modeling dispersion of pollutants associated with mobile sources. The current regulatory agency version of the model does not include the effects of near-road solid barriers, which have become very common in California. These barriers, which are designed to reduce the impact of highway noise on people living close to highways, can have significant effects on near road air quality. Field (Finn et al., 2010) and wind tunnel (Heist et al., 2009) studies using line sources of tracers to simulate roads indicate that these noise barriers reduce near-source concentrations by as much as 20-40% within 180 meters (m) from the tracer source relative to those in the absence of the barrier. The US EPA research model for line source, RLINE (Snyder et al., 2013), includes a roadside barrier algorithm to model these effects, but has yet to be evaluated for its applicability to estimating the impact of vehicular emissions on near-road air quality in the presence of real-world sound barriers. R-LINE algorithms have been incorporated into AERMOD; the roadside barrier algorithm has been included as an under review (Alpha) option. Note that Alpha options cannot be used for regulatory purposes at this time (EPA, 2019).

The objective of the project is to conduct tracer studies at three near-road sites and compile the findings into a database for evaluating the performance of the roadside barrier algorithm. The algorithm would be used to quantify the effects of roadside barriers on air pollutant dispersion and concentration. The tracer measurements will be supplemented with selected meteorological parameters and traffic count.

This research project includes conducting field studies at three sites along roadways in the Riverside/San Bernardino/Los Angeles area. The three sites include 1) a roadway without roadside barrier, 2) a highway with one roadside barrier, and 3) a highway with two roadside barriers; one on each side of the road. The measurements and finding for the work performed at the single-barrier were reported by Pankratz and Venkatram (2020).

1.2 Study Days

The tracer studies were conducted over a period of 3.5 hours on three days at the no-barrier site, and two days at the double barrier site. These were the primary samples for the project. For purposes of this report, these days are referred to as "study days" and the periods these samples were collected are referred to "study periods."

2 Description of Measurement Equipment

2.1 Tracer Gas Release

Tracer gas release systems were placed on four vehicles. The tracer gas was introduced into these vehicle exhaust wake using the tracer gas release system shown in Figure 2-1 and Figure 2-2. At the no barrier site, the four vehicles were assigned to each of the four traffic lanes while at the double barrier site only the two slowest traffic lanes for each highway direction were used. The release system for each vehicle included a small cylinder containing pure SF_6. Each cylinder contained an initial SF_6 fill of 3.3 kg. This fill amount was more than adequate for the five tracer release days (estimated to require 2 kg from each cylinder) yet low enough to prevent the exceedance of the project's California Air Resources Board (CARB) allowance of 35 kg, should the contents of a cylinder accidently leak out. The gas cylinder pressure regulator was connected to an electric solenoid that was controlled by an operator in the passenger seat of each vehicle. For some vehicles on one of the study day the driver operated the release system. The operator controlled a switch with light indicating the open or closed status of the solenoid. With the switch in the open solenoid mode, the tracer gas flowed from the solenoid to a mass flow controller. The mass flow controller set point and actual measured flow rate signals were controlled and logged by single board Arduino computers.

The position (latitude and longitude) and speed from onboard GPS units were also fed to the single board computers. Due to possible vehicle traffic slowdowns, the computer used the vehicles' speed to control the tracer gas release rate. The systems were programmed to provide the full 42 ml/s release rate for vehicle speeds of 100 km/hr (62 mph). The release rate was linearly reduced as vehicle speed dropped. This control kept the release rate at the desired 30 ml/km/s. The cylinders of SF_6 were weighed before and after each day's use using a scale with 0.01 kg resolution. Release data were logged by the Arduino computer. Laptop computers were added to independently log the data. The logging function was independent of the tracer release control; tracer gas was still released when the data logging function was inoperative. The before and after tracer cylinder weighing data along with the release data from the tracer release logs (Figure 2-5) were used to determine the tracer gas release for the periods where there were no logged data.

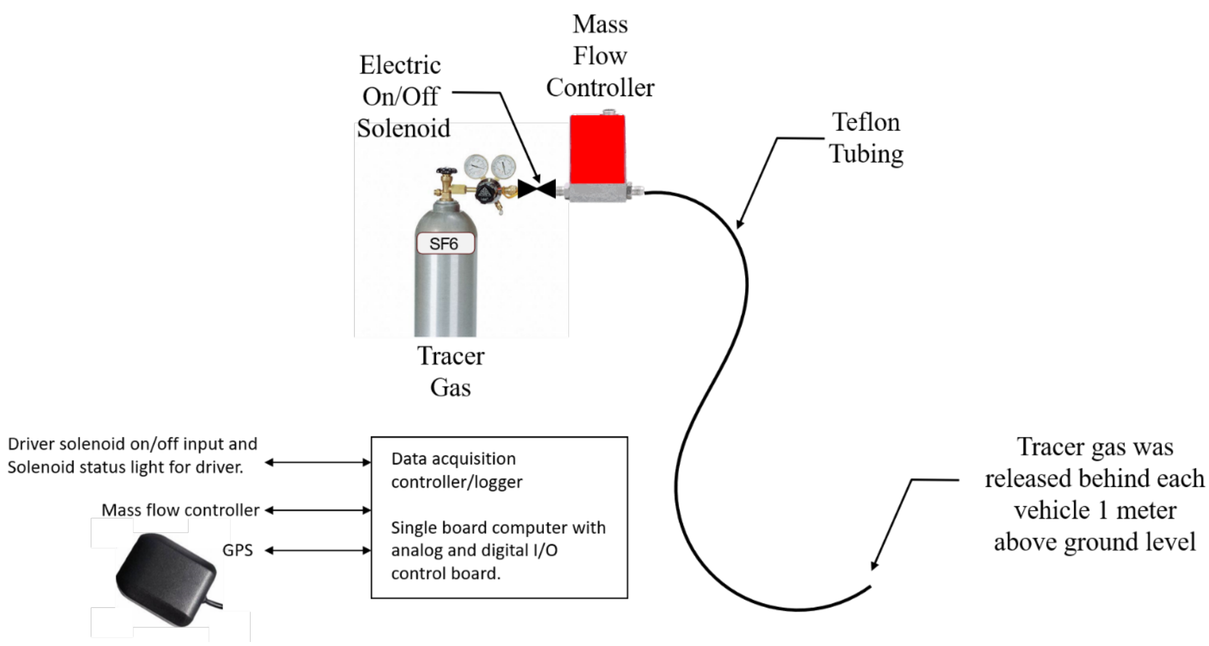

Figure 2-1 Tracer Gas Release System

The four tracer gas vehicles were staged at UCR's College of Engineering, Center for Environmental Research and Technology (CE-CERT) facility. The vehicles were started about 1.5 minutes apart from each other to obtain a more uniform tracer gas release along the tracer release zone. The coordinator for the tracer release was stationed at Le Conte Dr. at the no barrier site. At the no barrier site each vehicle stopped at that location during every loop through the circuit. Depending on the amount it time it took to complete each loop, the coordinator either directed the vehicles to continue or to wait a short period to maintain the overall tracer gas release rate at the desired level. The average time to complete a loop at the no-barrier site was 6 minutes. At the double barrier site there were no safe place to station a coordinator. Vehicle release logs from the double-barrier test show the average time to complete a loop was 5 minutes. At the no-barrier and double-barrier sites, existing roadway traffic signs were used to designate the location for the drivers and technicians to start and stop the tracer gas release (Figure 2-3, Figure 2-4). The total release distance at the no-barrier and double barrier sites are found in Section 4.3 and Section 5.3, respectively. At the end of the study day the tracer release vehicles returned to CE-CERT. The cylinders were reweighed at that time to obtain the net weight of tracer gas released from each cylinder.

The Acteck Model A-BC200 digital scale used to weigh the gas cylinders had a 100 kg weight capacity with a 1g resolution. During every set of cylinder weighing, calibration weights of 1 kg, 100g and 10g were added to the scale to check that the scale was performing the measurements within the projects +/-0.01 kg accuracy objective.

All mass flow controllers used for the tracer gas release were calibrated prior to field use using Bios DryCal DC-Lite Primary Flow Meters.

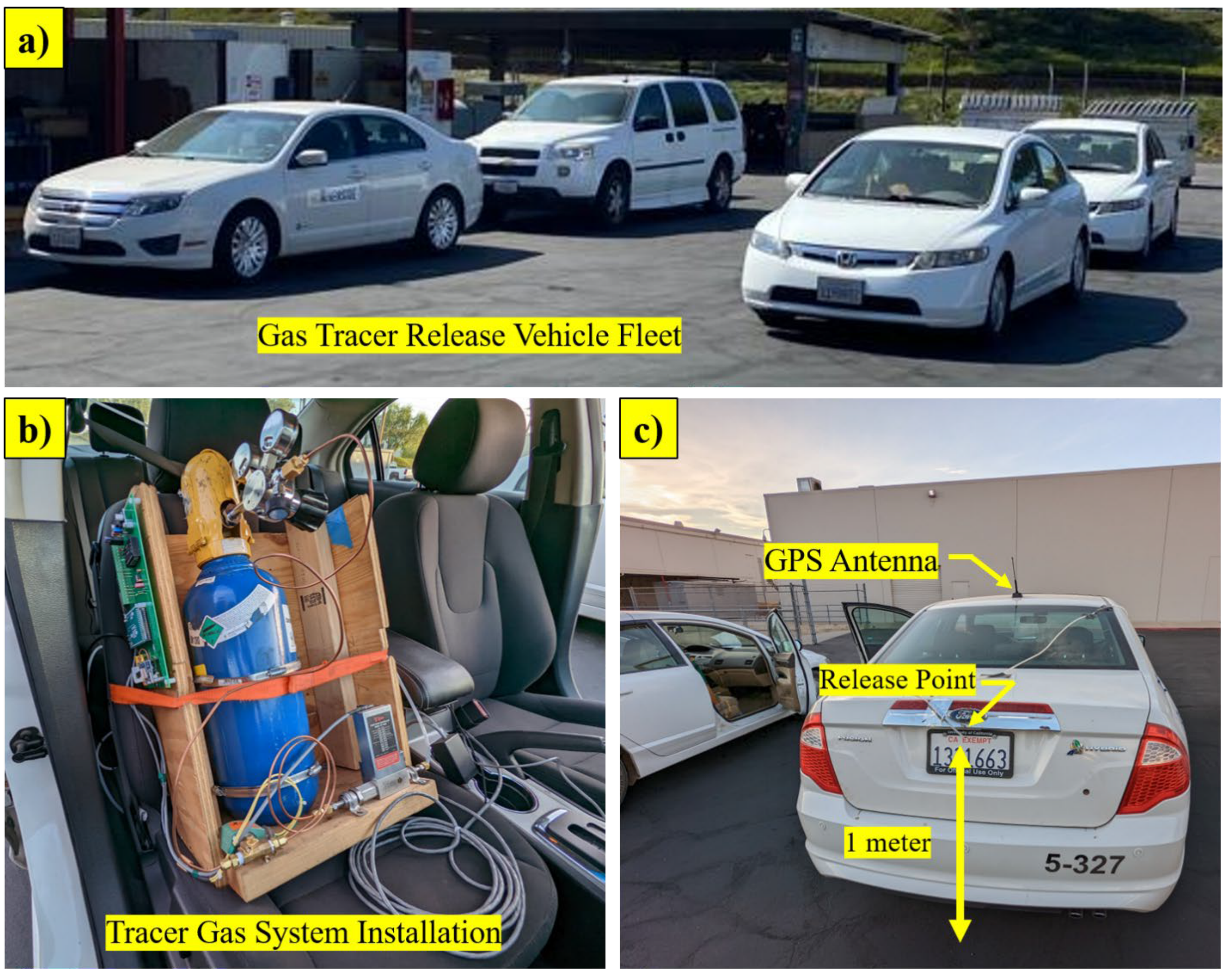

Figure 2-2 Vehicle equipped with tracer gas release system.

Figure 2-3 Tracer gas release start/stop locations at the no-barrier site.

Figure 2-4 Tracer gas release stat/stop locations at the double-barrier site.

Driver: Jose Rocha							Date: 07/28/22
System operator: Zain Khan							Notes
Cylinder #	MFC #	SV #	PR #	Start Pressure	End Pressure	Secondary Gauge Pressure Setting	
5	1	8	3	350PSI	220psi	40 PSI	
Release System Board Number: 8							
Vehicle Make and Model				Vehicle ID		Check List	
Ford fusion				5-327			
Release tubing connected:						✓	
System leak checked:						✓	
Power up system and verify GPS sync:							
Traffic lane assignment:							

Loop #	Start at Le Conte	Release towards MLK		Release towards Le Conte	
		Start	Stop	Start	Stop
1	11:44:57	11:44:57	11:45:51	11:47:18	11:48:04
2		11:49:58	11:50:24	11:51:54	11:52:54
3		11:54:35	11:55:22	11:57:09	11:57:51
4		11:59:00	11:59:47	12:01:24	12:02:17
5		12:03:52	12:04:50	12:07:25	12:08:20
6		12:09:[illegible]	12:10:40	12:12:02	12:13:03
7	12:14:26	[illegible]	12:15:20	12:17:52	12:18:54
8		12:21:00	12:22:00	12:23:57	12:24:54
9		12:25:10	12:27:05	12:29:37	12:30:26
10		12:33:08	12:34:10	12:35:45	12:36:35
11		12:37:37 12:38:[illegible]	12:38:23	12:39:59	12:40:52
12		12:42:14	12:43:00	12:44:29	12:45:30
13		12:47:02	12:49:56	12:50:09	12:51:08
14		12:53:12	12:54:06	12:55:16	12:56:17
15		1:00:18	1:01:09	1:02:31	1:03:31
16		1:04:34	1:05:20	1:06:40	1:07:45
17		1:09:32	1:10:16	1:12:23	1:13:25
18		1:14:50	1:15:42	1:17:01	1:17:55
19		1:19:44	1:20:37	1:22:35	1:23:19
20		1:25:35	1:26:24	1:28:29	1:29:26
21		1:31:50	1:32:36	1:34:29	1:35:30
22		1:36:59	1:37:52	1:39:14	1:40:16
23		1:41:27	1:42:19	1:44:41	1:45:27
24		1:46:41	1:47:32	1:48:59	1:50:00
25		1:51:46	1:52:45	1:55:00	1:56:05
26		1:56:57	1:57:53	1:59:28	2:00:23
27		2:01:26	2:02:14	2:03:35	2:04:29
28		2:05:30	2:06:22	2:07:36	2:08:32
29		2:10:05	2:11:01	2:13:16	2:14:18
30		2:16:14	2:17:16	2:19:20	2:20:16
31		2:21:09	2:21:56	2:23:30	2:24:24
32		2:25:39	2:26:27	2:27:48	2:28:43
33		2:29:50	2:30:00		

Figure 2-5 Tracer gas release log for vehicle 1 on 07/28/2022.

2.2 Integrated Bag Sampler Gas Sample Collection (SF_6)

Gas samplers designed and constructed by UCR were used to collect integrated air samples over 30-minute time periods for SF_6. These samplers consisted of a timer that controlled up to eight air-sampling pumps. For this study, six of the pumps were connected to 12-liter polyethylene bags. Rechargeable batteries were used to power the pumps and the timer. When activated, each pump was set to fill the respective bags at a rate of 220±50 ml/min from an inlet manifold to the bag to which it was connected. The timer consisted of a programmable single board computer (Z-World Rabbit Model 1810) with added drivers for each of the sample pumps. As shown in Table 2-1, the timer was programmed to collect a 30-minute background sample to look for potential SF_6 in the existing ambient air starting one hour prior to the start of the tracer gas release. The timer was also programmed for each subsequent pump to sequentially turn on fifteen minutes after the start of the tracer gas release and run for 30-minutes. Four subsequent 30-minute sample periods and collections were conducted. A total of six sample bags were collected from each sampler (one background and five 30-minute sample periods for each study day). All the equipment was housed in a polyethylene tote box (Figure 2-6). Numbered quick connectors were used to attach the bags and pumps. The bags were positioned in a carrier for easy and accurate installation and removal. At the end of the study period, project staff removed the sample media from the integrated samplers and returned them to the UCR project lab for analysis.

Table 2-1 General Tracer Gas Release and Integrated Sample Collection Periods.

Tracer gas release								
Integrated sample collected	1	N.S.	2	3	4	5	6	
Begin Time (HH:MM)	0:00	0:30	1:00	1:30	2:00	2:30	3:00	3:30

Tracer gas released during periods in green highlighting

Integrated samples collected during 30-minute periods shown in light blue highlighting

NS = No sample collection during the time period

UCR sample collecting teams that collected the samples from the multiple site locations filled out a chain of custody record for each set of samples in the field (Figure 2-8). The team members typically worked in groups of two; each group was responsible for collecting samples from 15 to 20 locations. The chain of custody records required the following information: the site location, the bag set at that location, the percent inflation of the bag set being removed, and a check on the conditions of the samplers. These forms were brought back to the lab along with the sample and checked off upon arrival at the lab by another set of team members who analyzed the samples. The data analysis team made a record for each bag set returned to the lab to ensure the prompt identification of potential air sampling anomalies.

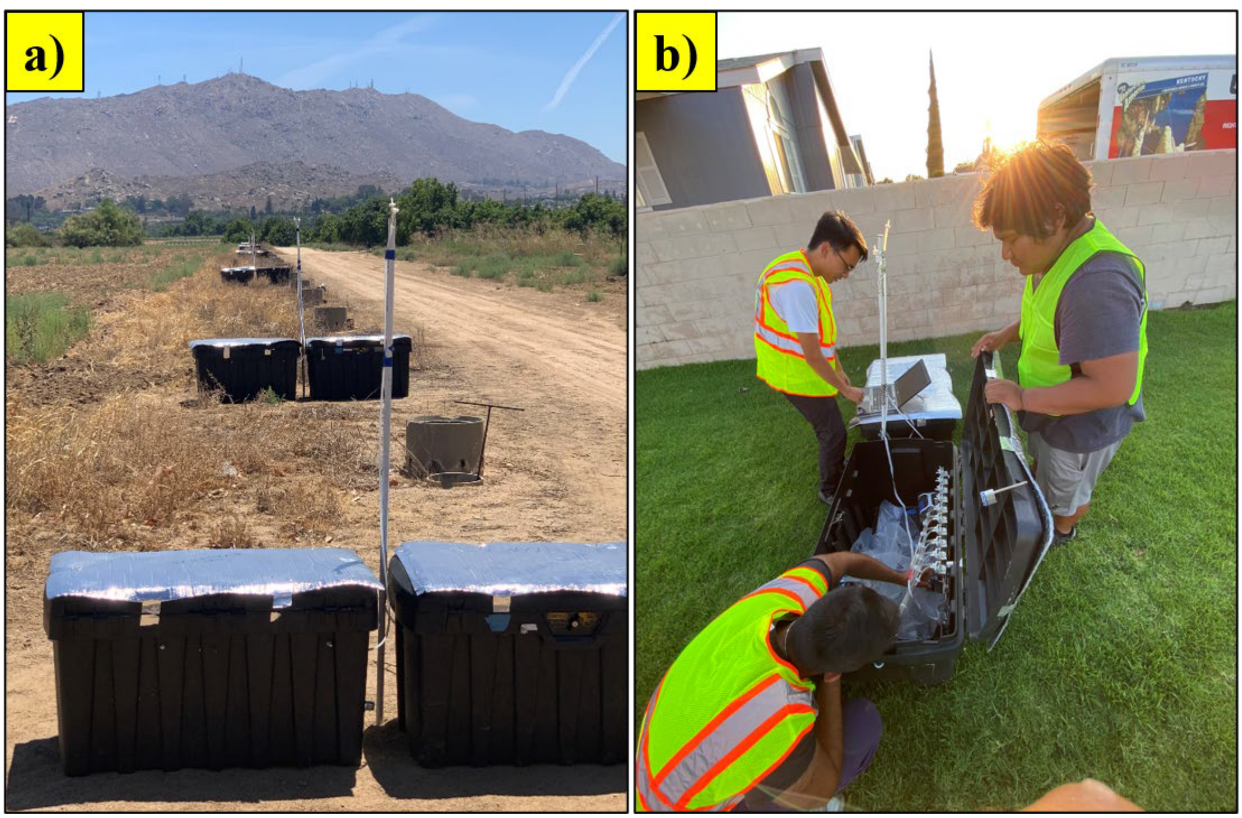

Figure 2-6 UCR gas sample collection system (bag sampler)

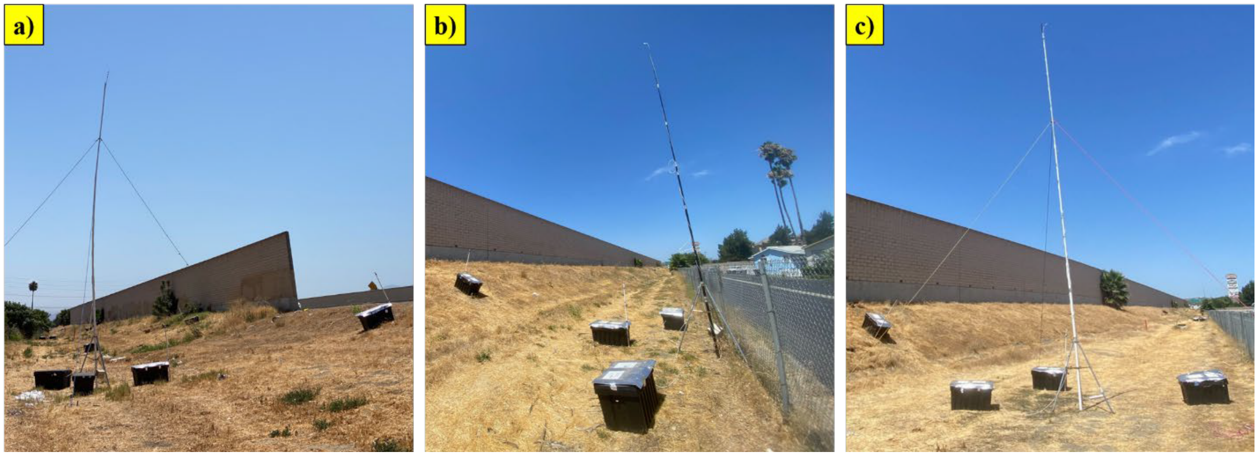

Figure 2-7 Pictures showing the tower sampling air at 1.8, 5 and 10 m.

Set 1	Pump #	%Full	Notes	Set 2	Pump #	%Full	Notes	Set 3	Pump #	%Full	Notes
A-3	1	20		A-3	1	50					
	2	50			2	100					
	3	30			3	60					
	4	30			4	50					
	5	30			5	[illegible]	80				
	6	40			6	50					
A-10	1	—	1.5 m FLAT BATT DISC	A-10	1	50	10 m	A-10	1	40	5m
	2	—			2	80			2	50	
	3	—			3	60			3	40	
	4	—			4	90			4	30	
	5	—			5	70			5	40	
	6	—			6	60			6	60	
A-20	1	100		A-20	1	60					
	2	70			2	40					
	3	90			3	60					
	4	60			4	70					
	5	50			5	70					
	6	90			6	60					
A-50	1	50		A-50	1	40					
	2	90			2	40					
	3	60			3	40					
	4	60			4	40					
	5	60			5	60					
	6	60			6	50					
A-100	1	70		A-100	1	80					
	2	80			2	60					
	3	40			3	60					
	4	40			4	50					
	5	50			5	60					
	6	40			6	70					
A-150	1	60		A-150	1	flat					
	2	60			2	50					
	3	60			3	50					
	4	80			4	40					
	5	60			5	50					
	6	80			6	70					
A-200	1	60		A-200	1	60					
	2	60			2	50					
	3	50			3	60					
	4	40			4	60					
	5	70			5	30					
	6	30			6	50					

Row A	Row B	Row C
Kenny	Harrison	Kenneth
Chloe	Khanh	Nathan
Bryan	Braxton	Adrian
Ranga	Jason	Javier

Kenneth Kenny Harrison
Khanh Bryan Jason

Figure 2-8 Field sampling checklist and claim of custody form.

2.3 Meteorological Measurements

Campbell Scientific Model CSAT3 sonic anemometers were used to measure winds on all three axes and temperature. The wind speeds for the three axes are determined from the time of flight from acoustic signals transmitted and received from three pairs of sensors covering the three axes using the calculations shown in Table B-2. The sensors are not orthogonal to each other nor are they aligned with the u-, v- or w-axes, rather the system electronics uses the known fixed angles of the sensors to calculate the winds for the u-, v- and w-axes using the sonic wind speed from the instrument's three pairs of sonic winds it determined. Temperature is obtained from the determination of the speed of sound from sensor data. At the no barrier site two downwind sonic anemometers were mounted at the heights of 3 m and 5 m. At the double barrier site only one upwind sonic anemometer was collection data on the Study Day 1 at 3 m. On Study Day 2 at the double barrier site two upwind sonic anemometers were measuring at 3 m and 5 m and one downwind sonic anemometer was measuring at 2.5 m. The sonic anemometers were placed at the locations shown in Figure 4-1 and Figure 5-1. Pictures of the meteorological towers are shown in Figure 2-9 and Figure 4-2. The lat-lon coordinates of the met towers installed at the no-barrier site and the double-barrier site are shown in Tables 4-1 and 5-2, respectively.

Figure 2-9 presents a photograph of the two-level upwind sonic anemometers at the double barrier site. The signals from the sonic anemometers were logged and processed by Campbell CR5000 data loggers. The sonic anemometers output their data to the data loggers twenty times per second (20 Hz). The raw 20 Hz data were recorded by the data loggers. The raw data were downloaded from the field sites and taken back to the UCR labs for additional processing. The raw wind data axes were rotated to align with true north. These data were processed into 30-minute averages for the parameters shown in Table 2-2. All the sonic anemometers were collocated at the CE-CERT facility prior to field deployment and allowed to collect ambient data over a 48-hour period.

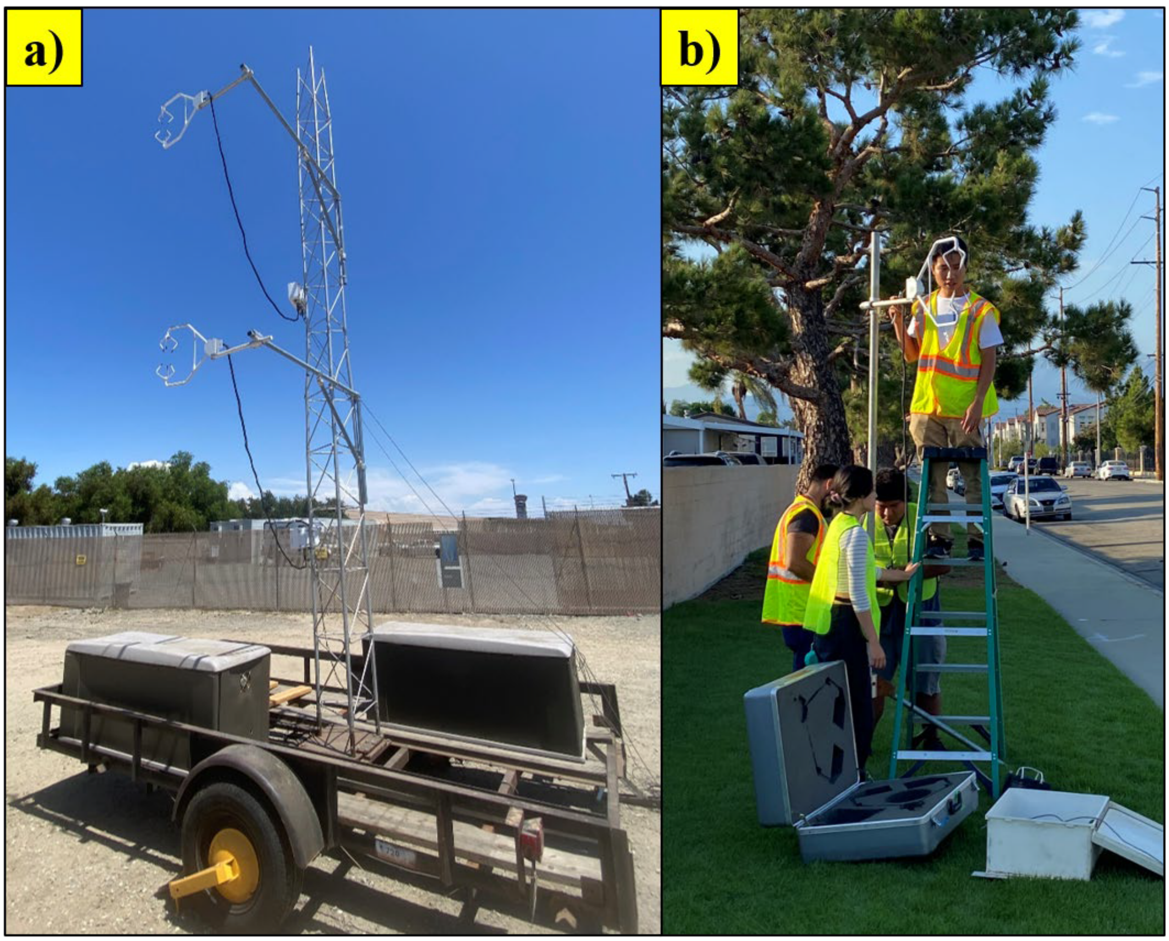

Figure 2-9 Tower-mounted sonic anemometers.

Table 2-2 Meteorological parameters logged and calculated.

column	unit	parameter
date		date/time in PDT
Ubar	m/s	wind speed vector averaging
Uscalar	m/s	wind speed scalar averaging
WindDirection	Degree	meteorology wind direction
Wbar	m/s	wind speed in z direction
Tbar	C	temperature
sigmau	m/s	Standard deviation of fluctuating wind velocity(Turbulence Strength) in x (along wind)
sigmav	m/s	Standard deviation of fluctuating wind velocity(Turbulence Strength) in y (crosswind)
sigmaw	m/s	Standard deviation of fluctuating wind velocity(Turbulence Strength) in z (vertical wind)
sigmaT	C	temperature fluctuation
HeatFlux	Km/s	kinematic flux
ustar	m/s	friction velocity
MOLenght	m	Monin-Obokov length

2.4 Traffic Count Measurement

After assessing several different software programs, it was determined that the most reliable and cost-effective way to process the video data would be manual counting the vehicles from the recordings into two categories, cars and heavy-duty trucks. For the no-barrier and two-barrier site studies, cargo and utility trucks were included with the heavy-duty vehicles. Because there was no in-ground Caltrans PeMs traffic count data at the no-barrier site and due to processing cost considerations, vehicle counting for both sites were done using our recorded video data.

2.5 Analysis System for SF_6

The UCR analysis system shown in Figure 2-10 and Figure 2-11 was used to analyze field samples in batches of three sites. All six sample bags from each of three samplers from the collection sites were attached to the custom-built auto sampler using the same quick connect plumbing as that used in the collector. Solenoid valves and pumps were used to control twenty-seven samples (18 field samples and 9 QC samples) which were directed to the measurement instruments. A PC with LabVIEW software was used to control the sampling from the bag, injection into the GCs and other instruments, quantification of the resulting instrument responses. This analysis system was "loaded" with the samples, determined their gas concentrations, performed zero and precision checks and reloaded for the next run in 36 minutes. The UCR analysis system has the capability of processing 660 samples and perform two complete calibration of the gas chromatographs in twenty-four hours (daytime and nighttime shifts). For this study we used daytime sample analysis work shifts only with a maximum analysis day of 17 hours. Three sample trains were used to analyze SF_6. At least fifteen percent of the samples were analyzed a second time by one of the three primary SF_6 sample trains.

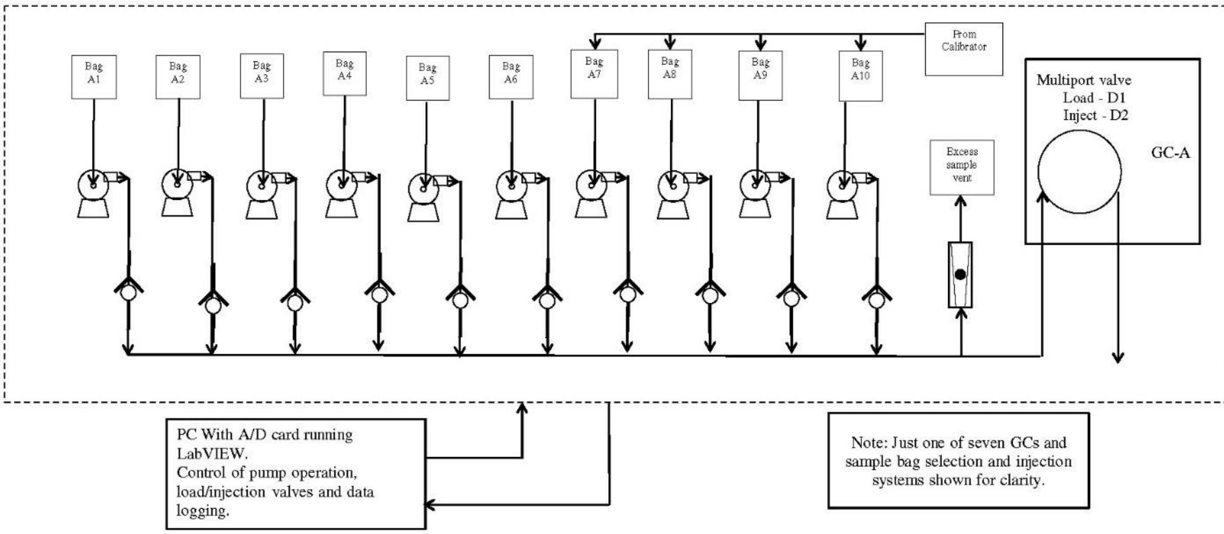

Figure 2-10 Sample selection, analysis and data logging analysis system.

Figure 2-11 UCR analysis system.

The integrated tracer samples were measured using a bank of Agilent Technology 6890N electron capture (ECD) gas chromatographs (GC) equipped with a 1/8-inch diameter Molecular Sieve 5A column and multi-port gas sampling valves.

Both a Thermo Electron Model 146C mass flowmeter calibrator and a UCR dilution system were used to calibrate the tracer gas analyzers. The Thermo calibrator was used to mix calibration gas and zero air to desired calibrations. The UCR dilution system consists for three mass flow controllers. It allowed mixing of cylinder standards of SF_6 in variable ratios with zero air for creating samples for the zero and precision checks that were performed approximately every 90 minutes with each set of sample bags as well multipoint calibrations at the beginning and end of each day analyses were performed. All mass flow controllers were calibrated prior to field use using Bios DryCal DC-Lite Primary Flow Meters.

The bag sets that were brought back to the lab were analyzed by a team of four students in the lab. The samples were analyzed within forty-eight hours of collection to ensure accuracy. Three sets of bags (each set included six bag samples, a zero check and two precision checks) could be analyzed in approximately 36 minutes. Analysis teams kept a written record (Figure 2-12) of the results shown on the computer display running the LabView sampling and analysis software.

Date:				Run#: 16	Operators: Braxton, Vennetta, Greene							
				GC #1			GC #2			GC #3		
Sample	Time	Comments	Cycle #	Bag Set: C-3-X-3			Bag Set: I-465-X-3			Bag Set: H-3-X-3		
				Bag Volume (%)	SF6 Peak (%)	GC Range	Bag Volume (%)	SF6 Peak (%)	GC Range	Bag Volume (%)	SF6 Peak (%)	GC Range
~~6000~~ 9000 ppt (Bag 7)	1:56		0		full scale	2		full scale	2		70	4
500 ppt (Bag 8)	2:00		1		25	2		15	2		5	4
Zero Air (Bag 9)	2:04		2		0	2		0	2		0	4
Bag 1	2:08		3	60	0	2	flat 0	0	2	50	0	4
Bag 2	2:12		4	70	full scale	2	70	10	2	70	20	4
Bag 3	2:16		5	60	full scale	3	60	15	2	90	30	4
Bag 4	2:20		6	70	full scale	4	0	0	2	1	0	4
Bag 5	2:24		7	1	1	4	70	25	2	70	30	4
Bag 6	2:28		8	50	70	5	70	40	2	50	40	4

Figure 2-12 Integrated sample analysis record.

3 Data Reduction and Validation

The objective of the data processing and validation effort is to obtain a quality assured data base containing the gaseous monitoring data in a consistent format. The procedures that our team used for data processing and validation ensure that reported data are valid and comparable to those collected by federal, state and local air pollution agencies. These procedures meet the requirements and guidelines of the Environmental Protection Agency; e.g., Appendices A and B of 40 CFR 58; Quality Assurance Handbook for Air Pollution Measurement Systems, Volumes I, II and IV (EPA, 1994, 1997, 1995). Data processing procedures for this program are discussed below.

Raw electronic data from the tracer gas release system and tracer gas analyzer were uploaded to a primary project computer. Sample logs, sample analysis records and copies of log book pages were entered into a project file. The data were processed electronically, applying calibration factors and removing or correcting data based on log entries. These data were output as Level 0.

The Level 0 data underwent further validation prior to being finalized. The validation performed included several outlier screening routines used to identify anomalous data. The validation included evaluating site concentrations against adjacent sites data, wind conditions and previous and subsequent hourly data for the site. The anomalous data were flagged.

All flagged data were reviewed by project scientists to assess if these outliers were reasonable or if they were erroneous. An entry was made in the data base of all erroneous data and these data were removed. The validated data were output as Level 1.

This Measurements Report includes the Level 1 data. The data quality goals for the project and the quality control activities necessary to obtain them are stated in terms of precision, accuracy and completeness.
A total of 1312 primary samples were analyzed: 804 from the no barrier site and 508 from the double barrier site. A total of 104 samples for SF_6 were invalidated. Reasons for invalid samples included flat bags, GC's going full scale (which happens when the SF_6 concentrations are outside of the equipment measurement range), and other instrument analysis anomalies.

3.1 Accuracy

An independent audit was originally planned to be conducted in September 2019, during the originally planned second field study. Because this field study has been moved to June 2022, the performance audit and accuracy determination was moved after the completion of the field study to August 2022.

A system audit was performed on 08/05/2022. The system audit found all of the project sample handling, data processing and recording keeping appropriate. The performance audit of the tracer gas analysis system to be within project accuracy goals. The audit report, including a description of the audit procedures and findings are attached as an electronic file named AudirReport.pdf.

3.2 Precision

Precision of the integrated bag samplers were assessed using two methods. The first was by collocating samplers at two locations to assess the precision of these measurements. The precision was determined from the degree of comparison between the pairs of collocated samples. The second method was by replicate analyses of the same sample. Analysis precision was determined from the replicate analysis variation. The goals for precision determined by both methods are presented in Table 3-1.

The precision for the measurements were determined using the following equations from the EPA QA Handbook Volume II (EPA, 2017):

The SF_6 sample precision was determined using equation below,

$$dd_{jj} = \frac{YY - XX}{\frac{(XX + yy)}{2}} \times 100\%$$

The individual coefficient of variation was then calculated for each measurement pair using the equation below,

$$dd_{ii} = \frac{dd_{jj}}{\sqrt{2}}$$

The precision is then determined as coefficient of variation for all of the measurement pairs using the following equation:

$$CCCC = \sqrt{\frac{\sum_{ii} dd_{ii}^2}{nn}}$$

where,

XX = analyzer response during first measurement

YY = replicate or collocated analyzer response

dd = individual precision check percent difference

dd = normalized precision check difference

nn = number of measurement pairs

CCCC= precision; coefficient of variation of the measurement pairs

These equations describe the instrument errors associated with the GC/ECDs. There were 92 pairs of replicate analyses that were not background.

The precision of the collocated data was determined in a similar manner. There were 272 pairs of collocated samples that were not background. The collocated precision includes assessing the instrument errors that the replicate measurements assessed as well as sampling and sample handling errors and uncertainties.

A total of 1318 30-minute average samples were collected and analyzed. The precision of the SF_6 measurements were satisfactory as shown in Table 3-2. The data precision was calculated based on 284 collocated samples and 89 repeat samples.

3.3 Completeness

The project goal was for completeness for the gaseous measurements to be at least 90%. The completeness goal for the meteorological parameters was for a minimum of 95% valid data. The completeness of the SF_6 measurements were satisfactory as shown in Table 3-2. The completeness of the meteorological data and traffic survey also met the project goals.

Table 3-1 Accuracy, precision and completeness goals.

	Project Goals		
Parameter	Accuracy	Precision	Completeness
Tracer Gas Release	NA	NA	90%
Integrated Sample Collection	NA	NA	90%
SF_6 Tracer Gas Analysis (concentrations > 100 ppt)	+/-20%	+/-20%	90%
SF_6 Tracer Gas Analysis (concentrations ≤100 ppt)	+50%/-100%	+50%/-100%	90%
Overall Valid Integrated Samples	NA	NA	90%
Meteorological Wind Measurements (Horizontal axis)	+/-0.2 m/s	+/-0.2 m/s	95%
Meteorological Wind Measurements (Vertical axis)	NA	NA	95%
Temperature Measurements	+/-1ºC	+/-1ºC	95%
Traffic counting	NA	NA	95%

NA = Not applicable

Precision and accuracy for the meteorological parameters are differences between the accepted value and the measured value.

Precision and accuracy for the non-meteorological parameters are the accepted value minus the normalized differences between the accepted value and the measured value, i.e.: (1-(A-B)/A) where A is the accepted value and B is the measured value.

Table 3-2 Summary of precision and completeness of the SF6 measurements.

Site	Study Day	Precision (%)	Completeness (%)
No Barrier	1	19.2	97.9
	2	19.3	95.8
	3	19.2	97.6
Double Barrier	1	13.4	91.9
	2	8.7	94.1

4 No-Barrier Measurement Site

4.1 Objectives of No-Barrier Site

The objective of the no-barrier field study is to develop a data base that can be used as a baseline when evaluating new AERMOD/RLINE[1] algorithms incorporating the effects of barriers. This base-line data will help quantify the roadside barriers' effects on air quality.

The specific objectives of the single-barrier site are as follows:

- Identify a site with no barriers alongside of the roadway for performing the requisite measurements.
- Perform measurements to obtain useful data for determining concentrations in absence of barrier and barrier edge effects.
- Compile the measurements results into a validated data base for future use.

4.2 No-Barrier Site Scope of Work

The no-barrier study was conducted during the July and August months of 2022 along the portion of Chicago Avenue that runs adjacent to the UCR campus. Sulfur hexafluoride tracer gas was released from four UCR vehicles that continuously looped along the study domain of Chicago Avenue for several hours for three study days. Fast-response sensors were deployed to measure key meteorological parameters at various heights. A collection of gaseous air samples was used to collect upwind and downwind samples at multiple locations at various distances from the roadway in the study corridor. The gaseous samples were analyzed at our laboratory at the UCR CE-CERT facility (College of Engineering, Center for Environmental Research and Technology) to determine the concentration of the tracer gas. All field measurement and laboratory analyses underwent screening and other quality control checks to obtain a validated data set.

[1] AERMOD/RLINE is recommended by the USEPA for estimating the impact of a single barrier on near-road air quality.

4.3 Site Description

The Chicago Avenue section laying between Martin Luther King Boulevard and Le Conde Drive was selected to perform the no barrier study. This section of Chicago Avenue has four lanes and runs approximately north (N) to south (S) as shown in Figure 4-1. The landscape on the eastern side of Chicago Avenue consists of agricultural land. The western side of Chicago Avenue is surrounded by residential homes. As shown in Figure 4-1, the gas tracer was released over a 0.77 km distance along all four lanes of Chicago Avenue running between the Martin Luther King Boulevard and Le Conde Drive intersections. The release was conducted on three different days at the no barrier site which will be called Study Day 1, 2 and 3 respectively at the no-barrier site.

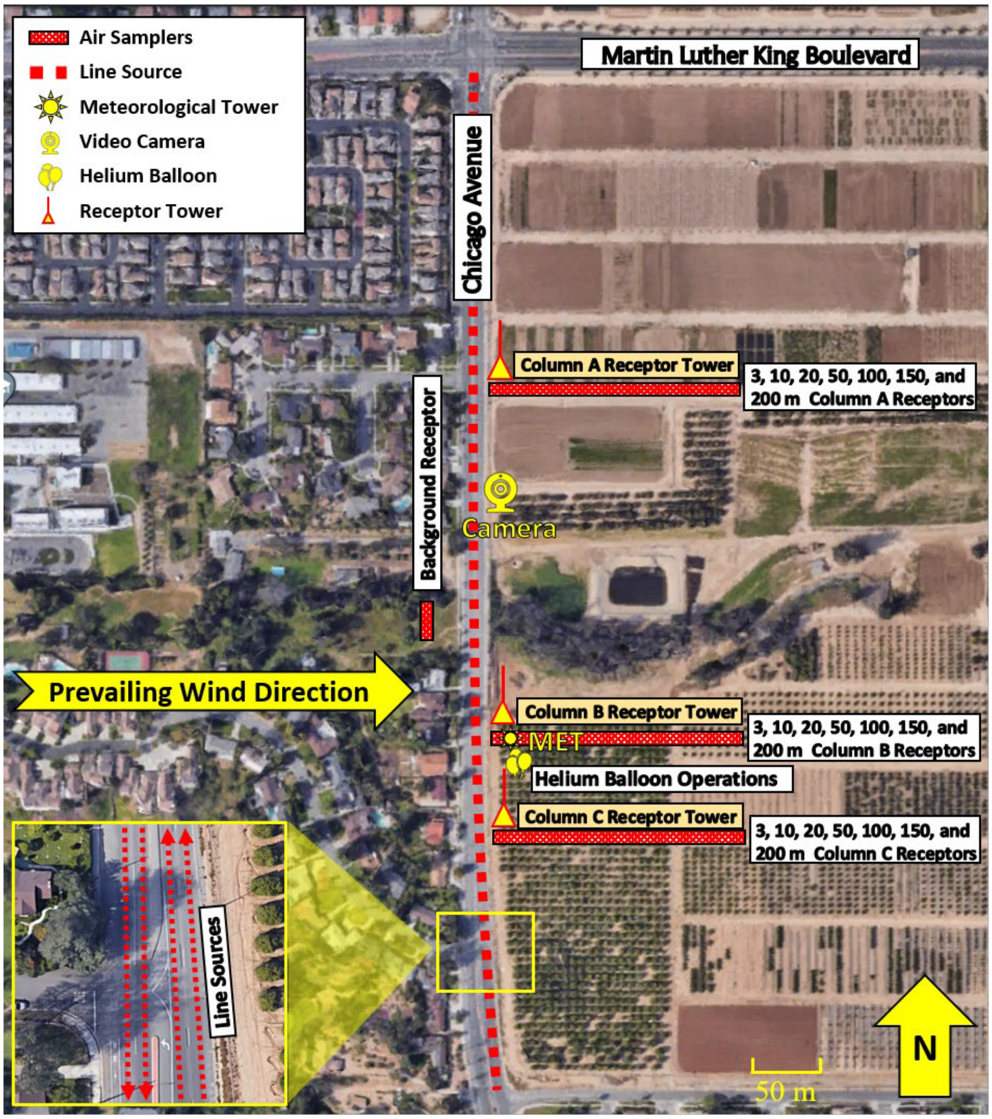

Figure 4-1. Aerial view of the no-barrier site.

Figure 4-2 Pictures showing the meteorological tower, measurements tower and the helium balloon at the no barrier site.

4.4 Measurement Equipment Locations

4.4.1 Air Samplers

At the no barrier site, tracer measurements were performed during two periods that were predicted to have unstable conditions (Study Day 1 (7/6) and 2 (7/15)) and one period that was predicted to have stable conditions (Study Day 3 (7/21)). A total of 46 air samplers were used at the no are provided barrier study. Downwind air samplers were placed in Rows A, B, and C approximately 3, 20, 50, 100, 150, and 200 m downwind from the roadside. The coordinates of the samplers are in Table 4-1. The 10 m downwind site at each of the three columns (A-10, B-10 and C-10) had a tower measuring at the heights of 1.8 m, 5 m and 10 m, except on Study Day 1 when only one tower was place at B-10. On Study Day 3 an additional measurement of concentration was performed at a height of 17 m from the ground and 14 m north of site C-10 using a sample inlet hoisted by a helium balloon (Figure 4-2). Meteorological variables were not obtained from balloon operations. The sample inlet height for all other sites and samplers was 1.8 m. One, two and three samplers respectively were placed upwind of the study, approximately 25 m from the roadside on Study Day 1, 2 and 3 respectively. All the samplers were collocated except at the sites containing the tower.

Table 4-1 Coordinates of the samplers, meteorological tower, and traffic camera at the no barrier site. The number assignation of each receptor column denotes the distance from the edge of the road.

Column	Site Location	Latitude	Longitude
Integrated Air Samplers			
A	A-3	33.965886	-117.348352
A	A-10	33.965889	-117.348279
A	A-20	33.965895	-117.348174
A	A-50	33.965889	-117.347855
A	A-100	33.965883	-117.347312
A	A-150	33.965883	-117.346771
A	A-200	33.965906	-117.346259
B	B-3	33.963516	-117.348378
B	B-10	33.963511	-117.348296
B	B-20	33.963505	-117.348168
B	B-50	33.963522	-117.347884
B	B-100	33.963516	-117.347336
B	B-150	33.963512	-117.346788
B	B-200	33.963513	-117.346263
C	C-3	33.962971	-117.348353
C	C-10	33.962977	-117.348274
C	C-20	33.962978	-117.384181
C	C-50	33.96298	-117.348053
C	C-100	33.96297	-117.347343
C	C-150	33.962966	-117.346781
C	C-200	33.962967	-117.346271
N/A	BKG	33.964352	-117.348516
Meteorological Tower			
A	MET-A	33.965551	-117.348358
B	MET-B	33.963505	-117.348168
Camera			
N/A	CMR	33.965219	-117.348370

4.4.2 Meteorology Towers

A meteorological tower with two 3-D sonic anemometers was placed 20 m downwind from the edge of the road measuring meteorological variable at 3 m and 5 m on all three study days. An additional sonic anemometer measuring at a height of 2.4 m was placed 3 m from the edge of the road along column A on Study Days 2 and 3 at the no barrier site. Table 4-2 tabulates the operation period of the anemometers at the no barrier site. Although there was sufficient sampling equipment and analysis capacity to allow sampling on consecutive days, or even more that one time per day, due to weather conditions and allowances to assess measurement results and perform equipment maintenance, the tracer release and measurements were performed on different days.

Table 4-2 Operation periods of the meteorology towers at the no barrier site

Column	A	B	B
Height (m)	2.4	3	5
Start-Stop (PDT)	07/20/2022 13:00:00- 07/24/2022 15:00:00	07/02/2022 13:00:00- 07/11/2022 17:30:00	07/02/2022 13:00:00- 07/11/2022 17:30:00
Start-Stop (PDT)		07/13/2022 16:00:00- 07/25/2022 14:30:00	07/13/2022 16:00:00- 07/25/2022 14:30:00

4.5 Results

4.5.1 Tracer Gas Release

The tracer gas release amounts for the three study days at the no barrier site are presented in Table 4-3. Both the total mass of tracer gas released for each period and the release rate of tracer gas released per unit distance are reported. The study vehicles released the tracer gas over a distance of 0.77 km at the no barrier site.

Due to problems with system data logging, one of the vehicle release rates were based on the mass of SF_6 released determined by the before and after weigh determinations and the information from the tracer gas release log (Figure 2-5).

Two major issues occurred with the tracer release system at the no barrier site. On Study Day 1 at the no barrier site one of the mass flow controllers failed leading to no release from one of the vehicles. But this reduction in the release rate was compensated for by one of the mass flow controllers releasing at double the intended flow rate. On Study Day 2 at the no barrier site one of the vehicles had a flat tire leading to just three vehicles releasing tracer gas. The study design had incorporated sufficient safety factors so that even with the loss of tracer release from one vehicle, there was sufficient tracer gas released to provide reliable detection of the tracer gas in the samples collected at even the most distant sampling locations.

Table 4-3 Tracer gas release at the no-barrier site.

Date		7/6/2022		7/15/2022		7/21/2022	
Study Day		1		2		4	
	Bag Sample #	Time (PDT)		Time (PDT)		Time (PDT)	
Presampling Release	NA	11:45-12:00		11:45-12:00		18:45-19:00	
Release Period 1	2	12:00-12:30		12:00-12:30		19:00-19:30	
Release Period 2	3	12:30-13:00		12:30-13:00		19:30-20:00	
Release Period 3	4	13:00-13:30		13:00-13:30		20:00-20:30	
Release Period 4	5	13:30-14:00		13:30-14:00		20:30-21:00	
Release Period 5	6	14:00-14:30		14:00-14:30		21:00-21:30	
		Release		Release		Release	
		g	mg/(m.s)	g	mg/(km.s)	g	mg/(m.s)
Presampling Release	1	142	0.0187	37	0.0049	116	0.0152
Release Period 1	2	354	0.0466	249	0.0327	285	0.0375
Release Period 2	3	324	0.0426	226	0.0297	268	0.0353
Release Period 3	4	360	0.0473	216	0.0284	274	0.0360
Release Period 4	5	327	0.0430	236	0.0310	231	0.0304
Release Period 5	6	328	0.0431	216	0.0284	253	0.0333
Total		1836	0.2415	1180	0.1552	1419	0.1866

4.5.2 Tracer Gas Measurements

A description of the electronic data files for all of the results for SF6 is included in Appendix A. The tracer gas release rate was sufficient to readily obtain measurable levels of SF_6 at the most distant sampling locations. Except for the upwind/background location and the prerelease samples collected at all sites prior to the start of the tracer release, all samples had quantifiable SF_6 concentrations. Most pre-release samples had concentrations of zero, except few that had concentrations in tens of ppt. Efforts were made to identify potential contamination or errors due to a sampler running at the wrong time. Because no measurement or analysis problems could be identified to account for the SF_6 in the prerelease samples, these samples and their SF_6 reading were kept in the data set as valid data but flagged. The maximum SF_6 levels measured were close to 15000 ppt. The measurement detection limit for SF_6 was 10-20 ppt. SF_6 values 100 ppt and lower have about a factor of two uncertainty in their actual concentration. A summary of the measured tracer concentration is presented in Figure 5-2.

4.5.3 Meteorology Data

Table 4-4 presents the 30-minute average wind speed (WS), wind direction (WD) and temperature (T) for all the study periods at the no barrier site. Appendix B includes a description of the electronic data files for the remaining 30-minute average data and the 20 Hz u-, v-, w-, and T-data.

As can be seen from Table 4-4 at the no barrier site the west winds dominated the study days with wind directions within 270 ± 45 degrees all the time. The wind speeds were highest during afternoon and lower in the morning and late night. The wind speed at 3 m varied between 0.9 m/s to 2.3 m/s. Temperatures varied from high 20°C's to a maximum of about 39°C during the tracer study periods at the no barrier site.

4.5.4 Traffic Count

The traffic count data are presented in Table 4-5. The average number of vehicles passing the freeway at the no barrier site during the half an hour measurement period were 151 and 49 during the daytime release and the nighttime release respectively. The traffic during the nighttime release was on average 0.35 times that during the daytime.

Table 4-4 Summary of the meteorological data collected at the no barrier site

	Integrated Sample Set Number		Row A 2.4m			Main Tower 3m			Main Tower 5m		
			WS	WD	T	WS	WD	T	WS	WD	T
7/6/2022			m/s	deg	°C	m/s	deg	°C	m/s	deg	°C
Background Sample Time	1	11:45-12:00				1.6	287	28.7	1.7	271	26.7
Release Period 1 (PDT)	2	12:00-12:30				1.5	296	29.3	1.6	278	27.3
Release Period 2 (PDT)	3	12:30-13:00				1.4	262	30.2	1.5	253	28.2
Release Period 3 (PDT)	4	13:00-13:30				1.7	294	31.2	1.7	283	29.3
Release Period 4 (PDT)	5	13:30-14:00				2.0	273	32.0	2.1	261	29.9
Release Period 5 (PDT)	6	14:00-14:30				2.2	308	32.6	2.3	297	30.5
7/15/2022											
Background Sample Time	1	11:45-12:00				1.6	280	34.4	1.7	270	32.3
Release Period 1 (PDT)	2	12:00-12:30				1.7	252	35.3	1.9	246	33.1
Release Period 2 (PDT)	3	12:30-13:00				1.9	251	36.5	2.1	245	34.3
Release Period 3 (PDT)	4	13:00-13:30				2.0	280	37.6	2.1	272	35.4
Release Period 4 (PDT)	5	13:30-14:00				2.0	300	38.5	2.2	291	36.1
Release Period 5 (PDT)	6	14:00-14:30				2.3	271	38.7	2.4	264	36.3
7/21/2022											
Background Sample Time	1	18:45-19:00	1.7	261	32.0	2.0	288	33.8	2.1	277	32.0
Release Period 1 (PDT)	2	19:00-19:30	1.7	274	30.6	2.0	302	32.2	2.1	291	30.6

Release Period 2 (PDT)	3	19:30-20:00	1.3	249	29.5	1.4	266	31.0	1.5	258	29.5
Release Period 3 (PDT)	4	20:00-20:30	1.2	245	28.5	1.3	273	30.0	1.4	262	28.5
Release Period 4 (PDT)	5	20:30-21:00	1.3	248	27.3	1.4	277	28.9	1.6	267	27.5
Release Period 5 (PDT)	6	21:00-21:30	0.9	226	26.2	0.9	259	27.6	1.0	246	26.3

Table 4-5 Traffic count during the measurement period from the no barrier site.

		No Barrier					
		1		2		3	
Date		07/06/2022		7/15/2022		7/21/2022	
Traffic Direction		North Bound	South Bound	North Bound	South Bound	North Bound	South Bound
Release Period 2	Time	12:00-12:30		12:00-12:30		21:00-21:30	
	Car	258	272	259	297	126	143
	Truck	1	1	1	8	0	0
Release Period 3	Time	12:30-13:00		12:30-13:00		21:30-22:00	
	Car	307	330	307	270	99	137
	Truck	2	0	2	8	0	0
Release Period 4	Time	13:00-13:30		13:00-13:30		22:00-22:30	
	Car	238	228	238	311	90	92
	Truck	15	0	15	12	1	1
Release Period 5	Time	13:30-14:00		13:30-14:00		22:30-23:00	
	Car	273	379	273	379	77	78
	Truck	10	10	10	10	0	0
Release Period 6	Time	14:00-14:30		14:00-14:30		23:00-23:30	
	Car	260	369	257	369	59	75
	Truck	7	14	7	14	0	0

5 Double-Barrier Measurement Site

5.1 Objectives of Double-Barrier Site

The objective of the double-barrier field study is to develop a data base that can be evaluate AERMOD/RLINE performance for double barrier configurations. This data set will be used along with the no-barrier and single-barrier data sets to improve modeling performance, allowing Caltrans as well as other agencies and parties to quantify roadside barriers' effects on air quality in accordance with federal modeling guidance. Once an acceptable algorithm is developed, transportation projects can quantify roadside barriers as an air quality mitigation measure for conformity determination. It will also enable modeling the impact of existing roadside barriers on air quality at nearby residences.

The specific objectives of the double-barrier site are as follows:

- Identify a site with barriers along each side of the roadway for performing the requisite measurements.
- Perform measurements to obtain useful data for determining concentrations in absence of barrier and barrier edge effects.
- Compile the measurements results into a validated data base for future use.

5.2 Double-Barrier Site Scope of Work

The double-barrier study was conducted in August 2022 along the section of CA-71 laying between Central Avenue and Ramona Avenue in Chino Hills, California, approximately 40 kilometers from the UCR campus. Sulfur hexafluoride tracer gas was released from four UCR vehicles that continuously looped along the study section of Highway 71 for several hours for two study days. Fast-response meteorological sensors and air samplers were used to collect upwind and downwind samples at multiple locations at various distances from the roadway in the study corridor. The gaseous samples were also analyzed at our laboratory at the UCR CE-CERT facility to determine the concentration of the tracer gas. All field measurement and laboratory analyses related to the double-barrier study underwent screening and other quality control checks for validation as well.

5.3 Site Description

The CA-71 section laying between Ramona Avenue and Central Avenue was selected to perform the no barrier study. This section of CA-71 has six lanes and runs approximately northwest (NW) to southeast (SE) as shown in Figure 5-1. As shown in Figure 5-1, the gas tracer was released over a 1.43 km distance along the two slowest lanes in each direction. The release was conducted on two different days at the double barrier site which will be referred as Study Day 1 and Study Day 2 at the double barrier site. Both the freeway-side and sampler-side height of the roadside barriers are presented inTable 5-1. Figure 2-7 shows photos of the downwind barrier and air sampler set up. The downwind barrier height varied from 5.9 m to 6.5 m on the sampler-side and between 4.2 m to 4.4 m on the freeway-side. The upwind barrier height varied between 4.5 m to 5.3 m on the freeway-side. The bottom 1 m of barrier on the freeway-side was constructed of concrete. The barrier above that level was cinderblock. The barrier included vent holes with an area of approximately 300 square centimeters (30 cm long by 10 cm high) spaced about every 3 m constructed into the barrier at the intersection of the concrete and cinderblock.

Figure 5-1 Aerial view of the double barrier site.

Table 5-1 Heights of the upwind and downwind barrier.

Barrier Height (m)	North	Centre	South
Downwind Barrier (Sampler-side)	5.9	6.5	6.3
Downwind Barrier (Freeway-side)	4.3	4.4	4.2
Upwind Barrier (Freeway-side)	4.5	5.3	5.3

5.4 Measurement Equipment Location

5.4.1 Air Samplers

Forty-seven air samplers were used in the study. Downwind air samplers were placed in thirteen columns with rows at approximately 3 m and 10 m from the downwind barrier, except in column I where the samplers were placed at 85, 127, 174, 227, 273 and 322 m north of the barrier. The site 10 m from the barrier at columns D, G and H had a tower sampling at 1.8 m, 5 m and 10 m. The sample inlet height for all other sites and samplers was 1.8 m. The columns A, B, C, D, K, L and M were placed in locations to determine edge effects based on the forecasted wind direction. Three samplers were placed upwind of the study, approximately 90 m from the upwind edge of the freeway. All the samplers in column I and the samples at site J-10 and I-10 were collocated.

5.4.2 Meteorology Towers

At the double barrier site, tracer measurements were made during one period predicted to have unstable conditions (Study Day 1 (7/28)) and one period that was predicted to have stable conditions (Study Day 2(8/2)). One upwind sonic anemometer was operating at a height of 3 m during the Study Day 1 at the double-barrier site. The upwind site was about 90 m away from the edge of the freeway. Two additional sonic anemometers were added on Study Day 2 at the double barrier site leading to meteorological measurements at 3 m and 5 m at the upwind site and at 2.5 m at a site downwind of the freeway. The downwind site was about 25 m away from the edge of the freeway. Sonic anemometers were added to compare upwind and downwind meteorological conditions. Table 5-3 tabulates the operation periods of the anemometers at the no barrier site.

Table 5-2 Coordinates of the samplers, meteorological tower, and traffic camera at the double barrier site.

Column	Site Location	Latitude	Longitude
Integrated Air Samplers			
A	A-3	33.978462	-117.701683
A	A-10	33.978512	-117.701653
B	B-3	33.978363	-117.701485
B	B-10	33.978413	-117.701439
C	C-3	33.978252	-117.701302
C	C-10	33.978310	-117.701233
D	D-3	33.978153	-117.701096
D	D-10	33.978214	-117.701027
E	E-3	33.977970	-117.700783
E	E-10	33.978020	-117.700752
F	F-3	33.977570	-117.700054
F	F-10	33.977623	-117.700027
G	G-3	33.977207	-117.699348
G	G-10	33.977238	-117.699303
H	H-3	33.976803	-117.698593
H	H-10	33.976871	-117.698586
I	I-85	33.976913	-117.697746
I	I-127	33.977291	-117.697739
I	I-141	33.977707	-117.697762
I	I-227	33.978153	-117.697754
I	I-273	33.978584	-117.697792
I	I-322	33.979031	-117.697784
J	J-3	33.976140	-117.697610
J	J-10	33.976185	-117.697594
K	K-3	33.975933	-117.697327
K	K-10	33.975967	-117.697273
L	L-3	33.975819	-117.697182
L	L-10	33.975868	-117.697144
M	M-3	33.975689	-117.697014

M	M-10	33.975727	-117.696968
N/A	BKG	33.979396	-117.706144
Meteorological Towers			
N/A	MET-UW	33.979353	-117.706061
N/A	MET-DW	33.977351	-117.697777
Camera			
N/A	CMR	33.968438	-117.689202

Table 5-3 Operation periods of the meteorology towers at the double barrier site

Tower Location	DW	UW	UW
Height (m)	2.5	3	5
Start-Stop (PDT)	08/02/2022 18:30:00-08/03/2022 10:00:00	07/26/2022 16:00:00-08/02/2022 23:30:00	07/26/2022 16:00:00-07/27/2022 17:00:00
Start-Stop (PDT)			08/01/2022 14:30:00-08/02/2022 23:30:00

5.5 Results

5.5.1 Tracer Gas Release

The tracer gas release amounts for two study days at the double barrier site are presented in

Table 5-4. Both the total mass of tracer gas released for each period and the release rate of tracer gas released per unit distance are reported. The release distance was around 1.43 km at the double barrier site.

Due to problems with system data logging, one of the vehicle release rates were based on the mass of SF_6 released determined by the before and after weigh determinations and the information from the tracer gas release log (Figure 2-5). No major issues occurred with the tracer release system at the double barrier site.

5.5.2 Tracer Gas Measurement Results

A summary of the tracer measurement results in presented in Figure 5-2. A description of the electronic data files for all the results for SF_6 are included in Appendix A. The tracer gas release rate was sufficient to readily obtain measurable levels of SF_6 at the most distant sampling locations. All downwind samples collected during the release had quantifiable SF_6 concentrations. Background measurements were collected at the double barrier site as well. None of the background measured concentrations were significant at the double-barrier site. However, SF_6 was detected in several of the prerelease samples. When possible, these samples were analyzed a second time to confirm the SF_6. Efforts were made to identify potential contamination or errors due to a sampler running at the wrong time. Because no measurement or analysis problems could be identified to account for the SF6 in the prerelease samples, these samples and their SF_6 reading were kept in the data set as valid data but flagged. The maximum SF_6 levels measured were close to 12000 ppt. The measurement detection limit for SF_6 was 10-20 ppt. SF_6 values 100 ppt and lower have about a factor of two uncertainty in their actual concentration.

Table 5-4 Tracer gas release at the double-barrier site.

Date		7/28/2022		8/2/2022	
Study Day		1		2	
	Bag Sample #	Time (PDT)		Time (PDT)	
Presampling Release	NA	11:45-12:00		18:45-19:00	
Release Period 1	2	12:00-12:30		19:00-19:30	
Release Period 2	3	12:30-13:00		19:30-20:00	
Release Period 3	4	13:00-13:30		20:00-20:30	
Release Period 4	5	13:30-14:00		20:30-21:00	
Release Period 5	6	14:00-14:30		21:00-21:30	
		Release		Release	
		g	mg/(km.s)	g	mg/(km.s)
Presampling Release	1	347	0.0244	285	0.0201
Release Period 1	2	763	0.0537	693	0.0488
Release Period 2	3	757	0.0533	802	0.0565
Release Period 3	4	809	0.0569	768	0.0541
Release Period 4	5	843	0.0593	750	0.0528
Release Period 5	6	865	0.0609	810	0.0570
Total		4389	0.3089	4111	0.2894

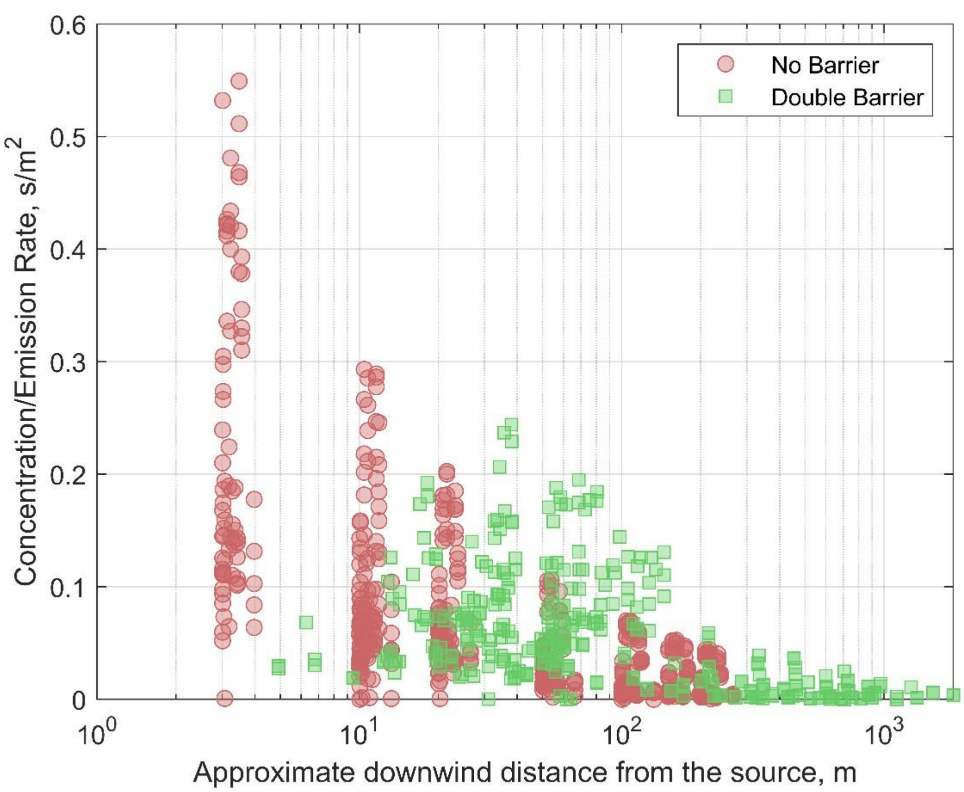

Figure 5-2 Summary of the measurements from the no barrier and the double barrier site.

5.5.3 Meteorological Measurements

Table 5-5 presents the 30-minute average wind speed (WS), wind direction (WD) and temperature (T) for all the study periods at the no barrier and double barrier site respectively. Appendix B includes a description of the electronic data files for the remaining 30-minute average data and the 20 Hz u-, v-, w-, and T-data.

As can be seen from Table 5-5 at the double barrier site, the west winds dominated the study days with wind directions within 2222222 +- 4444 degrees all the time except on the first measurement period of Study Day 1. The wind speed at 3 m varied between 1.3 m/s to 2.4 m/s. Temperatures varied from high 20ºC's to high 30ºC's during the tracer study periods at the double barrier site.

5.5.4 Traffic Count

The traffic count data are presented in Table 5-6. The average number of vehicles passing the freeway at the no barrier site during the half an hour measurement period were 151 and 49 during the daytime release and the nighttime release respectively. The traffic at the double barrier site was much higher with an average of 689 (daytime) and 263 (nighttime) vehicles passing the freeway during half an hour measurement period. The traffic during the nighttime release was on average 0.35 times that during the daytime. The traffic at the double barrier site was on average 5 times that at the no barrier site.

Table 5-5 Summary of the meteorological data collected at the double barrier site

	Integrated Sample Set Number		Downwind 2.5m			Main Tower 3m			Main Tower 5m		
			WS	WD	T	WS	WD	T	WS	WD	T
7/28/2022			m/s	deg	°C	m/s	deg	°C	m/s	deg	°C
Background Sample Time	1	11:45-12:00				1.5	328	31.3			
Release Period 1 (PDT)	2	12:00-12:30				1.6	281	32.6			
Release Period 2 (PDT)	3	12:30-13:00				2.0	252	33.2			
Release Period 3 (PDT)	4	13:00-13:30				1.8	289	33.8			
Release Period 4 (PDT)	5	13:30-14:00				2.0	287	33.9			
Release Period 5 (PDT)	6	14:00-14:30				1.8	270	33.9			
8/2/2022											
Background Sample Time	1	18:45-19:00	2.1	264	29.9	2.4	266	31.7	2.8	259	30.0
Release Period 1 (PDT)	2	19:00-19:30	1.9	270	29.2	2.1	277	30.9	2.4	268	29.3
Release Period 2 (PDT)	3	19:30-20:00	1.6	250	28.5	1.7	275	30.0	1.9	267	28.5
Release Period 3 (PDT)	4	20:00-20:30	1.1	242	27.6	1.5	273	29.2	1.7	263	27.7
Release Period 4 (PDT)	5	20:30-21:00	1.2	265	26.9	1.3	284	28.6	1.4	274	27.1
Release Period 5 (PDT)	6	21:00-21:30	1.4	270	26.1	1.4	286	27.7	1.6	274	26.3

Table 5-6 Traffic count during the measurement period from the no barrier and the double barrier site.

		Double Barrier			
		1		2	
Date		7/28/2022		08/02/2022	
Traffic Direction		North Bound	South Bound	North Bound	South Bound
Release Period 2	Time	12:00-12:30		21:00-21:30	
	Car	1344	852	486	912
	Truck	288	168	30	6
Release Period 3	Time	12:30-13:00		21:30-22:00	
	Car	1314	990	588	672
	Truck	252	150	18	6
Release Period 4	Time	13:00-13:30		22:00-22:30	
	Car	1314	990	462	684
	Truck	252	150	24	12
Release Period 5	Time	13:30-14:00		22:30-23:00	
	Car	1308	918	408	378
	Truck	150	108	24	18
Release Period 6	Time	14:00-14:30		23:00-23:30	
	Car	1152	1050	162	336
	Truck	270	156	12	18

Bibliography

Amini, S., Ahangar, F.E., Schulte, N., Venkatram, A., 2016. Using models to interpret the impact of roadside barriers on near-road air quality. Atmos. Environ. 138. doi:10.1016/j.atmosenv.2016.05.001

Benson, Paul E. CALINE4 – A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways. Office of Transportation Laboratory California Department of Transportation. Report FHWA/CA/TL-84/15. November 1984.

Caltrans (2019): Freeway Performance Measurement System (PeMS) http://pems.dot.ca.gov/. Accessed July-September, 2019.

Cimorelli, A.J., S.G. Perry, A. Venkatram, J.C. Weil, R.J. Paine, R.B. Wilson, R.F. Lee, W.D. Peters, and R.W. Brode: AERMOD: A dispersion model for industrial source applications. Part I: General model formulation and boundary layer characterization, *J. App. Meteo*., 44(5), 682-693, 2005. https://doi.org/10.1175/JAM2227.1

Environmental Protection Agency (1987): Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD). EPA Document EPA 450/4-87-007.

Environmental Protection Agency (1994): Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. I, Principles. EPA Document EPA600/976005.

Environmental Protection Agency (2017): Quality Assurance Handbook for Air Pollution Measurement Systems Vol. II, Ambient Air Specific Methods. EPA Document EPA600/477027a. Section 18. Pp 8.

Environmental Protection Agency (2006): Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. IV, Meteorological Measurements. EPA Document EPA600/R-94/038C.

Environmental Protection Agency (2019): AERMOD User Guide. EPA Document EPA454/B-19-027. https://www3.epa.gov/ttn/scram/models/aermod/aermod_userguide.pdf.

Federal Highway Administration (2020a): Noise Barriers. https://www.fhwa.dot.gov/environment/noise/noise_barriers/. Accessed April 2020.

Federal Highway Administration (2020b): Summary of Noise Barriers Constructed by December 31, 2010. https://www.fhwa.dot.gov/Environment/noise/noise_barriers/inventory/summary/stable713.cfm. Accessed April 2020.

Finn, D., Clawson, K.L., Carter, R.G., Rich, J.D., Eckman, R.M., Perry, S.G., Isakov, V., Heist, D.K., 2010. Tracer studies to characterize the effects of roadside noise barriers on near-road pollutant dispersion under varying atmospheric stability conditions. Atmos. Environ. 44, 204–214. doi:10.1016/j.atmosenv.2009.10.012

Heist, D.K., Perry, S.G., Brixey, L.A., 2009. A wind tunnel study of the effect of roadway configurations on the dispersion of traffic-related pollution. Atmos. Environ. 43, 5101–5111. doi:10.1016/j.atmosenv.2009.06.034

Pankratz, D. and Venkatram, A.(2020). Measurement Report for Quantifying the Effects of Roadside Barriers on Near Road Air Pollutant Dispersion and Concentration: Single Barrier Site. UCR Document UCR/ME-80114-MR-1-R2.

Snyder, M.G.M.G., Venkatram, A., Heist, D.K.D.K., Perry, S.G.S.G., Petersen, W.B.W.B., Isakov, V., 2013. RLINE: A line source dispersion model for near-surface releases. Atmos. Environ. 77, 748–756. doi:10.1016/j.atmosenv.2013.05.074

Appendix A: Electronic Data Files for SF_6 Analysis Results

The validated SF6 data are included electronically in the Excel workbook NoBarrier_AnalysisData.xlsx and DoubleBarrier_AnalysisData.xlsx for the no barrier and double barrier sites respectively. Each sheet in the workbook represents the study days which are identified in the sheet names. The data in each worksheet are presented in the format shown in Table A-1. Each Workbook has a sheet named Error Codes to identify the codes used for invalidated data.

The Table A-1 workbook row and column information are as follows. There are three sections of information:

- The left six columns indicate the Site ID, bag number (representing the measurement period), set number (to identify collocated samples), sampling height and site geolocation.

- The middle two columns present the measured concentration of SF6 in part per trillion (ppt) and flags. Flag value of 1 indicate the samples that were flagged during the Level 1 data validation.

- The right two columns present the data for the samples that were analyzed a second time (replicate data) for quality control check.

Table A-1 SF6 validated data file sample.

Sample Information						First Analysis		Repeat Analysis	
Site ID	Bag #	Set #	Receptor Heigth	Latitude	Longitude	SP6 ppt	Flags	SP6 ppt	Flags
A-3	1	1	1.8	33.965886	-117.3484	0	0		
A-3	2	1	1.8	33.965886	-117.3484	5918	0		
A-3	3	1	1.8	33.965886	-117.3484	4624	0		
A-3	4	1	1.8	33.965886	-117.3484	LZ1	1		
A-3	5	1	1.8	33.965886	-117.3484	5991	0		
A-3	6	1	1.8	33.965886	-117.3484	3467	0		
A-10	1	1	1.8	33.965889	-117.3483	0	0		
A-10	2	1	1.8	33.965889	-117.3483	2911	0		
A-10	3	1	1.8	33.965889	-117.3483	2355	0		
A-10	4	1	1.8	33.965889	-117.3483	4027	0		
A-10	5	1	1.8	33.965889	-117.3483	3693	0		
A-10	6	1	1.8	33.965889	-117.3483	2427	0		
A-20	1	1	1.8	33.965895	-117.3482	0	0		
A-20	2	1	1.8	33.965895	-117.3482	1523	0		
A-20	3	1	1.8	33.965895	-117.3482	1915	0		
A-20	4	1	1.8	33.965895	-117.3482	2096	0		
A-20	5	1	1.8	33.965895	-117.3482	2562	0		
A-20	6	1	1.8	33.965895	-117.3482	1784	0		
A-50	1	1	1.8	33.965889	-117.3479	0	0	114	0
A-50	2	1	1.8	33.965889	-117.3479	554	0	463	0
A-50	3	1	1.8	33.965889	-117.3479	673	0	559	0
A-50	4	1	1.8	33.965889	-117.3479	741	0	612	0
A-50	5	1	1.8	33.965889	-117.3479	601	0	492	0
A-50	6	1	1.8	33.965889	-117.3479	434	0	372	0
A-100	1	1	1.8	33.965883	-117.3473	0	0		
A-100	2	1	1.8	33.965883	-117.3473	143	0		
A-100	3	1	1.8	33.965883	-117.3473	193	0		
A-100	4	1	1.8	33.965883	-117.3473	211	0		
A-100	5	1	1.8	33.965883	-117.3473	242	0		
A-100	6	1	1.8	33.965883	-117.3473	289	0		
A-150	1	1	1.8	33.965883	-117.3468	L0	0		
A-150	2	1	1.8	33.965883	-117.3468	152	0		
A-150	3	1	1.8	33.965883	-117.3468	167	0		
A-150	4	1	1.8	33.965883	-117.3468	179	0		
A-150	5	1	1.8	33.965883	-117.3468	214	0		
A-150	6	1	1.8	33.965883	-117.3468	193	0		
A-200	1	1	1.8	33.965906	-117.3463	0	1		
A-200	2	1	1.8	33.965906	-117.3463	54	1		
A-200	3	1	1.8	33.965906	-117.3463	81	1		
A-200	4	1	1.8	33.965906	-117.3463	88	1		
A-200	5	1	1.8	33.965906	-117.3463	LZ2	1		
A-200	6	1	1.8	33.965906	-117.3463	108	1		
A-3	1	2	1.8	33.965886	-117.3484	5	0		
A-3	2	2	1.8	33.965886	-117.3484	5224	0		
A-3	3	2	1.8	33.965886	-117.3484	4776	0		
A-3	4	2	1.8	33.965886	-117.3484	6205	0		
A-3	5	2	1.8	33.965886	-117.3484	4660	0		
A-3	6	2	1.8	33.965886	-117.3484	2638	0		
A-10	1	2	1.8	33.965889	-117.3483	25	0	129	0
A-10	2	2	1.8	33.965889	-117.3483	2813	0	2967	0
A-10	3	2	1.8	33.965889	-117.3483	2584	0	2630	0
A-10	4	2	1.8	33.965889	-117.3483	4005	0	4597	0
A-10	5	2	1.8	33.965889	-117.3483	3111	0	3341	0
A-10	6	2	1.8	33.965889	-117.3483	1849	0	1698	0

Appendix B: Electronic Data Files for Meteorological Data

The meteorological data from the six sonic anemometers were collected at a 20 Hz rate. The collected data included the time (PDT), the wind velocity for the three axes (u, v and w) in meters per second and the sonic temperature in degrees Celsius. The data from the raw data files were processed into thirty minute averages for validation periods. For convenience, the sensors were not oriented to true north during setup. Compass measurements of the sensor orientations were made during the study and the axes for the raw 20 Hz data and the hourly average data were rotated during processing. The 20 Hz data included in the electronic data files have been rotated to true north.

The results from the no barrier and double barrier studies were separated into two folders named No Barrier and Double Barrier. The Excel® workbook 30min_AveragedData.xlsx contains the thirty-minute average meteorology data. The data from each of the sonic anemometers are in their own worksheet within the workbook. Table B-1 presents the first few rows from the B_3m worksheet in the 30min_AveragedMetData.xlsx workbook.

The workbook also includes the worksheet "Readme" that includes the descriptions presented in Table B 2 for the data in the workbook.

The 20 Hz meteorology data from the six sites are contained in six files occupying just under 7 Gigabytes of file space. The following is a list of the file names:

No Barrier Site:

A_2.4m.dat

B_3m.dat

B_5m.dat

Double Barrier Site:

UW_3m.dat

UW_5m.dat

DW_2.5m.dat

A description of the data in the 20 Hz files is presented in Table B-3. The 20 Hz meteorological data files contain the data in comma delimited format. Table B-4 presents an example of data that have been input into Excel using Excel's inputting and parsing operations.

Table B-1. File format for 30-minute averaged meteorological data.

Date	Ubar	Uscalar	WindDire	Wbar	Tbar	sigmau	sigmav	sigmaw	sigmaT	HeatFlux	ustar	MOLength
8/2/2022 18:30	1.967487	2.14256	263.6318	-0.16609	29.9441	0.962407	0.796451	0.533342	0.359457	0.062168	0.443273	-108.2164
8/2/2022 19:00	1.770573	1.930202	269.6957	-0.18857	29.23314	0.948469	0.706411	0.487332	0.288398	0.039272	0.436622	-163.3275
8/2/2022 19:30	1.395027	1.607969	249.7722	-0.02782	28.51316	0.884837	0.759278	0.469847	0.390849	0.037291	0.410691	-142.8015
8/2/2022 20:00	0.946311	1.144961	242.3255	-0.00964	27.61952	0.603132	0.616007	0.352717	0.35015	0.016163	0.283392	-107.933
8/2/2022 20:30	1.055612	1.174611	265.4174	-0.10545	26.92021	0.567535	0.482481	0.306965	0.311344	0.016486	0.253014	-75.1285
8/2/2022 21:00	1.303142	1.416014	269.553	-0.16864	26.10728	0.621547	0.512981	0.330389	0.25438	0.016242	0.278158	-101.0517
8/2/2022 21:30	1.141558	1.277917	269.5449	-0.11798	25.63202	0.643426	0.51141	0.341414	0.250007	0.012523	0.282226	-136.6796
8/2/2022 22:00	1.033493	1.20469	281.7094	-0.12827	25.08806	0.684253	0.556321	0.352749	0.247233	-0.01163	0.311002	196.55308
8/2/2022 22:30	1.015247	1.118596	261.114	-0.10249	24.84264	0.515043	0.423204	0.279412	0.172735	0.005196	0.25841	-252.1841
8/2/2022 23:00	0.468538	0.596006	247.7466	-0.00186	24.65009	0.371756	0.34073	0.190203	0.211035	-0.00426	0.187518	117.48783
8/2/2022 23:30	0.463727	0.566986	271.7096	-0.04789	24.30993	0.318274	0.285618	0.170735	0.142015	0.000255	0.143185	-872.4264
8/3/2022 0:00	0.32708	0.465596	250.363	0.00225	24.18084	0.293543	0.282018	0.154274	0.215098	-0.0057	0.133956	31.974081
8/3/2022 0:30	0.284088	0.380915	206.7373	0.046215	23.88518	0.207876	0.229964	0.140378	0.146885	-0.00366	0.100194	20.787037
8/3/2022 1:00	0.558873	0.628015	265.9042	-0.04397	23.88015	0.291044	0.258006	0.168747	0.15292	0.003767	0.149496	-67.14547
8/3/2022 1:30	0.482337	0.587057	253.6486	-0.01593	23.82718	0.318412	0.298746	0.194701	0.146643	0.003894	0.161334	-81.62556
8/3/2022 2:00	0.532011	0.608451	274.8653	-0.06612	23.77545	0.330177	0.25859	0.17881	0.132196	0.003789	0.157145	-77.49038
8/3/2022 2:30	0.36903	0.52756	243.4639	-0.03392	23.72276	0.237082	0.377378	0.147569	0.194933	-0.00333	0.113895	33.569807
8/3/2022 3:00	0.296307	0.408877	272.0035	-0.00573	23.36672	0.237375	0.24061	0.142252	0.121607	-0.00073	0.120039	179.74389
8/3/2022 3:30	0.194432	0.377259	202.0978	0.027586	23.01203	0.236702	0.271485	0.14597	0.241817	-0.00871	0.086128	5.5359105
8/3/2022 4:00	0.369777	0.485204	234.0029	0.013663	22.92323	0.284929	0.293491	0.16535	0.219051	-0.00445	0.147989	54.935511
8/3/2022 4:30	0.309596	0.427433	251.5493	-0.00848	22.65631	0.26873	0.264033	0.153572	0.147628	-0.00405	0.140047	51.088361
8/3/2022 5:00	0.171008	0.315656	270.9715	-0.00956	22.58057	0.239549	0.236208	0.116145	0.141899	-0.00353	0.092837	17.092458
8/3/2022 5:30	0.62282	0.702031	275.1312	-0.06574	22.44237	0.369041	0.294128	0.183456	0.169548	-0.0017	0.169659	216.35299
8/3/2022 6:00	0.520924	0.624383	298.9544	-0.09501	22.2115	0.343505	0.33384	0.209519	0.137633	-0.00171	0.152438	156.1478
8/3/2022 6:30	0.58372	0.675566	276.4627	-0.0745	22.10952	0.401526	0.31075	0.205269	0.126371	0.004011	0.1782	-106.1561
8/3/2022 7:00	0.413333	0.594276	282.3961	-0.0188	22.65385	0.333135	0.381467	0.205924	0.341302	0.012588	0.168607	-28.70493
8/3/2022 7:30	0.391903	0.63079	288.7707	-0.05505	23.48625	0.374632	0.451654	0.242559	0.405801	0.031937	0.178588	-13.48199

Table B-2. Meteorological parameters logged and calculated.

Column	Unit	Parameter	Formula
date		date/time in PDT	
U-bar	m/s	wind speed vector averaging	$\sqrt{\bar{u}^2+\bar{v}^2}$
U-scalar	m/s	wind speed scalar averaging	$\sqrt{\bar{u}^2+\bar{v}^2+\bar{w}^2}$
WindDirection	Degree	meteorology wind direction	$\tan^{-1}(\bar{u}/\bar{v})$
W-bar	m/s	wind speed in z direction	$\bar{w}$
T-bar	C	temperature	$\bar{T}$
sigma u	m/s	Standard deviation of fluctuating wind velocity(Turbulence Strength) in x (along wind)	$\sqrt{\sum_i (u_i-\bar{u})^2/N}$
sigma v	m/s	Standard deviation of fluctuating wind velocity(Turbulence Strength) in y (crosswind)	$\sqrt{\sum_i (v_i-\bar{v})^2/N}$
sigma w	m/s	Standard deviation of fluctuating wind velocity(Turbulence Strength) in z (vertical wind)	$\sqrt{\sum_i (w_i-\bar{w})^2/N}$
sigma T	C	temperature fluctuation	$\sqrt{\sum_i (T_i-\bar{T})^2/N}$
Heat Flux (Q_o)	Km/s	kinematic flux	$\overline{w'T'}$
u-star (u_*)	m/s	friction velocity	$[(\overline{u'w'})^2+(\overline{v'w'})^2]^{1/4}$
MO-Length	m	Monin-Obokov length	$\frac{\bar{T}u_*^3}{\kappa g Q_o}$

Table B-3. Description of the 20 Hz meteorological data.

u	v	w	Type	Meteorological Wind Direction
1	0	0	Horizontal	Wind from west (270 degrees)
0	1	0	Horizontal	Wind from south (180 degrees)
0	0	1	Vertical	Wind upward from the surface

The u vector is along the east-west axis; positive u are winds from true west.
The v vector is along the north-south axis; positive v are winds from true south.
The w vector is along the vertical axis; positive w are winds from the surface.

Table B-4. Description of the 20 Hz meteorological data file format.

Date	u	v	w	T
7/20/2022 13:05	0.081984	1.479664	-0.1035	32.2729
7/20/2022 13:05	0.284499	1.433699	-0.28625	32.19793
7/20/2022 13:05	0.114883	1.18159	-0.226	32.27987
7/20/2022 13:05	0.02779	1.059061	-0.298	32.33218
7/20/2022 13:05	-0.23831	0.860179	-0.047	32.53624
7/20/2022 13:05	-0.12099	0.894725	0.1575	32.63739
7/20/2022 13:05	0.215314	1.101763	0.2905	32.73685
7/20/2022 13:05	0.229752	0.919477	0.2405	32.59203
7/20/2022 13:05	0.317743	1.044298	0.24475	32.44202
7/20/2022 13:05	0.477812	1.135567	0.25625	33.03007
7/20/2022 13:05	0.342207	1.224076	0.29875	32.51532
7/20/2022 13:05	0.603204	1.174229	0.18575	32.5397
7/20/2022 13:05	0.240168	1.010786	0.0735	32.4211
7/20/2022 13:05	0.17443	0.99232	0.2215	32.64436
7/20/2022 13:05	0.230929	1.272385	0.17875	32.71417
7/20/2022 13:05	0.118491	1.117938	0.086	32.63217
7/20/2022 13:05	0.240357	1.363399	-0.18575	32.61471
7/20/2022 13:05	0.184657	1.349888	-0.21075	32.388
7/20/2022 13:05	-0.03247	1.314366	-0.05525	32.35133

The date and time are all in Pacific Daylight Time (PDT). The u-, v- and w-winds are in meters per second. The temperature (T) is in degrees Celsius.

Appendix C: Coordinates of Tracer Release Region

The extent of the tracer release at the no barrier and double barrier measurement sites are tabulated in Table C-1. The coordinates specify the part of the Chicago Avenue (no barrier site) and CA-71 freeway (double barrier site) where the tracer gas was released.

Table C-1 Extend of the tracer release at the no barrier and double barrier measurement sites.

Site	Extend of Release			
	Latitude	Longitude	Latitude	Longitude
No Barrier	33.967975	-117.348485	33.961084	-117.348327
Double Barrier	33.979447	-117.704088	33.970989	-117.692672