Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Ozone Concentrations In and Around the City of Arvin, California

Final Report
Prepared for

San Joaquin Valley Unified Air Pollution Control District
Fresno, CA

May 2014

Ozone Concentrations In and Around the City of Arvin, California

Final Report

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Prepared by

Clinton P. MacDonald
Paul T. Roberts
Michael C. McCarthy
Jennifer L. DeWinter
Timothy S. Dye
David L. Vaughn
Geoff Henshaw[1]
Scott Nester[2]
Hilary A. Minor
Andrew P. Rutter
Kevin Smith
Eric Winegar[3]

Sonoma Technology, Inc.
1455 N. McDowell Blvd., Suite D
Petaluma, CA 94954-6503
Ph 707.665.9900 | F 707.665.9800
sonomatech.com

[1]Aeroqual Ltd.

[2]Providence Engineering and Environmental Group

[3]Winegar Air Sciences

Prepared for

James Sweet
San Joaquin Valley Unified Air Pollution Control District
1990 East Gettysburg Avenue
Fresno, CA 93726-0244

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Cover photo: Aeroqual ozone sensors at the Di Giorgio monitoring site.

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1. Introduction

1.1 Study Overview

The San Joaquin Valley Unified Air Pollution Control District (the District) and the California Air Resources Board (ARB) operate monitoring stations throughout the District to determine compliance with federal air quality standards and to provide public notification of local air quality conditions. The District issues daily advisories to schools through the Real-time Air Advisory Network (RAAN). The ARB maintained an air quality monitoring station at the Arvin-Edison Water Storage District from June 1989 through December 2010. In July 2009, the managers of the Arvin-Edison Water Storage District informed ARB that the agency was no longer willing to lease a portion of their land located at 20401 Bear Mountain Boulevard in Arvin. Because of Arvin-Edison's decision, ARB was forced to relocate its station to a new site within the Arvin area, ultimately shutting down the Arvin-Bear Mountain Boulevard site in December 2010. The new site, located about two miles north of the prior site, is near Di Giorgio Elementary School (19405 Buena Vista Boulevard). The two sites were operated in parallel for about one year, encompassing the 2010 ozone season.

Although ozone concentrations measured at the new Di Giorgio site during the 2010 parallel monitoring were about 10% lower than concentrations measured at the Bear Mountain site, differences in 2010 ozone measurements between the two sites may have resulted from the relative accuracy levels of the monitoring equipment at each site.[1] Additionally, ARB has created a data imputation method to replace missing data with estimated values and used this methodology to estimate data for the former Bear Mountain site. The method, called I-Bot (short for Imputation RoBot), makes use of natural connections in the data from other monitors when stations share similar meteorological conditions and human activity patterns. Since air pollutant concentrations typically exhibit spatial and temporal correlation, concentrations at a particular place and time may be able to be estimated from measurements made at the same location before and after a missing measurement, or from measurements made at nearby locations. These connections are often consistent enough to use data from one site to impute accurate values for missing data at another site. As included in the District's 2013 Plan for the Revoked 1-Hour Ozone Standard,[2] ARB was able to impute 2011 data for the former Bear Mountain site and demonstrate that ozone levels were the lowest since 1995, including the lowest ozone concentrations and design value. Based on this decreasing trend in concentrations at Bear Mountain, the imputation analysis helps demonstrate that Arvin Bear Mountain would be in attainment of the 1-hour standard in the 2011 through 2013 timeframe, and beyond.

More importantly, data collected during portable monitoring in September 2011 may indicate that ozone concentrations at the Di Giorgio site are more representative of ozone levels to which Arvin residents are currently exposed.[3] However, these measurement differences have raised concerns in the community, and the U.S. Environmental Protection Agency (EPA)

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[1] Source: San Joaquin Valley Unified Air Pollution Control District's Request for Proposal for this project.

[2] http://www.valleyair.org/Air_Quality_Plans/OzoneOneHourPlan2013/11AppendixGWeightofEvidence20130816.pdf (See page G-3, Figure 9, on page G-9, and Appendix G-1).

[3] http://www.bakersfieldcalifornian.com/lifestyle/health-beat/x651158210/Preliminary-reading-Arvins-air-equally-bad.

has indicated that the differences may hinder EPA's ability to determine whether the region has attained federal ozone standards.

To respond to the concerns expressed by EPA, the District contracted an independent, scientific ozone saturation study to Sonoma Technology, Inc. (STI). The main goals of the study were to compare and to resolve uncertainties concerning the ozone concentrations at the new and prior site locations; examine ozone gradients in and around Arvin; determine the implications of the site relocation on the National Ambient Air Quality Standards (NAAQS); and to provide supporting information to ARB, EPA, and the District for decisions related to air monitoring in the area. Ancillary long-term benefits may be realized through the development of a formula to predict local ozone concentrations for the City of Arvin, providing enhanced accuracy for the daily forecasting and health advisories for which the District is responsible.

To meet these project goals, STI and their project partners (Providence Engineering and Environmental Group, LLC, Aeroqual Ltd., and Winegar Air Sciences) were directed by the District to establish a network of monitors to collect ozone readings in and around Arvin during the peak ozone season in the summer of 2013, conduct the ozone measurements at 21 sites for about six weeks, and analyze the collected data for indications of ozone gradients. STI was also requested to analyze the data collected to provide predictive formulae for local ozone concentrations at the City of Arvin and the old Arvin monitoring site at Bear Mountain Boulevard, based upon the expectation of continued monitoring at Edison, Bakersfield (California St.), and the new site in Arvin at Di Giorgio Elementary School.

The answers to questions regarding ozone concentrations in and around Arvin, and a summary of STI's findings from this study, are presented in Section 2. Field study methods are presented in Section 3. Data analysis methods are presented in Section 4. Section 5 provides discussion of the analysis and the precision of data, as well as detailed discussion of the results summarized in Section 2. The Field Study Plan is contained in **Appendix A**. The results from the collocation experiments, including information on instrument accuracy and precision, are contained in **Appendices B and C**. The daily peak 1-hr and 8-hr ozone concentrations, including the day, time, and site of occurrence, are provided in **Appendix D**, and a discussion of the residuals from the regression analysis is provided in **Appendix E**. The final data have been provided to the District on DVD. STI presented information regarding preparation for this study at a recent conference[4] and may publish additional technical articles pertaining to the evaluation of the ozone sensors or other subjects at a future date.

1.2 About Arvin

Arvin, a city of about 19,000 residents at the southern end of the San Joaquin Valley in California's Central Valley, is bounded immediately to the northeast and east by the Sierra Nevada range, immediately to the southeast by the Tehachapi Mountains, and further to the west by the coastal ranges of California (see **Figure 1-1**). Because Arvin is at the southern end of the San Joaquin Valley, predominant northwesterly winds in the region during the summer

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[4] MacDonald et al. (2013) Measuring spatial variability in ozone concentrations using a small-sensor network, Presented at the *A&WMA Air Quality Measurement Methods and Technology Conference, Sacramento, California, November 19–20, 2013* (STI-5750).

can transport air and associated pollution from areas to the north into Arvin, where the surrounding mountains can trap this air. The transported pollution, coupled with local emissions, high air temperatures, and clear skies, has resulted in some of the highest ozone concentrations observed in the Central Valley and, occasionally, in the United States.

Figure 1-1. Location of Arvin relative to natural features in California.

1.3 Summary of Methods

STI and the project team conducted an ozone saturation study from August 10 through September 25, 2013, and subsequently conducted data analysis. The field study consisted of ozone measurements taken by Aeroqual Series 500 ozone sensors at 21 sites in and around the Arvin area (see **Figure 1-2**). To calibrate the Aeroqual sensors, all sensors were collocated with a federal equivalent method (FEM) ozone monitor before deployment and after the field study was completed. In addition, during the field study, Aeroqual sensors were collocated at each of three ARB sites that had FEM ozone monitors, including the new regulatory site at Di Giorgio.

To represent the prior regulatory monitoring location at Bear Mountain Road, two locations were selected about 440 m east of the old regulatory site, with one sensor near the roadway and a second north of the roadway to avoid fresh emissions from traffic. Note that the project team was unable to place the monitor any closer than 440 m to the old regulatory site.[5]

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[5] The Air District contacted the Arvin-Edison Water District requesting authorization for placement of one of the temporary monitors precisely at the same location as the old regulatory site; however, this request was denied.

Surface wind measurements were made at five sites: three permanent wind measurement locations at the FEM sites (Bakersfield California Street, Edison, and Di Giorgio), and two temporary locations established for this study at Bear Mountain and at a site in the south side of the City of Arvin. Other sites were established to capture ozone concentrations (1) to the west, where the sites would often be upwind of Arvin; (2) in Arvin, where most people live; and (3) in and around Bear Mountain and Di Giorgio.

All 1-minute sensor data were transmitted in real time to STI's office and posted to a website for daily data review. STI quality-controlled the data by reviewing time-series plots of ozone concentrations and sensor quality assurance metadata. Ozone concentrations (1-hr and 8-hr) were then calculated from the quality-controlled 1-minute data. Using the collocation measurements, STI calibrated the data to be "FEM-like." Overall, data recovery rates were very high at all sites.

STI analyzed spatial and time-series plots of the 1-hr and 8-hr ozone concentrations to evaluate spatial gradients. In addition, STI compared the data to wind speed and wind direction data to evaluate the underlying factors influencing the gradients of ozone concentrations. STI developed algorithms to predict the City of Arvin's peak 1-hr and 8-hr concentrations using routinely available meteorological data collected on all study days and a combination of ozone data from Di Giorgio, Edison, and Bakersfield. These algorithms were requested by the District to supplement or replace existing forecast tools for prediction of daily peak 1-hr and 8-hr concentrations in Arvin. STI also developed algorithms that allow predictions of Bear Mountain ozone concentrations using the FEM data collected at Di Giorgio, Edison, and Bakersfield.

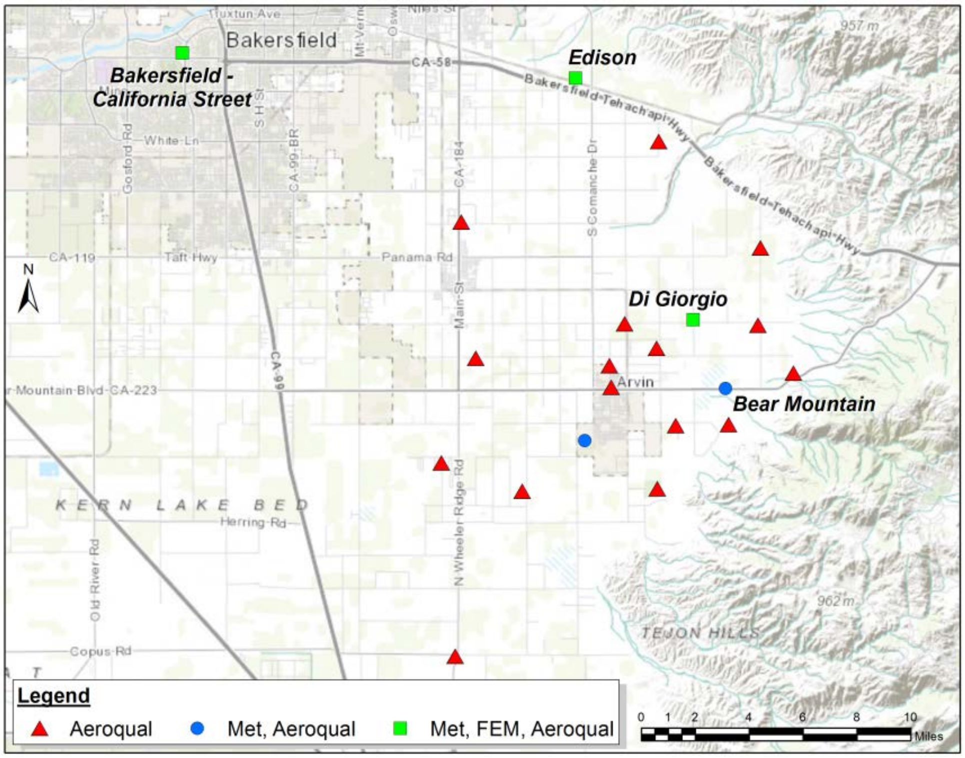

Figure 1-2. Monitor locations for measuring and evaluating ozone spatial gradients.

2. Summary of Findings

This section presents the key findings that address the project objectives. The methods used to derive these findings are presented in Section 4; details of the results supporting these findings are presented in Section 5. The findings are presented below as answers to several specific questions regarding ozone concentrations in and around Arvin.

1. ***Are the Aeroqual sensors sufficiently accurate and precise to assess spatial gradients in and around Arvin?***

   Yes, analysis of data from the four Aeroqual sensors that were collocated with FEM monitors during the entire study and the three additional sensors that were collocated for a portion of the main field study indicates the Aeroqual sensor data are accurate and precise enough to assess spatial gradients. The accuracy of the 1-hr measurements is about 3 ppb and the precision is ±4% at the 95% confidence level. This assumes that the other Aeroqual sensors that were not collocated during the study have similar measurement characteristics as those that were collocated. This assumption is valid because the pre- and post-study collocation experiments with all Aeroqual sensors and FEM monitors indicated that all sensors had similar characteristics.

   See Section 4.1 for details on the methods and Section 5.2 for details on the findings.

2. ***What are the general spatial gradients for peak 1-hr and 8-hr ozone concentrations in and around Arvin? Are there any key features evident that characterize gradients in the area?***

   There are strong gradients in peak 1-hr and 8-hr ozone concentrations within and around Arvin. At any given hour, 1-hr ozone concentrations varied on average by about 50-60 ppb across the study domain. Peak 1-hr ozone concentrations at each site on a given day can vary by as much as 30 ppb.

   Peak 1-hr and 8-hr ozone concentrations occurred earlier in the day at sites northwest of Arvin and later in the day at sites southeast of Arvin.

   The six sites that often had the highest ozone concentrations on each day were scattered throughout the area but were not located south or southwest of Arvin.

   See Section 4.2 for details on the methods and Section 5.3 for details on the findings.

3. ***On high ozone days (days when 1-hr ozone concentrations are greater than 75 ppb at any site), what are the diurnal patterns of ozone as a function of area/site, and what are the general processes that appear to influence those patterns?***

   Ozone concentrations are low (<25 ppb) at most sites, even those in rural areas, until approximately 7:00 a.m. Local Standard Time (LST). These low concentrations indicate the effects of ozone titration by fresh nitric oxide (NO) during the night. At the eastern sites nearest the mountains, however, ozone concentrations can remain above 50 ppb overnight and in the morning, because the downslope flow from the mountains does not contribute the NO needed to titrate the ozone out of the air.

A northwest-to-southeast ozone concentration gradient develops across the area at about 10:00 a.m. LST, with the highest concentrations first occurring in Bakersfield. As the day progresses, concentrations decrease in the northwest and increase in and southeast of the Arvin area. This gradient pattern may be the result of pollution from the Central Valley that is compounded in Bakersfield, transported by northwesterly flow, and blocked by the mountains, thus residing in the Arvin area later in the day.

The northwest-to-southeast ozone concentration gradient occurs on almost all days regardless of the magnitude of peak ozone concentrations. The spatial ozone patterns indicate that ozone titration by NO occurs in the late afternoon and evening throughout the study area each day. However, downslope flow near the mountains limits titration at nearby sites, except on the rare days when the northwesterly flow in the Arvin area continues into the evening. Nighttime ozone concentrations are higher at the eastern sites impacted by downslope flows than at other sites, and 8-hr average ozone concentrations for some hours are also higher at these eastern sites. In addition, higher baseline ozone concentrations are observed at these sites as daylight hours begin, reflecting the reduced overnight titration.

See Section 4.2 for details on the methods and Section 5.3 for details on the findings.

4. ***On high ozone days, what data collected at permanent sites during the study is useful for representing the City of Arvin's 1-hr and 8-hr ozone concentrations?***

Ozone concentrations measured at Di Giorgio site are very representative of the ozone concentrations measured in the City of Arvin; they are well-correlated and of about the same magnitude.

See Section 4.3 for details on the methods and Section 5.4 for details on the findings.

5. ***On high ozone days, does the Di Giorgio site have higher or lower 1-hr and peak 8-hr ozone concentrations than the old Bear Mountain site?***

The Di Giorgio monitoring site is very representative of high ozone concentrations in the area around the old Bear Mountain monitor. Note that the Di Giorgio site showed slightly higher peak 1-hr ozone concentrations than the temporary Bear Mountain site and had more 8-hr exceedances (eleven compared to six).

See Section 4.2 for details on the methods and Section 5.3 for details on the findings.

6. ***Can accurate equations be developed to predict the City of Arvin's peak 1-hr and 8-hr ozone equations using ozone data from the FEM monitors and permanent meteorological sites?***

Yes, very accurate equations can be and were developed for predicting the City of Arvin's peak 1-hr and 8-hr ozone concentrations. The predicted 1-hr and 8-hr ozone concentrations from the resulting equations versus the observed ozone have a correlation (R^2) of about 0.92. In addition, the absolute error is 1 ppb.

See Section 4.3 for details on the methods and Sections 5.4.2 and 5.4.3 for details on the findings.

7. ***Can accurate equations be developed to predict Bear Mountain's ozone concentrations using ozone data from the FEM monitors and permanent meteorological sites?***

   Yes, very accurate equations can be and were developed for predicting Bear Mountain's peak 1-hr and 8-hr ozone concentrations. The predicted 1-hr and 8-hr ozone concentrations from the resulting equations versus the observed ozone have a correlation (R^2) of about 0.90. In addition, the absolute error is at most 1.5 ppb.

   See Section 4.3 for details on the methods and Sections 5.4.4 and 5.4.5 for details on the findings.

3. Field Study Methods

To meet the project goals presented in Section 1, the STI team conducted a field program from August 10 through September 25, 2013, and subsequently conducted data analysis. The core of the field study consisted of ozone measurements taken by Aeroqual Series 500 ozone sensors at 21 sites in and around the Arvin area and meteorological measurements taken at two sites. These measurements were supplemented by permanent ozone and meteorological measurements taken at Di Giorgio, Edison, and Bakersfield at California Street.

During the main field study, the project team

- Designed a field program to meet the project objectives using low-cost ozone sensors;
- Selected and obtained low-cost ozone sensors;
- Identified and procured sites for the ozone measurements;
- Conducted a pre- and post-deployment collocation study of the Aeroqual sensors with an FEM monitor to calibrate the Aeroqual sensors;
- Installed, operated, and maintained the instruments for six weeks;
- Delivered and posted the data in real time to monitor the instruments; and
- Processed and quality-controlled the data.

This section discusses these study elements. Further details can be found in the Field Study Plan in Appendix A.

3.1 Instruments

A list of the measurement equipment used in the study is shown in **Table 3-1.** The primary sensor used for this study, an Aeroqual Series 500 ozone sensor, collected 1-minute ozone measurements. This sensor uses a sensitive semiconductor that relies on the conductance of heated tungstic oxide (WO_3) as a means to measure ozone. **Figure 3-1** shows the ozone sensor, which houses the semiconductor. **Figure 3-2** shows the Aeroqual sensors and supporting equipment used during the collocation experiment and one sensor used during the field study. Note that there were two sensors each at the Bear Mountain and Di Giorgio sites so that analysts could intercompare sensor data in these critical areas.

In the presence of ozone, surface conductance of WO_3 decreases. Changes in the conductance are calibrated to measure ozone concentrations. The air flow to the sensor is controlled with a fan, and the fan speed is modulated between two states—fan on and fan off. During the no-flow (fan off) state, the high temperature of the sensor results in thermal decomposition of surrounding ozone, and the sensor measures a “zero ozone” conductance. During the “fan on” state, the sensor responds to incoming ozone, and the sensor conductance decreases. The ozone measurement is proportional to the sensor conductance difference between these two states.

Table 3-1. Instrument and equipment list.

Parameter/Equipment	Manufacturer	Model	Number of Instruments	Sampling Interval
Ozone	Aeroqual	Series 500	23, plus 2 spare sensors	1 min.
Temperature (temp)	Sensiron	SHT-75	23	1 min.
Relative humidity (RH)	Sensiron	SHT-75	23	1 min.
SRB [diagnostic]	Aeroqual	Series 500	23	1 min.
SRG [diagnostic]	Aeroqual	Series 500	23	1 min.
Battery voltage	Aeroqual	Series 500	23	1 min.
GPS time	Aeroqual	Series 500	23	1 min.
GPS date	Aeroqual	Series 500	23	1 min.
Latitude	Aeroqual	Series 500	23	1 min.
Longitude	Aeroqual	Series 500	23	1 min.
Solar panel for Aeroqual instrumentation	SolarTech Power, Inc.	SPM055P-F	23	N/A
Data logger (in Series 500 Aeroqual instrumentation)	Aeroqual	Series 500	23	1 min.
Modem for Aeroqual instrumentation	GateTel	GT-HE910-G	23	15 min.
Ozone FEM instrument (for collocation study)	Teledyne	T400	1	1 min.
30-ft. tower	Universal Towers	9-30	2	N/A
PC with Dr. DAS (data logger for collocation study)	DR DAS LTD	N/A	1	N/A
Wind speed/wind direction	RM Young	AQ 5305-L	2	1 min.
Solar panel for meteorological instrumentation	Campbell Scientific	SP20	2	N/A
Data logger for meteorological instrumentation	Campbell Scientific	CR1000	2	1 min.
Modem for meteorological instrumentation	Sierra Wireless	RavenXT	2	1 min.

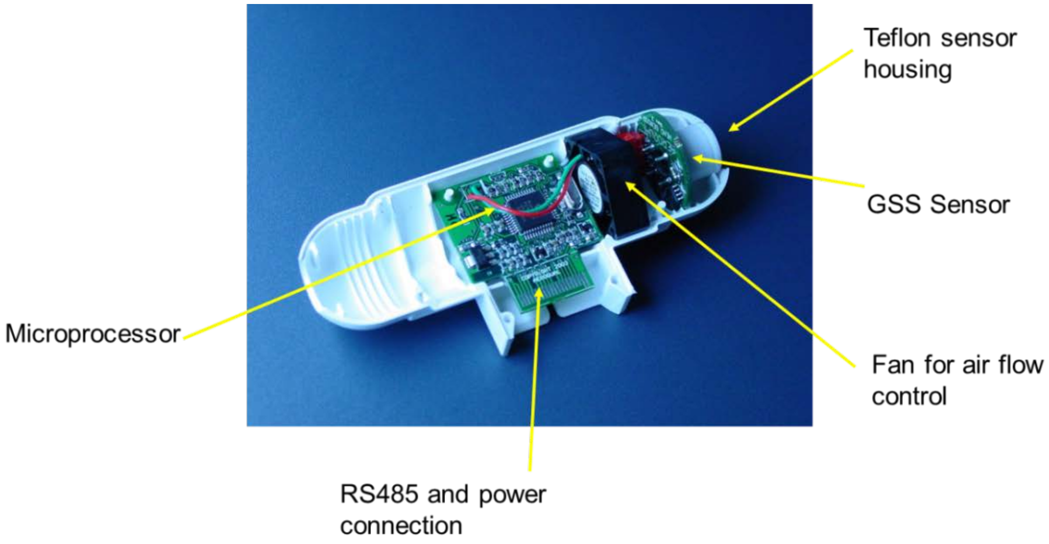

Figure 3-1. Aeroqual ozone sensor head.

Figure 3-2. Aeroqual sensors (left) during the initial collocation experiment and (right) at a field site.

Because of the high operating temperature, the sensor does not respond to ambient levels of carbon monoxide, sulfur dioxide, or nitrogen oxide. Furthermore, the difference measurement technique renders the sensor relatively immune to ambient humidity and temperature effects and interference by nitrogen dioxide. However, high concentrations of hydrocarbons (ppm levels) and hydrogen sulfide (hundreds of ppb) can overwhelm the ozone signal and result in a negative interference. During the study, the project team also learned that dust may reduce ozone sensitivity through enhanced ozone decomposition rates on dust-covered inlet and sensor surfaces. This baseline drift due to apparent dust was addressed by adjusting the data using results from the pre- and post-study collocation experiments, as discussed in Section 3.5.

Aeroqual sensor performance characteristics are shown in **Table 3-2**. Of key importance, the sensors met performance characteristics that were necessary to address spatial gradients in ozone concentrations on the order of 10 ppb. Further, differences of 10 ppb in ozone concentrations could be detected with more than 95% statistical confidence by stratifying and averaging data over an 8-hr period. While any single pair of 1-hr ozone measurements will have uncertainty ranges that overlap, the large number of available measurements enhanced the signal-to-noise ratio and allowed for successful analysis of the data to meet study objectives.

The Aeroqual sensor was also a useful choice because it has low power requirements, does not require a temperature-controlled enclosure, and provides continuous data 24 hours per day. It operates on solar power with modem-based data communications for remote deployment.

Table 3-2. Aeroqual ozone sensor performance characteristics.

Performance Characteristics	Value	Units	Performance Characteristics	Value	Units
Linear range	0 to 0.15	ppm	Precision	±0.005	ppm
Resolution	0.001	ppm	Baseline drift	< 0.004	ppm/ 1,000 hrs
Accuracy of calibration	±0.005	ppm	Operational range	0 to 40	deg C
Minimum detection limit	0.001	ppm	Relative humidity	10 to 90	%

3.2 Sites and Selection Criteria

Figure 3-3 shows the monitoring locations. The numbers on the map are cross-referenced with **Table 3-3,** which shows the site names, land use, instruments deployed, and position. The general site locations were chosen to address the following elements:

- Sites 2 through 21 were selected to characterize spatial gradients primarily in, upwind of, and downwind of Arvin and near the old and current regulatory sites (Bear Mountain [Site 18] and Di Giorgio [Site 14]). Note that the two sensors placed at Bear Mountain and Di Giorgio are in slightly different locations, as noted below in the discussion of Site 18.
- Sites 1 and 2 were selected as collocation sites with FEM monitors.
- Sites 2, 4, 5, and 6 were selected to measure ozone concentrations on the western boundary of the study area, which is often upwind of Arvin during the day.
- Sites 2, 3, and 15 were selected to measure ozone concentrations on the northern boundary, which is often upwind of Arvin during the night.
- Site 7 was selected to measure ozone concentrations at the southern boundary.
- Site 8 was selected to measure ozone concentrations just south of Arvin.

- Sites 9, 10, and 11 were selected to measure ozone concentrations in the City of Arvin.
- Sites 12, 13, and 16 were selected to measure ozone concentrations around Di Giorgio (Site 14).
- Site 14 (Di Giorgio) was selected to measure ozone concentrations at the current regulatory site. Two sensors were located at this site to allow comparison of sensor data during the study (to detect drift in sensor readings) and to provide a robust data set at this critical location.
- Sites 19 and 20 were selected to measure ozone concentrations around Bear Mountain (Site 18).
- Site 18 was selected to measure ozone concentrations near the old Bear Mountain regulatory site. Note that the site could not be placed at the exact location of the old regulatory site; thus, Site 18 was across the road from the old Bear Mountain site and about 440 m to the east (see **Figure 3-4**). Also note that the monitors were in two positions at Site 18: one near the road (Site 18a) and one recessed from the road by about 300 m (18b). This second location at Site 18 was to avoid impacts of fresh NO_x emissions on ozone concentrations. Site 18c is the meteorological site.
- Sites 15, 16, 17, 19, and 21 were selected to measure ozone concentrations along the eastern boundary, which is generally downwind of the main study area during the day and upwind at night when downslope flow from the mountains is often observed.

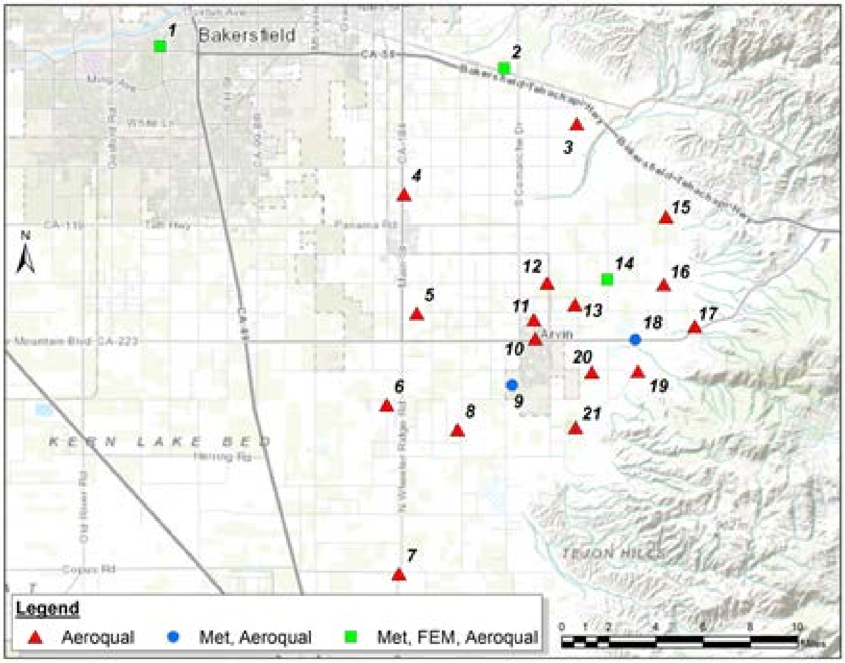

Figure 3-3. Monitoring locations.

Table 3-3. Sites and respective instrumentation. Note that at Bear Mountain (Site 18), there were three subsites: 18a, 18b, and 18c. 18c had the meteorological tower and was right next to 18a. 18b was about 300 m from 18a and 18c.

Site Name	Site ID	Land Use	Latitude	Longitude	Instrumentation
Bakersfield – California Street	1	Commercial	35.356619	-119.062611	Aeroqual, FEM ozone, Met
Edison	2	Agriculture	35.345611	-118.851831	Aeroqual, FEM ozone, Met
North of Di Giorgio	3	Agriculture	35.317917	-118.807222	Aeroqual
Northwest of Arvin	4	School	35.282861	-118.913139	Aeroqual
West boundary	5	Residential	35.223097	-118.905361	Aeroqual
West of Arvin	6	Residential	35.177164	-118.923839	Aeroqual
Gradient south	7	Agriculture	35.092436	-118.916325	Aeroqual
South of Arvin	8	Industrial	35.16475	-118.880389	Aeroqual
Arvin South	9	Industrial	35.187028	-118.846778	Aeroqual, Met
Arvin Central	10	Municipal office	35.210225	-118.832803	Aeroqual
Arvin North	11	School	35.219703	-118.833739	Aeroqual
West of Di Giorgio	12	Residential	35.238139	-118.825556	Aeroqual
Southwest of Di Giorgio	13	Residential	35.227417	-118.808472	Aeroqual
Di Giorgio	14a and 14b	Agriculture	35.239119	-118.788689	Aeroqual (2), FEM ozone, Met
Northeast of Di Giorgio	15	Agriculture	35.271361	-118.752694	Aeroqual
East of Di Giorgio	16	Agriculture	35.237472	-118.753972	Aeroqual
East of Bear Mountain	17	Agriculture	35.216528	-118.735056	Aeroqual
Bear Mountain	18a (c)	Agriculture	35.209778	-118.771306	Aeroqual, Met (c)
Bear Mountain	18b	Agriculture	35.213083	-118.770306	Aeroqual
Southeast of Bear Mountain	19	Industrial	35.194028	-118.76975	Aeroqual
Southwest of Bear Mountain	20	Residential	35.193472	-118.798083	Aeroqual
Southeast of Arvin	21	Golf Course	35.165808	-118.808003	Aeroqual

The precise site locations were selected to avoid fresh NO_x emissions from both mobile and stationary sources; to measure ozone near the height of human exposure; and to avoid buildings, other obstructions, and trees.

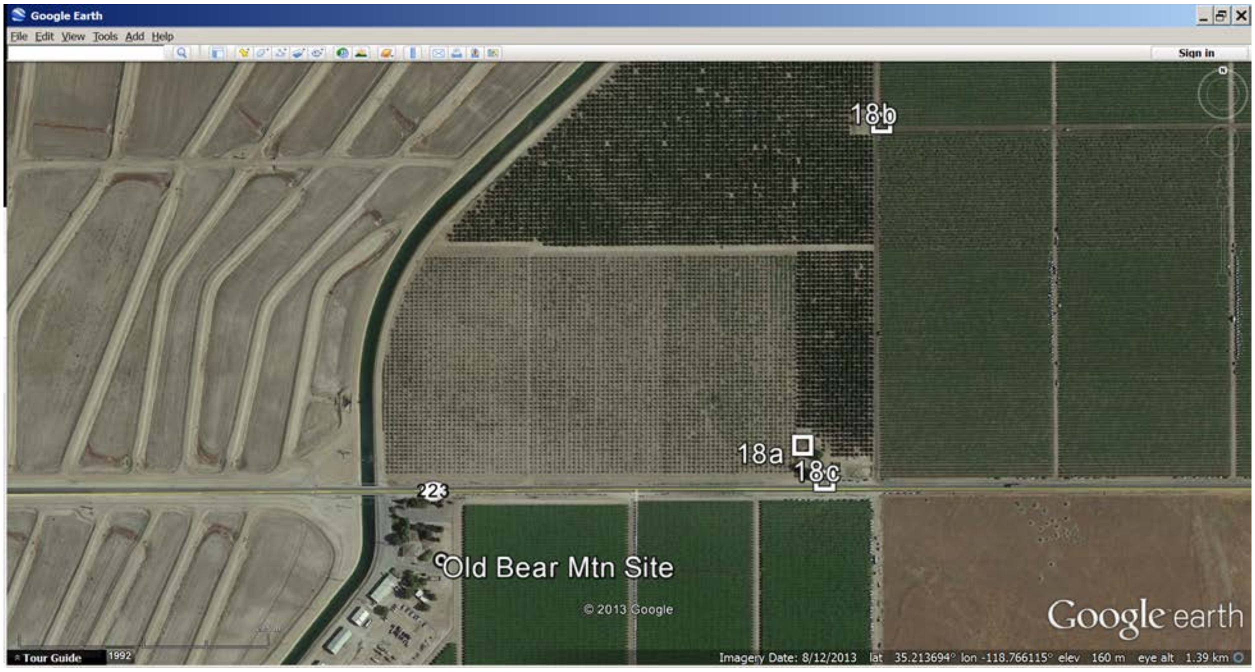

Figure 3-4. A close-up view of the area around the old Bear Mountain regulatory monitoring site. Site 18a is about 440 m from the old Bear Mountain site. Site 18b is recessed from the road by about 300 m. Site 18c is the meteorological tower and is about 20 m from Site 18a.

3.2.1 Mobile-Source NO_x Emissions

Emissions of NO can suppress nearby ozone concentrations via titration. This means that ozone sensors near NO_x sources, such as heavily traveled roads or stationary sources, may be unsuitable for representing spatially broader ozone concentrations. To minimize these interferences, the project team deployed monitors at sites that generally fulfilled the federal monitor siting guidance at 40 CFR 58, Appendix E (Appendix E).[6] Appendix E, Table E-1, summarized below in **Table 3-4**, requires that ozone monitors within 250 m of a roadway be sited at specified minimum distances, based on average daily traffic counts.[7]

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[6] 40 CFR 58, Appendix E, is intended for siting permanent monitoring stations used to assess compliance with NAAQS; those monitors are intended to represent much larger geographic areas than the monitors in this ozone saturation study. It is also noted that ozone monitors near NO_x sources can accurately represent the suppressed ozone concentrations affecting the residents and workers in close proximity to the monitoring site.

[7] 40 CFR 58, Appendix E, does not prohibit monitors at close proximities to roadways, but requires that the spatial scale for a monitor closer to the road be classified as microscale or middle scale rather than neighborhood or urban scale.

Table 3-4. Summary of the minimum distances between ozone monitors and nearby roadways specified by 40 CFR 58, Appendix E.

Roadway Average Daily Traffic, Vehicles Per Day	Minimum Distance for Post-2006 Ozone Monitors (m)
≤ 1,000	10
10,000	20
15,000	30
20,000	40
40,000	60
70,000	100
≥ 110,000	250

To assure consistency with these guidelines, STI staff reviewed California Department of Transportation annual average daily traffic (AADT) counts for the four state highways in the Ozone Saturation Study area: Hwy 99, Hwy 58, Hwy 184 (Weedpatch Highway), and Hwy 223 (Bear Mountain Boulevard). The busiest of the four highways, Hwy 99, is 5.5 km from the closest monitoring site and 16 km from Arvin High School (which is the approximate centroid of the monitoring area). Hwy 58 is approximately 600 m from the Edison monitoring station and 1.1 km from the closest monitoring site acquired specifically for this study. Therefore, because these sites are more than 250 m away from Hwy 58 and Hwy 99, all monitors in the study area were consistent with Appendix E with regard to Hwy 58 and Hwy 99. There were four monitoring sites within 250 m of Hwy 184 or Hwy 223, but all of the sites were sited in accordance with Appendix E, as shown in **Table 3-5**.

Table 3-5. Distances between ozone monitors and nearby roadways.

Site Number and Name	Nearest Highway	Nearest AADT	Appendix E Prescribed Distance	Actual Distance[a]
Site 4, Northwest of Arvin	Hwy 184	12,400	≥ 30 m	152 m
Site 7, Gradient South	Hwy 184[b]	4,000	≥ 20 m	202 m
Site 10, Arvin – Central	Hwy 223	9,600	≥ 20 m	116 m
Site 18, Bear Mountain	Hwy 223	1,800	≥ 20 m	28 m

[a] Distances are estimated using latitude-longitude coordinates recorded at monitoring sites, coordinates for permitted stationary sources provided by the District, and Google Earth coordinates for roads.

[b] The Gradient South site (#7) is on property adjoining Wheeler Ridge Road, which is the southern extension of Hwy 184, although not technically part of the state highway system.

3.2.2 Stationary Sources

Unlike the guidance for monitoring near roadways, 40 CFR 58, Appendix E, Section 3, “Spacing from Minor Sources,” does not specify minimum distances from stationary emissions sources; however, it provides the following general guidance for permanent monitoring stations intended to measure compliance with NAAQS:

> *(b) Similarly, local sources of nitric oxide (NO) and ozone-reactive hydrocarbons can have a scavenging effect causing unrepresentatively low concentrations of* O_3 *in the vicinity of probes and monitoring paths for* O_3*. To minimize these potential interferences, the probe or at least 90 percent of the monitoring path must be away from furnace or incineration flues or other minor sources of* SO_2 *or NO. The separation distance should take into account the heights of the flues, type of waste or fuel burned, and the sulfur content of the fuel.*

Using a methodology similar to that used for assessing emissions impacts from roadways, the project team assessed potential influences from stationary sources within a radius of 250 m. According to information provided by the District, there are 40 permitted NO_x sources in the study area. Total NO_x emissions from these sources are 31.6 tons per year. As shown in **Table 3-6**, two sites (Site 8, South of Arvin and Site 10, Arvin-Central) are within 250 m of at least one District-permitted NO_x source. The monitoring site closest to NO_x sources is Site 10 at Arvin City Hall. There are three NO_x-emitting facilities within 250 m of this site, emitting a total of 0.23 tons of NO_x per year (1.3 lb. of NO_x per day, averaged over 365 days). The largest of these sources emits 0.19 tons of NO_x per year (1.0 lb. per day) and is approximately 100 m south of the City Hall monitor. Site 8 is within 250 m of one source that emits 0.0034 tons of NO_x per year (0.02 lb. per day).

Table 3-6. Monitoring sites within 250 m of permitted NO_x sources and NO_x from those sources.

NO_x Source Facility ID	8. South of Arvin	10. Arvin - Central
3343	0.0034	
4051		0.0388
4182		0.0002
7716		0.1906
Total NO_x emitted near the site (tons per year)	0.00335	0.22957
Total NO_x emitted near the site (lb. per day)	0.02	1.26

3.3 Instrument Preparation, Installation, Operations, and Deinstallation

Instruments were prepared, installed, and operated in a manner that ensured high quality and high data recovery rates by following the Project Field Study Plan (Appendix A). Key elements of these tasks are presented in the following subsections.

3.3.1 Instrument Preparation

All Aeroqual sensors and associated equipment were prepared and tested in Fresno, California, before the collocation experiment with the FEM monitor and subsequent deployment to the field. During instrument preparation the following tasks were performed:

- Sensors were inspected to confirm that they were not damaged during shipment; all 23 sensors (including the 2 spares) were undamaged.
- All 21 sensor packages were assembled. Each package included the tripod for mounting the equipment, the Aeroqual sensor, a cellular modem for data communications, solar panels, and battery.
- After assembly, the sensor packages were run and all components were evaluated, including power, communications, and resulting ozone data. Problems were corrected as needed. For example, because the housing became too hot in the middle of the day, additional shade protection and an internal fan to cool the sensor housing were added.
- Once all systems were working correctly, field staff began a four-day collocation experiment with the Aeroqual S500 sensors and an FEM ozone instrument (Transfer Standard Teledyne API Model T400 UV absorption). Note that a second collocation experiment was completed at the end of the study. The results from the first collocation study were used to calibrate the Aeroqual sensors to be “FEM-like,” that is, to adjust the data so the Aeroqual measurements matched FEM measurements. For all sensors, the differences between the calibrated Aeroqual ozone measurements and the collocated FEM reference ozone instrument were ±3 ppb (see Section 3.5 for details). Therefore, the instruments were considered ready for deployment around Arvin.

3.3.2 Installation

The following steps were completed to install the Aeroqual sensors:

- The site owner or occupant was informed of the study team’s access requirements, and routine and emergency repair visits. The site owner or occupant was provided with contact information for the study team.
- The tripod with Aeroqual monitor, cellular modem, solar power, and battery were assembled according to procedures established during the preparation task. An example of an installed site (Di Giorgio) is shown in **Figure 3-5**.
- Solar power polarity was verified. All wiring was secured with UV-resistant cable ties.
- Additional ballast was added to the tripod, either by adding weight (for rooftop installations) or by staking (for ground installations).
- Data communications were tested and verified.
- Operation of the Aeroqual sensor data was verified based upon the manufacturer’s recommended protocols.
- The ozone data were checked for reasonableness by comparing the data to nearby FEM monitors and to other Aeroqual sensors.

- Two meteorological towers with 10-m wind speed and wind direction instruments were installed. After installation, internal performance audits were performed; all instruments passed the audits.

Figure 3-5. Two Aeroqual sensors installed on the roof of the Di Giorgio monitoring shelter.

3.3.3 Operations

Once site installations were completed, routine operations began. There were several components to the operations: remote data monitoring, routine in-field operations, and emergency visits.

3.3.4 Remote Data Monitoring

STI established a capability to remotely examine data collection and site conditions. The data was collected by the Data Management System (DMS) in detail, with summary information posted to the project website to allow District, ARB, and EPA review of the project in progress. The website included ozone readings, battery voltages, and meteorological data for the sites operated by STI.

The study team performed the following activities:

- Reviewed and evaluated the ozone data collected by the Aeroqual sensors and the ARB FEM monitors on a daily basis, using the project website and the DMS. **Figure 3-6** shows a screenshot of the data displayed in DMS shortly after installation of all sensors. **Figure 3-7** shows a screenshot of the project website. The only major issue identified during the study was ozone sensor drift as compared to the FEM monitor data. This issue was addressed via a second collocation experiment at the end of the study, as discussed in Section 3-5.

- Evaluated diagnostic information from the sites (battery voltages and other sensor diagnostics). For example, low battery voltage at two sites was observed on one day and it was determined that high winds had blown the sensors over. The problem was quickly fixed.
- Reviewed and evaluated daily the meteorological wind data collected at the two meteorological sites.
- Monitored the potential for smoke from wildland fires to impact the sensor network. Because high particulate matter concentrations from smoke could clog the filters and contaminate the ozone sensors, it would have been necessary to shut down the network during a major smoke event. Despite large wildfires present in the Sierra Nevada, no major smoke events impacted the study area.
- Documented problems and issues in the project log.

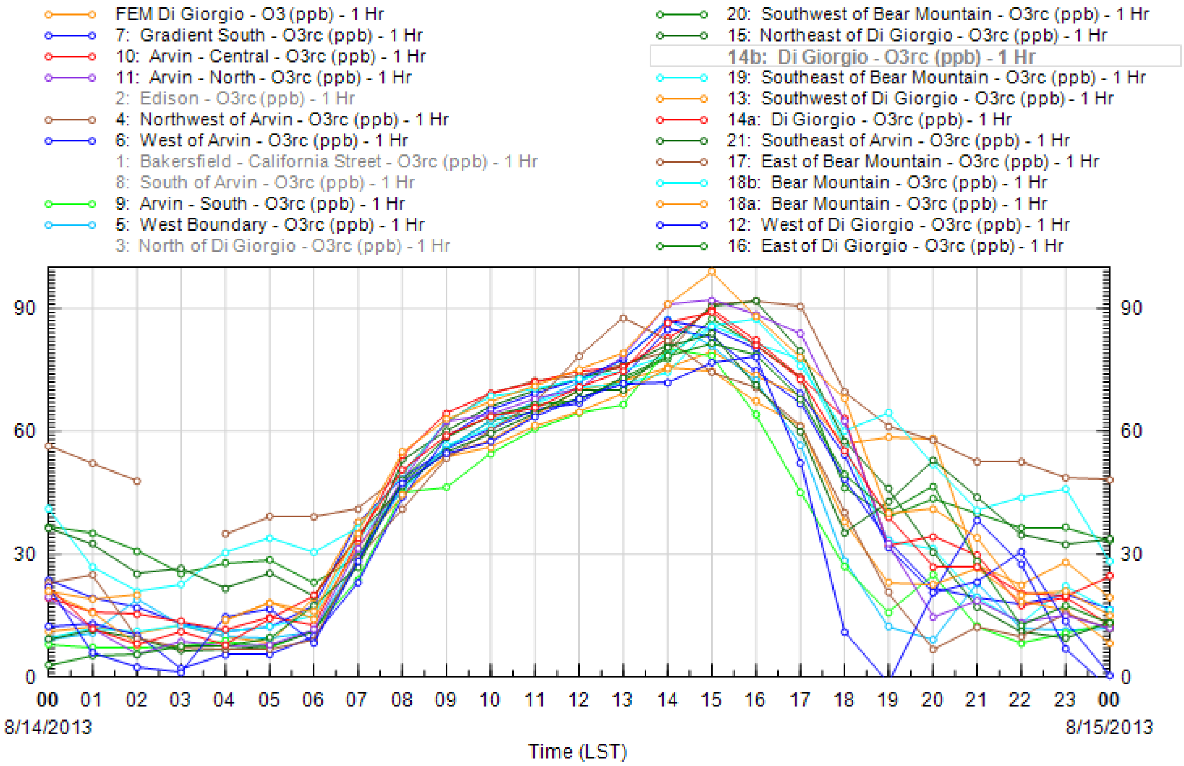
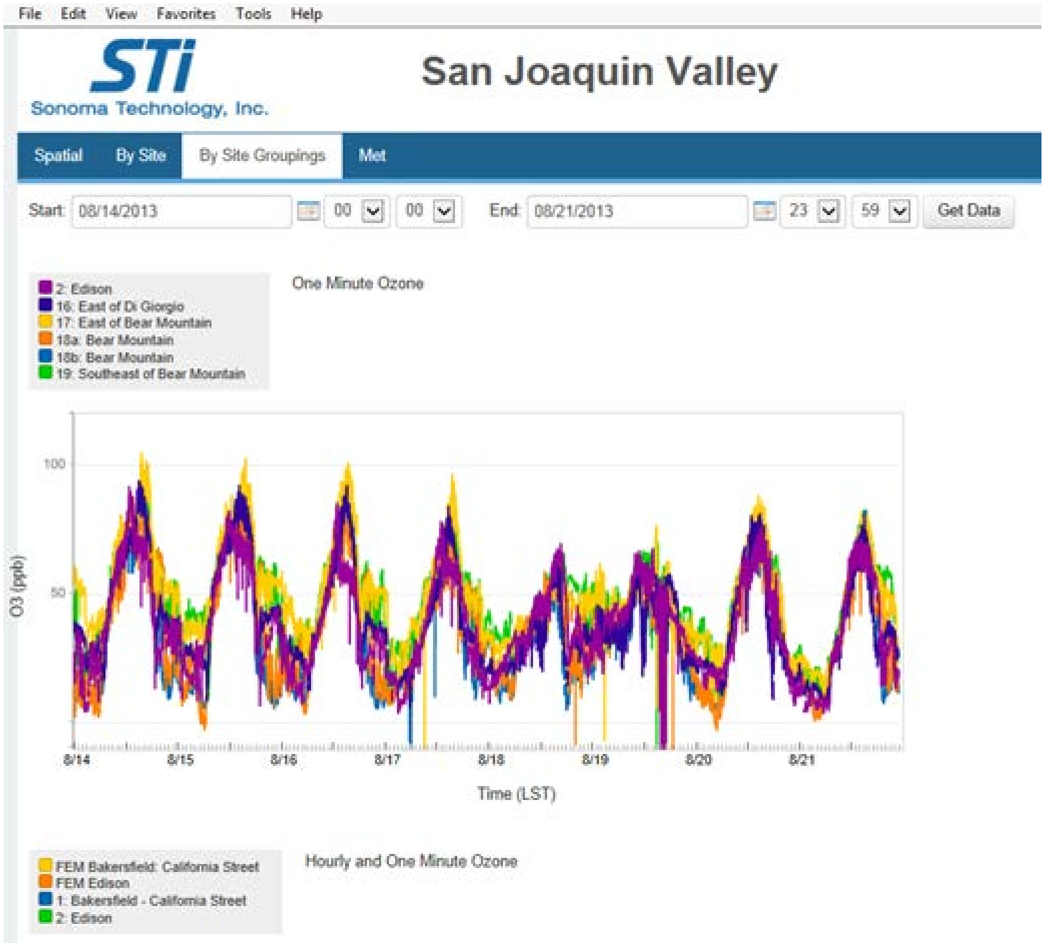


Figure 3-6. Raw ozone displayed in the DMS.



Start: 08/14/2013 00 00 End: 08/21/2013 23 59

Figure 3-7. Screenshot of the project website.

3.3.5 Routine Operations and Emergency Visits

To maintain the instruments, the following general in-field tasks were performed:

- Conducted routine visits to inspect all sensors. The technician checked the sensor inlet for any obstructions, inspected the site for any damage, checked the solar power supply, and documented any issues or major changes occurring around the site (e.g., construction). No problems were found during routine visits.
- Inspected the meteorological towers and wind instruments for any damage or issues. No problems were found during routine visits.
- Conducted emergency visits to address sensor problems. As discussed previously, three sensors systems were blown over by high winds; this problem was addressed via an emergency visit. No other emergency visits were required.

3.3.6 Sensor Removal

Once the monitoring campaign was completed, the systems were removed on a site-by-site basis. During removal, the study team conducted a final check of the sensor, disassembled the sensor package, and returned the site to its original state prior to the instrument installation. The sensors were then moved to Di Giorgio for the end-of-study collocation experiment.

For the meteorological towers, a final internal performance audit was performed prior to equipment removal. The instruments passed the audits.

3.4 Data Flow, Data Quality Control, and Processing

Data and information flowed from each site to the DMS, as shown in **Figure 3-8**. In summary:

- Raw data were collected in end-time format and reported at approximately 1-minute intervals. The actual sampling interval ranged from 105 to 120 seconds. Two date/time stamps were available for the raw 1-minute data: (1) instrument time field in LST, and (2) GPS time stamp in Coordinated Universal Time (UTC). GPS time stamps were used due to accuracy issues with the instrument time field. The raw 1-minute data were collected in end-time format for ingest to the Amazon Cloud Data System. The raw 1-minute end-time formatted data were then converted to begin-time and rounded to the nearest minute depending on the seconds value (i.e. seconds ≥30 were rounded up), for DMS ingest. The rounding resolved the 105-120 second sampling interval, but resulted in occasional “missing” minutes. However, the entire hour was still represented and used for calculating hourly average ozone.
- 1-minute raw sensor data were sent from the field via cellular modem to the Amazon Cloud Data System every 15 minutes, where they were stored for the duration of the study.
- 1-minute raw sensor data were then sent from the Amazon Cloud Data System every 15 minutes to STI and ingested into the DMS.
- Once in DMS, the raw ozone data were automatically quality-controlled to identify gross data issues. Other parameters were not quality-controlled.
- The auto-quality-controlled ozone data were reviewed by STI staff every day.
- Begin-hour hourly average ozone concentrations were calculated from the 1-minute data.
- Using correction algorithms developed from the initial collocation study (see Appendix B), hourly ozone data were corrected to be “FEM-like” and were called preliminary hourly-averaged ozone data.
- The hourly FEM data (in begin-hour) from the regulatory sites were downloaded in real time from AirNow and placed in DMS.

- All data were stored in the DMS in Coordinated Universal Time and converted to Local Standard Time for all data exports.
- The preliminary data and FEM data from the four regulatory sites were posted to the project website and reviewed on a daily basis.

After the study was complete, the following activities were performed:

- Manually quality-controlled the 1-minute auto-quality-controlled ozone data. Gross outliers and data that did not meet internal instrument quality assurance metrics were invalidated.
- Calculated and manually quality-controlled hourly average ozone concentrations for each site.
- Corrected the hourly average ozone concentrations using results from the pre-study, during-study (four sensors), and post-study collocation experiments.
- Calculated 8-hr average ozone concentrations from the final hourly ozone concentrations. The 8-hr averages required at least six of eight hourly values or the 8-hr value was reported as missing. The 1-hr and 8-hr average data are reported as begin-hour.
- Manually quality-controlled the corrected hourly-average data. The resulting data set is considered final.
- Manually quality-controlled hourly wind data from Bear Mountain and Arvin South at the end of the study. The resulting data set is considered final.

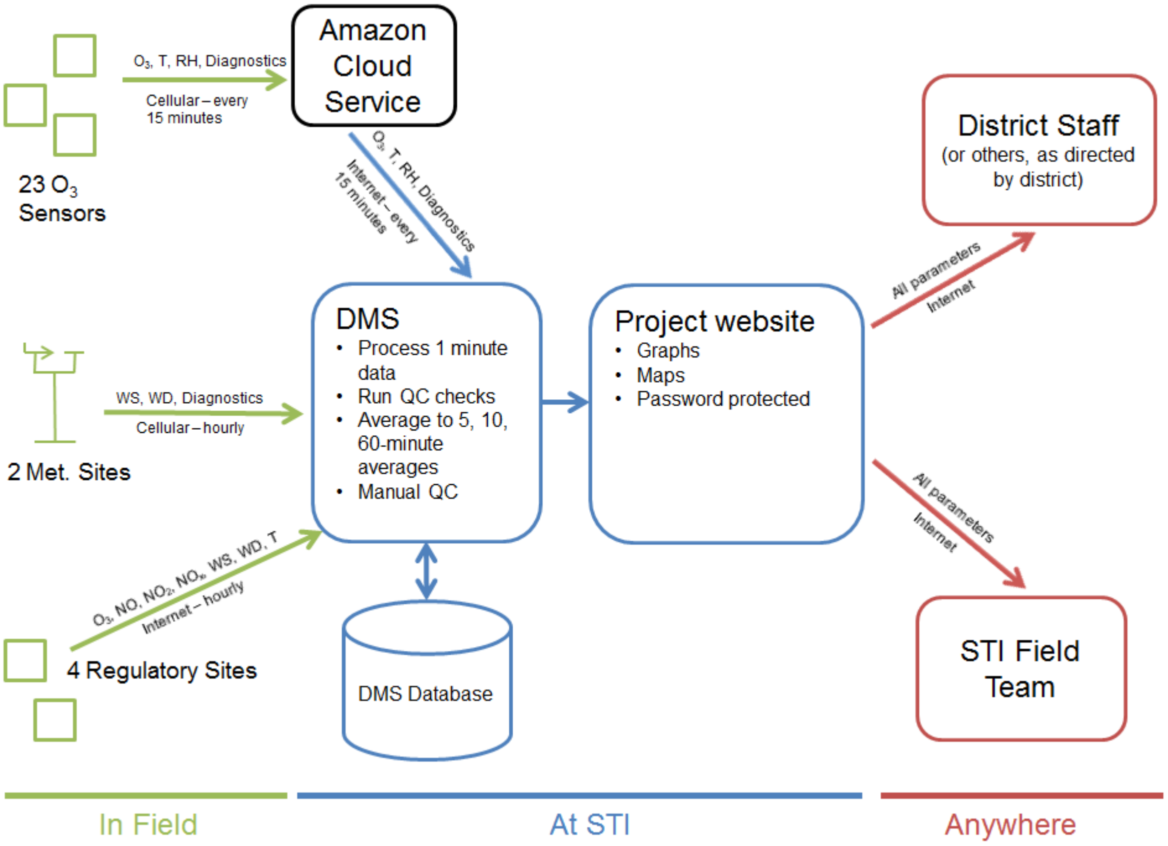


Figure 3-8. Schematic illustrating data flow from measurement to posting to the website.

3.5 Collocation Experiment and Data Corrections

Aeroqual sensor measurements were corrected to make ozone concentrations measured by each sensor “FEM-like.” These corrections were based on collocation measurements made for each sensor during the pre-study and post-study collocation periods. In addition, four sensors were collocated with FEM instruments during the study; one at the Bakersfield site, one at the Edison site, and two at the Di Giorgio site.

The first collocation experiment took place in Fresno, California, on August 2-6, 2013 (see Appendix B for details). During the first collocation experiment, the Aeroqual sensors were run next to a FEM ozone instrument (Transfer Standard Teledyne API Model T400 UV absorption). The second collocation experiment took place at Di Giorgio on September 26-29, 2013 (see Appendix C for details), where the Aeroqual sensors were run next to the permanent regulatory ozone monitor. For the second collocation, the Aeroqual sensors at Bakersfield and Edison were not moved to Di Giorgio because they were already collocated with FEM monitors.

Regression equations were initially developed from the pre-study collocation data to relate the Aeroqual sensor measurements to the FEM monitor measurements. These equations were used to adjust the Aeroqual measurements collected during the field campaign to be “FEM-like.” However, during the course of the field study, it became clear that Aeroqual sensor performance was degrading in an approximately linear fashion over time. This performance decay resulted in lower reported ozone concentrations from Aeroqual sensors than from collocated FEM ozone instruments at the Bakersfield, Edison, and Di Giorgio sites. In addition, the discrepancy between the FEM and Aeroqual sensor data was greater when ozone concentrations were higher.

Regression equations developed from the pre-study collocation period provided slope and intercept correction factors for each sensor, as documented in Appendix B. Given that the sensor performance was good for the first week of the study, as indicated by collocated FEMs, the initial collocation correction equations were used as a starting point for the final correction equation derivation, as shown in **Equation 3-1**.

$$AQ_{n,t_0} = (slope_{t_0} * FEM) + intercept_{t_0} \qquad \textbf{(Eq. 3-1)}$$

Here, AQ_n is the concentration measured by Aeroqual sensor n, where n is the number of the individual sensor and *FEM* is concentration measured by the API Model T400 during the initial collocation study. In contrast to the original Equation 1 from the technical memorandum of August 23, 2013 (see Appendix B), the slope and the intercept coefficients are now considered *time dependent* variables, as indicated by the subscript t_0 next to each coefficient.

The end-of-study collocation deployment provides a second set of time-dependent regression coefficients for each Aeroqual sensor against an FEM ozone instrument. This can be used as a second bookend for the time-dependent degradation of the individual Aeroqual sensors, as shown in **Equation 3-2.**

$$AQ_{n,t_z} = (slope_{t_z} * FEM) + intercept_{t_z} \qquad \textbf{(Eq. 3-2)}$$

Here, the equation is identical to Equation 1 from the technical memorandum of August 23, 2013 (Appendix B), except that the subscript for the slope and intercept coefficients is at t_z, which is the end-of-study deployment begin-hour.

As a result of the District's quality assurance requirements in the proposal phase, multiple Aeroqual sensors were collocated with FEM sensors at three sites throughout the study. Analysis of the sensor decay indicates an approximately linear degradation of the slope for approximately the first 30 days at the Bakersfield, Edison, and Di Giorgio sites, followed by stabilization. As shown in **Figure 3-9**, ozone concentrations reported by the Aeroqual sensor degrade over time, until approximately 700 hours into the study, as the orange and red triangle symbols are about the same slope relative to the FEM.

Data from the four permanent collocated sensors were used to empirically determine that the data degraded from the deployment time to hour 725 (~30 days) after deployment. After hour 725, no substantial degradation was observed. This was determined by evaluating the sum-of-squares error estimation of the data at each site relative to the FEM by hour. For each sensor in the study, the Equation 3-2 correction factor for t_{725} through t_z was applied. Prior to that, a time dependent slope and intercept correction factor was used for each sensor.

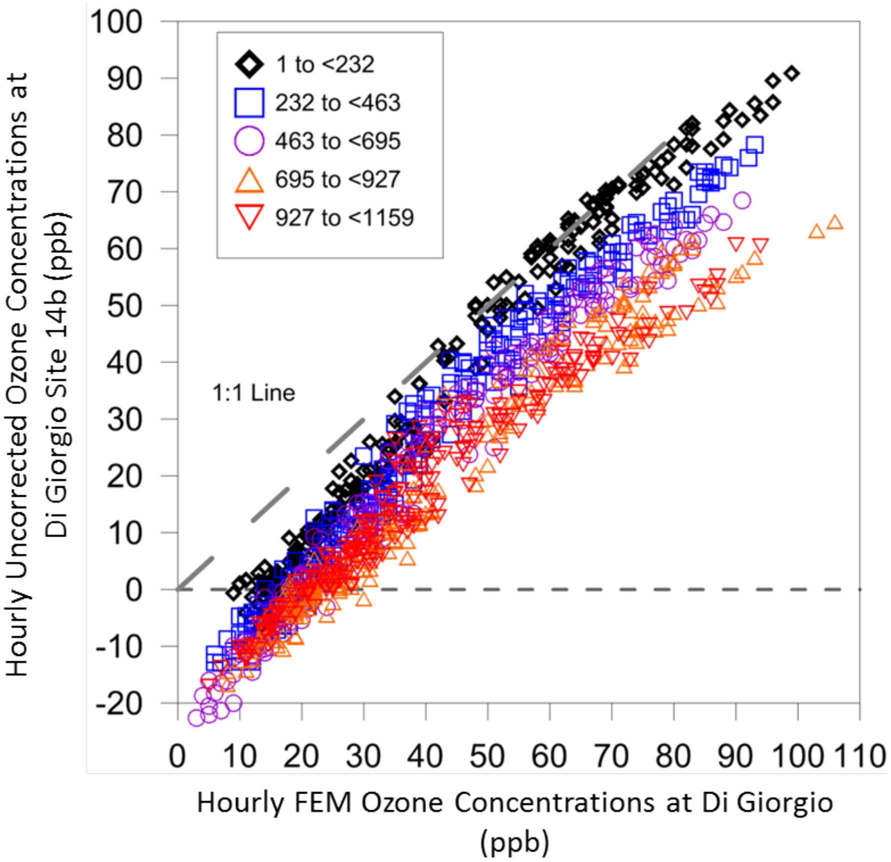


Figure 3-9. Binned scatter plot of ozone concentrations (ppb) reported by the FEM instrument and the uncorrected Aeroqual sensor. Colors and symbols indicate bins of time since the start of the study, in increments of about 232 hours, or just under 10 days.

Using a linear equation, a time-dependent correction factor was generated for each Aeroqual sensor slope and each Aeroqual sensor intercept as shown in **Equations 3-3 and 3-4**.

$$\left(slope_{t_z} - slope_{t_0}\right) * t_{725} = m_{AQ_n}$$ **(Eq. 3-3)**

$$(intercept_{t_z} - intercept_{t_0}) * t_{725} = l_{AQ_n}$$ **(Eq. 3-4)**

Here, the initial slope at t_0 is modified by the hour at which the slopes leveled off at t_{725}, multiplied by a slope coefficient (*m* or *l*, unique for each sensor) to generate the slope coefficient at t_z. In cases where the intercept is unchanged over time, intercept t_z is equal to intercept t_0 and the slope *l* is zero. Rearranging Equations 3-3 and 3-4 provides time-dependent slope factors, which were used to generate a final time-dependent correction factor for each sensor to generate “FEM-like” concentrations for any time step *N*, as shown in **Equations 3-5, 3-6, and 3-7**.

$$\text{If } \mathrm{t}_N < 725, slope_{t_N} = m_{AQ_n} * t_n + slope_{t_0}; \quad \text{else } slope_{t_z}$$ **(Eq. 3-5)**

$$\text{If } \mathrm{t}_N < 725, intercept_{t_N} = l_{AQ_n} * t_n + intercept_{t_0}; \quad \text{else } intercept_{t_z}$$ **(Eq. 3-6)**

$$AQ_{n,t_N} = (slope_{t_N} * FEM) + intercept_{t_N}$$ **(Eq. 3-7)**

The pre- and post-study coefficients, and time-dependent correction factors for each sensor, are shown in **Table 3-7**.

Table 3-7. Sensor pre- and post-study regression coefficients and time-dependent correction factors.

Site Number	Slope t_0	Intercept t_0	Slope t_{725} to t_z	Intercept t_{725} to t_z	Time-Dependent Slope Correction (*m*)	Time-Dependent Intercept Correction (*l*)
1, sensor 2[a]	1.12	-6.98	0.64	-6.1	-6.62X10^{-4}	1.21X10^{-3}
2	1.039	-4.716	0.71	-4.08	-4.54X10^{-4}	8.77X10^{-4}
3	1.139	-6.849	0.54	-2.14	-8.32X10^{-4}	6.49X10^{-3}
4	1.011	-5.938	0.57	-3.53	-6.02X10^{-4}	3.32X10^{-3}
5	1.159	-7.028	0.73	-2.11	-5.98X10^{-4}	6.79X10^{-3}
6	1.147	-11.036	0.76	-8.65	-5.29X10^{-4}	3.28X10^{-3}
7	1.057	-8.5	0.75	-7.82	-4.25X10^{-4}	9.44X10^{-4}
8	1.238	-14.179	0.73	-8.4	-7.07X10^{-4}	7.97X10^{-3}
9	1.038	-7.266	0.63	-2.48	-5.64X10^{-4}	6.61X10^{-3}
10	1.149	-7.432	0.76	-4.17	-5.37X10^{-4}	4.50X10^{-3}
11	1.088	-10.585	0.61	-4.21	-6.55X10^{-4}	8.80X10^{-3}
12	1.17	-8.525	0.7	-3.24	-6.51X10^{-4}	7.28X10^{-3}
13	1.256	-10.759	0.97	-11.07	-3.89X10^{-4}	-4.27X10^{-4}
14a sensor 1[a]	1.094	-9.108	0.91	-12.64	-2.54X10^{-4}	-4.87X10^{-3}
14a sensor 2[a]	0.93	0.77	0.87	-3.9	-8.28X10^{-5}	-6.44X10^{-3}
14b	1.25	-16.21	0.88	-17.56	-5.10X10^{-4}	-1.86X10^{-3}
15	0.965	-4.119	0.79	-5.25	-2.38X10^{-4}	-1.56X10^{-3}
16	1.1	-9.78	0.91	-9.09	-2.66X10^{-4}	9.54X10^{-4}
17	1.098	-10.248	0.81	-9.32	-3.96X10^{-4}	1.28X10^{-3}
18a	1.203	-12.29	0.93	-10.63	-3.77X10^{-4}	2.29X10^{-3}
18b	1.186	-6.847	0.8	-3.69	-5.31X10^{-4}	4.36X10^{-3}
19	1.217	-13.873	0.94	-12.82	-3.87X10^{-4}	1.45X10^{-3}
20	1.148	-12.167	0.91	-10.59	-3.25X10^{-4}	2.17X10^{-3}
21	1.114	-5.991	0.71	-2.47	-5.60X10^{-4}	4.86X10^{-3}
average	1.1215	-8.736	0.773	-6.914	-0.00048	0.00251
median	1.1295	-8.513	0.761	-5.676	-0.00052	0.00223

[a] Sensor heads for Sites 1 and 14 (instrument a) were replaced during the study. The replacement sensor for Site 1 is shown as “1, sensor 2” and was the second sensor and functioned for 90% of the study. The sensors for Site 14 (a) are shown as “14a, sensor 1” and “14a, sensor 2” and each had independent correction factors.

4. Data Analysis Methods

The main goals of the data analyses were to (1) understand ozone gradients in and around Arvin and (2) develop equations to predict ozone concentrations in the City of Arvin and at Bear Mountain using ozone and meteorological data from permanent sites. As a first step, the quality of the data collected by the Aeroqual sensors was assessed. This section discusses the methods used to determine the sensor accuracy and precision, and address data analysis goals. Findings are presented in Sections 2 and 5. Additional information on instrument accuracy is provided in Appendices B and C.

4.1 Sensor Accuracy and Precision

Aeroqual sensor accuracy and precision were assessed for each sensor using data collected during the collocation experiments before and after the field study and data collected from four sensors that were collocated with FEM instruments at Bakersfield, Di Giorgio, and Edison during the entire field study.

Sensor accuracy and precision were estimated for each sensor by creating scatter plots of the corrected Aeroqual and associated FEM data, determining a linear regression equation for each sensor, and examining the slopes and y-intercept, in addition to calculating standard errors. This assessment required assuming that the FEM instruments were 100% accurate and are not a source of error. Although Deming regressions are a plausible way to estimate error without attributing either instrument to owning the error, it was decided not to use them, given the possible uncertainty with the Aeroqual sensor measurements.

An example of the accuracy and precision of the pre-study collocation sensors is shown in **Figure 4-1.** Calibrated sensor concentrations were highly comparable to the FEM instrument. In this example, regression equations were developed using data collected from August 3-5, 2013, and then tested independently on August 6, 2013.

Calculating ordinary least squares regressions for each corrected sensor in the pre- and post-study collocation periods gave an estimate of the accuracy of the instruments. The standard error in the slope gave an estimate of the precision. Similar calculations for the full study collocation sensors provided estimates of the precision for the time-dependent corrected data.

Note that it is not possible to calculate the accuracy and precision for the entire study of any sensor that was not collocated with an FEM for the entire field study. In addition, to correct the data from these sensors to be “FEM-like,” the project team assumed that these sensors degraded at the same rate as the ones that were collocated with an FEM for the entire study. Thus, data collected in the middle of the study period has the greatest uncertainty.

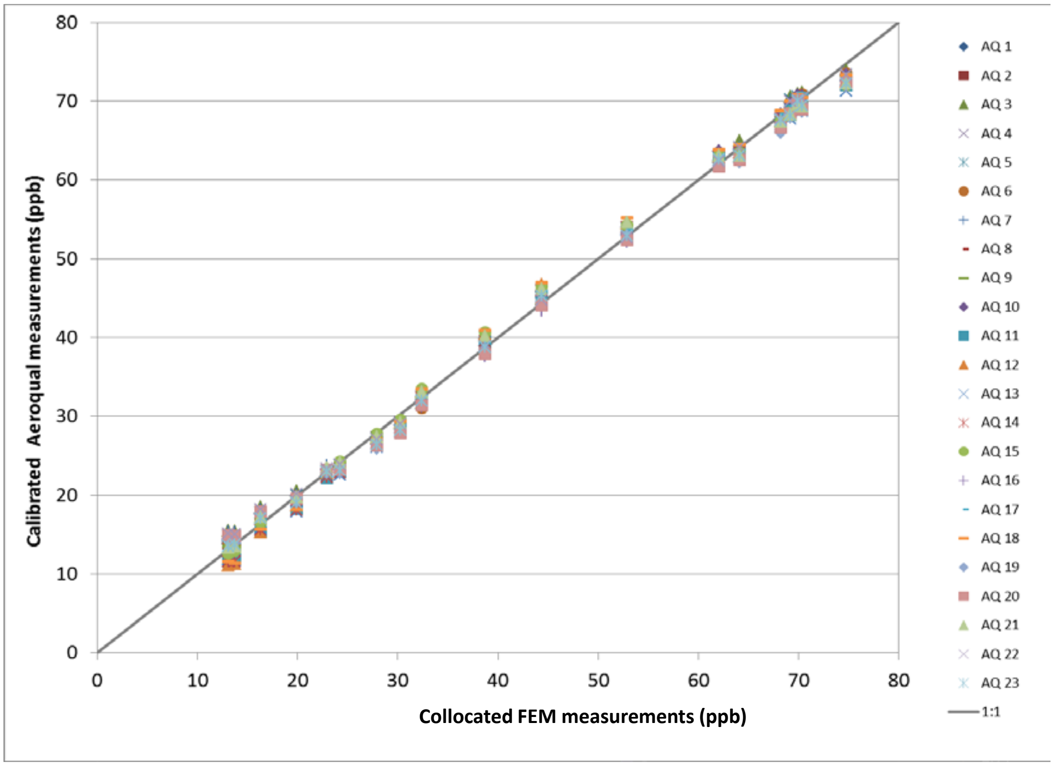


Figure 4-1. August 6, 2013, comparison of the FEM measurements with calibrated hourly Aeroqual ozone measurements after being adjusted with the linear regressions from the pre-study collocation study.

4.2 Gradient Analysis

To assess the spatial gradients in ozone concentrations in and around Arvin, STI produced maps of ozone concentrations for each date and hour during the study time period. Two sets of GIS maps were generated using (1) valid hourly ozone concentrations, and (2) valid running 8-hr ozone averages. Running 8-hr values were calculated for each hour of the day using the average of the hourly measurements within each 8-hr period; averages were expressed according to the begin-hour (e.g., the average for 12:00 p.m. LST was calculated using begin-hours 12:00–7:00 p.m. LST). Valid 8-hr averages required at least six hours to meet completeness requirements.

Hourly and 8-hr averages were interpolated using Inverse Distance Weighting (IDW), to produce gridded estimates of ozone for the study area. The IDW method estimates ozone concentrations for each grid cell using a weighted linear average of ozone concentrations from nearby Aeroqual monitors within a specified distance. Nearby monitor values are weighted according to the distance between the monitors and the grid cell to be estimated (e.g., closer monitors are weighted higher than monitors farther away). Interpolation using IDW assumes that ozone concentrations are less similar as distance increases, but does not estimate real physical processes. Two additional interpolation methods (ordinary kriging and empirical Bayesian kriging) were also evaluated, and although all methods were similar, IDW produced the most informative results. See **Figure 4-2** for sample maps using each method.

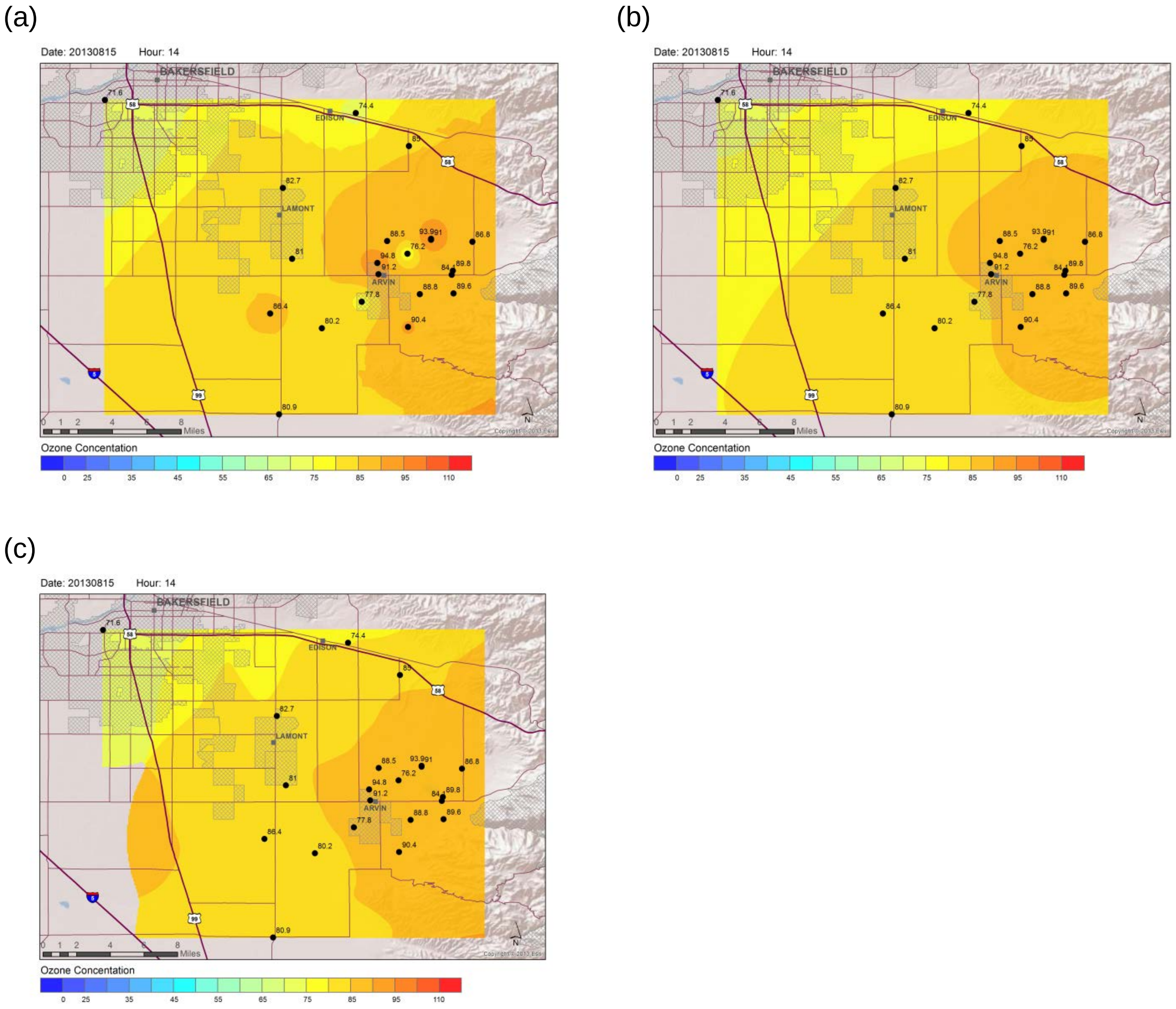


Figure 4-2. Comparison of IDW (a), ordinary spherical kriging (b), and empirical Bayesian kriging (c) of 1-hr ozone on August 15 at 2:00 p.m. LST.

STI reviewed the interpolated ozone maps to identify general spatial patterns for the entire domain and around Arvin specifically, focusing on the pattern during the peak hour of the day and the hour of the daily maximum 8-hr average. STI determined the peak hour to be the hour with the greatest value measured that day at any site. Similarly, the highest 8-hr average for each day across all sites is considered the 8-hr daily maximum.

Maps were evaluated for directional gradients (e.g., whether concentrations were higher in the north or south), the range in concentrations observed (e.g., strength of the gradient), consistency (e.g., whether patterns varied on high or low concentration days), any prominent or consistent spatial features, and whether the permanent monitors tended to be of a similar magnitude to temporary monitors in Arvin, Bear Mountain, and the surrounding area. In addition, analysts reviewed all hourly maps for selected days on which high concentrations (peak 1-hr exceeding 75 ppb at any of the 21 sites) were observed, in order to characterize the diurnal patterns on days exceeding regulatory standards.

The analysis of spatial and diurnal patterns and wind data were used to characterize the observed patterns. Main meteorological characteristics of concern included northwesterly winds that transport ozone into and downwind of Arvin, upslope and downslope flows, and a turning of the winds from northwest to southeast (a partial eddy) that typically forms in and around Arvin in the afternoon hours. Wind speed and directional data from Edison, Bakersfield, Di Giorgio, Bear Mountain, and South Arvin were used in this analysis. Spatial maps of ozone concentrations were reviewed in conjunction with the wind data to determine the effects of titration on ozone. For this analysis, ozone concentrations below approximately 40 ppb were assumed to represent titration by fresh NO_x emissions.

The results of the spatial gradient analyses are described in Section 5 and include

- A description of the main ozone spatial and diurnal patterns.
- An assessment of the frequency of each pattern.
- A determination of the representativeness of the Di Giorgio monitor of ozone concentrations in and around Arvin.
- An evaluation of the relationship between the ozone patterns and winds.

4.3 Predictive Equations

An objective of the study was to develop equations useful to predict ozone concentrations (1) in the City of Arvin and (2) at Bear Mountain, using data from permanent FEM ozone monitors and meteorological data. The City of Arvin equation will be used by District staff to supplement or replace existing methods to forecast ozone concentrations on a daily basis for this area. The Bear Mountain equation will be used by the District to better understand the relationship between ozone concentrations at permanent FEM sites and at the old Bear Mountain site.

4.3.1 Regression Background

Ozone concentrations are strongly related to meteorology; therefore, ozone is often predicted using statistical methods, such as regression modeling, that estimate ozone based on a linear or curvilinear relationship between meteorological conditions and ozone concentrations.

Regression modeling is a commonly used method to describe the relationship between a dependent (response) variable and independent (predictor) variable(s). **Equation 4-1** provides an example of a multilinear regression equation, where multiple predictors are used to estimate the response variable.

$$Response = c_1V_1 + c_2V_2 \ldots\ldots c_nV_n + constant \tag{Eq. 4-1}$$

where
c = coefficients (weighting factors)
V = predictor variables

4.3.2 Method

For this task, STI analysts developed regression equations using four response variables: (1) the City of Arvin's peak 1-hr ozone concentrations, (2) the City of Arvin's daily maximum 8-hr averages, (3) peak 1-hr ozone near the old Bear Mountain FEM site, and (4) daily maximum 8-hr averages near the old Bear Mountain FEM site. Prior to developing predictive equations, an analysis was conducted to determine how well the permanent sites represent the City of Arvin and Bear Mountain. Representativeness was evaluated using notched box plots, difference time-series plots, and scatter plots for all data and for high concentrations only. The analysis was used to determine how to best represent the City of Arvin (e.g., the Aeroqual monitor in northern, central, or southwestern Arvin) and the old Bear Mountain FEM site (e.g., the Aeroqual monitor at Bear Mountain Sites 18a, 18b, or near the rock quarry [Site 19]). STI analysts determined that the average concentration of Arvin North and Central best represented the City of Arvin ozone concentrations. They also determined that the average concentration of 18a and 19 best represented Bear Mountain. Concentrations at 18b were substantially lower than 18a and 19, likely due to titration of ozone at Site 18b, which is 28 m from the road.

The equations were developed using data from all days during the study. The predictive equations were developed using stepwise regression in the Systat statistical software program. Stepwise regression is a statistical technique to sequentially evaluate the performance of the regression equation when the predictor variable(s) are included or removed; the method allows for identifying the optimal combination of available variables for predicting ozone. For this analysis, backward stepwise regression was applied under the following procedure:

1. Develop a regression equation using only a constant.
2. Successively add more variables; variables with the lowest p-value are tested first (p-values < 0.1).
3. Review model performance metrics and graphical output.

Each variable (see below) was evaluated for use in the regression equations using the following metrics:

- **Regression coefficient.** Describes the relationship between the independent and dependent variables.
- **Tolerance.** Provides information on how co-linear variables are with each other, or the proportion of a variable's variance that is not accounted for by other variables in the equation. This information helps exclude closely related variables that introduce redundancy to the regression.

- **Standard error.** Shows the standard deviation of the sampling distribution from the mean.
- **The t-test.** Determines the statistical significance of the independent variable; in this application, the t-test evaluates whether the slope of a regression line differs significantly from zero at a specified level of confidence.
- **The two-tailed p-value.** Shows the likelihood of the equation performing as well with a random sample (such as when used operationally) as with the developmental data set.
- **Criteria for variable inclusion.** Threshold requirements for including a variable in the multivariate regression should be defined (e.g., variables with a t-test p-value less than 0.05 could be one criterion).

STI evaluated a combination of predictor variables (**Table 4-1**), including ozone data from the permanent monitors in Di Giorgio, Edison, and Bakersfield, and routinely available meteorological data. Because of the need to predict next-day ozone concentrations, forecast data for surface meteorological parameters were used. The surface data are from the 12Z model run of the global forecast system (GFS) model output statistics (MOS) for Bakersfield-Meadows Field Airport (KBFL), which is just northwest of Bakersfield. Vector average wind speed and direction were calculated for the morning (4:00 a.m. to 10:00 a.m.) and afternoon (1:00 p.m. to 7:00 p.m.). Archive model data were not readily accessible for the upper air meteorological parameters (850-mb temperature, 500-mb height, and 700-mb RH); instead, observation data were obtained from the weather balloons launched twice daily at Vandenberg Air Force Base.

Note that in practice, the District will use next-day forecasts of all of these variables to predict next-day ozone concentrations for the City of Arvin. The predictions for FEM ozone concentrations at Di Giorgio, Bakersfield, and Edison will be created using existing District forecast tools.

The resulting equations were evaluated for all study days and separately for the following ranges of 1-hr ozone: 60-75 ppb, 76-95 ppb, and 96-115 ppb. There were no dates when 1-hr ozone exceeded 115 ppb. Days were identified by concentrations at the FEM monitor in Di Giorgio. Finally, STI evaluated the accuracy of the equations by comparing the predicted and measured ozone concentrations.

Table 4-1. Predictor variables evaluated in the regression model. All times are LST.

Variable Name	Description
FEM Di Giorgio	Same-day peak 1-hr ozone concentrations (ppb) at the permanent Di Giorgio site
FEM Bakersfield	Same-day peak 1-hr ozone concentrations (ppb) at the permanent Bakersfield site
FEM Edison	Same-day peak 1-hr ozone concentrations (ppb) at the permanent Edison site
AM WS	Same-day vector average wind speed (m/s) for the morning (4:00 a.m. to 10:00 a.m.) at KBFL
PM WS	Same-day vector average wind speed (m/s) for the afternoon (1:00 p.m. to 7:00 p.m.) at KBFL
AM WD	Same-day vector average wind direction (degrees) for the morning (4:00 a.m. to 10:00 a.m.) at KBFL
PM WD	Same-day vector average wind direction (degrees) for the afternoon (1:00 p.m. to 7:00 p.m.) at KBFL
maxT	Same-day maximum temperature (°F) at KBFL
minT	Same-day minimum temperature (°F) at KBFL
AvgOfdpt	Same-day mean dew point (°F) at KBFL
850_tempC_4am	Same-day 850-mb temperature (°C) at 4:00 a.m. at Vandenberg AFB
850_tempC_4pm	Same-day 850-mb temperature (°C) at 4:00 p.m. at Vandenberg AFB
500_hgtm_4am	Same-day 500-mb height (m) at 4:00 a.m. at Vandenberg AFB
500_hgtm_4pm	Same-day 500-mb height (m) at 4:00 p.m. at Vandenberg AFB
700_RH%_4am	Same-day 700-mb relative humidity (%) at 4:00 a.m. at Vandenberg AFB
700_RH%_4pm	Same-day 700-mb relative humidity (%) at 4:00 p.m. at Vandenberg AFB

5. Results

5.1 Data Availability

Table 5-1 provides start and end dates, as well as data completeness statistics, for 1-hr and 8-hr ozone concentrations at all Aeroqual sites during the field program. Data collected after September 25, 2013, were not included in the gradient and prediction analyses because those data were part of the second collocation time period. The percent of data completeness for 1-hr and 8-hr averages was greater than 95% at nearly all sites, and typically was 100%. Notable data availability and data quality issues are as follows:

- 8/19/13-8/21/13: There was data loss due to high winds at three sites—north of Di Giorgio (Site 3), southeast of Bear Mountain (Site 21), and northwest of Arvin (Site 4).
- 8/24/13-8/25/13: There was data loss at the site North of Di Giorgio (Site 3) due to hardware damage by animals.
- 9/11/13: A sensor head was replaced on one of the sensors at Di Giorgio (Site 14); analyses relied on the other sensor at Di Giorgio.
- 9/11/13: North of Di Giorgio (Site 3) was relocated to Di Giorgio for sensor analysis.
- 9/11/13: South of Arvin (Site 8) was relocated to Di Giorgio for sensor analysis.

Hourly meteorological data from Arvin South (Site 9) are available from August 14 until September 25. Hourly meteorological data from Bear Mountain (Site 18) are available from August 15 until September 25.

Table 5-1. Data completeness by site for 1-hr and 8-hr ozone concentrations; start and end dates vary slightly for 8-hr averages.

Site	Name	Start Date and Time (LST)	End Date and Time (LST)	1-hr Completeness (%)	8-hr Completeness (%)
1	Bakersfield - California Street	8/14/2013 8:00	9/25/2013 23:00	99	99
2	Edison	8/8/2013 12:00	9/25/2013 23:00	99	99
3	North of Di Giorgio	8/8/2013 11:00	9/11/2013 7:00	92	92
4	Northwest of Arvin	8/8/2013 9:00	9/25/2013 23:00	96	96
5	West Boundary	8/12/2013 10:00	9/25/2013 23:00	100	100
6	West of Arvin	8/9/2013 15:00	9/25/2013 23:00	96	96
7	Gradient South	8/9/2013 14:00	9/25/2013 23:00	100	100
8	South of Arvin	8/9/2013 13:00	9/11/2013 8:00	100	100
9	Arvin South	8/8/2013 14:00	9/25/2013 23:00	100	100
10	Arvin Central	8/9/2013 10:00	9/25/2013 23:00	100	100
11	Arvin North	8/9/2013 11:00	9/25/2013 23:00	99	99
12	West of Di Giorgio	8/8/2013 11:00	9/25/2013 23:00	98	98
13	Southwest of Di Giorgio	8/9/2013 11:00	9/25/2013 23:00	100	100
14a	Di Giorgio	8/8/2013 17:00	9/11/2013 13:00	99	98
14a	Di Giorgio (replacement sensor)	9/11/2013 15:00	9/25/2013 23:00	100	100
14b	Di Giorgio	8/8/2013 17:00	9/25/2013 23:00	99	99
15	Northeast of Di Giorgio	8/9/2013 15:00	9/25/2013 23:00	96	95
16	East of Di Giorgio	8/9/2013 14:00	9/25/2013 23:00	100	100
17	East of Bear Mountain	8/9/2013 9:00	9/25/2013 23:00	98	98
18a	Bear Mountain	8/8/2013 16:00	9/25/2013 23:00	96	96
18b	Bear Mountain	8/9/2013 8:00	9/25/2013 23:00	97	99
19	Southeast of Bear Mountain	8/9/2013 10:00	9/25/2013 23:00	95	95
20	Southwest of Bear Mountain	8/8/2013 15:00	9/25/2013 23:00	100	100
21	Southeast of Arvin	8/9/2013 13:00	9/25/2013 23:00	100	100

5.2 Measurement Accuracy and Precision

The accuracy and precision estimates indicate that the available sensors were sufficiently accurate and precise to estimate ozone concentration gradients.

Accuracy of the Aeroqual sensors was evaluated using the collocated sensors at the permanent FEM sites. Corrected ozone concentrations calculated using Equation 3-7 (see Section 3.5) were compared to FEM ozone concentrations at the same sites and times. Ordinary least squares regressions were run to generate slope, slope standard error (SE), intercept, intercept SE, and R^2 values. Results are shown in **Table 5-2**.

Table 5-2. Regression statistics used to assess accuracy and precision of "FEM-like" ozone concentrations from the four Aeroqual sensors that were collocated with FEM monitors during the entire study, and for the two Aeroqual sensors that were moved to Di Giorgio on September 11.

Original Site Location and AQ #	Slope	Intercept	SE Slope	SE Intercept	R^2	Notes
3 - AQ 2	1.001	-0.015	0.014	0.604	0.926	Moved to Di Giorgio for special collocation starting 9/11
8 - AQ 9	1.001	-0.032	0.012	0.523	0.944	Moved to Di Giorgio for special collocation starting 9/11
1 - AQ 11-2	1.03	-1.785	0.004	0.201	0.981	Bakersfield
14a - AQ 12-1	1.022	-1.351	0.005	0.222	0.984	Di Giorgio; first sensor head used through 9/11
14a - AQ 12-2	1.031	-3.28	0.01	0.429	0.964	Di Giorgio; second sensor head started 9/11
14b - AQ 18	1.047	-1.984	0.005	0.243	0.971	Di Giorgio
2 - AQ 17	1.051	-2.375	0.007	0.301	0.957	Edison

All sensors showed a positive bias in the slope, ranging from 1.001 to 1.051. This results in slightly higher sensor ozone concentrations than an FEM, especially at higher ozone values. Standard errors about the slope ranged from 0.004 to 0.014, indicating that the precision in the slope was actually quite good.

Intercepts ranged from -3.28 to -0.015 ppb below FEM estimates. These slightly negative intercepts are a compensating error for the positive bias in the slope estimates and help reduce the actual bias in predicted concentrations at high (~75 ppb) ozone values. At very low ozone concentrations, the negative intercept bias causes underprediction (up to -6 ppb) of ozone concentrations.

Finally, the R^2, which account for the degrees of freedom in the regression, indicate that all of the sensors accounted for more than 92% of the variance in the predicted ozone concentrations. These values were even higher for those sensors with the longest collocation time periods, reaching values from 95% to 98%. This shows excellent agreement.

Summary statistics for the pre-study collocation (Appendix B) and post-study collocation (Appendix C) corrections also indicate very strong correlations and a high degree of confidence in the corrected fits at those end-point time periods. All R^2 values from the pre-study collocation were above 0.98 (see Appendix B); all R^2 values for the post-study collocation were above 0.94.

Sensor accuracy and precision are both a function of ozone concentration. Table 5-2 lists the regression slopes, intercepts, and standard errors (SE) for the slopes and intercepts for each of the sensors collocated with an FEM instrument during the study. The accuracy at a given ozone concentration can be estimated by using **Equation 5-1**.

$$Accuracy = 2*\{([O_3] * Slope + Intercept) - [O_3]\} \qquad \textbf{(Eq. 5-1)}$$

Here, $[O_3]$ is the true concentration of ozone; slope and intercept are individual sensor regression estimates from Table 5-2. The factor of two in the equation transforms the estimate from 1 SE to 95% confidence level. As an example, at an ozone concentration of 75 ppb, the least accurate of the seven collocated sensors (AQ18) shown in Table 5-2 would be biased high by 3.1 ppb, while the median sensor (AQ 12-1) was biased high by 0.6 ppb. Note that one sensor (AQ 12-2) was biased low by 2 ppb at an ozone concentration of 75 ppb. Sensors are slightly less accurate at higher ozone concentrations (4.5 ppb; at 100 ppb) and are biased low at low ozone concentrations (< 30 ppb). These accuracy values are sufficient to assess spatial gradients of greater than 5 ppb on an hourly basis.

Sensor precision is an estimate of the hourly noise in the any given hourly estimate. To estimate the precision, a similar manner to that for estimating accuracy can be used, but with the standard error estimates in the slope and intercept, as shown in **Equation 5-2**.

$$Precision\ (\%) = 2 * \{100*slope\ SE + intercept\ SE\} \qquad \textbf{(Eq. 5-2)}$$

As an example, sensor precision for the least accurate sensor (AQ 2) was ±4.0% at the 95% confidence level. The median sensor precision was ±2.0% at the 95% confidence level. The percentage is multiplied by ozone concentrations to obtain ppb estimates. Therefore, at true ozone concentrations of 75 ppb, 95% of observations would be predicted to be 78–72 ppb for a perfectly accurate sensor with ±4% precision; this range decreases to 76.5–73.5 ppb for 2% precision.

Note the assumption that sensors not collocated during the entire study decayed at a similar rate to those empirically observed at the collocation sites that operated during the entire study. If sensors decayed at a higher or lower rate, ozone predictions will be less accurate for those sensors. While no clearly invalid sensors were identified, it is possible that mid-study ozone concentration differences for 1-hr ozone may be larger than the 3 ppb accuracy and 4% precision estimates that were determined above.

5.3 Gradient Analysis

This section describes results from the analyses performed to characterize ozone concentrations in and around the Arvin area. Specifically, the objectives of these analyses were to answer the following questions:

- Where and when do daily peak 1-hr and 8-hr concentrations occur?
- What are the prevailing wind patterns and how do these patterns relate to observed concentrations?
- What are the general spatial patterns of ozone concentrations?
- What are the diurnal patterns of ozone concentrations on days with high ozone concentrations?
- How representative are the permanent monitors of high ozone concentrations in the City of Arvin?
- How representative is the permanent Di Giorgio monitor of ozone concentrations in and around Arvin?

Results for each question are described individually below.

1. ***Where and when do daily peak 1-hr and 8-hr concentrations occur?***

Daily peak 1-hr ozone concentrations occurred between 12:00 p.m. and 6:00 p.m. LST and ranged from 62 to 106 ppb during the study. On 65% of days, the peak hour occurred between 2:00 and 4:00 p.m. LST. During the 49-day study, peak 1-hr values occurred most often at

- Site 3, North of Di Giorgio (13 days); the highest 1-hr concentration at this site was 106 ppb.
- Site 17, East of Bear Mountain (12 days); the highest 1-hr concentration at this site was 106 ppb.
- Site 4, Northwest of Arvin (8 days the highest 1-hr concentration at this site was 99 ppb.
- Site 11 at Arvin North (9 days); the highest 1-hr concentration at this site was 106 ppb.

Note that the Bear Mountain (Site 18b) peak 1-hr concentration was 95 ppb and was about the same as Di Giorgio (Site 14b), which had a peak concentration of 94 ppb.

Also note that Di Giorgio (Site 14b) was on average within 9 ppb of the highest 1-hr concentration measured at any site for each day. Bear Mountain (Site 18b) was on average within 11 ppb of the highest 1-hr concentration measured at any site for each day.

Daily peak 8-hr ozone concentrations began between 9:00 a.m. and 12:00 p.m. LST, representing the 8-hr time periods of 9:00 a.m. to 5:00 p.m. through 12:00 p.m. to 8:00 p.m. LST. Daily peak 8-hr ozone concentrations on most days (88%) began at either 10:00 a.m. or

11:00 a.m. LST, capturing the middle of the day when temperature and sunlight are the highest. During the 49-day study, peak 8-hr averages ranged from 53-91 ppb and occurred most often at

- Site 17, East of Bear Mountain (15 days); the highest 8-hr concentration at this site was 91 ppb.
- Site 4, Northwest of Arvin (10 days); the highest 8-hr concentration at this site was 86 ppb.
- Site 3, North of Di Giorgio (6 days); the highest 8-hr concentration at this site was 87 ppb.

Note that the Bear Mountain (Site 18b) highest 8-hr concentration was 81 ppb and was about the same as Di Giorgio (Site 14b), which had a peak 8-hr concentration of 80 ppb.

Also note that Di Giorgio (Site 14b) was on average within 5 ppb of the highest 8-hr concentration measured at any site for each day. Bear Mountain (Site 18b) was on average within 8 ppb of the highest 8-hr concentration measured at any site for each day.

The locations of the peak 1-hr and 8-hr ozone concentrations are indicative of the general ozone spatial gradient (described below in Question 3).

Appendix D provides the daily peak 1-hr and 8-hr ozone concentrations.

2. *What are the prevailing wind patterns and how do these patterns relate to observed ozone concentrations?*

STI examined wind speed and direction using surface measurements from the permanent monitors in Bakersfield, Edison, and Di Giorgio, as well as from the two temporary monitors established at Bear Mountain and at Arvin South for this study. The wind roses for all hours and days of the study are shown in **Figures 5-1 through 5-5**. Wind roses for 10:00 a.m. to 5:00 p.m. for all days of the study are shown in **Figures 5-6 through 5-10.** The wind roses for 6:00 p.m. to 9:00 a.m. for all days of the study are shown in **Figures 5-11 through 5-15.** Note the different maximum scale on each wind rose.

An example of the typical afternoon wind pattern is shown in **Figure 5-16.** The following general wind patterns were observed:

- Northwesterly flow at the Bakersfield and Edison sites during the middle of the day (10:00 a.m. to 5:00 p.m. LST).
- Southwest/westerly flow at the Di Giorgio, Arvin South, and Bear Mountain sites during the middle of the day (10:00 a.m. to 5:00 p.m. LST).
- At approximately 7:00 p.m. LST, the wind pattern shifted from southwest/westerly to northeast at the Di Giorgio site and to southeast/east at the Arvin South and Bear Mountain sites; this was downslope flow out of the mountains.
- Variable wind conditions occurred during the late evening and overnight, driven by downslope flow out of the mountains.

These wind patterns had some influence on the ozone spatial patterns in the study area. Consistent northwesterly winds indicate that pollution is likely to travel into Edison, Lamont, and Arvin from Bakersfield and areas farther north in the Central Valley during the day. However, the contrast in wind patterns between the northern monitor in Bakersfield and the other monitors nearer to Arvin indicate that wind flow down the valley turns toward the east, and that a combination of northwest-west/southwesterly flow occurs throughout the study area. It is possible that the southwesterly winds toward the Sierra Nevada indicate upslope flow during the day. In that case, transported material from Bakersfield could impact Edison, Lamont, Di Giorgio, and northern Arvin more directly than sites farther south of Arvin.

The shift in wind conditions in the evening indicates that sites near the mountains (eastern sites) likely experience downslope flow out of the Sierra Nevada and Tehachapi Mountains, resulting in reduced titration relative to sites farther west. This finding is consistent with the ozone concentration maps.

For many days on which wind conditions differed from these general patterns (such as August 19 and September 7, when winds were from the northwest and west at all sites during the day), the spatial pattern of ozone concentrations did not show much change. However, on some days, such as August 21, there was no downslope flow in the evening; upslope flow and/or northwesterly wind conditions continued into the evening, resulting in greater titration at the sites closer to the mountains compared to evenings at those sites when downslope flow occurred.

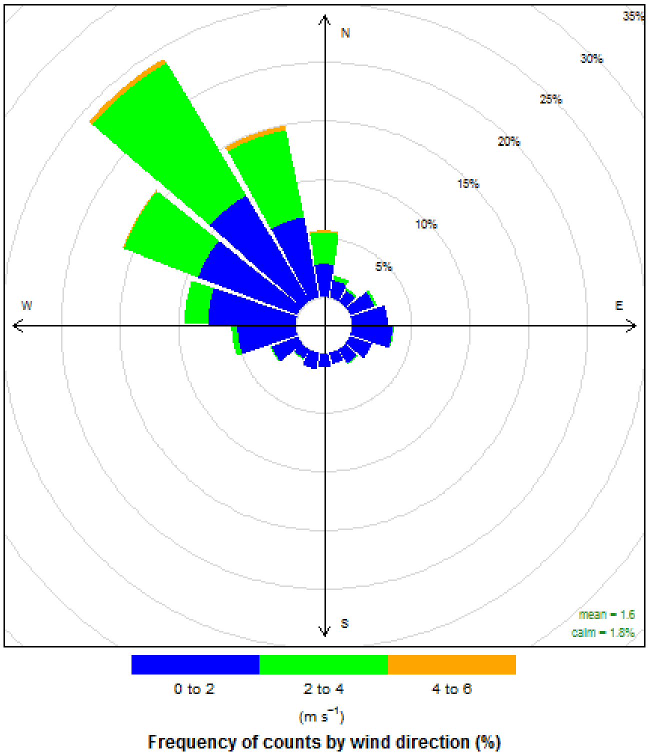


Figure 5-1. Wind rose at Bakersfield for all days and hours in the study time period.

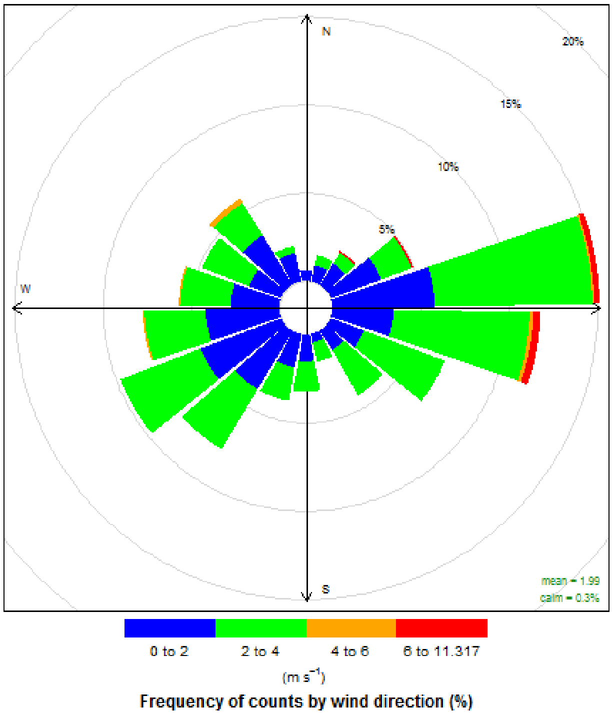


Figure 5-2. Wind rose at Edison for all days and hours in the study time period.

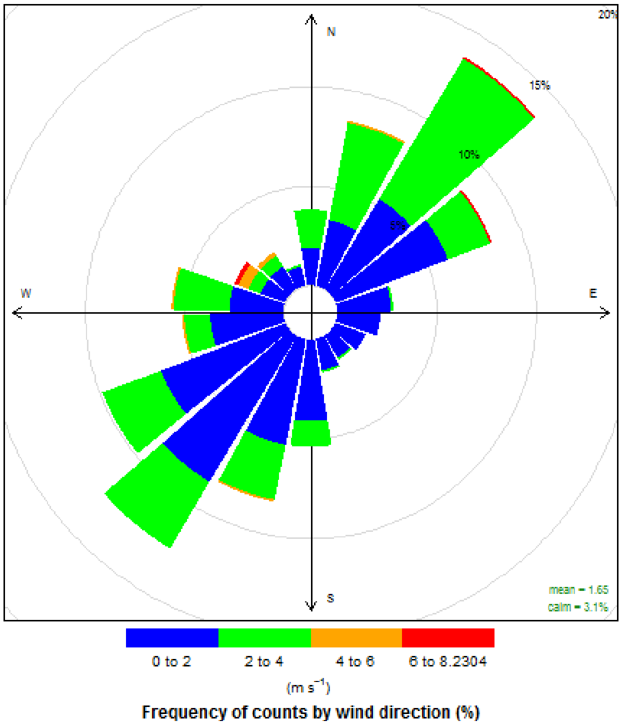


Figure 5-3. Wind rose at Di Giorgio for all days and hours in the study time period.

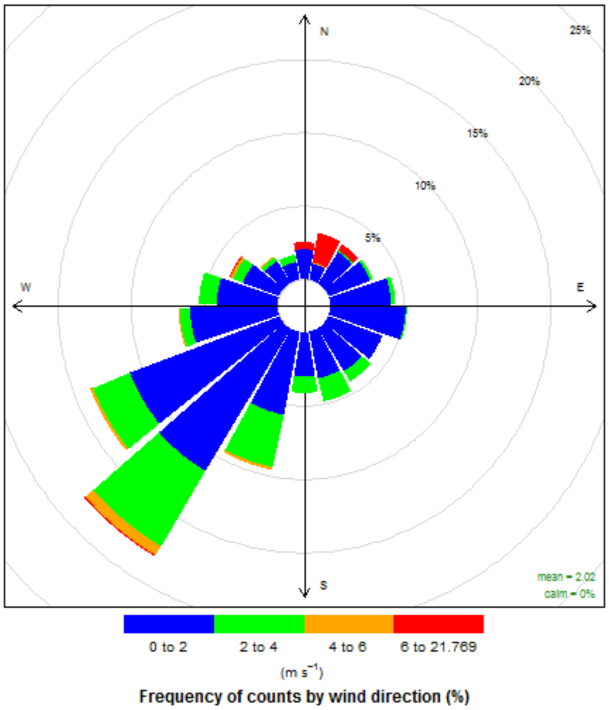


Figure 5-4. Wind rose at Bear Mountain for all days and hours in the study time period.

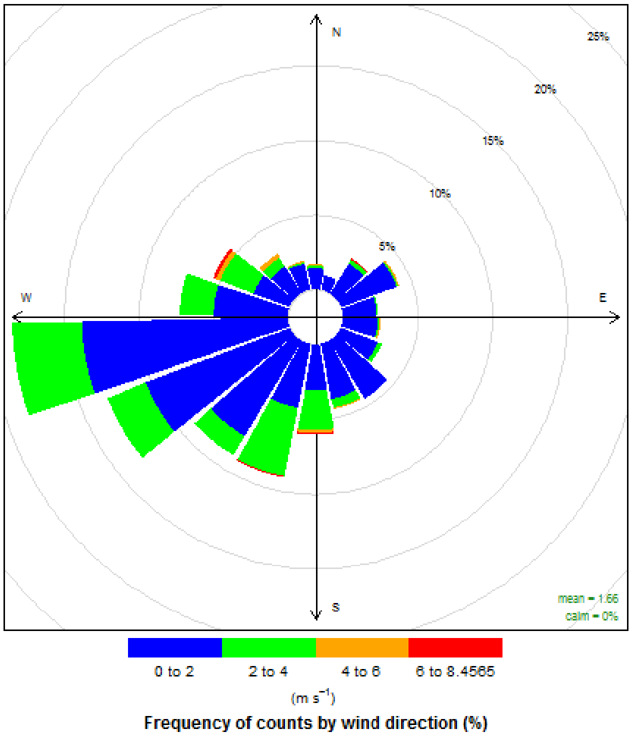


Figure 5-5. Wind rose at Arvin South for all days and hours in the study time period.

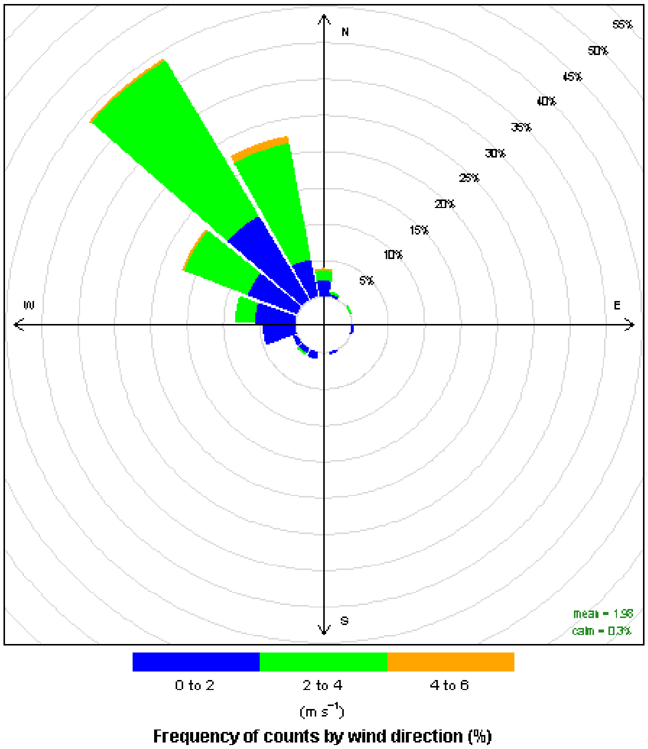


Figure 5-6. Wind rose at Bakersfield, including all data during 10:00 a.m. to 5:00 p.m.

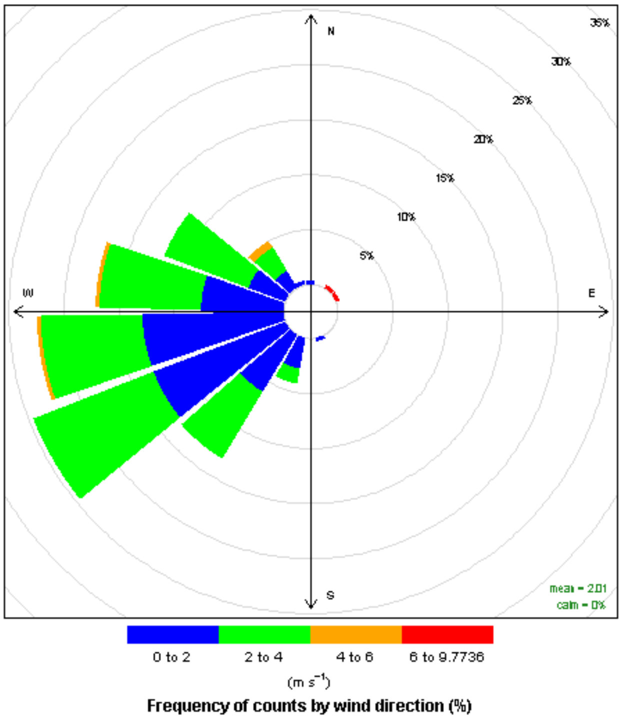


Figure 5-7. Wind rose at Edison, including all data during 10:00 a.m. to 5:00 p.m.

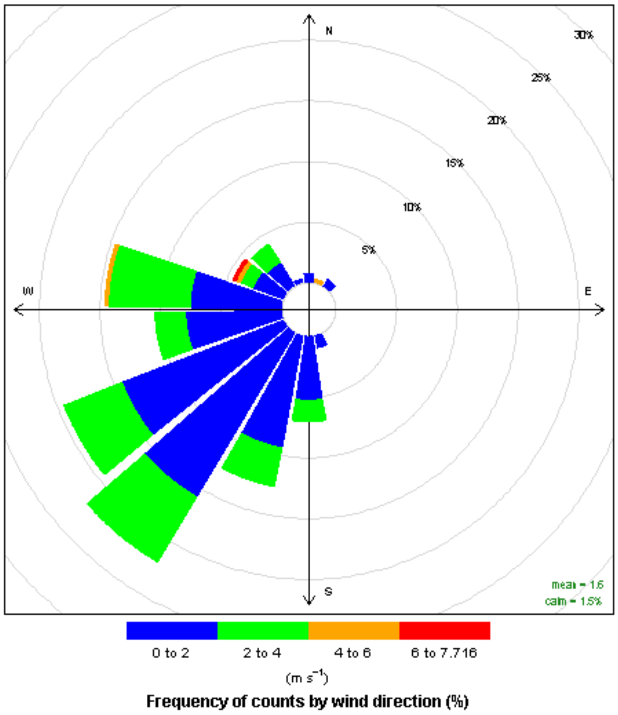


Figure 5-8. Wind rose at Di Giorgio, including all data during 10:00 a.m. to 5:00 p.m.

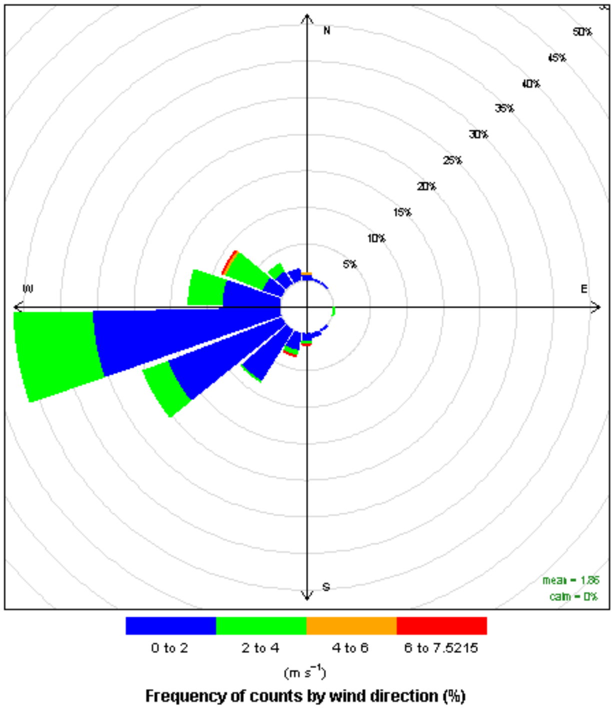


Figure 5-9. Wind rose at South of Arvin, including all data during 10:00 a.m. to 5:00 p.m.

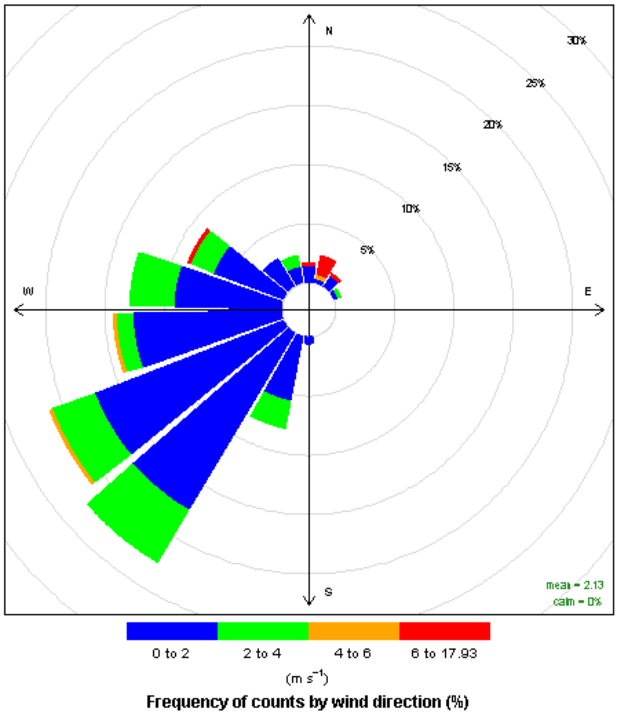


Figure 5-10. Wind rose at Bear Mountain, including all data during 10:00 a.m. to 5:00 p.m.

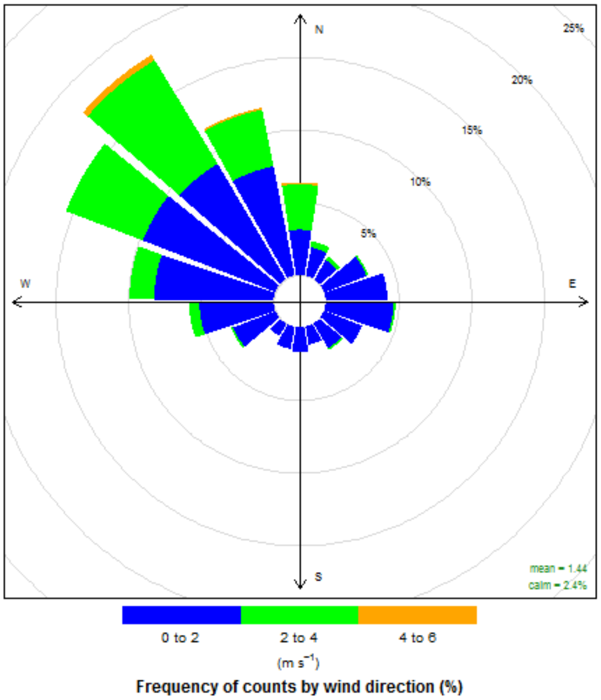


Figure 5-11. Wind rose at Bakersfield, including all data during 5:00 p.m. to 10:00 a.m.

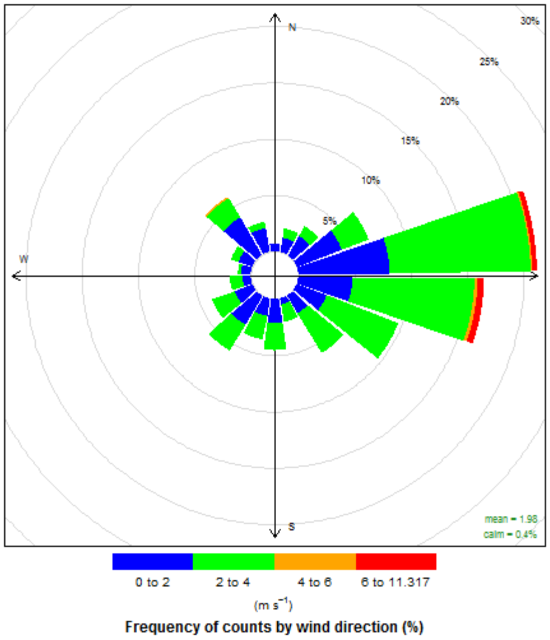


Figure 5-12. Wind rose at Edison, including all data during 5:00 p.m. to 10:00 a.m.

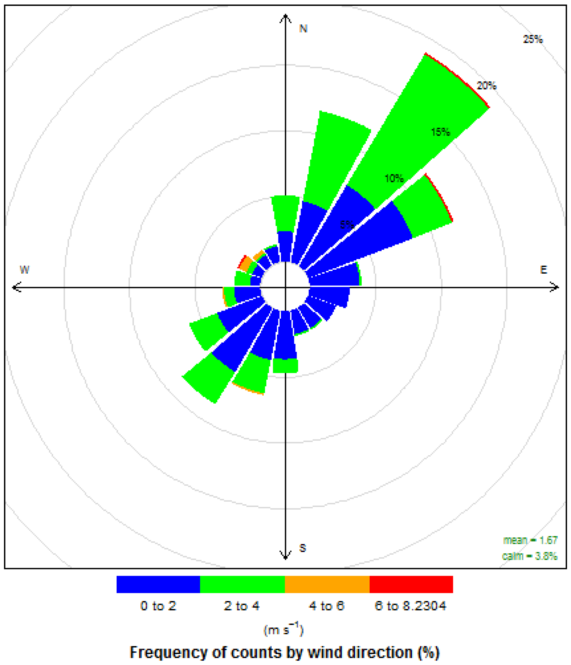


Figure 5-13. Wind rose at Di Giorgio, including all data during 5:00 p.m. to 10:00 a.m.

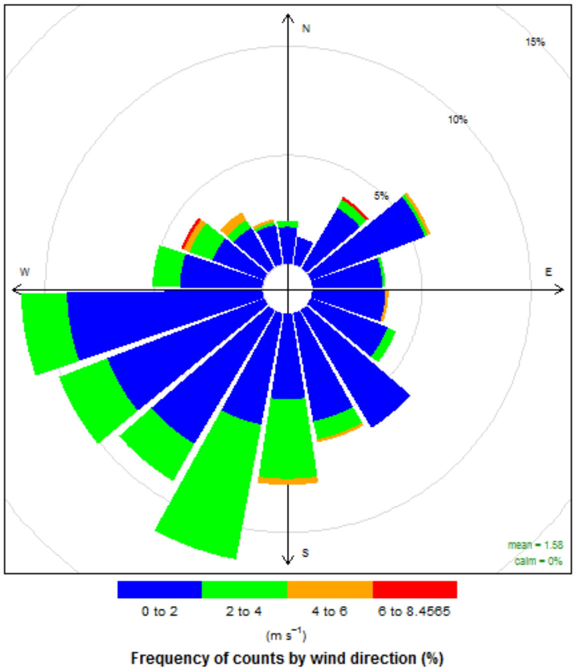


Figure 5-14. Wind rose at South of Arvin, including all data during 5:00 p.m. to 10:00 a.m.

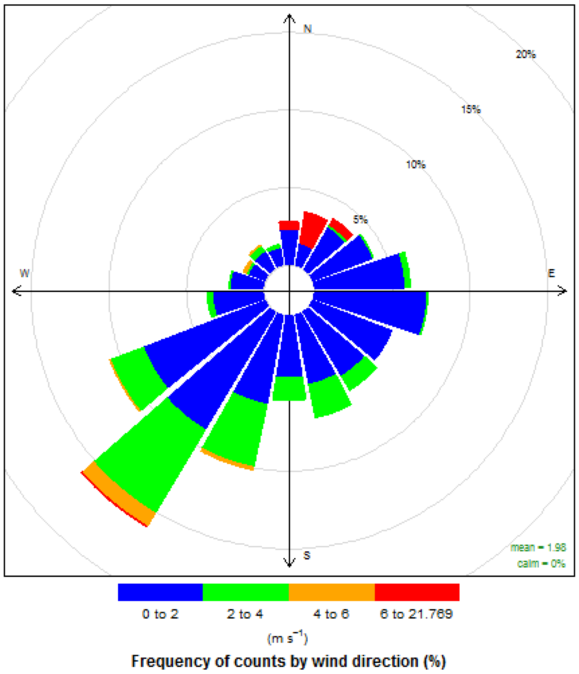


Figure 5-15. Wind rose at Bear Mountain, including all data during 5:00 p.m. to 10:00 a.m.

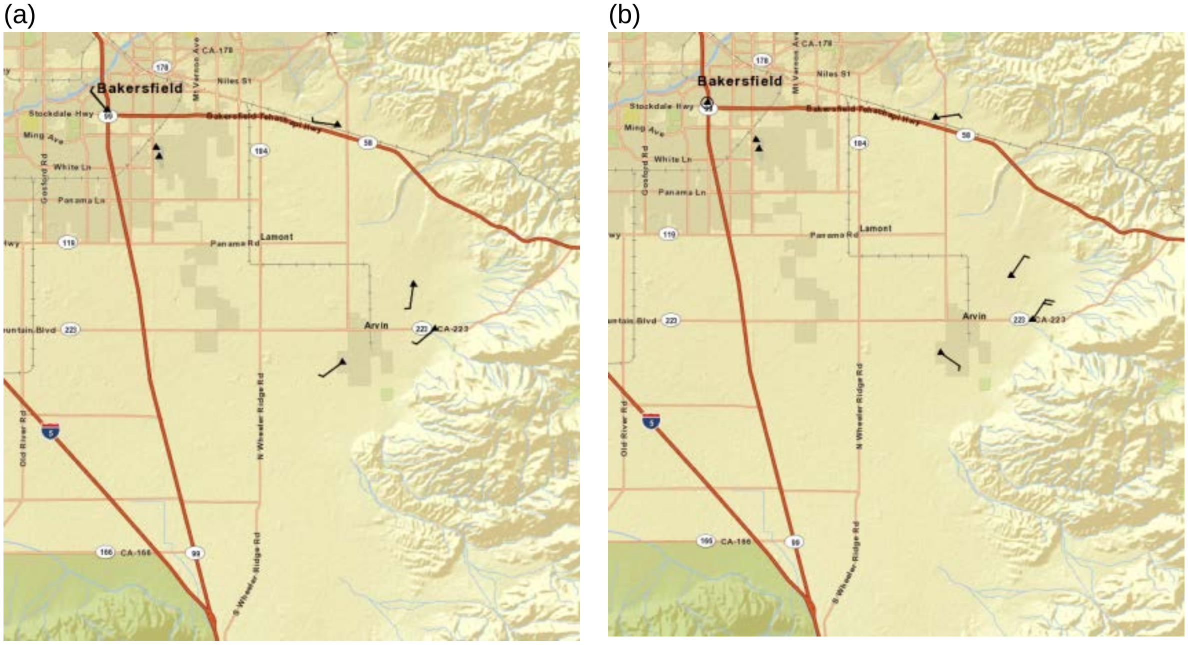


Figure 5-16. Wind barbs for all five sites at (a) 2:00 p.m., and (b) 8:00 p.m. (LST) on August 16, 2013. Plot was made using AirNow-Tech (http://airnowtech.org).

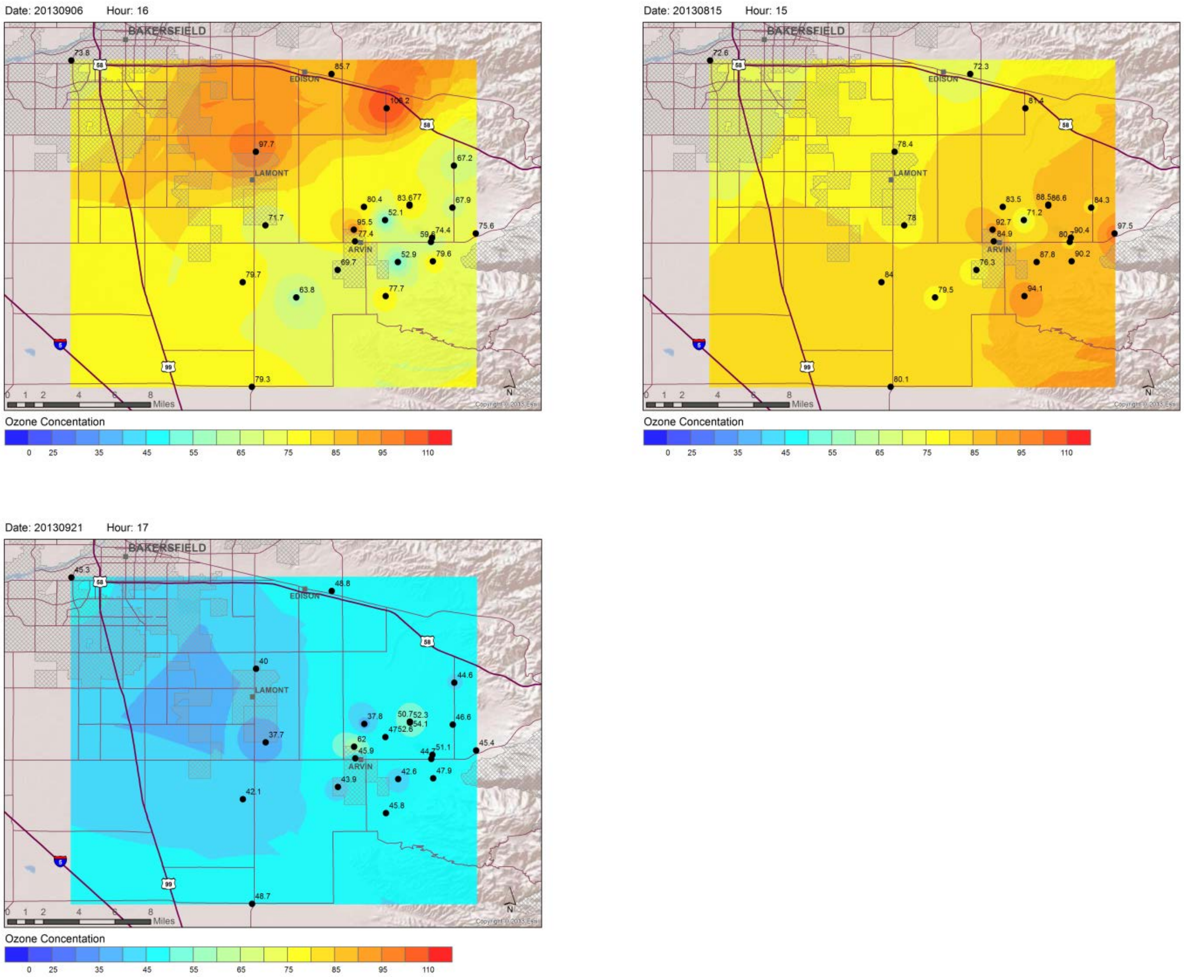
3. What are the general spatial patterns of ozone concentrations?

STI conducted an analysis of spatial gradients in ozone concentrations in and around the Arvin area. The analysis used daily maps of the peak 1-hr ozone concentrations, as well as the characterization of wind conditions described in the previous subsection. The general patterns described below were observed on high and low peak ozone days.

The most important observations are as follows:

- Daily peak 1-hr concentrations in the Arvin area of the study domain are well represented by the Di Giorgio site, as peak ozone concentrations at the Arvin-North (in the City of Arvin) and Di Giorgio sites are usually about the same.
- Peak 1-hr concentrations followed three major spatial patterns (**Figure 5-17**).
  - North-south gradient – On 34 days, high ozone concentrations were observed at the northern stations with a decreasing gradient at the southeasterly stations; this pattern was characterized by high concentrations at North of Di Giorgio (Site 3) and/or Northwest of Arvin (Site 4), and lower concentrations around Arvin.
  - High southeast gradient – On 10 days, high ozone concentrations were observed at the southeast stations, with lower concentrations in the northwest; high concentrations occurred at Arvin-North (Site 11), Di Giorgio (Site 14), and east of Bear Mountain (Site 17).
  - Flat spatial gradient – On 3 days, flat concentration gradients were observed, with similar ozone concentrations across the domain.
- Peak 1-hr ozone concentrations typically vary by 30 ppb across the domain.

- Peak 1-hr ozone concentrations showed a consistent hot spot pattern, with high concentrations Northwest of Arvin (Site 4), North of Di Giorgio (Site 3), Arvin-North (Site 11), Di Giorgio (Site 14), and at the sites near the Sierra Nevada (17, 19, 21). Bear Mountain (Site 18) was not the site with high concentrations.
- Ozone concentrations were consistently lower at Arvin-South (Site 9) and between Arvin and Di Giorgio (Sites 13 and 20).



(a)

(b)

(c)

Figure 5-17. Three patterns observed in the peak 1-hr maps: (a) the north-south gradient, (b) the high southeast gradient, and (c) the flat spatial gradient.

Furthermore, although the spatial gradient for the peak ozone hour may differ from day to day, a gradient with peak concentrations southeast of Arvin was consistently observed within a few hours after a peak ozone concentration was observed northwest of Arvin. These elevated ozone concentrations to the southeast of Arvin, as well as the observed wind conditions, suggest that transport from Bakersfield and the Central Valley into the study area is likely on most days, and that ozone concentrations increase in the Arvin area as evening titration begins to impact western sites, contributing to the southeast gradient.

Two consistent features are observed in the Arvin area on nearly all days: high concentration (hot spot) areas and low concentration areas. These features suggest complex local wind flow patterns and local titration around Arvin.

4. *What are the diurnal patterns of ozone on days with high ozone concentrations?*

The following diurnal patterns were observed:

- Ozone concentrations are low (<25 ppb) at most sites until approximately 7:00 a.m. LST.
- Ozone concentrations increase during the day (approximately 7:00 a.m. to 5:00 p.m. LST).
- A northwest-to-southeast ozone concentration gradient develops across the area at about 10:00 a.m. LST, with the highest concentrations in Bakersfield at this time. As the day progresses, concentrations decrease in the northwest and increase to the southeast (i.e., the Arvin area). This gradient pattern may be the result of pollution that is transported from the Central Valley, is compounded in Bakersfield, and moves to the Arvin area later in the day as a result of northwesterly flow and continuing ozone formation.
- Ozone is titrated in the evening and at night, resulting in concentrations below 25 ppb (starting at approximately 7:00 p.m. LST) at most sites.
- Titration of ozone is less at the eastern sites nearest the mountains; concentrations can remain above 50 ppb overnight.
- On days with the highest ozone concentrations, less titration occurred at the Edison site the previous night.
- The spatial ozone and wind patterns indicate that titration occurs in the late afternoon and evening throughout the study area each day. However, downslope flow near the mountains limits titration at nearby sites, except on days during which the Arvin area experiences continued northwesterly flow in the evening. The sites east and south of Bear Mountain (Sites 17, 19, 21) are most often affected by this downslope flow, which results in characteristic high nighttime ozone concentrations. Reduced titration contributes to higher 8-hr average ozone concentrations for some hours at these sites. In addition, higher baseline ozone concentrations were observed at these easternmost sites as daylight hours began, since overnight titration was reduced.

5. *How representative are the permanent monitors of high ozone in the City of Arvin?*

The Di Giorgio monitor is representative of high ozone concentrations in the city of Arvin. The finding is based upon analysis of the relationship between 1-hr and 8-hr ozone concentrations at the permanent Di Giorgio site and the temporary monitors in Arvin (North and

Central), the 8-hr ozone exceedances at the temporary monitors, and the results described in the previous subsections. A summary of the representativeness of the Di Giorgio is as follows:

- The Di Giorgio FEM ozone data and the average of the Arvin-North and Arvin-Central ozone data are well correlated, with an R^2 of 0.79 (see **Figure 5-18, Table 5-3, and Table 5-4**).
- Ozone concentrations in the City of Arvin, using the average of the Arvin-North and Arvin-Central monitors, were comparable to the Di Giorgio FEM data (see Figure 5-18). Ordinary least squares regressions were calculated for the relationship between each Arvin monitor and each FEM; the strongest relationship was between the City of Arvin average and the Di Giorgio FEM for high concentrations (see Table 5-3). The negative bias in the slope (0.9) indicates concentrations are slightly higher at Di Giorgio and the low slope standard error (0.028) indicates good precision.
- An analysis of the residuals (the difference between the actual ozone measurement and the concentration predicted by the linear regression equation), provided in Appendix E, shows that the residual error is not related to the ozone concentration, and thus the predictive equations do not show a bias with increasing ozone concentration. There is slightly greater scatter of residuals in the 70-80 ppb ozone concentration range than below 70 ppb and above 80 ppb, but in general, there is little or no bias in the residuals, and thus little or no bias in the predictive equation with increasing ozone concentration.
- Days when the 8-hour standard was exceeded at Di Giorgio and Arvin-North were often the same and the concentrations were similar (see **Table 5-5**).

These finding indicates the permanent Di Giorgio site can be used to predict ozone concentrations in the city of Arvin with reasonable accuracy and precision as presented in the next section.

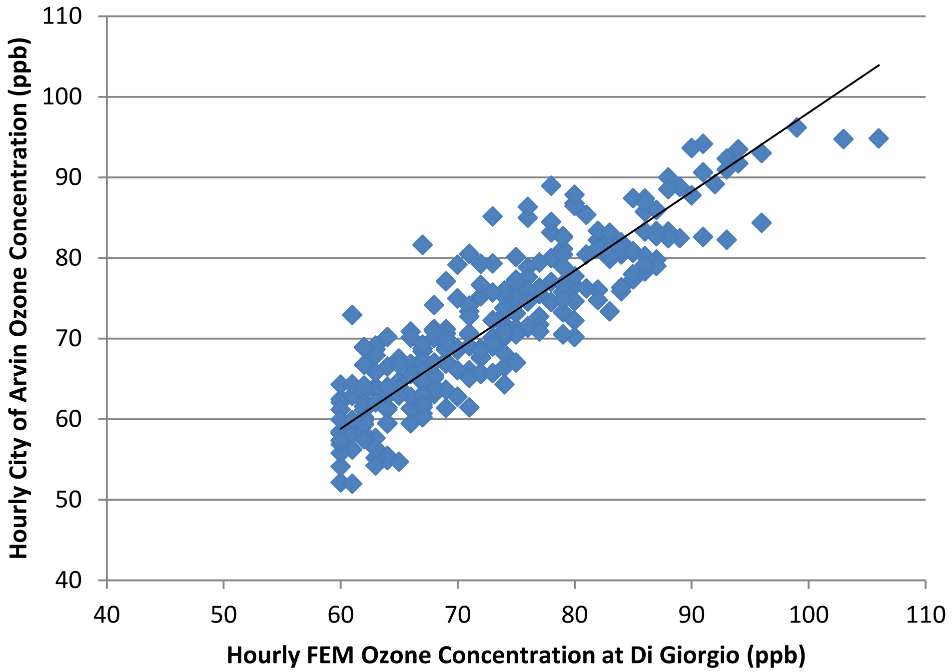


Figure 5-18. Scatter plot of the Di Giorgio FEM and City of Arvin (average of Arvin-North and Arvin-Central monitors) 1-hr ozone concentrations for FEM concentrations ≥ 60 ppb.

Table 5-3. Ordinary least square regression results to describe relationship between the City of Arvin (using Arvin North, Arvin Central, and the average of Arvin North and Arvin central data), and data from the permanent FEM monitors at Di Giorgio, Edison, and Bakersfield; only coincident data having concentrations ≥ 60 ppb at Di Giorgio were included.

Dependent	Independent	Slope	Y Intercept	SE Slope	SE Intercept	R^2
Arvin North	FEM Di Giorgio	1.009	1.102	0.035	2.613	0.749
Arvin Central	FEM Di Giorgio	0.792	10.785	0.029	2.137	0.732
Arvin-Average	FEM Di Giorgio	0.903	5.723	0.028	2.094	0.787
Arvin North	FEM Edison	0.531	39.775	0.062	4.142	0.214
Arvin Central	FEM Edison	0.405	41.789	0.05	3.313	0.199
Arvin-Average	FEM Edison	0.473	40.442	0.054	3.607	0.222
Arvin North	FEM Bakersfield	0.51	39.847	0.072	4.999	0.153
Arvin Central	FEM Bakersfield	0.341	45.257	0.058	4.043	0.108
Arvin-Average	FEM Bakersfield	0.433	42.038	0.063	4.375	0.144

Table 5-4 compares the 8-hr average ozone concentrations at Di Giorgio and in City of Arvin on days when 8-hr concentrations exceeded NAAQS at any of these sites. As noted in the table, Di Giorgio 8-hr ozone is very similar to concentrations in the City of Arvin.

Table 5-4. Comparison of the 8-hr average ozone concentrations at Di Giorgio and in the City of Arvin on days when 8-hr concentrations exceeded NAAQS at any of these sites.

Date	FEM Di Giorgio	14b: Di Giorgio	11: Arvin - North	10: Arvin - Central
13-Aug	74	76*	78	74
14-Aug	81	79	85	80
15-Aug	82	80	84	79
16-Aug	75	74	77	72
20-Aug	77	74	75	72
24-Aug	78	78	81	75
4-Sep	72	76	74	69
6-Sep	71	77	78	68
8-Sep	72	79	79	75
9-Sep	72	79	81	73
10-Sep	72	78	83	73
13-Sep	85	78	84	72
14-Sep	83	76	80	70
20-Sep	80	78	88	73
13-Aug	74	76	78	74
14-Aug	81	79	85	80
15-Aug	82	80	84	79
16-Aug	75	74	77	72
20-Aug	77	74	75	72
24-Aug	78	78	81	75
4-Sep	72	76	74	69
6-Sep	71	77	78	68
8-Sep	72	79	79	75
9-Sep	72	79	81	73
10-Sep	72	78	83	73
13-Sep	85	78	84	72
14-Sep	83	76	80	70
20-Sep	80	78	88	73

Table 5-5 provides the number of days with a daily maximum 8-hr ozone average that exceeded the regulatory standard (75 ppb) at each site. The sites having the greatest number of exceedances are Arvin North (12 days), Di Giorgio (11 days), North of Di Giorgio (8 days), East of Bear Mountain (10 days), and Northwest of Arvin (9 days). Other sites had significantly fewer days with ozone concentrations above the standard (Bear Mountain has only six exceedances). Exceedance days were very similar between the Di Giorgio and the Arvin North temporary monitors; 11 exceedance days were observed at Di Giorgio, while 12 exceedance days were observed at Arvin North, and all exceedance days corresponded at both sites with the exception of three days (August 13, 16, 24).

Table 5-5. Number of days when the maximum 8-hour ozone concentration exceeded 75 ppb at each site

Site Number / Name	# Days
11 / Arvin North	12
14 / Di Giorgio	11
17 / East of Bear Mountain	10
4 / Northwest of Arvin	9
3 / North of Di Giorgio	8
21 / Southeast of Arvin	7
19 / Southeast of Bear Mountain	7
18b / Bear Mountain	6
1 / Bakersfield	4
12 / West of Di Giorgio	2
6 / West of Arvin	2
2 / Edison	2
10 / Arvin Central	2
7 / Gradient South	2
16 / East of Di Giorgio	1
20 / Southwest of Bear Mountain	1

6. How representative are ozone data collected at the Di Giorgio monitoring site of ozone data near the old Bear Mountain site?

In 2010, the ozone concentrations at the Di Giorgio site were about 10% lower than measurements at the Bear Mountain site for both 1-hr and 8-hr average ozone concentrations. In 2013, we found that the Di Giorgio monitoring site is representative of high ozone concentrations in the area around the former Bear Mountain monitor. However, we also found that the Di Giorgio site experiences slightly higher peak 1-hr ozone concentrations than at Bear Mountain and more 8-hr exceedances. These finding are based upon analysis of the relationship between 1-hr data collected at Di Giorgio and at Bear Mountain (Sites 18a and 18b), an examination of the number of 8-hr ozone exceedances at these sites, as well as the results described in the previous subsections. Note that the Southeast of Bear Mountain sensor data (Site 19) was also included in this analysis because it was on the same side of the road as the old Bear Mountain monitor, albeit further away from the old Bear Mountain site than Sites 18a and 18b.

Figure 5-19 shows a scatter plot of peak 1-hr ozone concentrations collected by Aeroqual sensors for Di Giorgio (Site 14b[8]) and Bear Mountain (Site 18a) on all study days. Site 18a is the one closest to the road, and it shows evidence of titration. As noted in the figure, concentrations at Di Giorgio are higher than concentrations at Bear Mountain Site 18a. On average, the peak 1-hr ozone concentrations are about 15% higher at Di Giorgio. The correlation (R^2) is 0.60, which means the concentrations are only modestly correlated. An analysis of the residuals (the difference between the actual ozone measurement and the concentration predicted by the linear regression equation), provided in Appendix E, shows that the residual error is not related to the ozone concentration, and thus the predictive equations do not show a bias with variation in the ozone concentration.

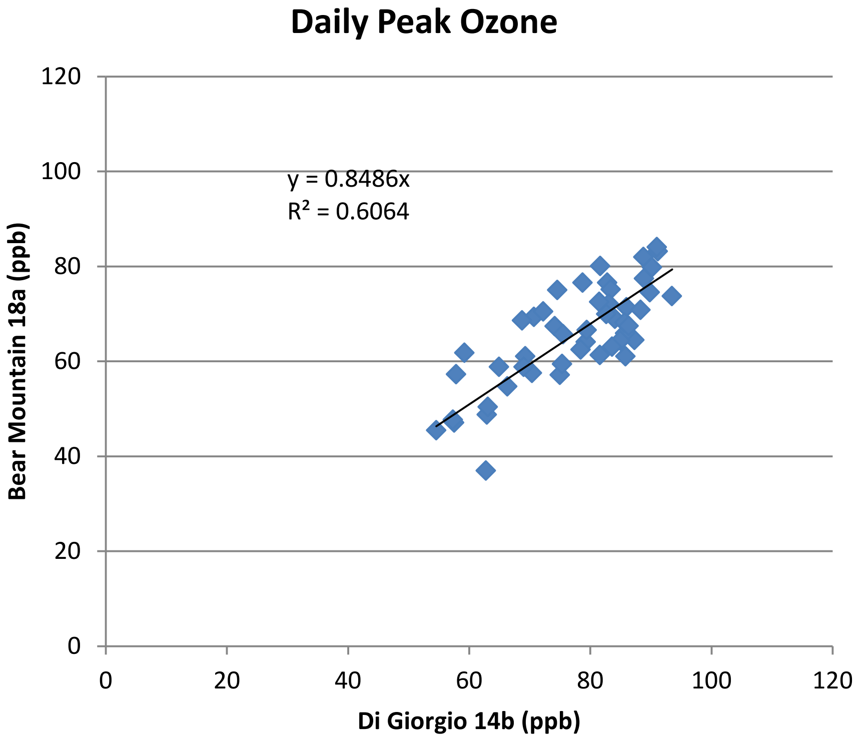


Figure 5-19. Scatter plot of peak 1-hr ozone concentrations collected by Aeroqual sensors for Di Giorgio (Site 14) and Bear Mountain (Site 18a) on all study days.

Figure 5-20 shows a scatter plot of peak 1-hr ozone concentrations collected by Aeroqual sensors at Di Giorgio (Site 14b) and Bear Mountain (Site 18b) on all study days. Site 18b is the one further from the road, and it does not show evidence of titration during the day.

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[8] Site 14b was used because Site 14a had a sensor replaced partway through the study. The data from 14a and 14b were almost identical since the sensors were only a few feet apart.

As noted in the figure, concentrations at Di Giorgio are very similar to concentrations at Bear Mountain Site 18a, but slightly higher. On average, the peak 1-hr concentrations are about 3% higher at Di Giorgio. The correlation (R^2) is 0.86, which means the ozone concentrations are well correlated. An analysis of the residuals (the difference between the actual ozone measurement and the concentration predicted by the linear regression equation), provided in Appendix E, shows that the residual error is not related to the ozone concentration, and thus the predictive equations do not show a bias with variation in the ozone concentration.

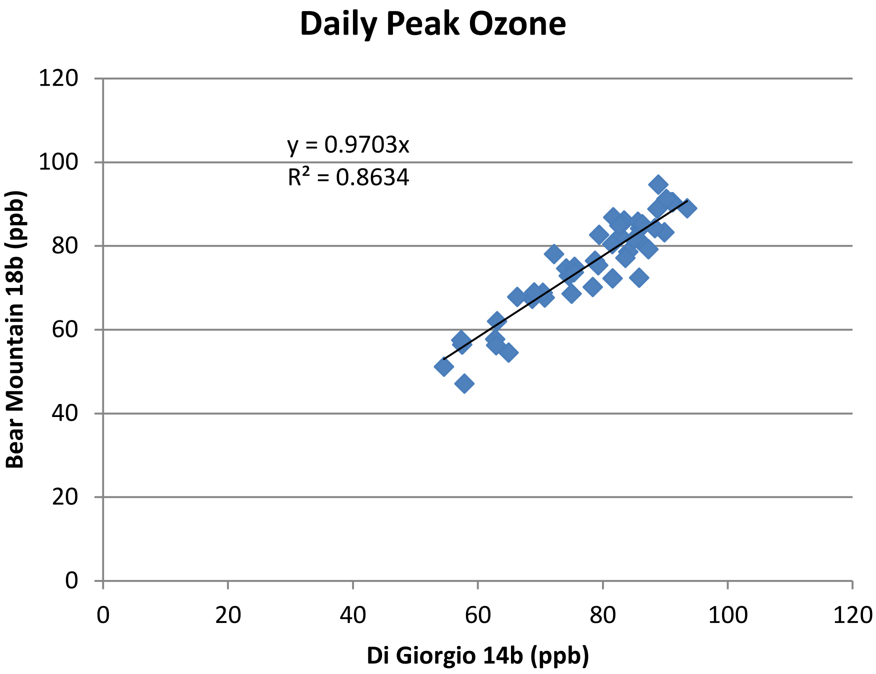


Figure 5-20. Scatter plot of peak 1-hr ozone concentrations collected by Aeroqual sensors for Di Giorgio (Site 14b) and Bear Mountain (Site 18b) on all study days.

Figure 5-21 shows a scatter plot of 1-hr ozone concentrations by Aeroqual sensors at Di Giorgio and Southeast of Bear Mountain (Site 19) on all study days. Site 19 is on the same side of the road as the old Bear Mountain site, but much further away (over a mile) from the old Bear Mountain site than 18a and 18b; it does not show evidence of titration during the day. As noted in the figure, concentrations at Di Giorgio are very similar to concentrations at Bear Mountain Site 19, but slightly higher. On average, the peak 1-hr concentrations are about 2% higher at Di Giorgio. The correlation (R^2) is 0.91, which means the concentrations are well correlated. An analysis of the residuals (the difference between the actual ozone measurement and the concentration predicted by the linear regression equation), provided in Appendix E, shows that the residual error is not related to the ozone concentration, and thus the predictive equations do not show a bias with variation in the ozone concentration.

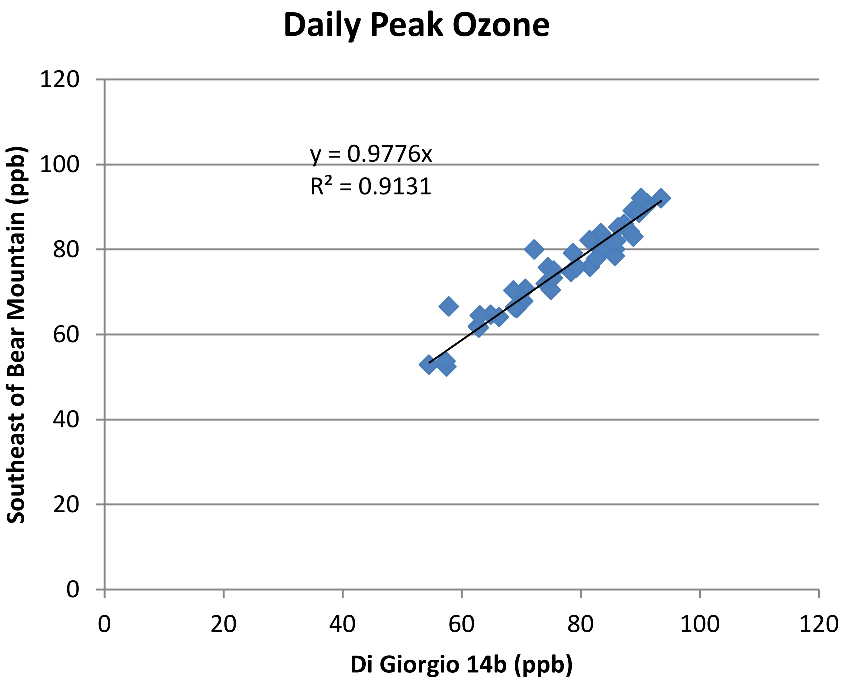


Figure 5-21. Scatter plot of peak 1-hr ozone concentrations collected by Aeroqual sensors for Di Giorgio (Site 14) and southeast of Bear Mountain (Site 19) on all study days.

In addition, the Aeroqual sensor with the highest concentrations near the old Bear Mountain (Site 18b and 19) experienced fewer days exceeding the 8-hr ozone standard than the Di Giorgio Aeroqual sensor. Concentrations exceeded the 8-hr standard six times at Site 18b and seven times at Site 19; whereas, concentrations exceeded the 8-hr standard at Di Giorgio 11 times.

5.4 Predictive Equations

Linear regressions equations were developed to predict 1-hr and 8-hr peak ozone concentrations (1) in the City of Arvin and (2) at Bear Mountain using data from permanent FEM ozone monitors and meteorological data. The City of Arvin equations will be used by District staff to supplement or replace existing methods to forecast ozone concentrations on a daily basis for this area. The Bear Mountain equation will be used by the District to better understand the relationship between ozone concentrations at permanent FEM sites and at the old Bear Mountain. The resulting equations are very accurate.

Note that in practice, the District will use next-day forecasts of all of these variables to predict next-day ozone concentrations for the City of Arvin. The predictions for FEM ozone concentrations at Di Giorgio, Bakersfield, and Edison will be created using existing District forecast tools.

5.4.1 Data Used to Represent Ozone Concentrations

For the City of Arvin 1-hr ozone equations, STI averaged the ozone concentrations from Arvin North (Site 11) and Arvin Central (Site 10) by hour and selected the highest average for each day to represent the peak 1-hr ozone concentrations in the City of Arvin.

For the City of Arvin 8-hr ozone equations, STI averaged the peak 8-hr ozone concentrations from Arvin North and Arvin Central for each day to represent the peak 8-hr ozone concentrations in the city.

For the Bear Mountain 1-hr ozone equations, STI averaged the ozone concentrations from Bear Mountain (Site 18b) and Southeast of Bear Mountain (Site 19) by hour and selected the highest average for each day to represent the peak 1-hr ozone concentrations at Bear Mountain. Site 18a was not used because daytime ozone measurements at this location appeared to reflect titration and were almost always lower than Sites 18b and 19.

For the Bear Mountain 8-hr ozone equations, STI averaged the peak 8-hr ozone concentrations from Bear Mountain (Site 18b) and Southeast of Bear Mountain (Site 19) for each day to represent the peak 8-hr ozone concentrations at Bear Mountain. Again, Site 18a was not used because daytime ozone measurements at this location appeared to reflect titration and were almost always lower than Sites 18b and 19.

Note that all predictor variables are for the same day as the prediction. For example, if a next-day prediction is desired, then all predictor variables are for the next day as well.

5.4.2 1-Hour Ozone Equations for the City of Arvin

Forward step-wise multiple linear regression was used to predict 1-hr peak ozone concentrations for the City of Arvin. A total of 16 variables were evaluated, as described in Section 4.3. Entering a predictor variable with each step required a p-value less than 0.1. In four steps, four predictors were entered into the regression, and no variables were removed, resulting in a final predictive equation that included

- Peak daily 1-hour ozone concentrations from the Di Giorgio FEM;
- Daily minimum temperature in Bakersfield;
- Mean daily dew point in Bakersfield;
- Afternoon wind speed in Bakersfield; and
- A constant.

The predictive equation is provided in **Equation 5-3** and in **Table 5-6**, which also includes the regression statistics for the equation.

The Di Giorgio FEM data explain 90% of the variance; the inclusion of the Bakersfield temperature, dew point, and wind speed data increased the R^2 value to 0.92, which means that 92% of the variance of the City of Arvin peak 1-hr ozone concentration is explained.

As shown in **Table 5-7**, the accuracy for each concentration bin is ±1 ppb and the percent error is less than 1%. The accuracy of this equation is very good.

$$\begin{gathered}\textit{Arvin 1-hr ozone} = 21.361 + 0.759{*}\textit{FEM Di Giorgio} + 0.595{*}\textit{Min Temp} - \\ 0.759{*}\textit{Dew Point} - 0.718{*}\textit{PM Wind Speed}\end{gathered} \tag{Eq. 5-3}$$

Table 5-6. Regression results and statistics for predicting daily peak 1-hour ozone concentrations for the City of Arvin.

Predictor	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-Value
Constant	21.361	8.045	0.000	.	2.655	0.011
FEM Di Giorgio	0.759	0.046	0.846	0.644	16.414	0.000
Min Temp	0.595	0.179	0.246	0.314	3.332	0.002
Dew Point	-0.759	0.202	-0.243	0.410	-3.759	0.001
PM Wind Speed	-0.718	0.340	-0.105	0.687	-2.112	0.041

Table 5-7. Error estimates for predicting peak 1-hour concentrations in the City of Arvin.

Concentration Bin (ppb)	Absolute Error (ppb)	Relative Error (fraction)	Mean Ozone at Di Giorgio (ppb)
40-60	-0.06	0.00	53.00
61-75	-0.65	-0.01	69.50
76-95	0.49	0.01	84.92
96-115	-0.73	-0.01	99.25

5.4.3 8-Hour Ozone Equations for the City of Arvin

Forward step-wise multiple linear regression was used to predict 8-hr peak ozone concentrations for the City of Arvin. A total of 16 variables were evaluated, as described in Section 4.3. Entering a predictor variable with each step required a p-value less than 0.1. In five steps, five predictors were entered into the regression, and no variables were removed, resulting in a final predictive equation including

- Peak daily 8-hour ozone concentrations from the Di Giorgio FEM;
- Daily minimum temperature in Bakersfield;
- Mean daily dew point in Bakersfield;
- Afternoon wind speed in Bakersfield;
- 500 mb height at 4 am from Vandenberg; and
- A constant.

The predictive equation is provided in **Equation 5-4** and in **Table 5-8**, which also includes the regression statistics for the equation.

The Di Giorgio FEM data explain 88% of the variance. The inclusion of the daily minimum temperature, mean dew point, wind speed, and pressure height increased the R^2 value to 0.92, which means that 92% of the variance of the peak 8-hr ozone concentration for the City of Arvin is explained.

As shown in **Table 5-9**, the accuracy for each concentration bin is ±1 ppb and the percent error is less than 1%. The accuracy of this equation is very good.

$$\text{Arvin 8-hr ozone} = 171.231 + 0.762*\text{FEM Di Giorgio} + 0.563*\text{Min Temp} - 0.687*\text{Dew Point} - 0.669*\text{PM Wind Speed} - 0.026*\text{500 mb heightM 4am} \quad \textbf{(Eq. 5-4)}$$

Table 5-8. Regression results and statistics for predicting daily peak 8-hour ozone concentrations for the City of Arvin.

Predictor	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-Value
Constant	171.231	84.508	0.000	–	2.026	0.049
FEM Di Giorgio	0.762	0.048	0.867	0.601	15.764	0.000
Min Temp	0.563	0.152	0.293	0.291	3.703	0.001
Dew Point	-0.687	0.164	-0.276	0.417	-4.185	0.000
PM Wind Speed	-0.669	0.287	-0.124	0.649	-2.334	0.024
500 heightM 4AM	-0.026	0.015	-0.099	0.544	-1.720	0.093

Table 5-9. Error estimates for predicting peak 8-hour concentrations in the City of Arvin.

Concentration Bin (ppb)	Absolute Error (ppb)	Relative Error (fraction)	Mean Ozone at Di Giorgio (ppb)
40-60	-0.47	-0.01	53.78
61-75	0.39	0.01	70.14
76-95	-0.47	-0.01	80.75
96-115	NA	NA	NA

5.4.4 Predicting Peak 1-hour Concentrations for Bear Mountain

Forward step-wise multiple linear regression was used to predict 1-hr peak ozone concentrations for Bear Mountain. A total of 16 variables were evaluated, as described in Section 4.3. Entering a predictor variable with each step required a p-value less than 0.1. In two steps, two predictors were entered into the regression, and no variables were removed, resulting in a final predictive equation that included

- Peak daily 1-hour ozone concentrations from the Di Giorgio FEM;
- 500 mb height at 4:00 a.m. from Vandenberg; and
- A constant.

The predictive equation is provided in **Equation 5-5** and in **Table 5-10**, which also includes the regression statistics for the equation.

Di Giorgio FEM ozone data explained 89% of the variance in the daily peak 1-hr ozone concentration for the Bear Mountain area. The complete equation explains about 90% of the variance, with an R-square value of 0.9.

As shown in **Table 5-11**, the accuracy for each concentration bin is ±1.5 ppb and the percent error is less than 1%. The accuracy of this equation is very good.

$$\textit{Bear Mountain 1-hr ozone} = 271.231 + 0.815 * \textit{FEM Di Giorgio} - 0.044 * \textit{500 heightM 4AM} \qquad \textbf{(Eq. 5-5)}$$

Table 5-10. Regression results and statistics for predicting daily peak 1-hour ozone concentrations for Bear Mountain.

Predictor	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-Value
Constant	271.231	92.042	0.000	.	2.947	0.005
FEM Di Giorgio	0.815	0.043	1.021	0.725	18.804	0.000
500 heightM 4AM	-0.044	0.016	-0.150	0.725	-2.766	0.008

Table 5-11. Error estimates for predicting peak 1-hour concentrations in Bear Mountain.

Concentration Bin (ppb)	Absolute Error (ppb)	Relative Error (fraction)	Mean Ozone at Di Giorgio (ppb)
40-60	-0.51	-0.01	53.00
61-75	-0.33	0.00	69.50
76-95	0.52	0.01	84.92
96-115	-1.42	-0.01	99.25

5.4.5 Predicting Peak 8-Hour Concentrations for Bear Mountain

Forward step-wise multiple linear regression was used to predict 8-hr peak ozone concentrations for Bear Mountain. A total of 16 variables were evaluated and are described in Section 4.3. Entering a predictor variable with each step required a p-value less than 0.1. In two steps, two predictors were entered into the regression, and no variables were removed, resulting in a final predictive equation including

- Peak daily 8-hour ozone concentrations from the Di Giorgio FEM;
- 500 mb height at 4:00 a.m. from Vandenberg; and
- A constant.

The predictive equation is provided in **Equation 5-6** and in **Table 5-12**, which also includes the regression statistics for the equation.

Di Giorgio FEM ozone data explained 89% of the variance. The inclusion of the 500 mb height at 4:00 a.m. increased the R^2 value to 0.9, which means 90% of the variance in 8-hr ozone for Bear Mountain is explained.

As shown in **Table 5-13**, the accuracy for each concentration bin is ±1 ppb and the percent error is less than 1%. The accuracy of this equation is very good.

$$\text{Bear Mountain 8-hr ozone} = 169.667 + 0.811 * \text{FEM Di Giorgio} - 0.027 * \text{500 heightM 4AM} \quad \textbf{(Eq. 5-6)}$$

Table 5-12. Regression results and statistics for predicting daily peak 8-hour ozone concentrations for the Bear Mountain area.

Predictor	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-Value
Constant	169.667	76.988	0.000	.	2.204	0.033
FEM Di Giorgio	0.811	0.045	0.992	0.786	18.194	0.000
500 heightM 4AM	-0.027	0.013	-0.109	0.786	-2.005	0.051

Table 5-13. Error estimates for predicting peak 8-hour concentrations in the Bear Mountain area.

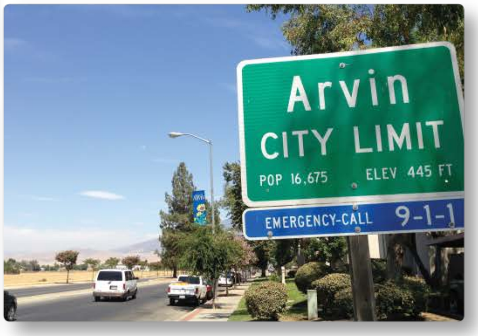
Concentration Bin (ppb)	Absolute Error (ppb)	Relative Error (fraction)	Mean Ozone at Di Giorgio (ppb)
40-60	0.01	0.00	53.78
61-75	0.21	0.00	70.14
76-95	-0.79	-0.01	80.75
96-115	NA	NA	NA

Appendix A

Ozone Saturation Study Field Plan

Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Ozone Saturation Study Field Plan



Prepared for

San Joaquin Valley Air Pollution Control District
Fresno, CA

July 2013

Ozone Saturation Study Field Plan

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Prepared by

David L. Vaughn[1]
Timothy S. Dye[1]
Charley A. Knoderer[1]
Hilary A. Minor[1]
Scott Nester[2]
Clinton P. MacDonald[1]
Paul T. Roberts[1]

[1]Sonoma Technology, Inc.
1455 N. McDowell Blvd., Suite D
Petaluma, CA 94954-6503
Ph 707.665.9900 | F 707.665.9800
sonomatech.com

[2]Providence Engineering and Environmental Group, LLC
1713 Tulare Street, Suite 124
Fresno, CA 93721-2529

Prepared for

James Sweet
Senior Air Quality Specialist
San Joaquin Valley Air Pollution Control District
1990 East Gettysburg Avenue
Fresno, CA 93726-0244

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Cover photo shows, clockwise starting at the top left, a Mountain View Oil Field oil well within agricultural fields near Arvin, CA (source: Scott Nester); the view looking east from Bear Mountain (source: Scott Nester); the Arvin City limits (source: Scott Nester); Arvin City Hall (source: Scott Nester), and an Aeroqual 500 sensor.

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1. General Plan

The San Joaquin Valley Air Pollution Control District (SJVAPCD) seeks to (1) determine ozone gradients in and around Arvin and (2) develop an algorithm to predict ozone concentrations within the City of Arvin and at the old Arvin monitoring site, using data collected at permanent monitors at sites including Edison, Bakersfield (California Street), and Di Giorgio in Arvin. The main project elements include

- designing a field program to meet these objective using low-cost ozone sensors;
- identifying and procuring sites for the ozone measurements;
- installing, operating; and maintaining the instruments for a six-week field program in August and September 2013;
- conducting data analysis to characterize the gradients and develop the predictive algorithms; and
- delivering quality-controlled data, the predictive algorithms, and a report that details the study methods and results.

To meet these project objectives, Sonoma Technology, Inc. (STI) and our team members, Providence Engineering and Environmental Group LLC, Eric Winegar, and Aeroqual Ltd., are performing this work. This document provides details about the activities needed to perform the field measurement study. Measurements will be made using 23 Aeroqual ozone sensor systems and two surface meteorological stations during the six-week field program from approximately August 15 to September 30, 2013. The field study will take place in four phases:

1. Collocation (late July): operate all Aeroqual Series 500 ozone sensors next to a Federal Equivalency Method (FEM) ozone monitor to calibrate each sensor and ensure instrument comparability.
2. Preparation (July to early August): procure sites and sensors, set up data processing and quality control procedures, and install sensors and meteorological instruments.
3. Operations (~August 15 to September 30): operate sensors, ingest data, quality control data, troubleshoot problems, and report real-time data on a website.
4. Removal and Validation (October): remove sensor systems and validate ozone and meteorological data.

The remainder of this document provides plans for the field operations including: discussion of safety procedures, siting, field activities, data flow, quality assurance, and contact information. **Appendix A** contains STI's draft *Health and Safety Plan for Field Operations*. **Appendix B** contains STI's *Standard Procedures for Operating a Meteorological Tower*. **Appendix C** contains Aeroqual's *Standard Operating Procedures for the Aeroqual Airmote Sensor*.

2. Safety Procedures

Providing a safe and healthful workplace for employees and subcontractors is the first consideration in the operation of business. It is both a moral obligation and sound business practice to prevent occupational injuries and illness. No phase of operations is more important than injury and illness prevention. Safety always takes precedence over expediency or shortcuts. As a condition of employment, each employee and subcontractor is expected to assume responsibility for working safely at all times. The following statement is, and shall be, the philosophy under which all field operations shall be performed: SAFETY IS NOT A LUXURY; IT IS A MUST!

The draft health and safety plan in Appendix A provides guidance for the safe conduct of employees and subcontractors during any field operation at any field station site operated by STI.

If at any time you have questions about the health and safety guidelines, please contact Clinton MacDonald at STI for all operational health and safety issues. If he is unavailable, contact other management personnel at STI at (707) 665-9900.

3. Site and Instrument List

The proposed site locations are shown in **Figure 3-1**. Note that the final locations will be determined during the siting task (Section 4). Additionally, preliminary site names, site IDs, and instrumentation located at each site are listed in **Table 3-1**. Detailed information about the instrumentation, equipment, and measured parameters is provided in **Table 3-2**.

Figure 3-1. Map of the proposed site locations. The preliminary site names corresponding to the site IDs and proposed instrumentation at each site are listed in Table 3-1. Sites marked “X” were proposed sites that are no longer going to be used.

Table 3-1. Site name, site ID, and instrumentation table.

Site Name	Site ID	Instrumentation
Bakersfield: California Street	1	Ozone sensor
Bakersfield: California Street	1	California Air Resources Board (ARB) ozone instrument
Bakersfield: California Street	1	Meteorological instrumentation
Edison	2	Ozone sensor
Edison	2	ARB ozone instrument
Edison	2	Meteorological instrumentation
North of Di Giorgio	3	Ozone sensor
Northwest of Arvin	4	Ozone sensor
West boundary	5	Ozone sensor
West of Arvin	6	Ozone sensor
Gradient south	7	Ozone sensor
South of Arvin	8	Ozone sensor
Arvin - South	9	Ozone sensor
Arvin site	10	Ozone sensor
Arvin site - Tentative	10	Meteorological instrumentation
Arvin - north	11	Ozone sensor
West of Di Giorgio	12	Ozone sensor
Southwest of Di Giorgio	13	Ozone sensor
Di Giorgio	14	Ozone sensor (two)
Di Giorgio	14	ARB ozone Instrument
Di Giorgio	14	Meteorological instrumentation
Northeast of Di Giorgio	15	Ozone sensor
East of Di Giorgio	16	Ozone sensor
East of Bear Mountain	17	Ozone sensor
Bear Mountain	18	Ozone sensors (two)
Bear Mountain	18	Meteorological Instrumentation
Southeast of Bear Mountain	19	Ozone sensor
Southwest Bear Mountain	20	Ozone sensor
Southeast of Arvin	21	Ozone sensor

Table 3-2. Instrument and equipment list.

Parameter/Equipment	Manufacturer	Model	Number of Instruments	Sampling Interval
Ozone	Aeroqual	Series 500	23	1 min.
Temperature (TEMP)	Sensiron	SHT-75	23	1 min.
Relative humidity (RH)	Sensiron	SHT-75	23	1 min.
SRB [diagnostic]	Aeroqual	Series 500	23	1 min.
SRG [diagnostic]	Aeroqual	Series 500	23	1 min.
Battery voltage	Aeroqual	Series 500	23	1 min.
GPS time	Aeroqual	Series 500	23	1 min.
GPS date	Aeroqual	Series 500	23	1 min.
Latitude	Aeroqual	Series 500	23	1 min.
Longitude	Aeroqual	Series 500	23	1 min.
Solar panel for Aeroqual instrumentation	SolarTech Power, Inc.	SPM055P-F	23	N/A
Data logger (in Series 500 Aeroqual instrumentation)	Aeroqual	Series 500	23	1 min.
Modem for Aeroqual instrumentation	GateTel	GT-HE910-G	23	15 min.
Ozone FEM instrument (for collocation study)	Teledyne	T400	1	1 min.
30 ft. tower	Universal Towers	9-30	2	N/A
PC with Dr. DAS (data logger for collocation study)	DR DAS LTD	N/A	1	N/A
Wind speed/wind direction	RM Young	AQ 5305-L	2	1 min.
Solar panel for meteorological instrumentation	Campbell Scientific	SP20	2	N/A
Data logger for meteorological instrumentation	Campbell Scientific	CR1000	2	1 min.
Modem for meteorological instrumentation	Sierra Wireless	RavenXT	2	1 min.

4. Siting

4.1 Selection Methodology

While three of the ozone monitors for this study will be located at permanent ARB monitoring stations, STI's subcontractor Providence will adhere to the following methodology for siting the other 20 monitors. In addition, two meteorological stations measuring wind speed and direction will be deployed as well. See Section 4.3 for exceptions to this procedure.

4.1.1 General Site Characteristics

Ideally, each ozone sensor will be mounted on a free-standing base (for an example, see **Figure 4-1**), so monitoring sites do not need a support structure such as a utility pole, but the exact site setup will depend on the site location and logistics. The monitors are also not dependent on connections to electrical power or land-line phone service. The sites will need to be physically accessible by a field technician during regular business hours on a weekly basis. Depending on local security needs, monitor assemblies can be installed at ground level or on top of flat-roof buildings. We will seek to mount the sensors at a height between 6 and 9 feet above ground level.

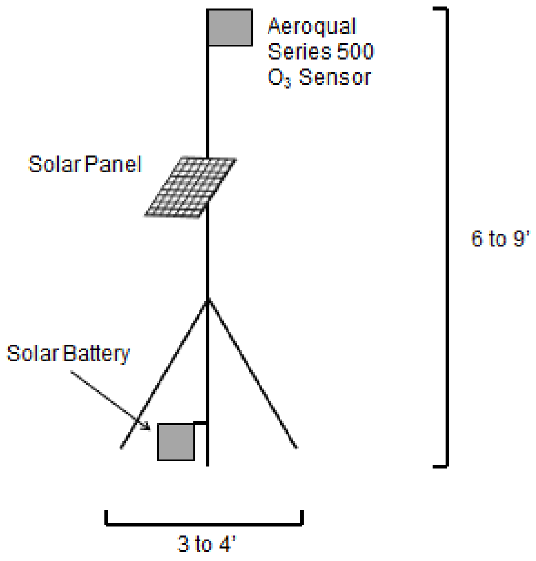

Figure 4-1. Schematic of a complete sensor system (showing tripod, pole, sensor, solar panel, battery, and height and width). Please note that we may mount the ozone sensor below the solar panel to provide shade for the instrument. O_3 is ozone.

4.1.2 Review Satellite Imagery of the Study Area

Using Google Maps or a similar web-based application, we will first identify a number of potentially secure and suitable locations corresponding to each of the site flags identified in Figure 3-1 and Table 3-1 in Section 3. To assure the security of the equipment, we will look for an inhabited, fenced-in area, or an industrial, commercial, or institutional building with a flat roof. We will also use Google Maps to look for a spot at each site that is sufficiently removed from obstructions and interferences such as trees and buildings. For the sensors immediately around the Arvin, Bear Mountain, and Di Giorgio sites, sites will be selected that are very close (within approximately one-half mile) to the permanent sites. The locations of the western background sites (those further from Arvin), however, are less critical and may be not as close to the corresponding flags in Figure 3-1.

4.1.3 Discuss Receptive Site Hosts with SJVAPCD

If needed, we will meet with SJVAPCD personnel to discuss landowners who might be receptive to hosting a monitoring site. Potential site hosts may include public agencies, school districts, hospitals and clinics, churches, utility districts, private utilities, and previous recipients of SJVAPCD grants. Using this information, we will match potential site hosts with needed site locations.

4.1.4 Avoid Impacts from Emissions Sources

Understanding that emissions from both stationary sources and mobile sources will impact ozone measurements, we will review SJVAPCD data on regulated facilities, as well as California Department of Transportation (Caltrans) data on traffic along the two state highways in the Arvin area, and we will use this information to place monitors at appropriate distances from significant emission sources. Highway 58 and Highway 99 serve as the northern and western boundaries of the study area, and Highway 223 (Bear Mountain Boulevard) and Highway 184 (Weedpatch Highway) are the busiest roads within the study area. STI and Providence staff will seek to site monitors in accordance with 40 CFR 58, Appendix E, “Probe and Monitoring Path Siting Criteria for Ambient Air Quality Monitoring.”

4.1.5 Site Visits

After identifying general candidate areas for monitoring sites, we will make a series of site visits for the purpose of ground-truthing for security issues and obstructions, testing cellular coverage in the area, and meeting with potential hosts for the purpose of procuring sites, as discussed below.

4.2 Procurement Procedure

4.2.1 Contacts with Municipal Officials

Providence staff will first contact the Arvin City Manager, as well as the Kern County Supervisor who represents the Arvin area and the Supervisor who represents Kern County on the SJVAPCD Governing Board. We will seek their assistance in finding public facilities that can accommodate monitoring sites, and seek their support in procuring monitoring sites from Arvin-area businesses and institutions.

4.2.2 Contact Prospective Site Hosts

Providence staff will contact each potential site host either in person, by telephone, or by email. We will provide a package of information on the project that includes the following:

- A brief description of the project;
- A description and photograph of a monitor assembly;
- What to expect regarding installation, operation, and removal, including a planned calendar of events; and
- Contact information for project staff.

4.2.3 Execute Agreement

We will request the site host to sign a brief agreement that allows us to enter the property to install, maintain, and remove the equipment. The agreement will specify the duration of the sampling campaign, any monetary consideration necessary for use of the site, and that STI and its subcontractors are covered by their own liability insurance. We will ask the site host to fax the agreement to us once it is signed, or to notify us when we can pick it up.

4.3 Exceptions to this Procedure

Authorization to use the ARB monitoring stations (Bakersfield California Avenue, Edison, and Di Giorgio) has been obtained via direct contact with SJVAPCD and with ARB staff. STI will directly contact the Arvin-Edison Water Storage District for access to that location; lacking approval by the Water Storage District, STI and Providence will seek a nearby site following the procedures above.

5. Field Activities

5.1 General

This field project may attract attention or interest of the media. STI and its subcontractors will not engage with the media unless directed to by the SJVAPCD Communications staff.

Field work involves complex tasks in challenging environments. As a member of the field operations team, each employee and subcontractor is expected to follow safe-practice rules, render every possible aid to safe operations, and report all unsafe conditions to appropriate supervisory personnel. For additional vital information, see STI's draft Health and Safety Plan (Appendix A).

5.2 Installation Plan

Procedures for site selection, contact with site owners, and approvals for use of the selected sites are covered in Section 4. Each site will be visited prior to actual deployment of monitoring equipment to verify that minimum siting criteria are met.

Once the sites are selected and approvals are finalized, logistics to complete installation of the monitoring equipment and supporting peripheral hardware (solar power, cellular modems) will be planned to minimize the number of days to complete the deployment. These logistics will include

- **Setup and tracking of appointment dates and times for each site owner or occupant**. A single individual should be responsible for setting up appointments early on, and verifying with the site owner or occupant *the day before the scheduled installation* that the appointment time is still workable and access to the site will be accommodated. It is important that this individual keep the field team apprised of the appointment schedule and of any last-minute changes that occur. Experience suggests that failure to track and verify appointments for the installation of a large number of monitoring sites can lead to stoppages and delays.
- **Transport of monitoring hardware from the collocation study site in Fresno to the selected monitoring sites**. All of the Aeroqual sensors and mounting hardware (tripods), cellular modems, and some of the solar power hardware will be included in the collocation study in Fresno. It would be most efficient if this hardware could be moved to the Arvin study area *en masse* and stored in a nearby facility. The study area is approximately 140 miles from the Fresno collocation site, so round trips consume several hours. If a nearby facility could be found to store the hardware, moving all of the equipment in a single trip from Fresno would improve the efficiency of the installation process. The meteorological towers and associated sensors will need to be transported from Petaluma to the study site or to the nearby temporary storage facility.
- **Site-specific installation procedures**. All sites will be set up in a similar fashion as each site permits, so that they act as duplicates except for the spatial differences. A

checklist and photographs will be used to ensure uniform installation across sites. Site identification information (address, GPS coordinates, etc.) will be collected. The installation process at each site will include

- *Evaluation of the site for adherence to siting criteria*. The monitoring equipment will be placed using the siting criteria for guidance as outlined in the U.S. Environmental Protection Agency's (EPA) *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Ambient Air Quality Monitoring Program* (U.S. Environmental Protection Agency, 2013).
- *Setup of tripod with Aeroqual monitor, cellular modem, and solar power*. Solar power polarity will be verified (if needed per manufacturer instructions). All wiring will be secured with UV-resistant cable ties. If necessary, additional ballast will be added to the tripod, either by adding weight (for rooftop installations) or by staking (for ground installations). Communications will be tested and verified. Operation of the Aeroqual 500 series data will be verified based upon manufacturer's recommended protocols.
- *Communication with site owner or occupant*. The site owner or occupant will be informed of all of the study team's access requirements, planned and unplanned (repair visits). This can be handled in large part by the individual responsible for initial scheduling of appointments, but the field team needs to remain cognizant of any specific request that might be made by site owner or occupant. The site owner or occupant will be provided with contact information for the study team.
- *Meteorological towers*. The 10-meter meteorological towers with wind speed and wind direction instruments will be installed independently of the ozone sensor systems. The meteorological instruments will undergo a performance audit at the time of installation. Any instruments not meeting specifications will be either repaired or replaced, and then re-audited.

5.3 Operations Plan

Once site installations have been completed, routine operations will begin. There are several components to the operations plan: remote operations, routine in-field operations, and emergency visits. Below we provide an overview of the activities that the team will perform.

5.3.1 Remote Operations

- Review and evaluate daily the ozone data collected by the Aeroqual 500 Series sensors and the ARB ozone sites. We will use the project website and the Data Management System (DMS) to review the data.
- Review and evaluate daily the meteorological wind data collected at the two meteorological sites.
- Evaluate diagnostic information from the sites (battery voltages and other sensor diagnostics).
- Identify any problems and coordinate with the field staff to visit the site and investigate and/or fix any problem.

- Monitor the potential for smoke from wildland fires to impact the sensor network. Because high particulate matter concentrations from smoke could clog the filters and contaminate the ozone sensors, we might need to shut down the network during a major smoke event. We are working with the sensor manufacturer to determine at what level the smoke would affect the sensors.
- Document problems and issues in the project log.

5.3.2 Routine In-Field Operations

- Prior to visit, review all data to determine if any sites have potential issues that will need special attention.
- Coordinate visits with land owners.
- Prepare tools and other equipment needed for instrument cleaning and potential repairs.
- Conduct weekly site visits to inspect all instruments. During the visit, the technician will check the sensor inlet for any obstructions, inspect the site for any damage, check the solar power supply, and document any issues or major changes occurring around the site (e.g., construction).
- Check sensors for excessive particle buildup. Clean sensors as needed.
- For the meteorological towers, inspect the tower and wind instruments for any damage.
- Document any issues, resolutions, and findings in the project log.

5.3.3 Emergency Visits

Situations may arise that require an emergency visit to a site(s). Prior to the deployment, we will prioritize each site so that during these emergency situations, the team can address problems at the high priority sites first. During these situations, the STI team will notify SJVAPCD and prioritize the appropriate response.

We will document any issues, resolutions, and findings in the project log.

5.4 Removal Plan

Once the monitoring campaign has been completed, the systems will be removed on a site-by-site basis. The study team member will schedule the final visit, and the field team will remove all hardware. The team will take pictures of the final setting.

6. Data Flow and QA Plan

Data quality assurance (QA) and control is a key component of producing a data set ready for data analysts and modelers to use. STI data analysts and meteorologists who understand the data collected, and the instruments used to collect the data, will quality-assure and validate the data using STI's in-house data quality control programs (e.g., DMS). Several stages, or "Levels," in the data validation process are used:

- *Level 0.0*. Raw, non-quality-controlled data.
- *Level 0.5.* Data subjected to automatic quality control (QC) screening by software.
- *Level 1.0.* Data subjected to quantitative and qualitative reviews for accuracy, completeness, and internal consistency.

6.1 Data Flow

Data and information flow from each site to the central system at STI is shown in **Figure 6-1**.

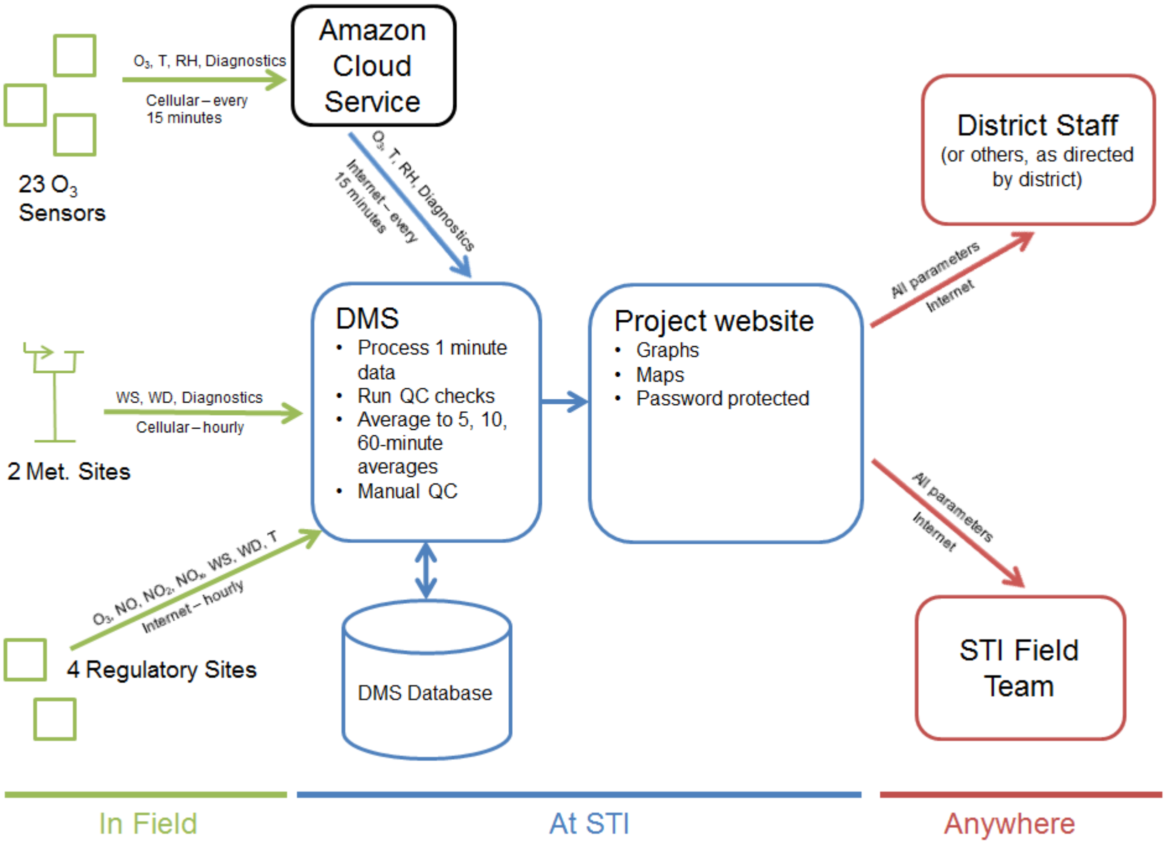

Figure 6-1. Data flow schematic illustrating data flow from measurement through to the website.

6.2 Quality Assurance Activities

Quality assurance activities are needed to ensure that data are of sufficient quantity and quality for meeting project objectives. A number of activities will be performed to achieve the data quality objectives (DQO) listed in **Table 6-1**. The data quality objectives for this project include the following:

- Data completeness
  - Monitor – 90% data completeness for each monitor. For the collocation period, this will provide representative data to assess each monitor's precision and accuracy. For the field study, this will provide sufficient measurements for the development of the algorithms needed to accurately model ozone concentrations in Arvin.
  - Daily – 75% data completeness for a valid 8-hr average. Any 8-hr period with less than 75% completeness will not be considered valid for use in calculating an 8-hr average. However, if the available hourly data do indicate that the mean for the period collected was above the 8-hr standard, the data will be marked as such and a note will be made that further investigation by analysts is needed.
- Data quality
  - Monitors – Individual Aeroqual Series 500 ozone sensors are expected to perform within acceptable bounds of accuracy and precision as measured during the collocation experiment.
  - Each ozone monitor should be accurate to ± 15%, with Pearson R correlation values above 0.85 of other Series 500 sensors' monitored concentration slope responses as assessed by weighted Deming Regression from the collocation trial.
  - Zero response should be at 0 ± 5 ppb for 1-hr concentration values.
  - Aeroqual 500 series sensors should have a known and reproducible slope when compared to a Transfer Standard Teledyne API Model T400 UV absorption ozone instrument (FEM T400). Slope response can have standard error bounds of ± 20% with Pearson R correlation values above 0.85.
- Data validation
  - Each monitor's data will be processed to ensure that data reported are of good quality.
  - Automated checks include sticking checks (i.e., the same value is recorded for more than four hours in a row), range checks, and rate-of-change checks. Data failing these checks will be flagged and inspected by an analyst.
  - Visual inspection of the data by trained analysts will be made on a daily basis.

Data meeting these DQOs will be included in the evaluation of collocated Aeroqual sensors and will be used in the evaluation of spatial and temporal patterns of ozone concentrations in the Arvin ozone saturation study. Data failing these DQO criteria will be flagged as invalid or suspect.

Table 6-1. Data quality objectives for the field study.

Performance Characteristics	Value	Units
Aeroqual Series 500 Ozone Sensors		
Accuracy of calibration	± 0.005	ppm
Minimum detection limit	0.001	ppm
Precision	± 0.005	ppm
Baseline drift	< 0.004	ppm/1,000 hrs
Meteorological Instruments		
Wind speed accuracy	±0.2 + 5%	m/s
Wind direction accuracy	± 5°	deg
Other Metrics		
Overall Data Completeness	90	%
8-hr Average Data Completeness	75	%

6.2.1 Pre-Deployment QA Activities

Prior to the field deployment, the STI team will perform the following quality assurance activities:

- Perform a collocation experiment consisting of the following:
  - Collocate all Aeroqual sensors with an FEM monitor for at least four days. The FEM monitor will be a Transfer Standard Teledyne API Model T400 UV absorption instrument.
- Use the data from the Aeroqual sensors and the T400 to compute comparative statistics, specifically
  - Perform Aeroqual/Aeroqual comparisons to get individual collocation slopes and intercepts using Deming regressions. This will yield confidence limits for between-sensor precision.
  - Use the T400 FEM data as the basis for comparison to each of the Aeroqual 500 sensors and obtain collocation slopes and intercepts using Deming regressions. This will yield confidence limits for the accuracy of the Aeroqual 500 sensors.
  - Address any inconsistencies with the ozone sensors.
  - Document the results in a table for the final report and notify SJVAPCD of the results.
  - Note: in the event that sensors do not meet the needed data quality standards, we will work with SJVAPCD to develop a plan to address this problem.
- Set up the DMS with automated quality control checks for each ozone sensor site and for the meteorological sites. Quality control methods will include minimum range, maximum range, stuck value, rate-of-change, and buddy checks.
  - Range checks – Data falling below a minimum value or above a maximum value

  - *Sticking checks* – Data stuck on the same value for more than four hours in a row
  - *Rate-of-change checks* – Data reporting values that change by more than a specified threshold between consecutive hours
  - *Buddy checks* – Comparisons with data values at nearby sites
- Set up a process to ingest ozone data from the nearby ARB monitoring sites into the DMS system.
- Establish a field log system to ensure comparability in QC activities between sites.

6.2.2 In-Field QA Activities

During the six-week field operations, the STI team will perform the following QA activities:

- Use the real-time website, observe data from the sub-daily data downloads to ensure that equipment is operating and to assess reasonableness of the data.
- Use DMS to automatically quality control all hourly ozone and meteorological data.
- Perform daily review of all flagged data from automated screening checks, and inspect diurnal patterns at all sites to ensure that instrument problems resulting in invalid data are caught quickly and that remedial actions are taken.
- Visit each site weekly to inspect the sensors, communications, and immediate surroundings. Document any issues and changes in the field log system.
- Compare sensor measurements at collocated sites every week to ensure that instruments remain comparable over time. Collocation comparisons will include data from FEMs at ARB-operated sites.

6.2.3 Post-Field QA Activities

Perform Level 1 data validation of the ozone and meteorological data collected during the six-week study using the following steps:

- Review site and operational logs for any indicators that would affect data quality.
- Review and validate data based on internal (Level 1) consistency checks using the manual quality control tools in the DMS software.

7. Contact Information

Important contact information is listed in **Table 7-1**.

Table 7-1. Contact list.

Name	Company	Phone	Cell	Email
Clinton MacDonald	STI	707-665-9900	415-827-0051	Clint@sonomatech.com
Tim Dye	STI	707-665-9900	707-310-5541	Tim@sonomatech.com
Dave Vaughn	STI	707-665-9900	559-906-8388	David@sonomatech.com
Paul Roberts	STI	707-665-9900	415-847-4322	Paul@sonomatech.com
Local Site Technician	STI	TBD	TBD	TBD
Hilary Minor	STI	707-665-9900	630-849-5032	hminor@sonomatech.com
Eric Winegar	Winegar Air Sciences	916-837-4251	916-837-4251	winegar.eric@gmail.com
Scott Nester	Providence	559-549-6351	559-709-9759	scottnester@providenceeng.com
Geoff Henshaw	Aeroqual Ltd	Direct dial-in +64 9 623 4749 ph + 64 9 623 3013 Skype: geoff.henshaw	+64 2 177 4431	geoff.henshaw@aeroqual.com
Simon Bennett	Aeroqual Ltd			Simon.bennett@aeroqual.com
Mark Bart	Aeroqual Ltd			mark.bart@aeroqual.com

8. Reference

U.S. Environmental Protection Agency (2013) Quality assurance handbook for air pollution measurement systems, Volume II: ambient air quality monitoring program. Prepared by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division, Research Triangle Park, NC, EPA-454/B-13-003, May. Available at http://www.epa.gov/ttn/amtic/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf.

A-1

Appendix A: Health and Safety Plan for Field Operations

Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Health and Safety Plan for Field Operations

DRAFT

STI-911998-5714-HASP





Prepared by
Sonoma Technology, Inc.
Petaluma, California

July 2013

STI field sites and equipment, clockwise from top left: meteorological instruments powered by a solar panel for a study at Oceano Dunes, CA; trailer with air quality and meteorological instruments for a near-road study in Utah; the Chevron Brazos platform offshore of Louisiana equipped with a surface meteorological tower, mini-sodar, IR skin temperature sensors, ceilometer, flux packages, microwave radiometer, and oceanographic measurements equipment; a radar wind profiler at New Braunfels, TX; and a meteorology tower in Tracy, CA.

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Section **Page**

1. Overview

This health and safety plan provides guidance for the safe conduct of employees and subcontractors during any field operation at any field station site operated by Sonoma Technology, Inc. (STI).

Providing a safe and healthful workplace for employees and subcontractors is the first consideration in the operation of business. It is both a moral obligation and sound business practice to prevent occupational injuries and illness. No phase of operations is more important than injury and illness prevention. Safety always takes precedence over expediency or shortcuts. As a condition of employment, each employee and subcontractor is expected to assume responsibility for working safely at all times. The following statement is, and shall be, the philosophy under which all field operations shall be performed:

SAFETY IS NOT A LUXURY; IT IS A MUST!

This plan provides a set of general health and safety guidelines for use by all personnel, regardless of the component of the field operations in which they are participants, and some specific guidelines for specific field operations. This guidance is important during all field activities, including traveling to and from monitoring sites and while at the sites. This health and safety plan shall not be considered a field plan or set of standard operating procedures (SOPs); instead, it augments existing operations plans, manuals, and other site requirements. This guide shall be followed by all employees and subcontractors responsible for the setup, routine operations, quality assurance, and removal of air quality monitoring equipment.

1.1 Core Expectations

As a member of the field operations team, each employee and subcontractor is expected to follow safe-practice rules, render every possible aid to safe operations, and report all unsafe conditions to appropriate supervisory personnel. Employees and subcontractors will be trained in the proper use of all equipment and will be provided with this health and safety plan. Employees and subcontractors are expected to adhere to the health and safety guidelines provided by STI and by equipment manufacturers, as well as to use common sense under circumstances when no explicit guidelines are available. All employees and subcontractors are expected to observe all local laws and regulations, including seat belt laws and posted speed limits, as well as requirements of site owners and operators.

1.2 Contacting Project Staff

Field personnel should contact the Project Manager (PM) for all operational health and safety issues. If the PM is unavailable, contact other management personnel at STI at (707) 665-9900.

2. Safety Operating Procedures

2.1 General

Common sense should prevail at all times. All employees and subcontractors are responsible for following safety procedures and standard operating procedures (SOPs) to help prevent injury to themselves or others.

- Field staff are responsible for maintaining routine communication with the PM. This includes informing the PM prior to visiting any field site.
- Site work and driving will normally occur between 7 a.m. and 10 p.m. to allow the greatest possibility of obtaining help in an emergency. Work outside these hours is discouraged but may occasionally be conducted at the discretion of an individual employee or subcontractor in consultation with the PM.
- No eating or drinking is permitted within the shelter that houses the electronic equipment.
- Safety belts shall be worn in all vehicles. The belts should be completely secured before the vehicle is put into gear and moved for any distance.
- Injuries shall be reported immediately to the employee's or subcontractor's direct supervisor and PM.
- Visitors to any site shall be directed to a safe distance from work being performed.

2.1.1 Personal Protective Equipment (PPE)

It is the responsibility of each employee and subcontractor to have all safety equipment required during each field effort.

- **Wear safety glasses** while soldering, while using any power tools or striking tools (e.g., hammering), and during any other activity that may cause particles, liquids, or gases to be ejected from the work surface.
- **Wear hard hats and safety glasses** when required.
- **Wear safety shoes** during any activity that may present a foot injury hazard (e.g., mowing, heavy equipment operation, or shelter placement).
- **Wear work gloves** while installing or performing maintenance on the radar wind profiler (RWP) and meteorological tower.

2.1.2 Electrical Hazards

- Completely power down equipment before conducting any work on the equipment.
- Do not wear jewelry, such as rings, watches, bracelets, earrings, and necklaces, while working inside a case containing electrical equipment.

- Do not repair power supplies or other high voltage devices in the field. If replacing them, replace them with the power source disconnected or the power shut off at the breaker in the electrical panel.
- When there is a chance that activation of an electrical circuit can produce physical harm or death, the device shall be labeled with such information.

2.1.3 Severe Weather Issues

It is likely that weather conditions may impact some field operations. Weather conditions, including severe wind and rain storms and periods of poor visibility due to fog or high winds, must be treated seriously. **The overriding concern is the health and safety of the participant.** Protection of equipment is secondary. Personnel located in the field must be aware of weather conditions and forecasts at all times.

- No outdoor activity will take place during lightning storms, hail storms, heavy rain, or any other weather condition that, in the opinion of an individual employee or subcontractor, represents an unreasonable hazard. Before arriving at each site, assess local conditions to avoid danger from natural hazards.
- In the event of an emergency, employees and subcontractors must take every precaution to protect sensitive equipment prior to evacuation. Precautionary measures, such as relocating portable electronic equipment or other gear vulnerable to weather damage to a protected area, is expected. Employees and subcontractors are to use common sense to determine the practicality of what equipment can be protected prior to evacuation. If possible, relocate portable computers, and cover and strap down other equipment as tightly as possible.
- Employees and subcontractors are required to follow all safety instructions from local civil authorities and field and project managers. If ordered to do so, all personnel must leave. If employees or subcontractors must leave their post due to severe weather or must interrupt the normal operation of the measurements, the PM must be notified at the earliest opportunity. Maintain periodic contact with the PM .

2.2 Radar Wind Profiler/Radio Acoustic Sounding System/Minisodar Safety

- Power down the RWP/Radio Acoustic Sounding System (RASS) system prior to any servicing or maintenance. Refer to the SOP for instructions.
- Wear ear protection around the RASS or minisodar while these instruments are operating.
- Mark all guy wiring and earth anchors with fluorescent tape to avoid injury.

2.3 Tower Safety

No tower shall be climbed by STI or subcontractor staff.

2.4 Roadside Safety

- When parking and/or stopping on the shoulder area of a highway, always park the vehicle as far off the paved shoulder area as possible if it is not intended to be used as a physical barrier. Carefully choose a location so the vehicle will not affect passing traffic, or interfere with employee sight distances.
- Where possible, park motor vehicles in a manner that will minimize exposure to moving vehicular traffic as well as provide a physical barrier between employees and any traffic that may enter the work zone.
- Wear the PPE provided. This includes a hard hat, eye protection, and a high-visibility, reflective vest made of fluorescent orange, yellow, or yellow-green material. Hearing protection is recommended when working along busy highways.
- Do not stand in a roadway.

2.5 Platform and Offshore Safety

The meteorological and air quality instruments are located on both private and government property. Employees and subcontractors are expected to become familiar with the specific safety requirements related to individual sites. Platforms used during any project are under the direct control of the owner/operator (private or public). Project participants must observe all rules and regulations established by the owner/operator (private or public). Safety rules regarding protective clothing, personal safety while on the platform, restricted areas, and proper communications protocol, specific to each platform, must be observed. This plan provides general guidelines for personnel while on owner’s platforms.

- Before employees or subcontractors (personnel) visit an offshore platform, the owner/operator of the platform shall be contacted to confirm requirements for personal protective equipment and to schedule a safety orientation upon arrival, including emergency procedures.
- Generally, personnel are required to wear non-metal hard hats, safety glasses with side-shields, fire retardant clothing, and safety-toed boots. Safety clothing is not available on the platform and must be brought by each employee or subcontractor.
- Swimming is strictly prohibited; any person in the water shall be considered a person overboard, and appropriate action will be taken.
- A pre-job safety meeting shall be held on the platform before any work is begun.
- Personnel shall not assist in the operation of the platforms and shall not interfere with the safe operation of the platforms.
- No firearms, alcoholic beverages, or drugs are allowed, except for prescription medication if issued by a qualified physician for the person carrying and using the medicine. Smoking is allowed only in designated areas.
- A functioning two-way radio or telephone must be available when personnel are aboard a platform.

2.6 Helicopter Operations

During the course of the project, personnel are required to use platform owner/operator-provided or -chartered helicopter transportation to and from the platforms. This plan provides general guidelines for helicopter operations:

- A platform owner/operator-provided helicopter service may require a safety orientation and/or training prior to first-time flights by personnel.
- Personnel must observe all instructions from pilot and crew.
- Helicopters used for offshore flights must carry at least one U.S. Coast Guard approved flotation device (PFD) on board for each person, including crew. Wearing approved PFDs is required when flying over water.
- Hearing protection is required when participants are riding as passengers in a helicopter.
- Personnel shall always approach a running helicopter from the front, ducking to stand below the level of the main rotor. A helicopter must never be approached from the rear. Personnel shall use extreme caution to avoid the main rotor, tail rotor, and the pitot tubes on the front of the aircraft (these can be very hot from air friction).
- Personnel shall not assist in the operation of the helicopters and shall not interfere with the safe operation of helicopters.

2.7 Other Issues

Meteorological instruments (including towers, trailers, and computers) are located on both private and government property. Employees and subcontractors are expected to treat this property and nearby residences with respect during the conduct of all work.

Employees and subcontractors are expected to be familiar with the specific safety requirements related to individual sites.

Employees and subcontractors are expected to be familiar with the safe operation of all equipment they are employed to operate and shall not operate equipment for which they have not received proper training.

All personnel shall remain at a safe distance away from towers when lightning is occurring in the vicinity.

3. Emergency Procedures

In the case of a medical emergency,

- Call 911 for emergency assistance and provide necessary first aid measures.
- Immediately report all injuries to the PM and company management.

Appendix B: Standard Procedures for Operating a Meteorological Tower

Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Standard Procedures for Operating a Meteorological Tower

STI-5721-SOP Version 2.0

Prepared by

Sonoma Technology, Inc.
Petaluma, California

July 2013

Cover image shows an STI meteorological tower with equipment powered by solar panels at Oceano Dunes, California.

Table of Contents

Section **Page**

1. Introduction

This document provides Sonoma Technology, Inc.'s (STI) step-by-step instructions for servicing a meteorological tower. Use these instructions in conjunction with the Site Log and Maintenance Checklist to record information during your site service visit.

2. Site Service Visit Frequency

The meteorological site should be serviced once every four weeks. If no problems are encountered, the site visit will take about one hour. You may be asked to service the site upon request when problems arise. If you have questions regarding the servicing schedule, the Maintenance Checklist, or the meteorological tower, call

Charley Knoderer: (707) 665-9900

3. Site Service Visit Tasks

The major tasks involved in servicing the meteorological tower are as follows:

1. Record your visit in the Site Log.
2. Inspect the meteorological tower.
3. Archive the meteorological tower's data.

3.1 Record Your Visit in the Site Log

The function of the Site Log is to document everything that happens at the site. Your first task when arriving at the site should always be to record

- Date
- Arrival time in local standard time (LST) (occurs automatically when you log in)
- Reason for visit
- All observations
- Departure time in LST

As you progress through the following steps, record **all changes** in the Site Log.

3.2 Inspect the Meteorological Tower

Record any problems, changes, or adjustments in the Site Log. Report any problems or damage to Charley Knoderer or Clinton MacDonald at STI (707-665-9900). The physical condition of each component of the surface meteorological tower should be checked as described below.

3.2.1 Tower Checks to Perform During Maintenance Visit

Tower:

- Check that tower base is securely anchored to the ground.
- Generally check tower for signs of damage or excessive wear.
- Inspect all tower bolts at the base for any signs of corrosion (rust).

Wind Monitor:

- Note if any component (tail, propeller) is missing or has suffered obvious damage.
- Check that the whole sensor moves freely with changing wind direction and that the propeller rotates freely when windy.
- Confirm that wind tower and sensor is properly aligned via compass.

Temperature/RH Sensor and Shield:

- Inspect hardware holding temperature/RH sensor shield assembly to tower and tighten bolts if necessary.
- Clean the sensor shield and screen.
- Check that cable connections are secure.

Data Logger CR1000 Enclosure:

- Verify the enclosure is locked and secured to tower.
- Check that cabling to the enclosure is secure and undamaged.

Cables:

- Check the integrity of the cables connecting the CR1000 box to the trailer.
- Check that wind sensor cable is attached to tower.

Guy Wires:

- Check that guy wires are taut and attachment points are not loose. If they are loose, call STI for instructions on how to tighten them.
- After physically inspecting the meteorological sensors, record the current weather observations in the Electronic Site Log and Maintenance Checklist. This observation should include general wind direction, wind speed, approximate temperature, clouds, current weather, and the time. For example, an observation might read as follows:

  "Moderate southwest breeze, temps in the 50s F, damp with fog and rain at 1030 CST"

- Next, monitor data from the meteorological tower by connecting a laptop to the CR1000 data logger using an RS232 cable. Open LoggerNet by double clicking on the LoggerNet icon.

- Access the **Connect** tab to view the data.
- Observe all of the meteorological data parameters on the screen and determine whether they are physically plausible and reasonable (i.e., is a value that should be positive, negative, etc.).
- Monitor wind speed and wind direction on the screen and compare with visually estimated orientation of wind monitor and strength of wind.

Note: The typical range for wind speed is from 0 m/s to 10 m/s. Use the following tables to help estimate wind speed and temperature.

Term	Wind Speed Range	Description
Description	(m/s)	How to estimate speed
Calm	0 to 0.2	Calm, smoke rises vertically
Light air	0.3 to 1.5	Smoke drifts with the wind
Light breeze	1.6 to 3.3	Wind felt on face; leaves rustle
Gentle breeze	3.5 to 5.4	Leave and small twigs in constant motion; wind extends light flags
Moderate breeze	5.5 to 7.9	Raises dust and loose paper; small branches are moved
Fresh breeze	8.0 to 10.7	Small trees with leaves begin to sway

Unit	Temperature											
°F	25	30	35	40	45	50	55	60	65	70	75	80
°C	-4	-1	2	4	7	10	13	16	18	21	24	27

- If any parameter appears unreasonably high, low, or simply implausible, try to identify the cause (check cables, connections). If you cannot find the source of the problem, contact STI.

3.3 Archive the Meteorological Tower Data

All data are stored on the datalogger. To archive these data, you will need to connect to the datalogger using LoggerNet by accessing the **Connect** tab. Choose **Collect Now** tab to collect all of the data. The data will be stored under C:\Campbellsci\LoggerNet\.

After you have downloaded the data, verify that the files contain the latest data. Remove the cable from the laptop and secure the datalogger enclosure.

Appendix C: Standard Operating Procedures for the Aeroqual Airmote Sensor

Standard Operating Procedures for the Aeroqual Airmote Sensor

This document was provided by Aeroqual.

3.4 Tools

- Laptop with Internet access and login/password for viewing pushed data
- Flat head screwdriver
- Philips screwdriver
- Voltmeter
- Lint free tissue
- Clean compressed air if available (don't use canned dust cleaners - they leave residue)

3.5 Prior to Site Visit

1. Check latest data to make sure the unit is pushing data correctly. If not, then prepare to troubleshoot one of these potential problems:
    a. Modem connectors loose (antenna, serial power cables)
    b. Modem SIM card fault
    c. Power failure
    d. S500 instrument fault
2. Check to see if reported battery voltage is greater than 10.5V. If not, then prepare to troubleshoot power issues, including
    a. Solar panel/regulator not working
    b. Solar cable not connected
    c. Battery fault

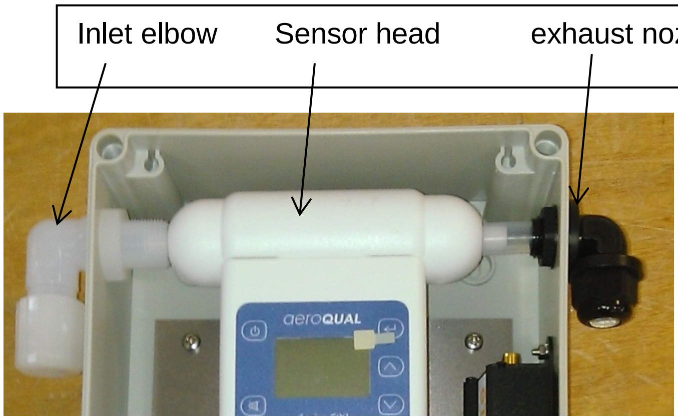
3.6 Onsite Maintenance

1. Inlet Nozzle.
    a. Unscrew inlet nozzle cap and inspect. Clean mesh with clean compressed air if available.
    b. Check inside inlet elbow for any signs of spider webs or dirt. Clean out if necessary with a lint-free tissue.
    c. Replace inlet nozzle cap.

Inlet nozzle with inlet cap and mesh removed.

3. Outlet nozzle
    a. Unscrew outlet nozzle cap and check for spider webs/dirt. Clean with compressed air.

4. Internal Inspection
    a. Remove front cover by unscrewing the four screws
    b. Check for insects/contaminants inside and remove if necessary
    c. Check to see whether positions of GPS and GSM antennas are correct
    d. Replace lid



5. General Cleaning

In areas with high particle concentrations, it may be necessary to clean the intake fan and other components to ensure proper air flow. To do so, clean surfaces with a soft rag. Note that it is not possible to clean the sensor head. If high ambient $PM_{2.5}$ concentrations (i.e., 24-hour concentrations greater than about 50 µg/m^3) have occurred, then the sensor head may need to be replaced.

Appendix B

Results of the Pre-Deployment Collocation Study (Technical Memorandum dated August 23, 2013)

Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Technical Memorandum

August 23, 2013 STI-913040-5742-TM

To: James Sweet, SJVAPCD

From: Andrew Rutter, Michael McCarthy, Clinton MacDonald

Re: Results of the Pre-Deployment Collocation Study

Overview

As part of the ozone saturation field study in Arvin, California, ozone data from 23 AeroQual S500 sensors were compared to ozone data from a Federal Equivalence Method (FEM) ozone instrument (Transfer Standard Teledyne API Model T400 UV absorption) in Fresno, California, in a pre-deployment collocation study. The results from the study were used to calibrate the S500 sensors against the FEM reference instrument. The results of the collocation are the subject of this technical memorandum.

In summary, the AeroQual instruments demonstrated sufficient performance to justify progressing to the field study phase of the project. Additionally, regression equations were developed from the collocation data to relate the AeroQual sensor measurements to the FEM monitor measurements. These equations will be used to adjust the AeroQual measurements collected during the field campaign to be FEM-like.

Regressions

Four days of measurements were collected August 2-6, 2013, during the collocation study. The data collected over August 2-5 were used to produce least squares linear regressions between hourly averages of the AeroQual sensor measurements and hourly averages of the FEM reference measurements. The linear regression took the y = mx+b form, as shown in **Equation 1**. The FEM instrument was treated as an independent variable with no measurement error for the purpose of these calibration regressions.

$$AQ_n = (slope * FEM) + intercept \qquad (1)$$

Here, AQ_n is the concentration measured by AeroQual sensor *n*, where *n* is the number of the individual sensor and *FEM* is concentration measured by the API Model T400. The regression coefficients and statistics are presented in **Table 1**. Note that Sensor AQ 18 was not functioning correctly until the last day of the collocation study, so only data collected on August 5 and 6 were used for the regression presented in Table 1. An example of a scatter plot and regression is presented in **Figure 1**; plots and regressions for ozone data from all the AeroQual sensors against the FEM reference instrument are shown in **Figure 2**.

Table 1. Linear regression results for the AeroQual S500 calibrations using the Teledyne T400.

Instrument	Slope	Standard Error	Intercept (ppb)	Standard Error (ppb)	Number of Hourly Averages	R^2
AQ 1	1.10	0.02	-9.8	0.8	80	0.985
AQ 2	1.14	0.02	-6.9	0.8	80	0.986
AQ 3	1.17	0.02	-8.5	1.0	80	0.978
AQ 4	1.20	0.02	-12.3	0.9	80	0.984
AQ 5	1.19	0.02	-6.8	1.0	80	0.98
AQ 6	1.10	0.02	-10.2	0.8	80	0.983
AQ 7	1.16	0.02	-7.0	0.8	80	0.985
AQ 8	1.04	0.01	-7.3	0.7	80	0.985
AQ 9	1.24	0.02	-14.2	0.9	80	0.986
AQ 10	1.11	0.02	-6.0	0.7	80	0.987
AQ 11	1.16	0.02	-10.9	0.9	80	0.982
AQ 12	1.09	0.02	-9.1	0.7	80	0.986
AQ 13	1.15	0.02	-11.0	0.8	80	0.987
AQ 14	1.26	0.02	-10.7	0.8	80	0.987
AQ 15	1.22	0.02	-13.8	0.9	80	0.984
AQ 16	1.01	0.01	-5.9	0.7	80	0.986
AQ 17	1.04	0.01	-4.7	0.7	80	0.988
AQ 18	1.16	0.03	-13.0	1.4	51	0.994
AQ 19	1.09	0.02	-10.6	0.8	80	0.985
AQ 20	0.97	0.01	-4.1	0.7	80	0.985
AQ 21	1.15	0.02	-12.2	0.8	80	0.986
AQ 22	1.15	0.02	-7.4	0.9	80	0.983
AQ 23	1.06	0.02	-8.5	0.7	80	0.985

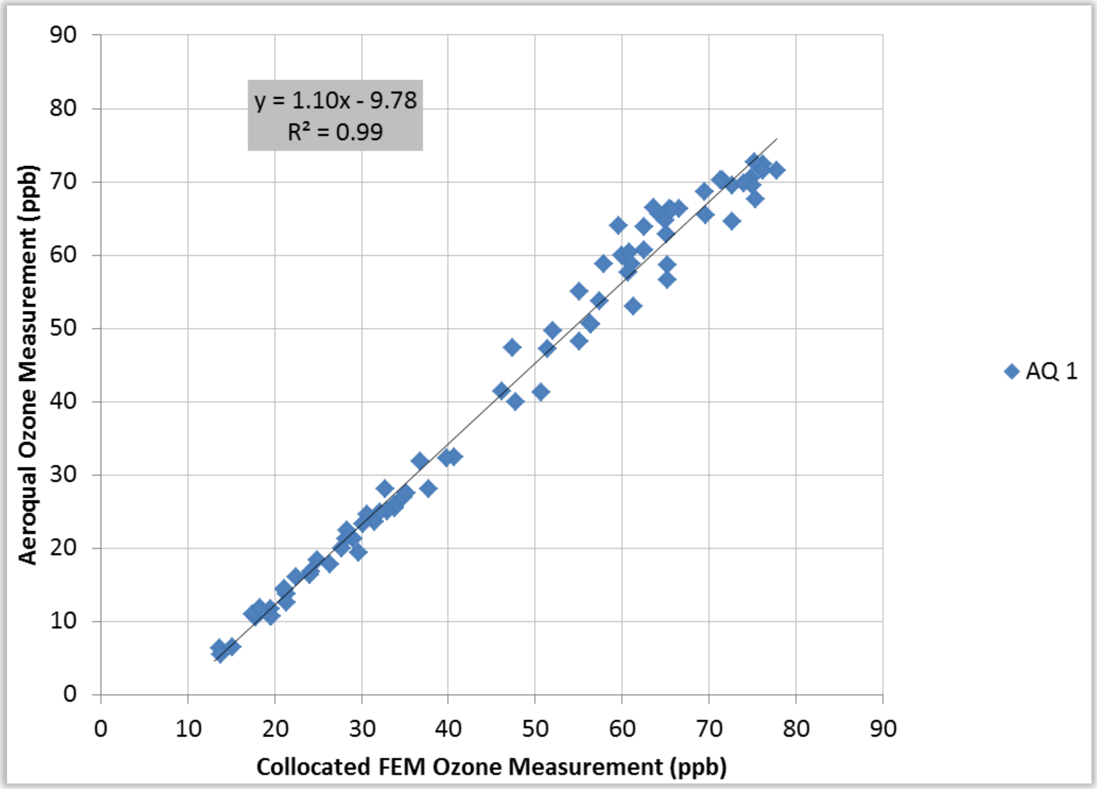


Figure 1. Example of the calibration regressions between hourly averaged ozone data from the collocated FEM reference instrument and from the AeroQual ozone sensors.

Use of the Regression Equations to Calibrate the Data

The regressions determined during the collocation study were used to calibrate the AeroQual measurements collected on August 6, 2013. The regressions are also being used to automatically calibrate the AeroQual data collected during the field study. This automatic calibration is performed after the data is transmitted to STI from the field sites, but before it is ingested into the Data Management System (DMS) database. Both the raw and calibrated data are stored in the DMS database. The calibrated data are posted on the field study website. The regressions presented in Table 1 are used to calibrate the AeroQual data by essentially rearranging Equation 1 and redefining one of the variables, as shown in **Equation 2**:

$$AQ_{n,cal} = (AQ_n - intercept)/slope \qquad (2)$$

Here, $AQ_{n,cal}$ is the AeroQual data for a given sensor *(n)* after calibration *(cal)*. This parameter takes the place of the *FEM* variable in Equation 1. The slope and intercept terms are those presented in Table 1.

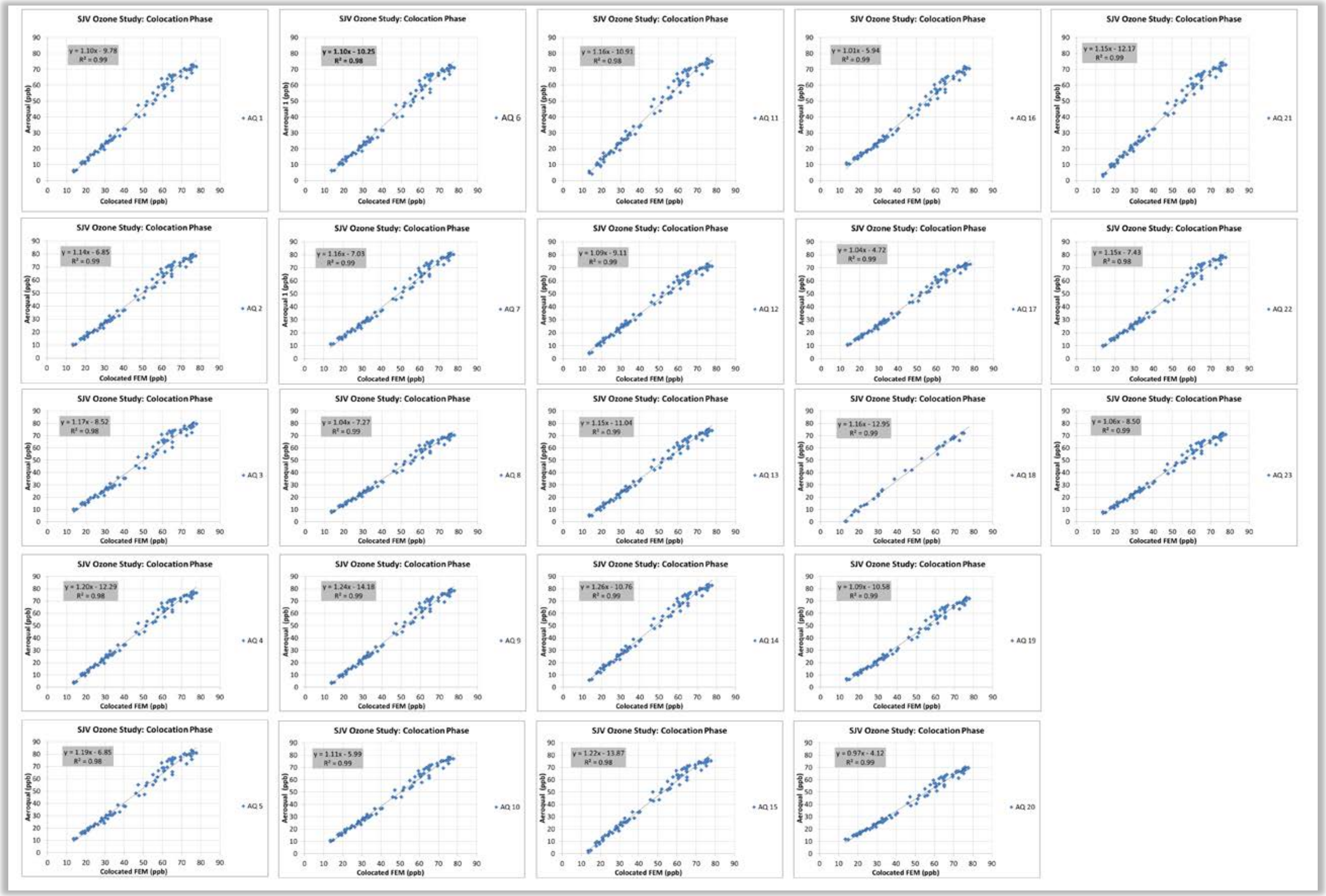


Figure 2. Scatter plots and regressions of hourly ozone measurements made by the FEM reference instrument and each of the AeroQual S500 sensors. The regression statistics are presented in Table 1. The axis units are ppb, the AeroQual data are plotted on the y-axis, and the FEM data are plotted on the x-axis.

Verification

Regressions were used to calibrate the ozone data from the AeroQual S500 collected on August 6. These calibrated data were then compared to the ozone data from the collocated FEM instrument in a variety of ways. **Figure 3** presents the calibrated AeroQual ozone data and the reference FEM ozone data from 00:00 to 18:00 on August 6 as a time-series. Note the close agreement of all the AeroQual ozone measurements to the FEM ozone data, which appears to be consistent at all concentrations. **Figure 4** presents a scatter plot of the FEM ozone measurements with calibrated AeroQual ozone data from August 6. All the measurements lie on or very close to the 1:1 line. The scatter of the measurements from the 1:1 line increases below 20 ppb, showing lower precisions at lower concentrations. In all cases, the differences between the calibrated AeroQual ozone measurements and the collocated FEM reference ozone instrument are ±4 ppb and in all but one case are ±3 ppb, all of which are inside of our data quality objectives of 5 ppb (**Figure 5**). The differences are shown by an S shape of higher and lower biases at different concentration ranges. Given the small amount of available data, it is unclear whether this is a systematic bias or random error.

We note that the linear range of ozone concentration experienced in Fresno did not exceed 77 ppb during our collocation study and thus does not cover the full range of concentrations we expect to see in and around Arvin. Comparisons of AeroQual sensors that are collocated with FEM or FRM instruments at the Edison, Di Giorgio, and California St. sites will be used to assess whether the correction equations developed during the collocation experiment should be corrected at higher concentrations. This will be explored during the final data analysis phase of the project.

Conclusions and Implications

The data presented demonstrate that the agreement between the calibrated AeroQual sensors and a collocated FEM reference instrument was within the data quality objectives established for the study. We concluded that the AeroQual instruments met our data quality objectives and thus deployed them for the field study. Over the course of the study, the AeroQual sensors are expected to distinguish differences in hourly average concentrations of greater than 5 ppb between sites [i.e., instrument precision is on the order of ±3 ppb; random error distribution = $\sqrt{(3^2 + 3^2)}$= 4.3 ppb].

The sensors were deployed to the field on August 8 and 9, after the collocation experiment. **Figure 6** shows a preliminary time-series of the regression-adjusted AeroQual data during the collocation study (August 2-6) and after the deployment (August 8 onward). We observe very good agreement in the ozone concentrations for the four days of the collocation study, and observe differences between the various sites once the sensors were deployed for the field study. A full analysis and interpretation of these data will occur once the study is completed.

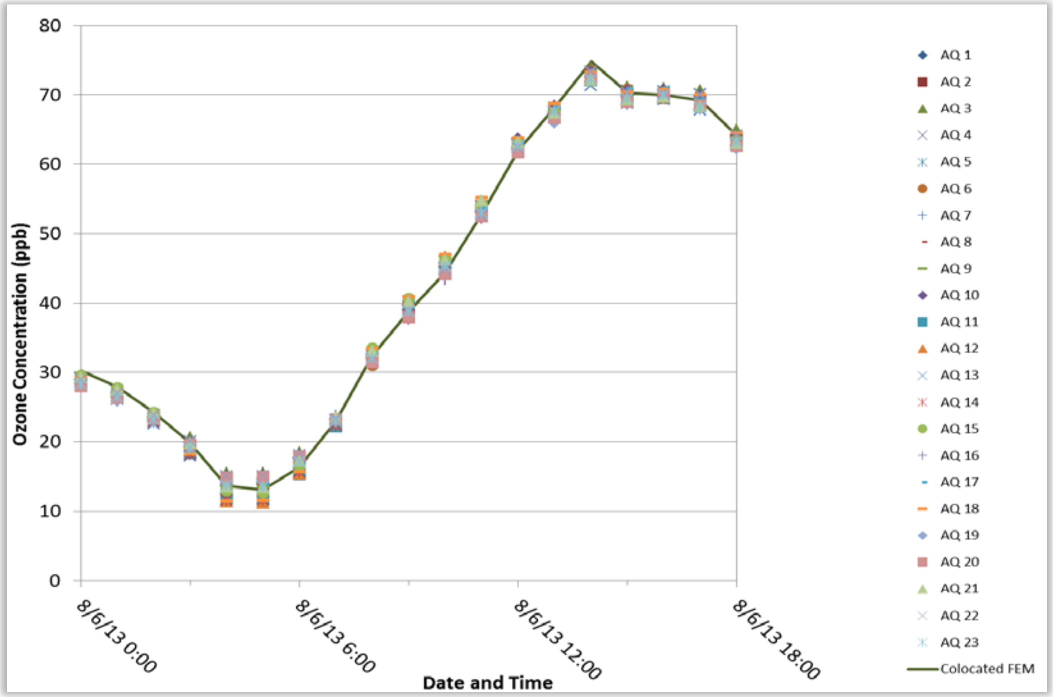


Figure 3. Time-series example of calibrated AeroQual hourly ozone data compared to hourly ozone data from the FEM reference instrument.

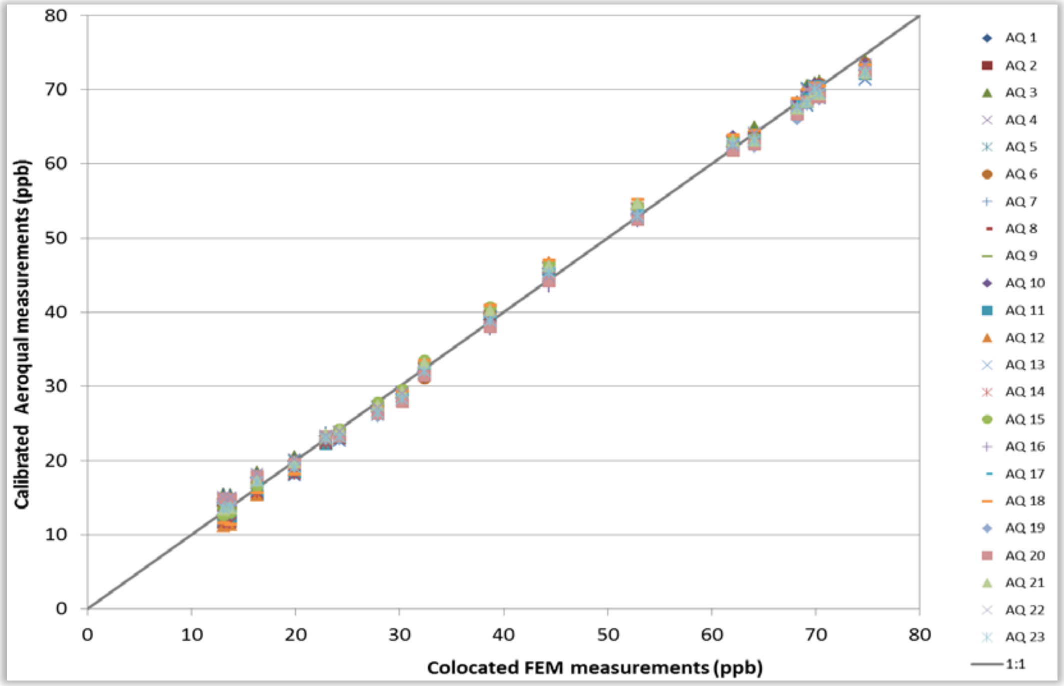


Figure 4. August 6 comparison of the FEM measurements with calibrated hourly AeroQual ozone measurements after being calibrated with the linear regressions from the collocation study.

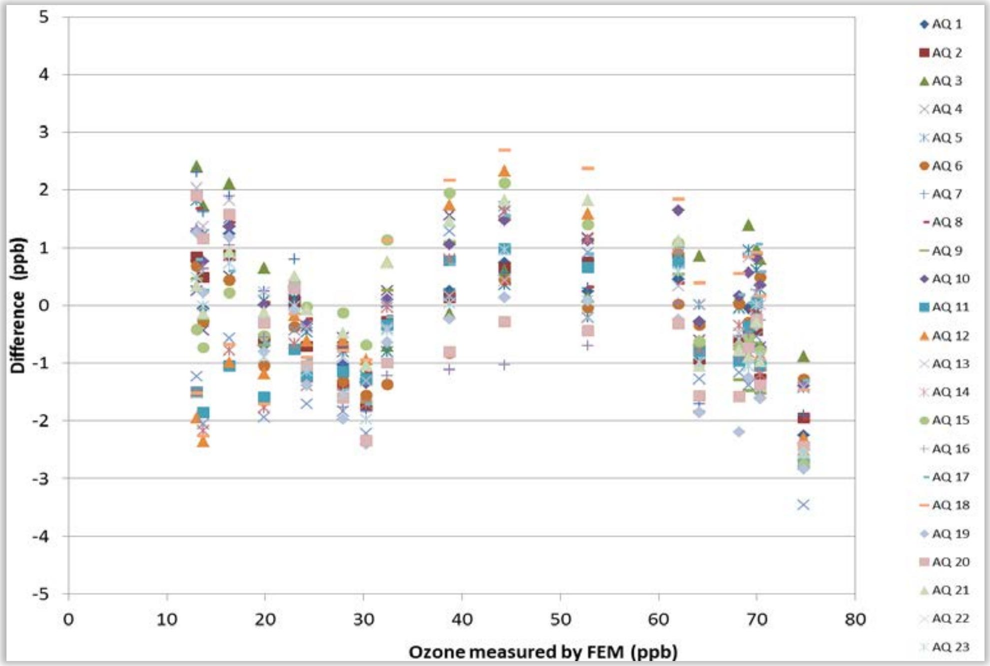


Figure 5. Difference in hourly ozone concentrations measured by the calibrated Aeroqual S500 and the FEM reference instrument, as a function of ozone concentration.

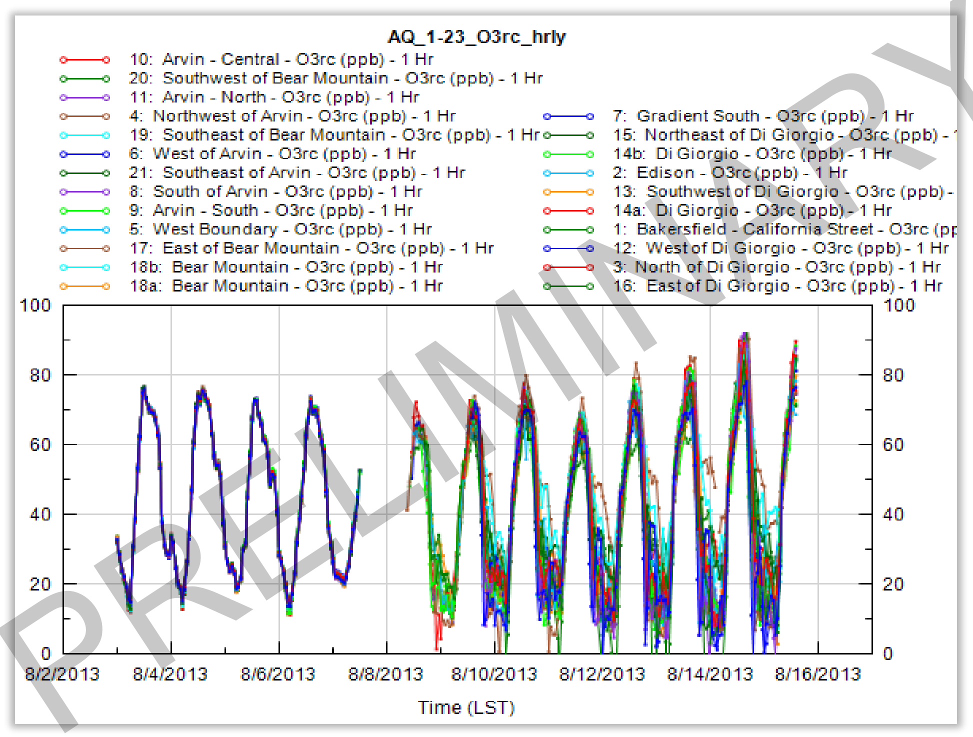


Figure 6. Preliminary hourly averages of the calibrated AeroQual ozone measurements made at all air quality sites during the collocation study (August 2-6) and during the first few days of the field study.

Appendix C

Post-Deployment Collocation

Overview

As part of the ozone saturation field study in Arvin, California, ozone data from Aeroqual S500 sensors were compared to ozone data from a Federal Equivalence Method (FEM) ozone instrument (Transfer Standard Teledyne API Model T400 UV absorption) at the Di Giorgio FEM site near Arvin, in a post-deployment collocation study. A post-study collocation study was necessary because Aeroqual sensors instrument response degraded throughout the course of the saturation study. The pre- and post-study collocation data were used to generate time-dependent correction equations for each sensor to provide measurements that are equivalent to the FEM measurements. The results of the post-deployment collocation are the subject of this Appendix.

Sensor Sensitivity Degradation

Upon completion of the initial collocation study, sensors were deployed to the field. Multiple sensors were collocated with FEMs for quality assurance purposes. Corrected sensor concentrations were displayed on an STI website and checked daily for validation purposes. Within a few weeks of the deployment, sensors collocated with FEMs were showing a negative bias in their corrected concentrations, especially when ozone concentrations were highest. This bias continued to grow as the study continued, although it tailed off in the last few weeks (as shown in Figure 3-9 of the main report).

STI worked with the instrument manufacturer to attempt to determine the cause of the sensor degradation. Several symptoms appeared in the data during the study. At the time, we didn’t know if there were different causes or if the symptoms were different manifestations of the same issue. One sensor was reporting negative ozone values every morning about 4:00–7:00 a.m. LST, and several sensors were reporting negative ozone values in the middle of the day. After about two weeks, it was also noticed that all sensors which were collocated with FEM ozone monitors were drifting lower, relative to the FEM concentrations (whereas they had agreed quite well with the collocated FEM concentrations at the beginning of the ambient study). We took a multi-pronged approach to addressing these issues, including searching the literature, discussing the issue with the manufacturer, reviewing potential emissions sources near sites, and inspecting the sensor systems; the potential causes of these issues and the results of those investigations include the following:

- We confirmed with the manufacturer that ozone sensor drift had not been present during past studies spanning several months in Vancouver, B.C., and in the ship channel area of Houston. The presentations and published papers did not indicate any sensor drift, even in the hot ambient temperatures and polluted atmosphere of the Houston ship channel. In fact, Aeroqual stated that they had looked at the effect of various gases and had run the sensor in various environments, including near-road, forest, suburban, urban/industrial, urban/megacity, and in winter and summer. The sensor had functioned well relative to a reference in all these environments except for the urban/megacity (Delhi) when PM_{10} concentrations exceeded 500 µg/m^3 hourly averages and associated hydrocarbon concentrations caused negative ozone readings. We experienced much lower PM_{10} concentrations than found in Delhi, and lower hydrocarbon concentrations than the Houston ship channel. There is a pumping oil well near one site (Bakersfield – California Avenue) which might have caused negative ozone values at times, but since sensors at all the sites were having drift problems, we assumed this was not a universal problem.
- The manufacturer suggested that there might be interference from nearby sources at several of the monitoring sites. Potential interferents that were suggested included hydrocarbons (aromatics, alcohols, and aldehydes) at ppm levels, ammonia at ppm levels, hydrogen sulfide at concentrations higher than 100 ppb, or organophosphates. Potential sources of concern included restaurants, dry cleaners, combustion sources, refineries or oil-field operations, and animal feeding operations. Since only Bakersfield and Edison had urban-type local sources nearby, but the Di Georgio sensor was also showing drift problems, it was judged that the local sources were not the cause of the universal problem. There probably is a fairly uniform concentration of ammonia in the southern San Joaquin Valley, but there are no current measurements to evaluate this interferent. Hydrogen sulfide and organophosphate concentrations are probably not very high and probably not very uniform over the study area. Note, however, that the general environment for most sensor sites was agriculture operations with some oil-field operations, some dirt roads, and some small-city traffic, etc., so there are various sources near many sensors. STI had tried to locate sensors away from large or major local sources when originally selecting the sites.
- The manufacturer suggested that there might be possible clogging of the cooling fan or inlet with excessive dust, or possible coating of the sensor itself with excessive dust. Several sensor systems at different sites were evaluated for excessive dust but were found to have little accumulated dust on the fan, in the inlet, or on the sensor head; thus, excessive dust was judged to not be the cause of the overall drift in sensor response.

Unfortunately, the troubleshooting did not result in a suitable course of action to fix the sensors. STI proposed a secondary post-study collocation period to provide the data necessary to develop a time-dependent ozone correction that accounted for the sensor degradation.

Post-Study Collocation and Regressions

Four days of measurements were collected during September 26–29, 2013, for the post-study collocation. The data collected were used to produce least squares linear regressions between hourly averages of the Aeroqual sensor measurements and hourly averages of the FEM reference measurements. The linear regression took the y = mx+b form, as shown in **Equation C-1**. The FEM instrument was treated as an independent variable with no measurement error for the purpose of these calibration regressions.

$$AQ_n = (slope * FEM) + intercept \quad \textbf{(Eq. C-1)}$$

Here, AQ_n is the concentration measured by Aeroqual sensor *n*, where *n* is the number of the individual sensor and *FEM* is the ozone concentration reported by the FEM instrument. The regression coefficients and statistics are presented in **Table C-1**. Note that Sensor AQ 18 was not functioning correctly until the last day of the collocation study, so only data collected on August 5 and 6 were used for the regression presented in Table C-1. An example of a scatter plot and regression is presented in **Figure C-1**; plots and regressions for ozone data from all the Aeroqual sensors against the FEM reference instrument are shown in **Figure C-2**.

Table C-1. Linear regression results for the Aeroqual S500 post-study calibrations.

Instrument	Slope	Slope Standard Error	Intercept (ppb)	Standard Error (ppb)	Number of Hourly Averages
AQ 1	0.91	0.021	-9.09	0.82	81
AQ 2	0.54	0.007	-2.14	0.32	417
AQ 3	0.70	0.017	-3.24	0.63	82
AQ 4	0.93	0.026	-10.63	0.99	87
AQ 5	0.80	0.021	-3.69	0.81	87
AQ 6	0.81	0.024	-9.32	0.90	87
AQ 7	0.73	0.019	-2.11	0.72	87
AQ 8	0.63	0.015	-2.48	0.48	44
AQ 9	0.73	0.009	-8.40	0.38	425
AQ 10	0.71	0.017	-2.47	0.66	82
AQ 11-2	0.64	0.010	-6.10	0.44	400
AQ 12-1	0.91	0.008	-12.64	0.37	100
AQ 12-2	0.87	0.010	-3.90	0.44	80
AQ 13	0.76	0.021	-8.65	0.77	57
AQ 14	0.97	0.023	-11.07	0.88	82
AQ 15	0.94	0.023	-12.82	0.88	87
AQ 16	0.57	0.015	-3.53	0.59	88
AQ 19	0.61	0.019	-4.21	0.71	56
AQ 20	0.79	0.020	-5.25	0.75	82
AQ 21	0.91	0.022	-10.59	0.84	87
AQ 22	0.76	0.019	-4.17	0.74	87
AQ 23	0.75	0.017	-7.82	0.66	82

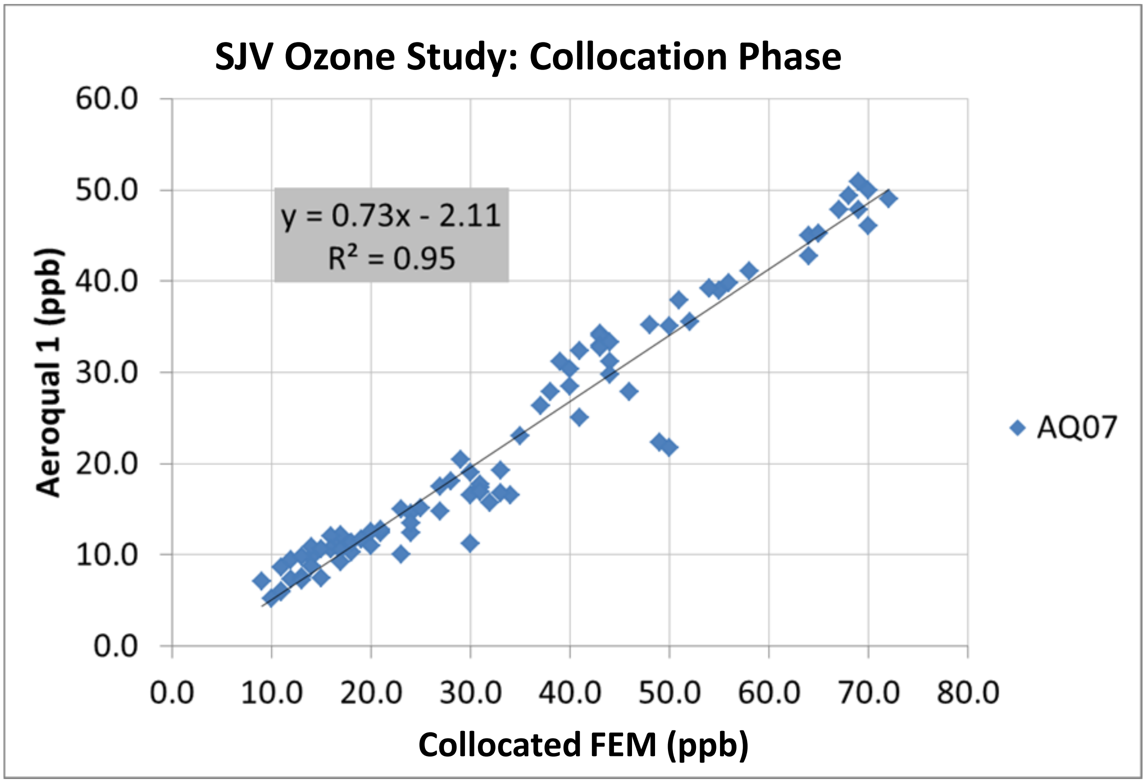


Figure C-1. Example of the calibration regressions between hourly averaged ozone data from the collocated FEM reference instrument and from the Aeroqual ozone sensors.

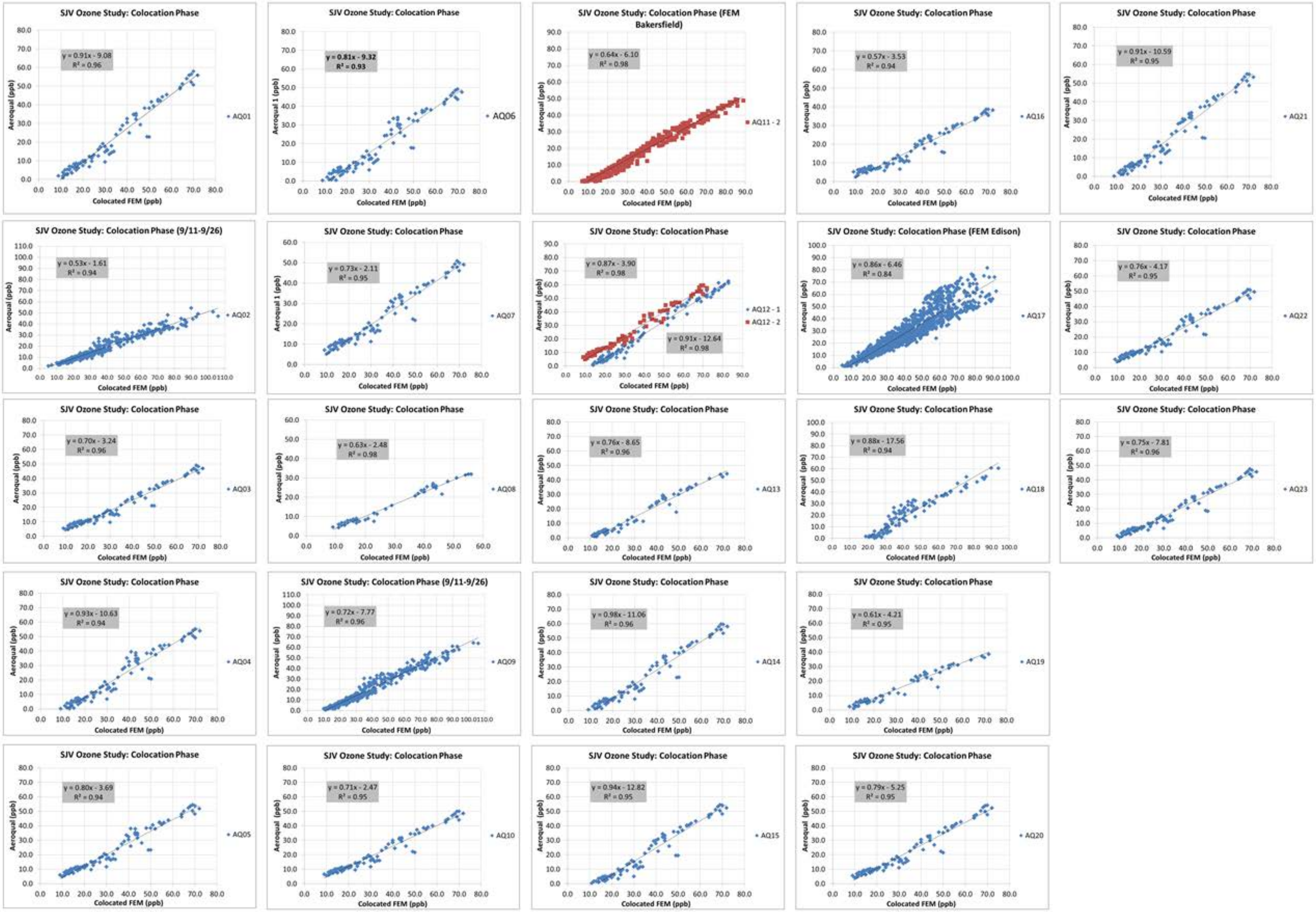


Figure C-2. Scatter plots and regressions of hourly ozone measurements made by the FEM reference instrument and each of the Aeroqual S500 sensors. The regression statistics are presented in Table C-1. The axis units are ppb, the Aeroqual data are plotted on the y-axis, and the FEM data are plotted on the x-axis.

Time-Dependent Correction Equations

Analysis of the degrading sensor readings at the collocated sites revealed that the individual sensors declined at an approximately linear rate over time for about the first 725 hours of deployment, and then stopped degrading. The cause of the leveling off is unclear. Minimizing the variance in least squares regression fits to the collocated data at the four sensors with data collocated with FEMs for at least 800 hours showed that the best fit to the data occurred when degradation leveled off at 725 hours.

STI then applied the time-dependent correction factors that are derived and detailed in Section 3.5 in the main body of the report. These corrections were applied to each sensor head individually, using the pre-study and post-study calibration data as end points with which to derive the time-dependent correction.

Figure C-3 illustrates the time-dependent corrected data compared to the FEM ozone at the Di Giorgio site. Agreement of the slope and intercept is within tolerable accuracy goals, and the $R^2 > 0.98$ indicates excellent agreement.

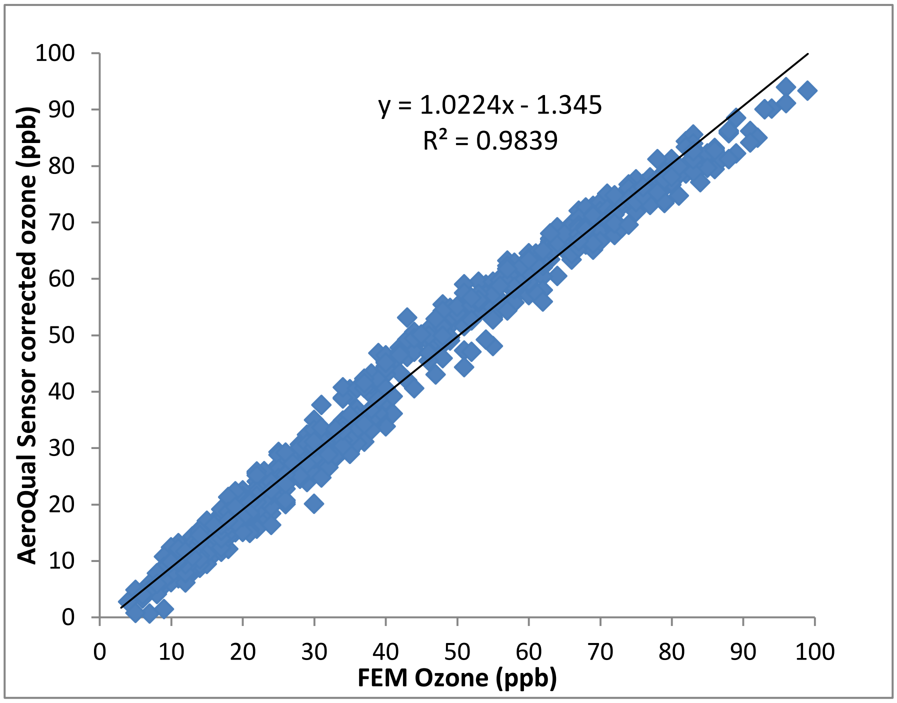


Figure C-3. Scatter plots and regression of hourly ozone concentrations at the Di Giorgio site of the FEM ozone instrument and the Aeroqual Sensor after the application of the time-dependent correction.

Appendix D

Summary of Ozone Concentrations

This appendix provides (1) the peak 1-hr and 8-hr ozone concentrations by site and (2) the site with the peak 1-hr and 8-hr ozone concentration for each day during the study.

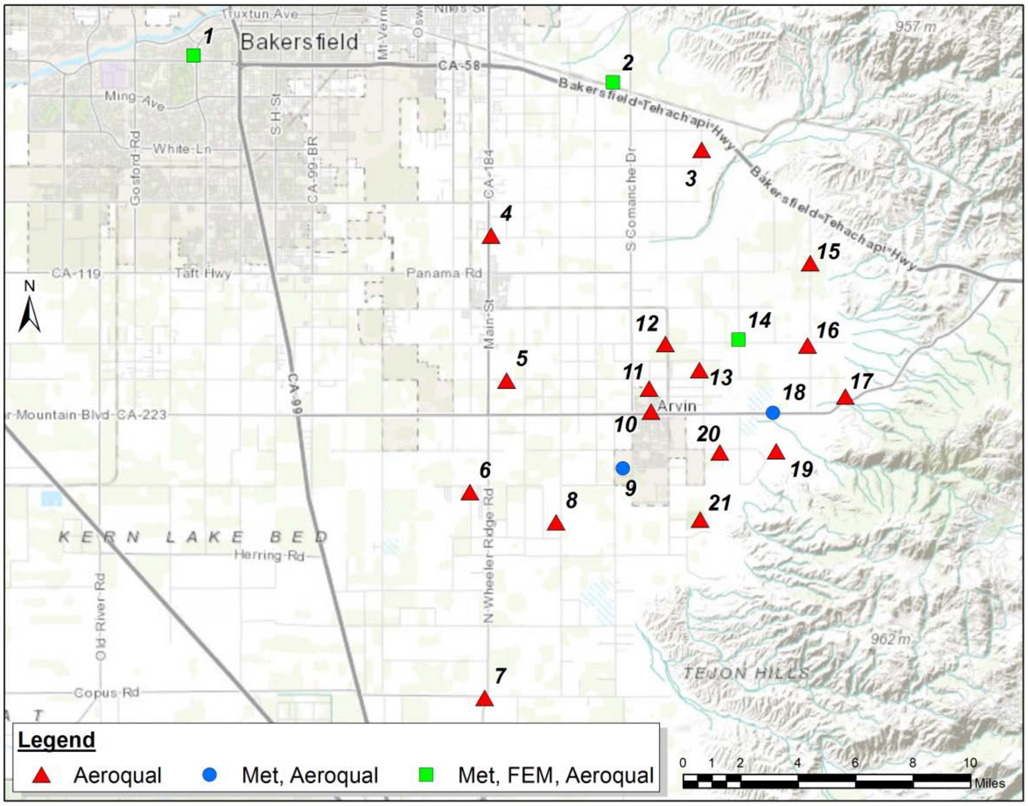


Figure D-1. Monitoring locations.

Table D-1. Highest 1-hour values for each site (August 8 to September 25). Please note the official study began on August 10; however, a few sites began operation on August 8.

Site	Name	Maximum 1-Hour Value (ppb)
3	North of Di Giorgio	106
n/a	**FEM Di Giorgio**	**106**
11	Arvin North	106
17	East of Bear Mountain	106
14a	**Di Giorgio (replacement sensor)**	**104**
4	Northwest of Arvin	99
21	Southeast of Arvin	97
n/a	FEM Bakersfield	97
12	West of Di Giorgio	96
18b	**Bear Mountain**	**95**
10	Arvin Central	94
14a	**Di Giorgio**	**94**
14b	**Di Giorgio**	**94**
7	Gradient South	92
19	Southeast of Bear Mountain	92
n/a	FEM Edison	92
6	West of Arvin	92
1	Bakersfield - California Street	91
2	Edison	91
15	Northeast of Di Giorgio	90
16	East of Di Giorgio	90
5	West Boundary	89
20	Southwest of Bear Mountain	89
8	South of Arvin	87
9	Arvin South	86
18a	**Bear Mountain**	**84**
13	Southwest of Di Giorgio	81

Table D-2. Highest 8-hour average values for each site (August 8 to September 25). Please note the official study began on August 10; however, a few sites began operation on August 8.

Site	Name	Maximum 8-hour Average Value (ppb)
17	East of Bear Mountain	91
11	Arvin North	88
3	North of Di Giorgio	87
14a	**Di Giorgio (replacement sensor)**	**86**
4	Northwest of Arvin	86
n/a	**FEM Di Giorgio**	**85**
21	Southeast of Arvin	83
1	Bakersfield - California Street	83
n/a	FEM Bakersfield	83
14a	**Di Giorgio**	**82**
19	Southeast of Bear Mountain	81
18b	**Bear Mountain**	**81**
14b	**Di Giorgio**	**80**
6	West of Arvin	80
10	Arvin Central	80
7	Gradient South	79
n/a	FEM Edison	79
12	West of Di Giorgio	78
20	Southwest of Bear Mountain	78
2	Edison	78
16	East of Di Giorgio	77
18a	**Bear Mountain**	**75**
8	South of Arvin	74
5	West Boundary	74
15	Northeast of Di Giorgio	72
9	Arvin South	69
13	Southwest of Di Giorgio	69

Table D-3. Peak 1-hour Aeroqual ozone site for each day during study by concentration.

Page 1 of 2

Daily Maximum Peak Hour Ozone (ppb)	Site	Month	Day	Hour
106	3	September	6	16
106	17	September	13	16
106	11	September	20	14
104	3	September	9	13
103	3	September	8	13
102	3	August	31	14
100	3	August	14	13
99	11	September	10	15
98	17	August	15	15
98	4	August	22	15
98	4	September	5	15
97	11	August	16	14
97	4	August	30	14
96	11	August	24	14
94	17	September	14	15
91	17	August	17	16
91	3	August	29	15
91	1	September	7	12
90	3	August	13	14
90	3	August	27	13
90	11	September	19	15
89	17	August	20	15
89	4	August	23	15
88	4	August	28	15
88	6	September	11	14
87	4	August	21	16
87	11	September	24	15
86	17	August	12	15
86	4	September	4	14
82	3	September	3	15
82	14a	September	12	14
81	17	August	10	14
81	17	September	15	16
79	3	August	26	14

Table D-3. Peak 1-hour Aeroqual ozone site for each day during study by concentration.

Page 2 of 2

Daily Maximum Peak Hour Ozone (ppb)	Site	Month	Day	Hour
76	1	August	19	14
76	4	September	1	14
75	17	August	11	15
75	3	August	18	16
75	17	September	17	14
74	17	August	9	15
73	1	September	23	15
72	3	August	8	13
71	11	August	25	16
71	17	September	18	16
70	2	September	16	16
67	3	September	2	13
62	11	September	21	17
58	14b	September	22	16
58	11	September	25	14

Table D-4. Peak 8-hour average Aeroqual ozone site for each day during study by concentration.

Page 1 of 2

Daily Maximum Peak 8-hr Ozone (ppb)	Site	Month	Day	Hour
91	17	September	13	11
88	11	September	20	10
87	3	September	8	10
86	4	August	22	11
85	11	August	14	10
85	17	September	14	10
84	11	August	15	10
83	3	September	9	10
83	3	September	10	10
81	21	August	24	10
81	4	September	5	11
80	17	August	16	11
79	17	August	13	10
79	3	September	6	11
78	17	August	20	11
78	4	August	23	11
77	4	September	4	11
77	1	September	19	11
76	19	August	30	11
76	4	August	31	10
74	17	August	12	11
74	19	August	21	12
74	4	August	28	11
74	14a	September	12	10
74	11	September	24	10
73	17	August	10	10
73	17	August	17	11
73	19	August	27	10
72	4	August	29	11
72	17	September	15	11
70	14b	September	7	9
68	17	September	11	10
67	17	August	9	11
66	3	August	8	9

Table D-4. Peak 8-hour average Aeroqual ozone site for each day during study by concentration.

Page 2 of 2

Daily Maximum Peak 8-hr Ozone (ppb)	Site	Month	Day	Hour
66	1	August	19	9
65	17	August	11	10
65	17	September	17	10
64	19	August	26	12
64	14b	September	3	11
64	1	September	23	11
62	3	August	18	11
62	4	August	25	11
62	17	September	18	10
61	4	September	1	10
59	17	September	16	11
58	4	September	2	10
53	11	September	21	11
53	14b	September	25	10
52	1	September	22	10

Appendix E

Residuals Analysis

1. Overview

As described in Section 5-3 of the main report, STI used linear regression analysis to answer the following questions:

1. How representative are the permanent monitors of high ozone in the City of Arvin?
2. How representative are ozone data collected at the Di Giorgio monitoring site of ozone data near the old Bear Mountain site?

Overall correlation values were provided and demonstrated that the permanent Di Giorgio monitor is representative of high ozone concentrations in the city of Arvin (R^2 = 0.79). The analysis also demonstrated that the Aeroqual monitor at Di Giorgio is representative of high ozone concentrations in the area around the former Bear Mountain monitor; overall correlations varied for the Aeroqual monitors at Bear Mountain Site 18a (R^2 = 0.61), at Bear Mountain site 18b (R^2 = 0.86), and Site 19 southeast of Bear Mountain (R^2 = 0.91). For each regression analysis, STI evaluated the residuals (defined in Section 2, below) to determine whether or not the error associated with the regression is independent of ozone concentrations, and thus whether the overall correlation statistics are representative of the relationship across a range of ozone concentrations. The results are provided in Section 3, below.

2. Statistics Background

In regression statistics, the *residuals* are calculated as the difference between the real (measured) values and predicted (using regression analysis) values of the dependent variable. A residual plot is a common and useful statistical technique to evaluate linear association between variables and heteroscedasticity:

- *Linear association between variables* – In a residual plot, a linear relationship between variables is evidenced by equal/symmetrical scatter of residuals across the horizontal axis (i.e., residuals are not predominantly positive or negative for different ranges of X values). Linear association is also demonstrated by a linear (non-curved) pattern in a scatter plot of real values.
- *Heteroscedasticity* – In a residual plot, heteroscedasticity is evidenced by a difference in the scatter of the residuals for different ranges of values of the independent (X) variable (i.e., in heteroscedastic data, there might be more or less scatter in residuals for low

versus high ranges of X values). If heteroscedasticity is observed, then a regression model may be unable to predict the dependent variable (Y) consistently; this might result in biases in the standard errors of regression coefficients, and thus require caution when results are interpreted.

3. Results

The following residual plots supplement the regression analyses describing the relationship between ozone concentrations in (1) Di Giorgio and ozone concentrations in the city of Arvin, and (2) Di Giorgio and the Bear Mountain area. These plots are used to support the use of linear regression analysis and the interpretation of overall correlation statistics. **Figures E-1 through E-4** show residual plots corresponding to Figures 5-18 through 5-21 in the main report.

Question 1: How representative are the permanent monitors of high ozone in the City of Arvin?

Linear regression analysis was used to describe the relationship between hourly ozone concentrations at the FEM at Di Giorgio and the city of Arvin (average of Arvin-North and Arvin-Central Aeroqual sites); data were limited to hours when ozone at Di Giorgio exceeded 60 ppb (roughly 12:00–5:00 p.m.). In **Figure E-1**, the residual plot for this relationship shows symmetrical scatter across the horizontal (X) axis, indicating a linear relationship between ozone concentrations in Arvin and at the FEM at Di Giorgio, and supporting the use of linear regression analysis. The plot shows slight heteroscedasticity: residuals are more scattered when concentrations in Di Giorgio are between 70 ppb and 80 ppb, compared to higher or lower concentrations. However in general, there is little or no bias in the residuals, and thus little or no bias in the predictive equation with increasing ozone concentrations.

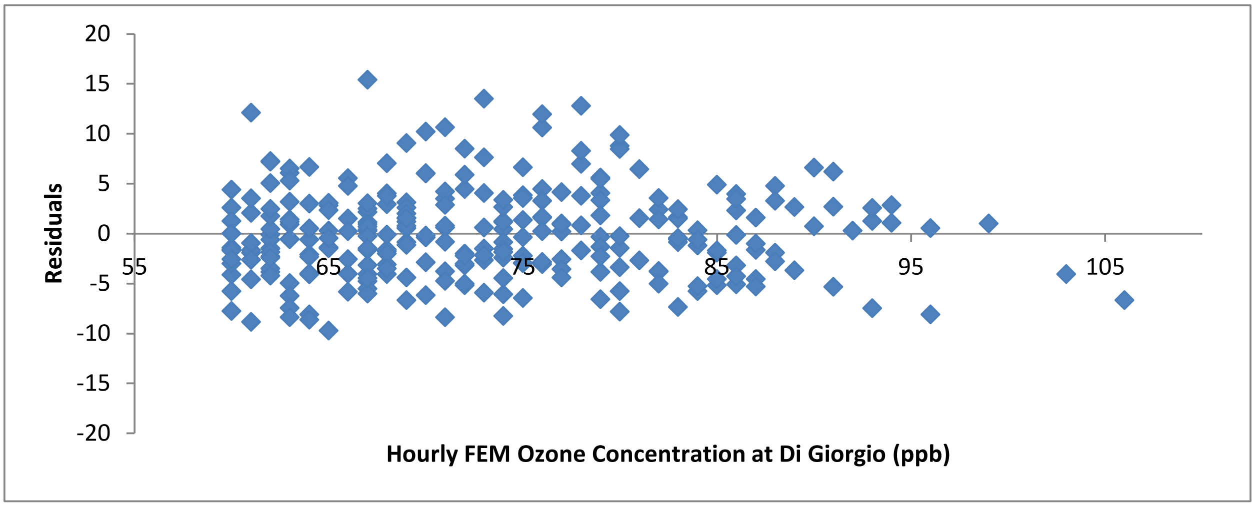


Figure E-1. Residual plot describing the error (residual) in estimating average ozone concentrations in Arvin across the range of concentrations at the FEM at Di Giorgio. This plot is related to the analysis described by Figure 5-18 in the main report.

Question 2: How representative are ozone data collected at the Di Giorgio monitoring site of ozone data near the old Bear Mountain site?

Linear regression analysis was used to describe the relationship between daily peak 1-hr ozone concentrations at the Aeroqual monitor in Di Giorgio (Site 14b) and in the area around the former Bear Mountain monitor. The following plots show the regression residuals for the relationship between ozone concentrations at the Aeroqual monitor in Di Giorgio, and Aeroqual Site 18a (**Figure E-2**), Aeroqual Site 18b (**Figure E-3**), and Aeroqual Site 19 (**Figure E-4**). The results are consistent for each monitor. In general, the residual plots show symmetrical scatter across the horizontal (X) axis, indicating a linear relationship between peak ozone concentrations at Di Giorgio and Bear Mountain, and supporting the use of linear regression analysis. Slight positive bias is observed for ozone concentrations less than 75 ppb. The plots do not show heteroscedasticity and in general, there is little or no bias in the residuals, and thus little or no bias in the predictive equation with increasing ozone concentrations.

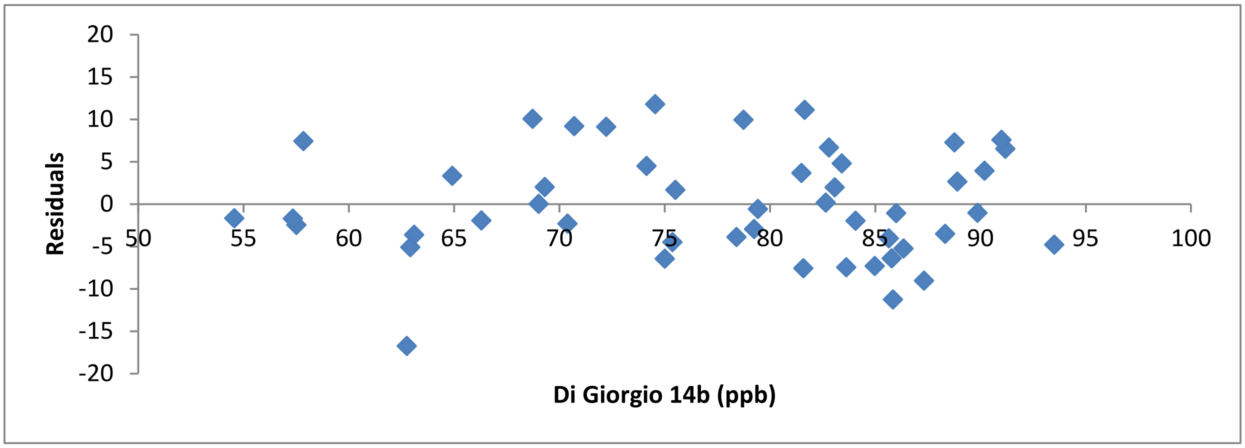


Figure E-2. Residual plot describing the error (residual) in estimating daily peak 1-hr ozone concentrations collected by the Aeroqual sensor for Bear Mountain (Site 18a) across the range of concentrations collected by the Aeroqual sensor at Di Giorgio (Site 14b) and on all study days. This plot is related to the analysis described by Figure 5-19 in the main report.

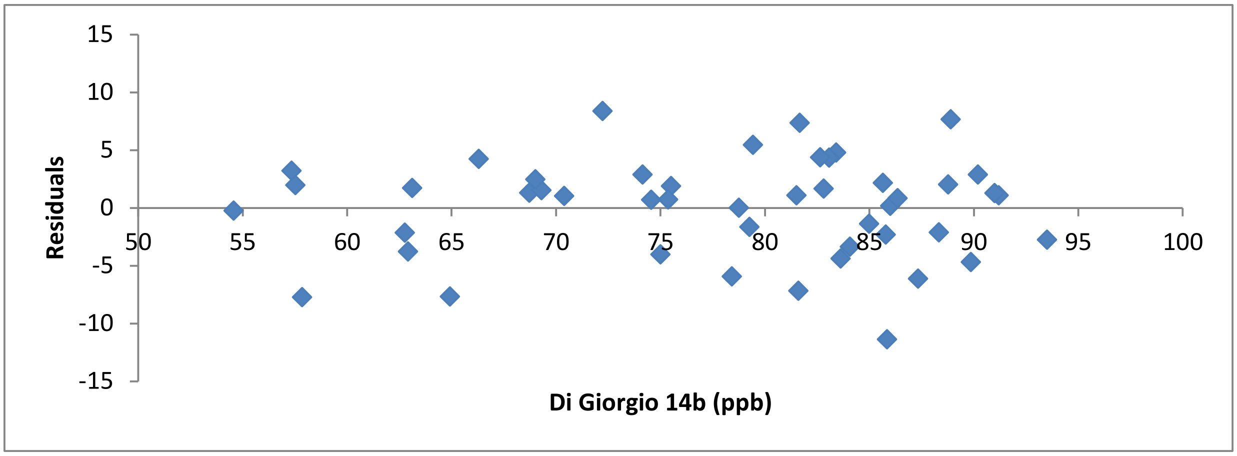


Figure E-3. Residual plot describing the error (residual) in estimating daily peak 1-hr ozone concentrations collected by the Aeroqual sensor for Bear Mountain (Site 18b) across the range of concentrations collected by the Aeroqual sensor at Di Giorgio (Site 14b) and on all study days. This plot is related to the analysis described by Figure 5-20 in the main report.

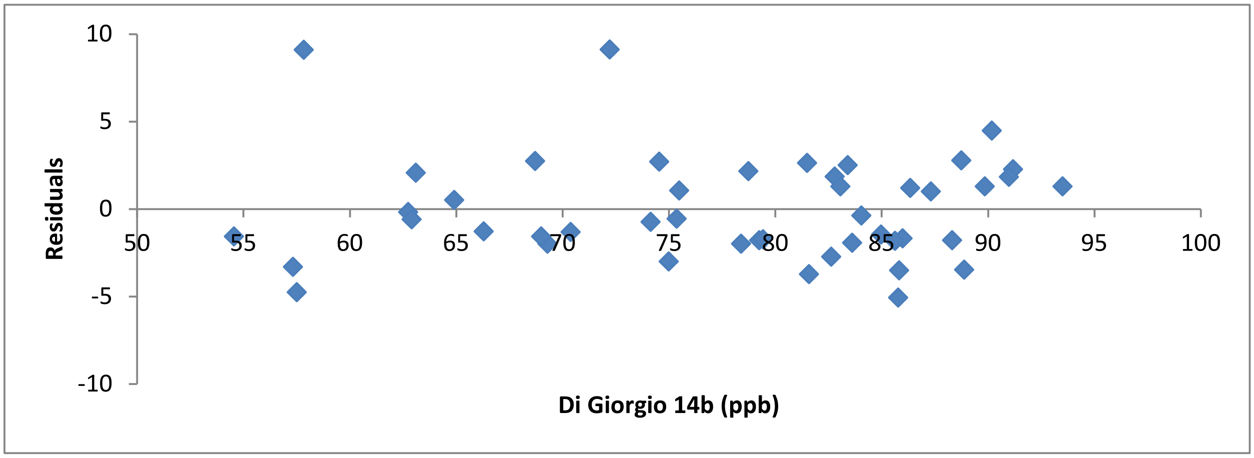


Figure E-4. Residual plot describing the error (residual) in estimating daily peak 1-hr ozone concentrations collected by the Aeroqual sensor southeast of Bear Mountain across the range of concentrations collected by the Aeroqual sensor at Di Giorgio (Site 14b) and on all study days. This plot is related to the analysis described by Figure 5-21 in the main report.