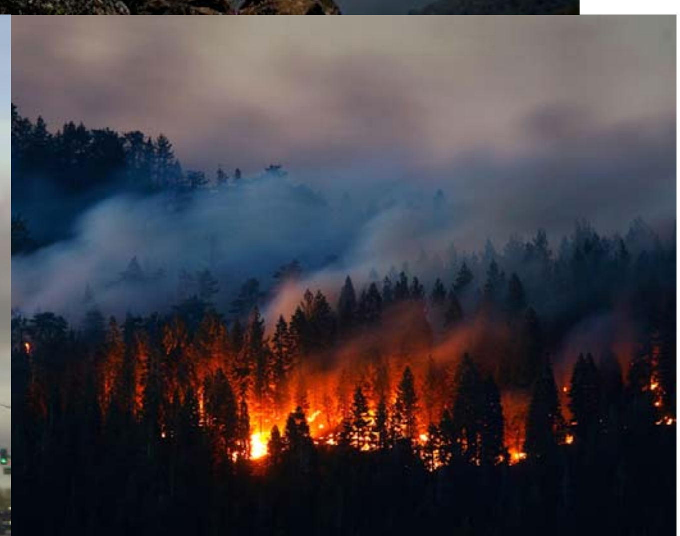
Exceptional Events Demonstration for 1-Hour Ozone Exceedances in the Sacramento Regional Nonattainment Area Due to 2008 Wildfires

Updated Documentation
March 30, 2011



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1. <u>Introduction and Rule Overview</u>

A. Scope of Report

The purpose of the report is to provide additional clarifying documentation in the form of a standalone document on the 2008 catastrophic wildfires that contributed to exceedances of the federal 1-hour ozone standard at the Folsom-Natoma Street monitor in the Sacramento federal 1-hour ozone nonattainment area. Specifically, this document demonstrates that 1-hour ozone exceedances on June 23, June 27, and July 10, 2008 at Folsom meet the requirements for having been influenced by an exceptional event as stipulated in the U. S. Environmental Protection Agency's (U.S. EPA) Exceptional Events Rule published on March 22, 2007. Table 1 lists the specific hours and associated 1-hour ozone concentrations at Folsom that are included in this request.

Table 1
1-Hour Federal Ozone Exceedance Values at Folsom-Natoma Street

Site	Day	Hour	Observed Concentration (ppm)
Folsom	6/23/08	13	0.129
Folsom	6/23/08	14	0.151
Folsom	6/23/08	15	0.161
Folsom	6/23/08	16	0.132
Folsom	6/27/08	15	0.129
Folsom	7/10/08	11	0.126
Folsom	7/10/08	12	0.150
Folsom	7/10/08	13	0.141

B. Exceptional Event Definition and Demonstration Criteria

The Exceptional Events Rule defines an exceptional event in 40 CFR §50.1(i) as an event that affects air quality, is not reasonably controllable or preventable, and is an event caused by human activity that is unlikely to recur at a particular location or is a natural event.

The following analysis will address this definition and provide documentation to establish that the summer 2008 wildfires met the criteria as set forth in 40 CFR 50.14(c) (3)(iv). Specifically, that the event affected air quality by demonstrating that: 1) there was a clear causal relationship between the 1-hour ozone concentrations at Folsom and the event, 2) that the event was above normal historical fluctuations, (including background), and 3) the 1-hour ozone concentrations at Folsom would not have exceeded the standard but for the event. In addition, documentation is provided demonstrating that the emissions from these lightning ignited wildfires were natural events whose emissions were not reasonably preventable or controllable. Finally, information regarding reasonable and appropriate actions taken to protect public health and to provide the public with an opportunity to review this analysis is attached. Table 2 provides an overview of where documentation on each of these criteria can be found within the document.

Table 2
Exceptional Events Rule Technical Demonstration Elements for Sacramento 1-Hour Ozone Exceptional Events Demonstration

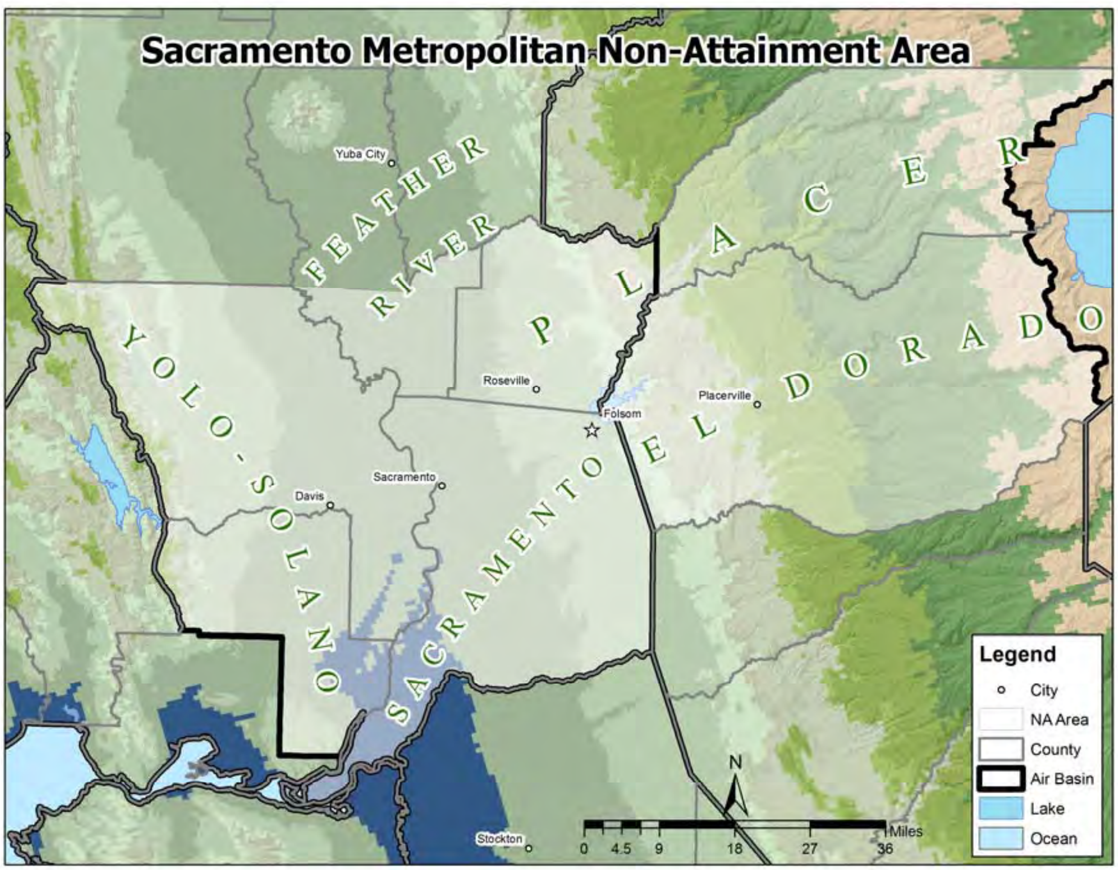
Element	**Section of this Document Containing Additional Explanation**
Background on region and basic conceptual model	2
Clear causal relationship between the measurement and the event	3.A, B, C, D, E
Evidence that the event is associated with a concentration in excess of normal historical fluctuations, including background	3.F
No exceedance or violation but for the event	4
Affects air quality	5.A
Not reasonably controllable or preventable	5.B
Caused by human activity unlikely to recur at a particular location OR a natural event	5.C
Mitigation and public comment	6

2. Setting and Basic Conceptual Model

A. Area Description

The Sacramento federal 1-hour ozone nonattainment area (Sacramento region) consists of Sacramento County, Yolo County, the eastern portion of Solano County, the western portion of Placer County, the western portion of El Dorado County, and the southern portion of Sutter County (see Figure 1). The region covers over 5,600 square miles, and has a population of over 1.8 million. Air pollution planning for the Sacramento regional nonattainment area is the responsibility of five air pollution planning agencies: Sacramento Metropolitan Air Quality Management District (lead agency), El Dorado County Air Quality Management District, Feather River Air Quality Management District, Placer County Air Pollution Control District, and Yolo-Solano Air Quality Management District.

Figure 1



The Sacramento region is located in the Central Valley of northern California. The Central Valley is a 500-mile long northwest-southeast oriented valley that is composed of the Sacramento Valley and the San Joaquin Valley air basins. Elevations in the Central Valley extend from a few feet above sea level to almost 500 feet (see Figure 2). This long valley is surrounded by the Coast Range Mountains on the west, the Cascade Range on the northeast, the Sierra Nevada Mountains on the east, and the Tehachapi Mountains on the south.

The Coast Range Mountains (also referred to as the Coast Ranges) are actually a series of north/south mountain ranges that extend 800 miles from the northwest corner of Del Norte County south to the Mexican border. The San Francisco Bay Area separates the Coast Range Mountains into northern and southern ranges. The Coast Range Mountains generally form a barrier, or wall, between the Pacific Ocean and the Central Valley, with occasional breaks created by low elevation passes and the small gap between the northern and southern ranges in the San Francisco Bay area known as the Carquinez Strait. Elevations in the Coast Range Mountains generally range between 2,000 and 4,000 feet, but can reach above 7,000 feet. In contrast, elevations in the Cascade Range and Sierra Mountains in northern California are typically above 5,000 feet and can exceed 10,000 feet.

Because of its inland location, the climate of the Sacramento region is more extreme than that of more coastal regions, such as the San Francisco Bay Area. The winters are generally cool and wet, while the summers are hot and dry. Both seasons can experience periods of high pressure and stagnation which are conducive to pollutant buildup. These climate conditions result in seasonal patterns where ozone concentrations are highest during the summer, while $PM_{2.5}$ concentrations are highest during the winter. The lack of summertime precipitation, coupled with the extent of forested regions which surround the Central Valley, also creates conditions conducive to wildfires during the summer months.

The Sacramento Valley's usual summer daytime circulation pattern is characterized by onshore flow through the Carquinez Strait (which flows from the Bay Area to Sacramento and is known as the sea breeze). Once through the Strait, the wind flow divides. A portion of the wind flow turns south, blowing into the San Joaquin Valley, a portion continues eastward, across the southern Sacramento Valley, and a portion turns north, blowing into the upper Sacramento Valley. At night, the sea breeze weakens, and the wind direction in the Sacramento Valley changes. Typical downslope flow, known as nocturnal drainage, brings air from the Coast Range and Sierra Nevada Mountains into the Sacramento Valley. With the weakened sea breeze, an eddy circulation pattern forms in the southwest portion of the Sacramento Valley which serves as a mechanism to recirculate and trap air within the region.

Figure 2
Topographic Map of Northern California

B. Characteristics of Ozone Formation

Anthropogenic emissions contributing to ozone formation in the Sacramento Region comprise reactive organic gases (ROG) and oxides of nitrogen (NO_x). The main sources of these emissions include mobile sources (cars, trucks, locomotives, off-road equipment) along with stationary and area sources which include industrial processes, consumer products, and pesticides. Mobile source emissions dominate the anthropogenic emissions, accounting for more than 85 percent of the total NO_x inventory.

ROG and NO_x emissions have decreased significantly over the past several decades. This reduction directly translates into fewer days above the former federal 1-hour ozone standard. In 1990, ROG and NO_x precursor emissions were estimated at 262 and 242 tons per day (tpd), respectively. In 2008, these emissions had decreased more than 50 percent, to 136 tpd of ROG and 167 tpd of NO_x. These significant improvements occurred despite increases in population, vehicle activity, and economic development.

The ozone season in the Sacramento region occurs from May through October. Although exceedances of the 1-hour federal ozone standard are infrequent, they are most likely to occur under certain meteorological conditions.

Sonoma Technology Inc. (STI) evaluated high ozone concentrations and associated meteorological conditions in the Sacramento region and developed several rules of thumb to predict when ozone concentrations will be elevated in Sacramento County (see Appendix Y for details). In general, the synoptic (large-scale) weather conditions leading to elevated ozone concentrations occur in the Sacramento region when a ridge of high pressure is located over California, causing the air to subside, or sink. As the air sinks, it warms, which forms a temperature inversion that stabilizes and dries the atmosphere. This process limits the vertical mixing of boundary layer air, which traps pollutants near the ground. The process also limits cloud production, which increases ozone photochemistry. In addition, surface wind flow patterns conducive to high ozone concentrations occur when the thermal surface low is over or just west of Sacramento. This results in a sea breeze which weakens or occurs late in the day. This prevents the dispersion of pollutants and leads to high ozone concentrations.

Nighttime drainage flows can bring biogenic emissions from the Coast Range and Sierra Nevada Mountains into the Sacramento Valley. During daytime wind flow patterns, anthropogenic precursor emissions in the Bay Area and Sacramento combine with biogenic emissions to undergo photochemical reactions generating ozone. Due to the general daytime flow pattern from west to east, as well as the time needed for photochemical reactions to occur, the highest concentrations in the Sacramento region generally occur in the afternoon in the downwind, eastern portion of the region, such as Folsom.

C. Wildfire Description

From June 20 to June 22, 2008, over 6000 lightning strikes from a series of thunderstorms ignited numerous wildfires throughout northern and central California. At its peak, what became known as the Northern California Lightning Siege (or the Lightning Complex Fires) comprised thousands of wildfires in 26 counties and sent smoke throughout the western United States. California firefighters were assisted in their efforts to control these blazes by units from throughout the U.S., as well as Australia, Canada, Greece, Mexico, and New Zealand.

With thousands of individual fires (subsequently grouped into fire complexes) in 26 counties, the summer of 2008 was one of the most severe wildfire seasons in California history. Most of these fires were not contained until late-July or early-August, with some continuing to burn through October. Vast areas experienced smoke impacts, especially areas in northern California. Table 3 summarizes the number of wildfires and acreage burned by county from mid-June to mid-July 2008, in the counties surrounding Sacramento. Figure 3, provides a map of fire locations. A detailed table listing the fires, distance from Folsom, and acreage burned is included in Appendix A.

Air quality in northern California deteriorated because of the smoke. From June 23 through much of July, the Sacramento region was covered in a thick blanket of smoke. Many of the air monitors recorded extremely high ozone concentrations, along with hazardous concentrations of particulate matter. The hazardous air quality levels prompted air pollution control and air quality management districts in the Sacramento region to issue air quality advisories and warnings. The wildfires and smoke spread throughout the Sacramento region and were widely recognized by residents in the region and the public media. Figures 4, 5, and 6 provide satellite maps illustrating the extent of the smoke impacts on June 23, June 27, and July 10, 2008.

Table 3
Summary of Wildfires by County
Mid-June through Mid-July, 2008

County Name	*Number of Fires*	*Total Acreage*	*Average Distance from Folsom (miles)*
Butte	10	73,123	74
Calaveras	1	104	39
Colusa	1	11,173	75
Del Norte	1	17,552	241
El Dorado	3	68	33
Humboldt	8	16,421	191
Imperial	1	53	505
Kern	2	37,393	281
Lake	1	1,566	108
Lassen	2	12,449	155
Madera	4	450	126
Marin	1	7	101
Mariposa	7	5,184	111
Mendocino	60	58,979	134
Merced	1	797	110
Monterey	4	163,668	166
Nevada	2	3,582	52
Placer	6	21,009	33
Plumas	8	20.538	83
San Benito	1	3.787	139
San Mateo	1	211	97
Santa Clara	2	1,042	118
Santa Cruz	1	594	126
Shasta	15	105,477	149
Sierra	2	478	59
Siskiyou	10	155,105	223
Solano	1	4,102	60
Stanislaus	2	115	71
Tehama	10	85,395	124
Trinity	52	214,682	162
Tuolumne	2	2.975	82
Yuba	2	1,382	48

Figure 3
California Wildfires June 20 through July 10, 2008

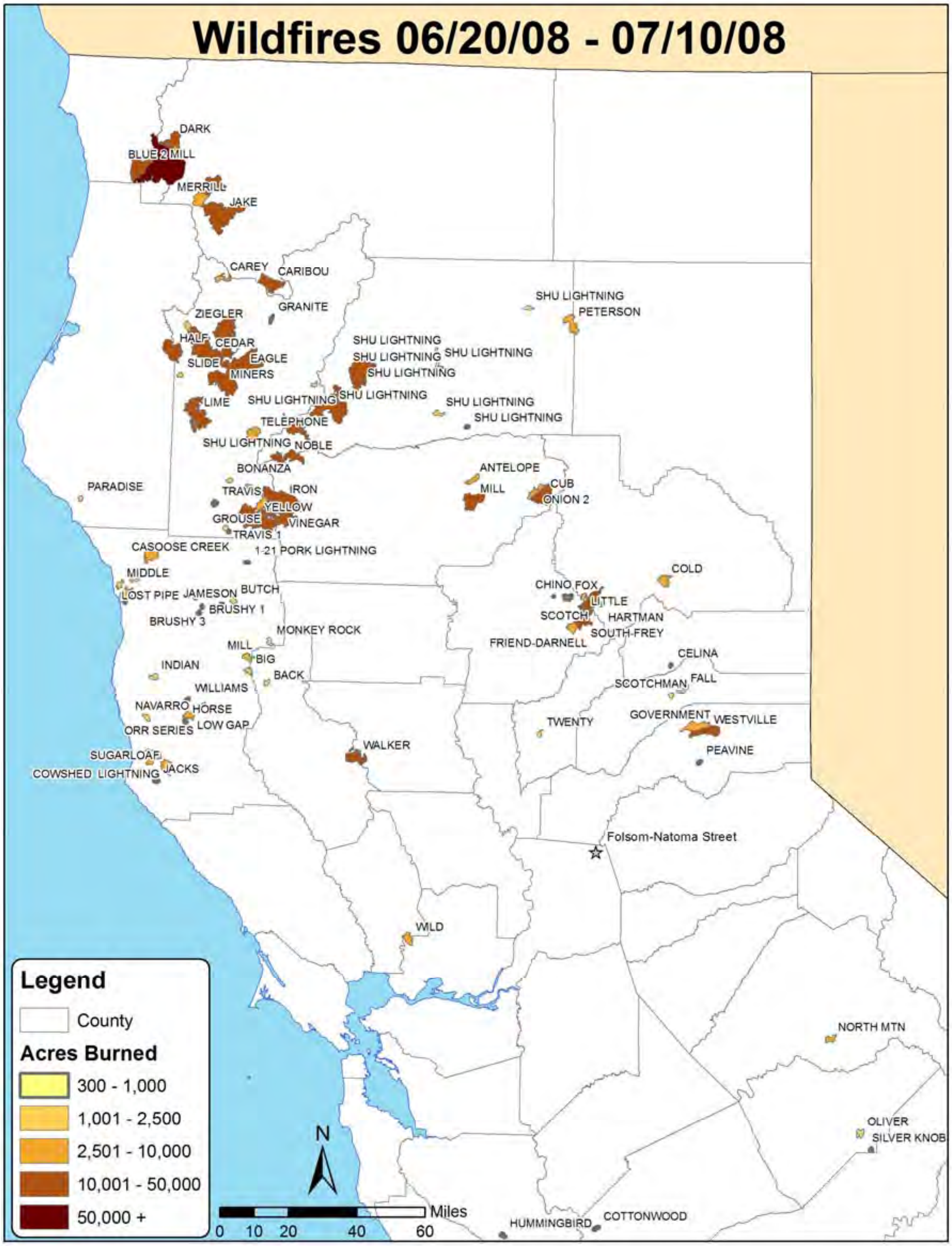
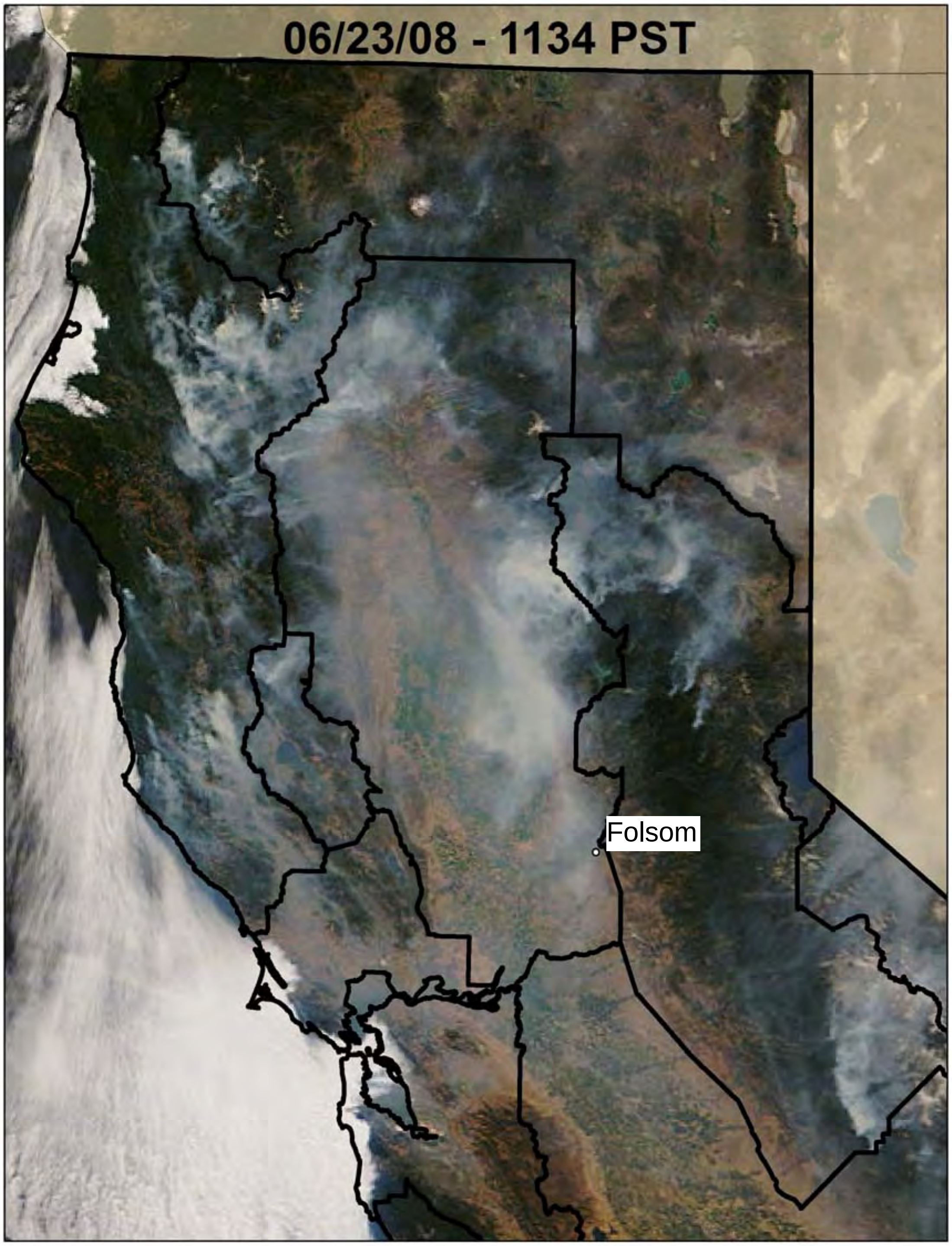
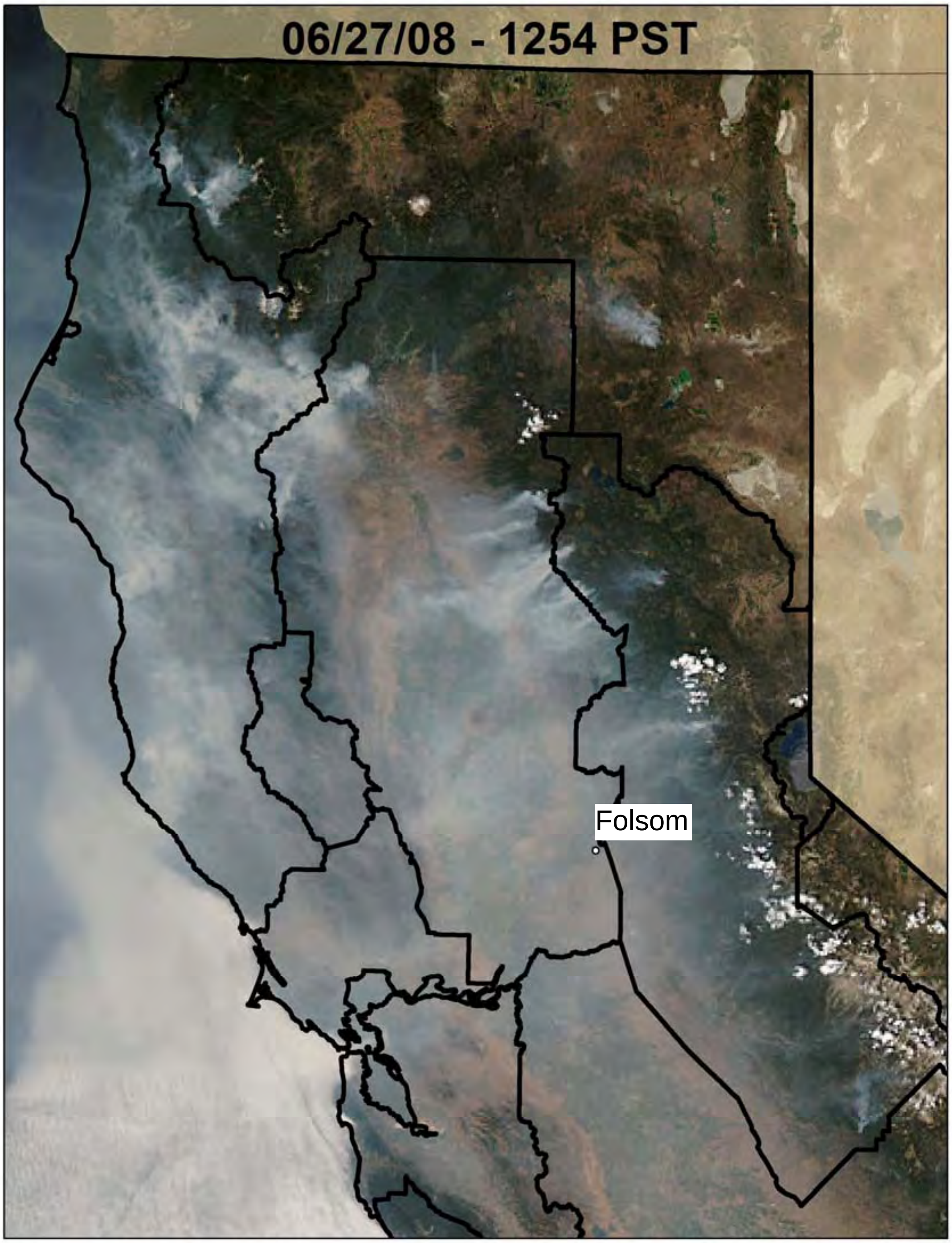


Figure 4
MODIS Satellite Image - June 23, 2008



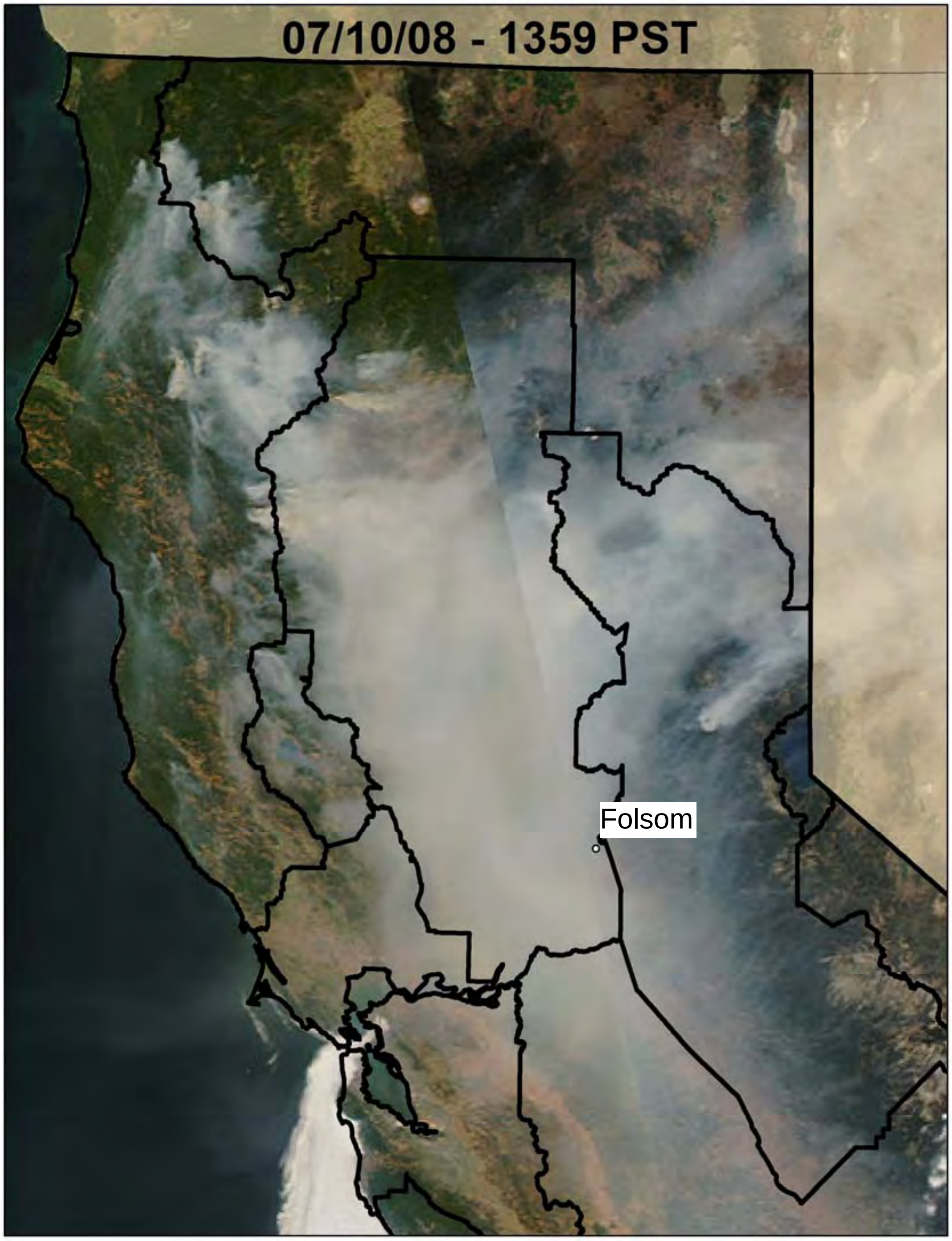
NASA Visible Terra MODIS True Color Satellite Image (250 meter resolution)
http://rapidfire.sci.gsfc.nasa.gov/subsets/?subset=USA1

Figure 5
MODIS Satellite Image - June 27, 2008



NASA Visible Aqua MODIS True Color Satellite Image (250 meter resolution)
http://rapidfire.sci.gsfc.nasa.gov/subsets/?subset=USA1

Figure 6
MODIS Satellite Image – July 10, 2008

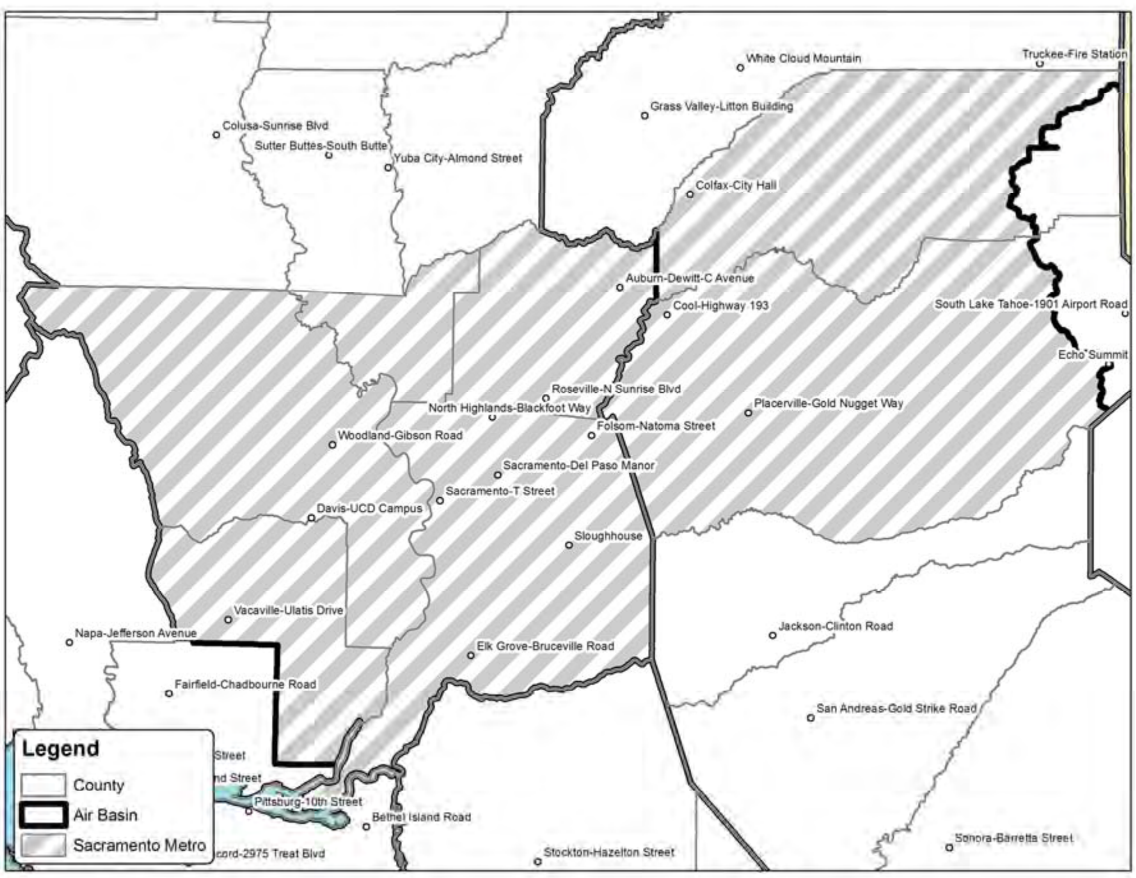


NASA Visible Aqua MODIS True Color Satellite Image (250 meter resolution)
http://rapidfire.sci.gsfc.nasa.gov/subsets/?subset=USA1

D. Monitoring

During 2008, there were 15 monitoring sites operating in the Sacramento nonattainment area, as shown in Figure 7, below. Ozone was dramatically elevated throughout the nonattainment area and much of northern and central California during the fire period. In the Sacramento nonattainment area, five monitoring sites recorded ozone concentrations above the 1-hour standard. More detailed information about the exceedances at these sites is shown in Table 4.

Figure 7
Air Quality Monitoring Sites
in the Sacramento Nonattainment Area during 2008*



** Sacramento-Airport site not included on map because site closed in late July 2008.*

Table 4
2008 Sacramento Metro Nonattainment Area
Federal 1-Hour Ozone Exceedance Days*

Air Monitoring Site Name	Date	Daily Maximum 1-Hour Ozone Concentration (ppm)
Cool-Highway 193	7/7/2008	0.130
Cool-Highway 193	7/10/2008	0.129
Folsom-Natoma Street	6/23/2008	0.161
Folsom-Natoma Street	6/27/2008	0.129
Folsom-Natoma Street	7/7/2008	0.166
Folsom-Natoma Street	7/10/2008	0.150
Folsom-Natoma Street	8/13/2008	0.132
Placerville-Gold Nugget Way	7/7/2008	0.139
Placerville-Gold Nugget Way	7/10/2008	0.137
Roseville-N Sunrise Blvd	6/25/2008	0.125
Roseville-N Sunrise Blvd	7/7/2008	0.134
Sloughhouse	7/7/2008	0.148
Sloughhouse	7/9/2008	0.128
Sloughhouse	7/25/2008	0.130

** 1-Hour Federal Ozone Standard = 0.12 ppm*

This document is focused only on the exceedances of the 1-hour ozone standard that occurred at the Folsom-Natoma Street monitoring site on June 23, June 27, and July 10, 2008, because these exceedances meet all of the requirements of U.S. EPA's Exceptional Events Rule, and they impact the region's design value for purposes of demonstrating attainment of the federal 1-hour ozone standard. Table 1 in Section 1 previously summarized the measured hourly ozone concentrations at the Folsom site that exceeded the 1-hour ozone standard on these three dates.

E. Wildfire Effects on Ozone Formation

1. Research

Wildfires can generate both NO_x and Volatile Organic Carbon (VOC) emissions, with different burning stages generating different types of emissions. Biogenic VOCs are generated by vegetation throughout the burning cycle. NO_x is generated primarily during the hot, flaming stage of the fire, and small reactive hydrocarbons, such as ethane and acetylene, are generated during the smoldering phase (Finlayson-Pitts and Pitts, 2000; Jaffe et al., 2008).

Very near fires, ozone concentrations can potentially be suppressed, despite the increase in ozone precursors generated by the wildfires. Bytnerowicz et al. (2010), Finlayson-Pitts and Pitts (2000), and Sandberg et al. (2002) explain several reasons why ozone can potentially be low at the fire sites: 1) thick smoke can prevent sufficient UV light from reaching the surface, thereby inhibiting photochemical reactions, and 2) the wildfire plume typically contains high NO concentrations, which can titrate ozone concentrations. Downwind of the fire (or at the top of the plume (Sith et al., 1981, qtd in Sandberg et al., 2002), away from fresh NO sources and with reduced aerosol optical depth, considerable amounts of ozone can be generated. The plume does not need to be very far downwind of fire emissions to generate ozone. Sith et al. (1981) found ozone beginning 10 km downwind of wildfires, in plumes less than one hour old (quoted in Sandberg et al., 2002). Ozone and ozone precursors can also be transported quite far from a wildfire site (Finlayson-Pitts and Pitts, 2000 and Jaffe et al., 2008). Therefore, similar to the impacts of anthropogenic emissions in urban airsheds, the highest ozone concentrations due to wildfires are often found downwind of the area of greatest precursor emissions.

The impact of wildfires on ozone concentrations at both the local and regional level has been extensively evaluated in recent years. Field observations of ozone formation in smoke plumes from fires date back nearly 25 years when aircraft measurements detected elevated ozone at the edge of forest fire smoke plumes far downwind (see *Wildland Fire in Ecosystems Effects of Fire on Air*). More recently, aircraft flights through smoke plumes have demonstrated increased ozone concentrations of 15 to 30 ppb in California (Bush, 2008), while ozonesonde measurements in Texas found enhanced ozone aloft ranging from 25 to 100 ppb attributable to long-range transport of smoke plumes from Canada and Alaska (Morris, 2006).

In addition, air quality modeling has shown increased levels of ozone from a number of large fires. McKeen (2002) found that Canadian fires in 1995 enhanced ozone concentrations by 10 to 30 ppb throughout a large region of the central and eastern United States. Lamb (2007) found similar results simulating the impacts of fires in the Pacific Northwest in 2006, with increases of over 30 ppb. Junquera (2005) further found that within 10 km of a fire, ozone concentrations could be enhanced by up to 60 ppb. Finally, in one of the most recent studies, Pfister (2008) simulated the large 2007 fires in both northern and southern California. The author found ozone increases of approximately 15 ppb in many locations and concluded that "Our findings demonstrate a clear impact of wildfires on surface ozone nearby and potentially far downwind from the fire location, and show that intense wildfire periods frequently can cause ozone levels to exceed current health standards."

2. Conceptual Model of Ozone Formation from 2008 Wildfires

Substantial amounts of NO_x and VOCs were generated from the 2008 wildfires during late June and early July across a broad area surrounding the Sacramento Valley, corresponding to the 1-hour ozone exceedances at Folsom on June 23, June 27, and July 10, 2008. Surface wind flow conditions on these days were typical for the summertime, including nighttime drainage flow from the Coast Range and Sierra Nevada Mountains, coupled with an eddy circulation in the southern Sacramento Valley, followed by the daytime sea breeze. These wind flow patterns transported, and subsequently trapped within the Sacramento region, wildfire precursor emissions coming from multiple upwind locations. In addition to surface transport, due to the buoyancy of fire plumes, substantial amounts of precursors were emitted aloft by the wildfires. An increase in the mixed layer during the morning and early afternoon on each day allowed additional wildfire precursors aloft to reach the surface.

Under typical daytime photochemistry, the increased levels of wildfire-related precursor emissions in the Sacramento region resulted in enhanced levels of ozone throughout the region, including Folsom. Although these surface windflow patterns would also have transported anthropogenic emissions to Folsom, the meteorological conditions that existed on the three exceedance days were not sufficient to have caused a 1-hour ozone exceedance without the added burden of the additional wildfire-related precursor emissions. In addition, given the lengthy duration of the fires, by June 27 and July 10 there were also substantial amounts of wildfire-related ozone carried over from the day before the exceedance, further increasing ozone concentrations.

Although, as discussed earlier, NO from fires can result in ozone titration very close to the source of a fire, Folsom was sufficiently far enough downwind that a reduction in ozone concentrations due to this phenomena was unlikely. In addition, while the increased smoke from the fires may have reduced the amount of solar insolation, thereby potentially reducing photochemical activity, this was compensated for by the substantially increased levels of ozone precursors generated by the fires, resulting in a net ozone enhancement.

Section 3 provides a more detailed discussion of the day-specific meteorological conditions that existed on each of the three 1-hour ozone exceedance days included in this request to support the clear causal connection between the wildfires and the ozone concentrations. In addition, Section 4 provides information to demonstrate that the 1-hour ozone concentrations at Folsom on each of these days would not have exceeded the federal standard but for the impacts of the wildfire emissions.

3: <u>Clear Causal Relationship</u>

A. Introduction

This section will demonstrate a clear causal relationship between the occurrence of the wildfires and the 1-hour ozone exceedances that occurred at the Folsom monitor on June 23, June 27, and July 10, 2008. Specifically, the section provides compelling evidence that: 1) the wildfires occurred, 2) the smoke plume from these wildfires reached the Folsom monitor, and finally 3) that the pollutants within the smoke plume increased ozone concentrations at the Folsom monitor.

This comprehensive weight of evidence includes documentation of the extensive nature of the fires. For each of the three exceptional events days, the evidence includes discussion of the day specific meteorological analysis, satellite data, $PM_{2.5}$, NO_x and ozone air quality data, ozone chemistry leading to elevated 1-hour ozone concentrations, and finally a discussion of how the 1-hour ozone concentrations exceed the normal historical fluctuations for the Folsom monitor.

B. Description of Fires

On June 20 and 21, 2008, a storm system moved through northern and central California. The storm system generated numerous thunderstorms, with countless cloud-to-ground lightning strikes. Because of record dry conditions, these lightning strikes started nearly 200 wildfires in the Coast Range and Sierra Nevada Mountains that surround the Sacramento Valley, eventually burning more than 1,000,000 acres. Most of the fires were not contained until late July or early August, with some continuing to burn through October. For more detailed information on the fires see Section 2, Appendix A Fire Table, and Appendix B, C, and D Meteorological Analysis for June 23, June 27, and July 10, 2008 respectively.

C. June 23, 2008

1. Transport Patterns

The hundreds of wildfires resulted in smoke, particulate matter, and ozone precursor emissions which spread throughout the Sacramento Valley. A detailed analysis of the transport patterns leading up to the 1-hour ozone exceedance at Folsom on June 23 is provided in Appendix B, Meteorological Analysis for June 23, 2008. Overall, the weather-related factors responsible for bringing fire emissions to Folsom were the drainage flow from the Coast Range and Sierra Nevada Mountains, the sea breeze flow from the San Francisco Bay Area (Bay Area), and the eddy circulation pattern in the southern Sacramento Valley which trapped wildfire emissions within the region. In addition, the midday increase in the height of the mixed layer allowed wildfire emissions aloft to reach the surface.

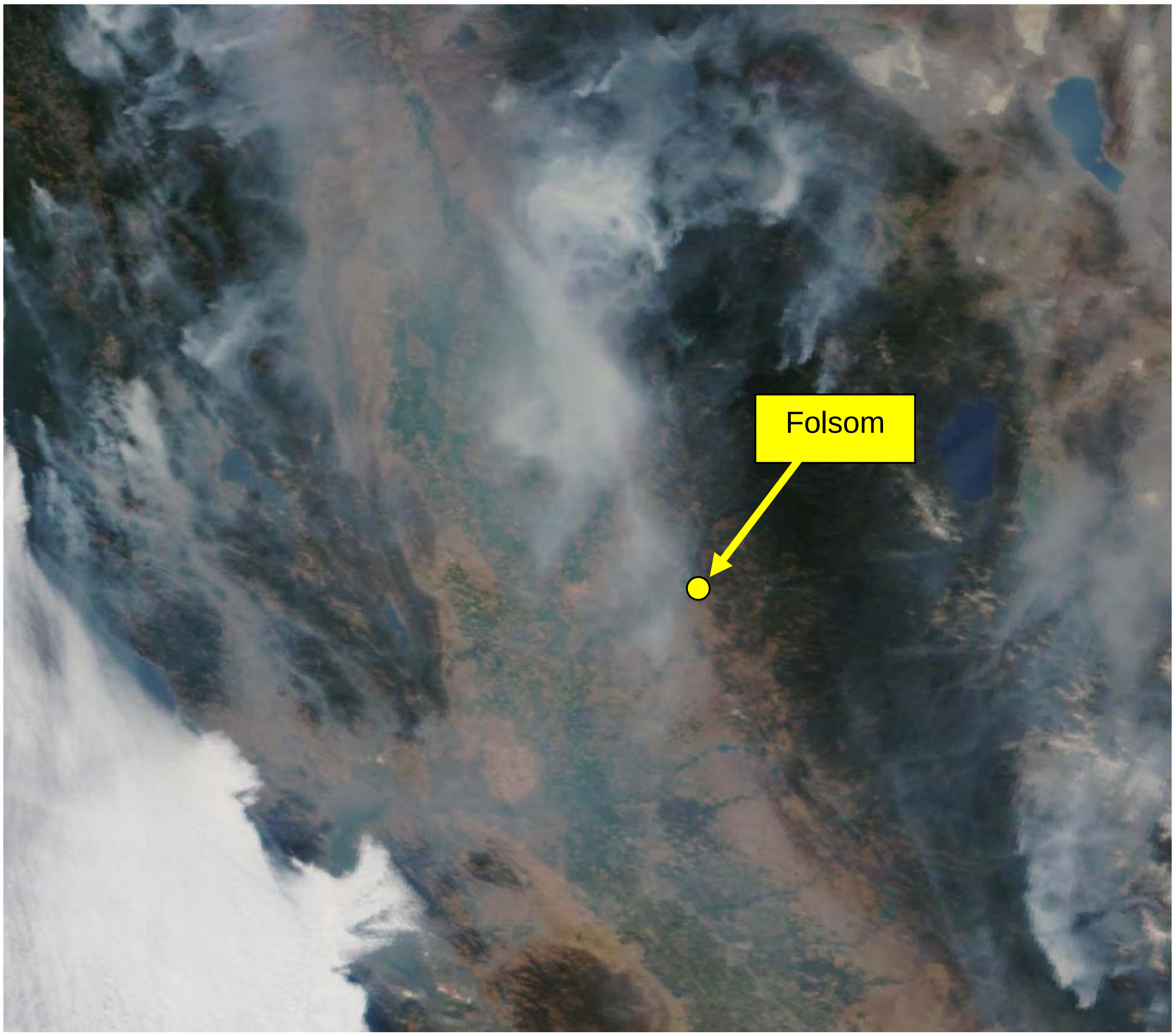
During the daylight hours on June 22, prevailing surface winds blew from the southwest, from the Bay Area into the southern Sacramento Valley. These winds carried emissions from wildfires burning out of control in the Coast Range Mountains into the southern Sacramento Valley.

During the overnight hours, air movement in the southern Sacramento Valley was controlled by the typical overnight downslope pattern on both sides of the Valley. Drainage flow from the east carried emissions from wildfires burning in the Sierra Nevada Mountains to the Sacramento Valley, while drainage flow from the west carried emissions from fires burning in the Coast Range. In addition, there was a sea breeze flow from the Bay Area through the Carquinez Strait that also brought emissions from fires in the Coast Range into the Sacramento Valley. The morning eddy circulation pattern subsequently trapped and accumulated these emissions in the southern Sacramento Valley. Figure 8 below, provides a satellite view on June 23 at 1143 PST illustrating the smoke observed in the Sacramento Valley. Surface weather observations also noted smoke at both 1000 and 1500 PST, as well as reduced visibility of 3 to 5 miles throughout the Bay Area and Sacramento Valley, including Folsom (see Appendix B for detailed discussion).

During the late morning/early afternoon of June 23, the eddy pattern dissipated and wildfire emissions that were previously trapped in the eddy were subsequently transported to Folsom. In addition, prevailing sea breeze winds continued to bring wildfire emissions from the Coast Range into the Sacramento region. Consistent with typical summer weather patterns, the height of the mixed layer increased throughout the day, especially in the afternoon, from approximately 150 meters to 600 meters. The change in the height of the mixed layer allowed fire emissions above the surface (but below the inversion) to reach the ground.

Figure 8

June 23, 2008 1143 PST Visible Satellite Image



NASA Visible Aqua MODIS True Color Satellite Image (250 meter resolution)
http://activefiremaps.fs.fed.us/imagery.php

2. $PM_{2.5}$ Concentrations

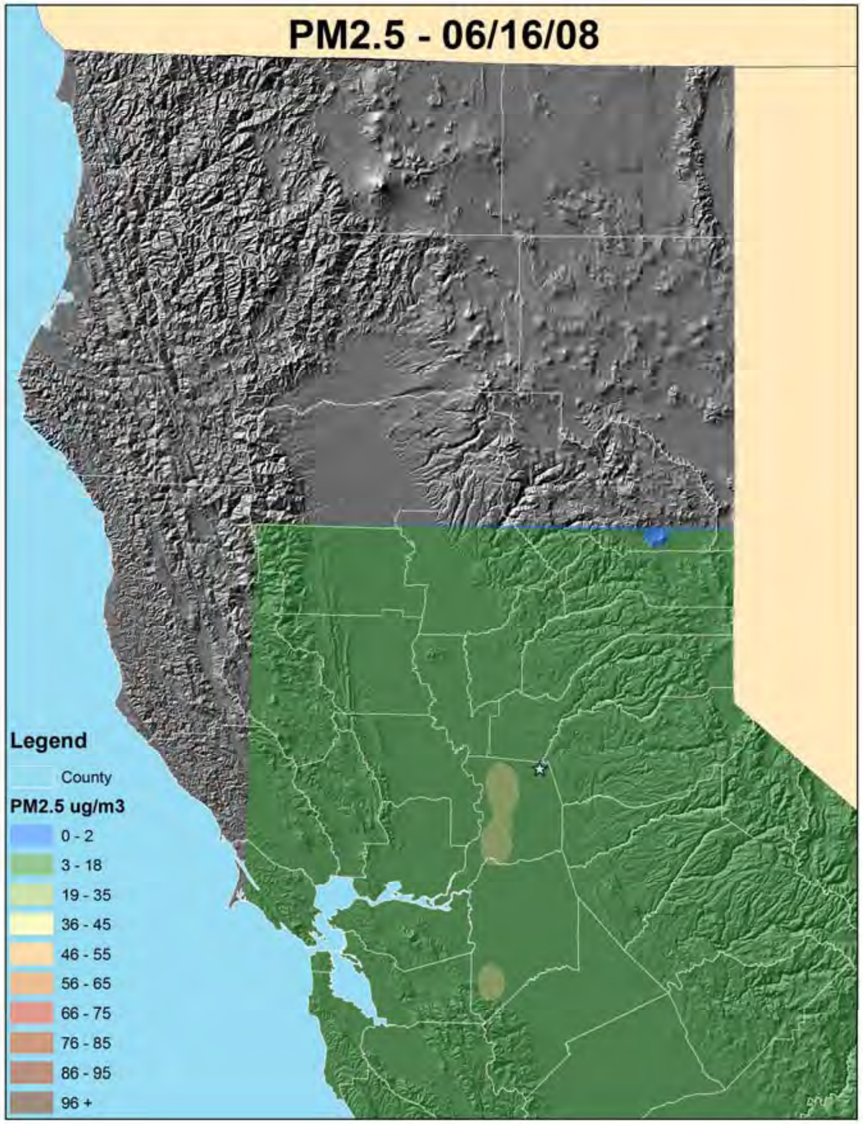
$PM_{2.5}$ is directly emitted during combustion, and elevated concentrations are an important indicator that emissions from the wildfires reached ground level monitors in the Sacramento region. Prior to the start of the fires, the $PM_{2.5}$ filter-based sites in northern and central California had typical concentrations far below the 24-hour national ambient air quality standard (NAAQS) of 35 µg/m^3 and even below the annual average NAAQS of 15 µg/m^3. Based on historical data for 2005 through 2007 in June and July, 24-hour average $PM_{2.5}$ concentrations at sites in the Sacramento area ranged from an average of 7.3 to 9.9 µg/m^3, and 98th percentile concentrations for the three year period ranged from 14.5 to 25.5 µg/m^3. For more information, please refer to the $PM_{2.5}$ Natural Events document submitted to U.S. EPA on July 20, 2009.

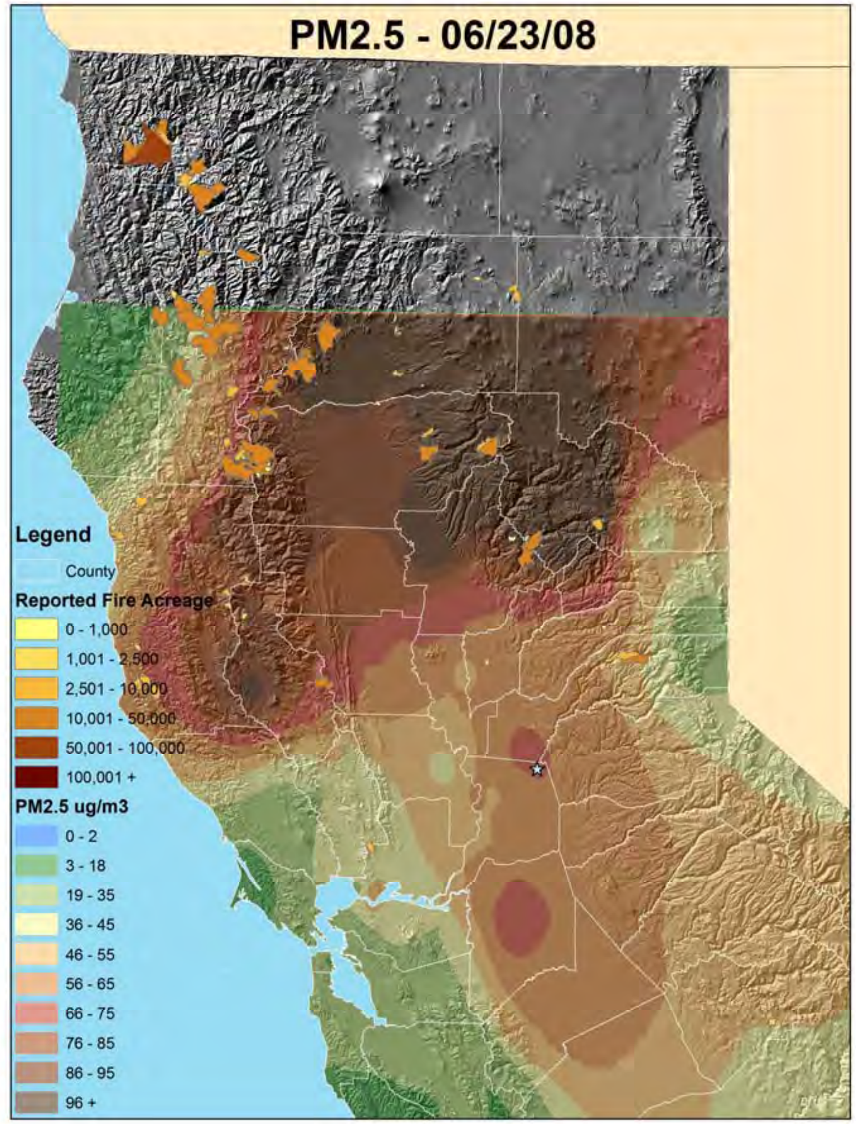
This changed after the fires started, when $PM_{2.5}$ concentrations rose from typical low summer seasonal levels to daily averages that exceeded the 24-hour NAAQS at many sites. In the Sacramento region, 24-hour average $PM_{2.5}$ concentrations ranged from 47 to 69 µg/m^3 by June 23, which is two to four times higher than the typical peak summer levels. Work conducted by STI identified June 16, 2008, as a day with similar meteorological conditions (referred to as the surrogate day). STI's analysis is detailed in Appendix Y. In order to determine the surrogate day, STI used local and regional-scale weather data at the surface and aloft. The analysis included average morning and afternoon surface winds and temperatures at various locations. The specific criteria used were intended to evaluate a variety of meteorological processes including transport, recirculation, and horizontal dispersion of pollution, the vertical mixing and dilution of pollution within the atmospheric boundary layer, and air temperature. Figure 9 compares 24-hour average $PM_{2.5}$ concentrations on the June 16, 2008 surrogate day to the June 23, 2008 fire day. The peak 24-hour average $PM_{2.5}$ concentration in the Sacramento region on June 23 of 69 µg/m^3 was more than three times the peak 24-hour average concentration of 19.4 µg/m^3 on the surrogate day.

ARB staff evaluated June 23 and the surrogate day and found there was no evidence to suggest that anthropogenic emission-generating activities differed significantly between the two days. Therefore, the most likely difference between the $PM_{2.5}$ concentrations measured on the two days, given the similarity in key meteorological parameters, was the presence of wildfire emissions on June 23.

Figure 9

24-hour Average $PM_{2.5}$ Concentrations on Surrogate and Fire Days





(Represents monitored data, surface $PM_{2.5}$)

3. $PM_{2.5}$ Speciation

Evaluation of $PM_{2.5}$ speciation data provides further evidence that the elevated $PM_{2.5}$ concentrations can be attributed to impacts from the wildfires. As shown in Figures 10 and 11 below, 24-hour average organic carbon levels were extremely high on June 23, and monthly average levoglucosan was much higher in June of 2008, compared to June of 2007. 24-hour average organic carbon levels in Sacramento County on June 20 were 7.7 $\mu g/m^3$, increasing on June 23 to 45 $\mu g/m^3$. In addition, monthly average levoglucosan levels were 0.01 $\mu g/m^3$ in June 2007 compared to 0.208 $\mu g/m^3$ in June 2008, a 20-fold increase. Both of these species are markers for biomass burning.

Figure 10
24-hour Average Particulate Matter Composition during Summer Months in 2008

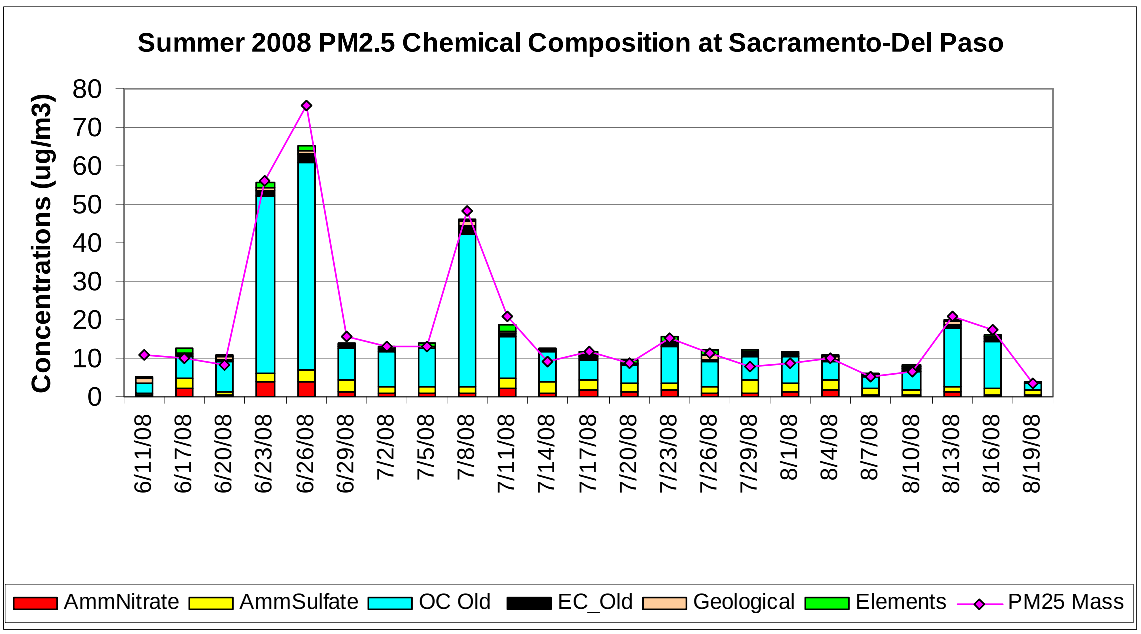
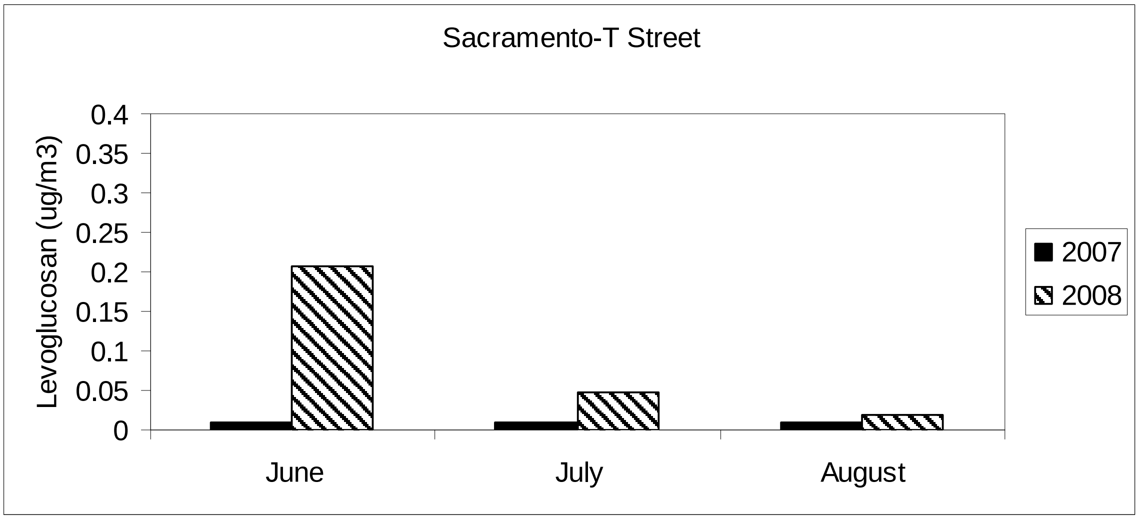


Figure 11
Monthly Average Levoglucosan Concentrations during Summer Months in 2007 versus 2008



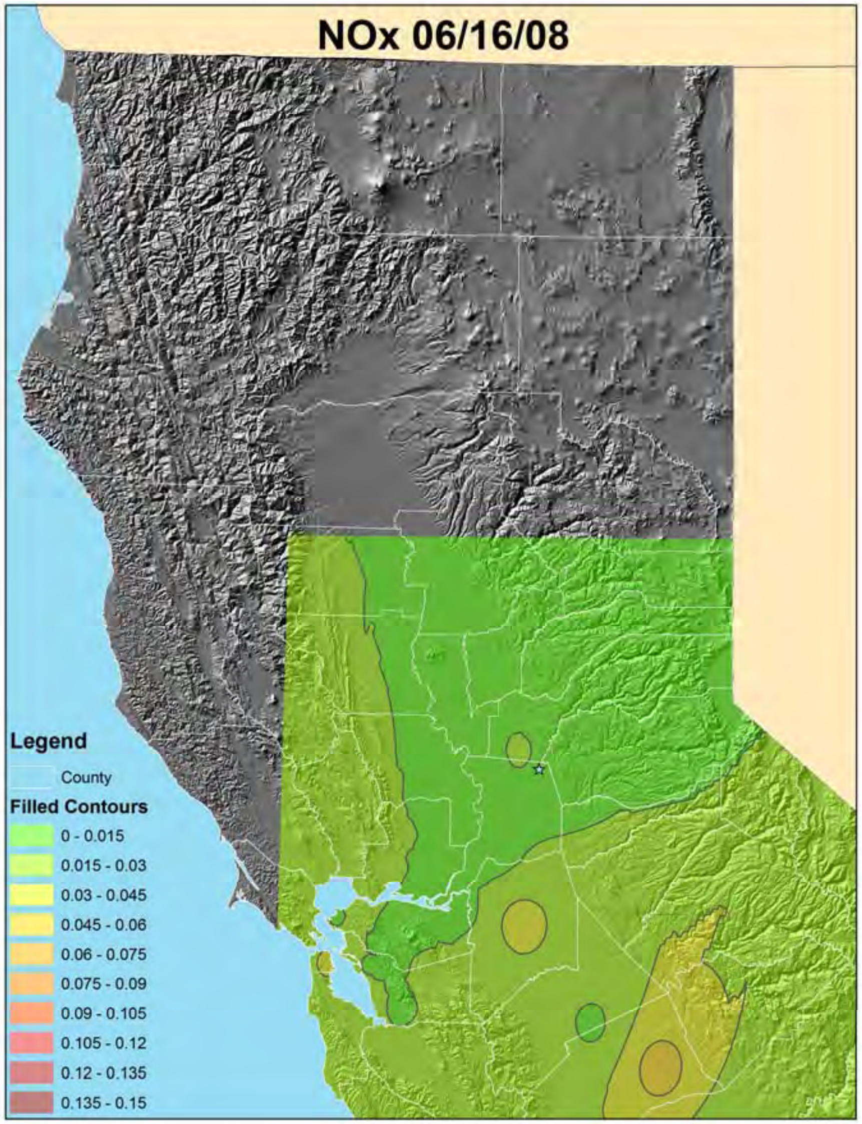
Note: *June 2007 average based on samples collected on 6/5, 6/11, 6/17, 6/23, and 6/26*
June 2008 average based on samples collected on 6/11, 6/17, 6/23, and 6/29
July 2007 average based on samples collected on 7/5, 7/11, 7/17, 7/23, and 7/29
July 2008 average based on samples collected on 7/5, 7/8, 7/17, 7/23, and 7/29
August 2007 average based on samples collected on8/4, 8/7, 8/16, 8/22, and 8/28
August 2008 average based on samples collected on 8/4, 8/10, 8/16, and 8/19

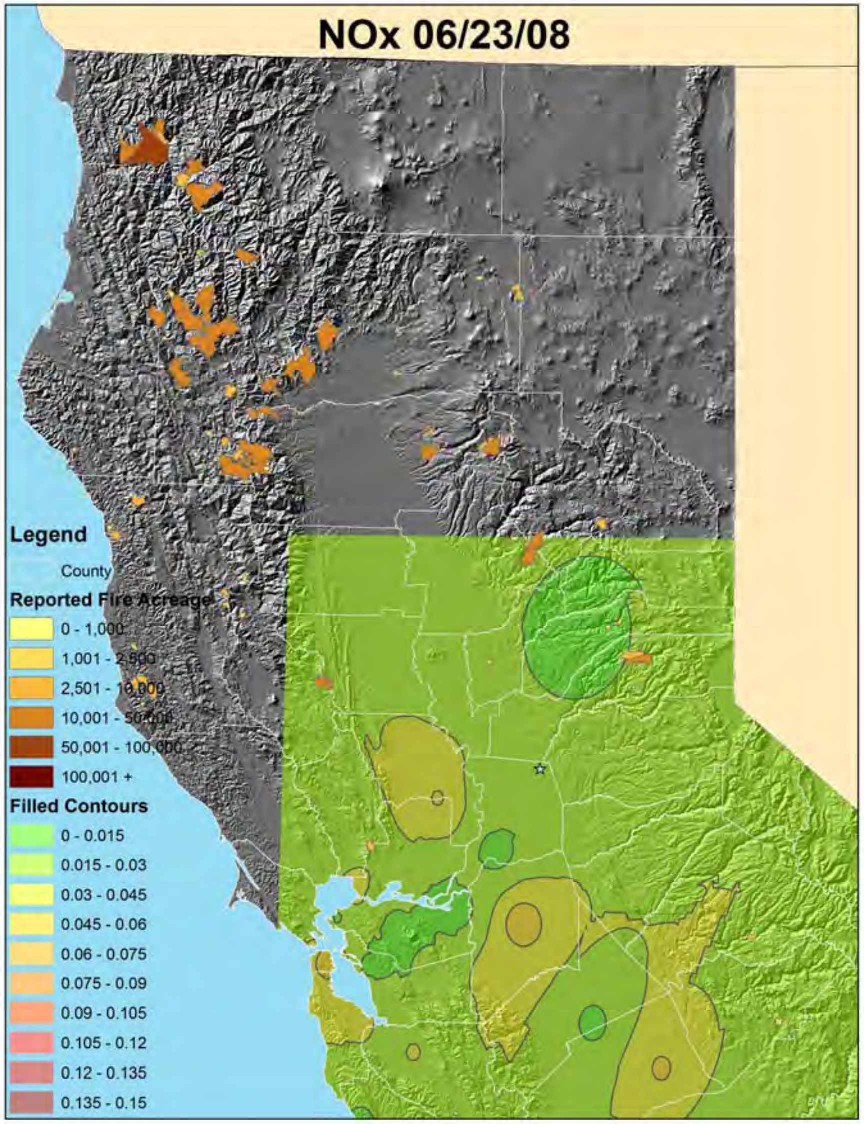
4. Ozone Precursor Concentrations

The previous sections have demonstrated that significant smoke and elevated $PM_{2.5}$ concentrations were observed throughout the Sacramento Valley on June 23, 2008. Evaluation of satellite data and comparison to concentrations on the surrogate day further indicate that there were also elevated levels of NO_x, a key precursor to ozone, both at the surface and aloft on June 23, 2008. As shown in Figure 12, on the June 16, 2008 surrogate day, most of the sites in the southern Sacramento Valley, including Folsom, had 1-hour maximum NO_x concentrations below 18 ppb. In contrast, on June 23, 2008, NO_x concentrations were significantly higher than on the surrogate day at many sites in the region. Maximum 1-hour NO_x concentrations at Folsom reached 16 ppb compared to 9 ppb, indicating the presence of additional precursors for ozone formation in the vicinity of Folsom. In addition, maximum 1-hour NO_x concentrations at Sacramento T Street reached 26 ppb compared to 9 ppb on the surrogate day, Davis reached 46 ppb compared to 12 ppb, and Sacramento Airport Road reached 29 ppb compared to 17 ppb. These sites are upwind of Folsom during the morning eddy circulation and daytime sea breeze flow from the west, providing additional evidence of higher levels of ozone precursors along several of the key transport pathways to Folsom. As noted previously, there were no known differences in anthropogenic NO_x emissions. Thus, the most likely difference in measured NO_x concentrations was the presence of wildfire emissions on June 23.

Figure 12

Maximum 1-hour Average Surface NO_x Concentration on Surrogate and Fire Days





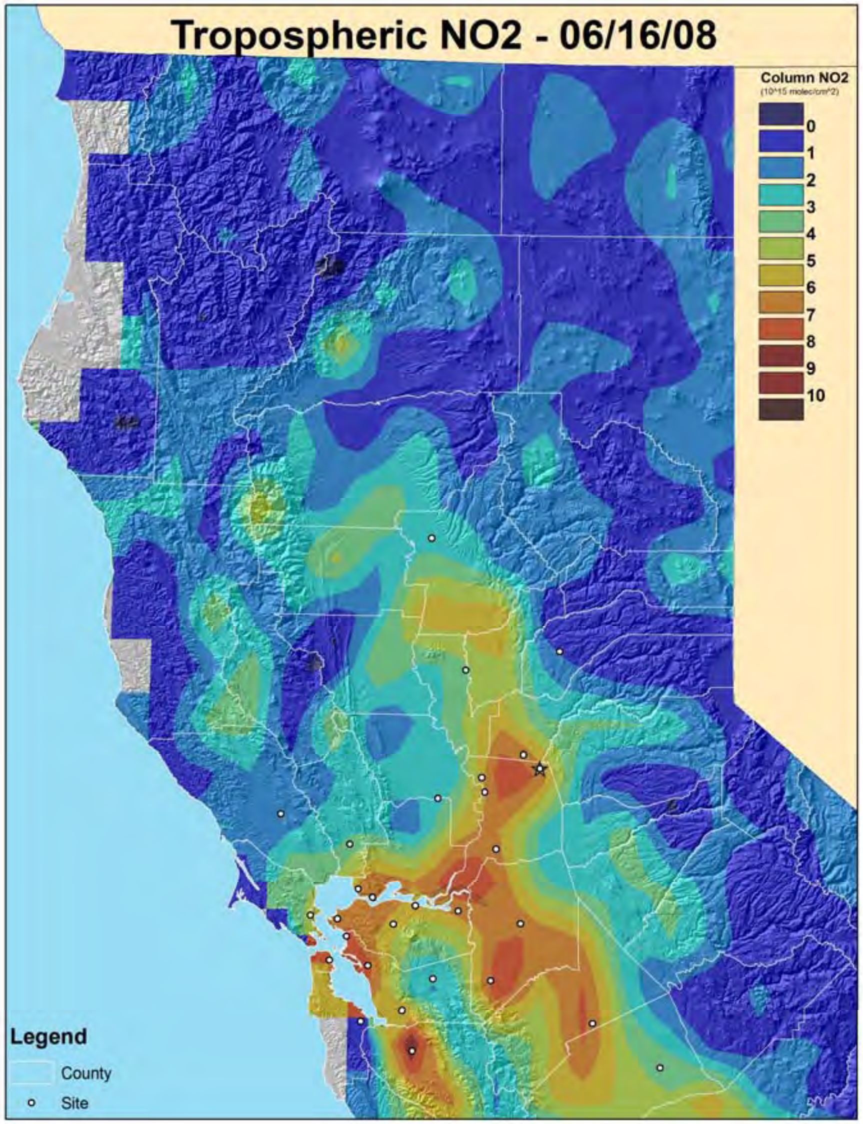
(Represents monitored data, surface NO_x)

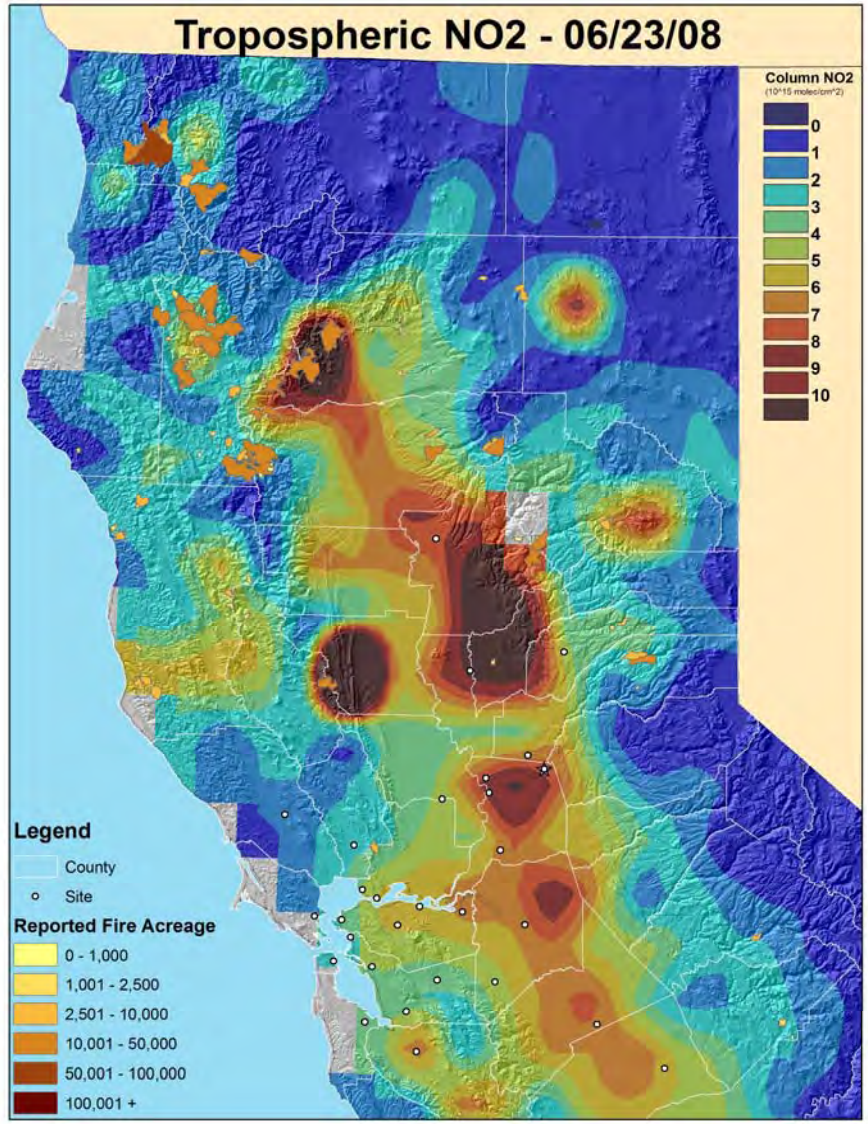
In addition to elevated NO_x at the surface, transport of NO_x above the surface layer can also be inferred from the satellite images taken by NASA's Ozone Monitoring Instrument (OMI). These satellite images derive from snapshots of the atmosphere as the satellite passes over northern California. OMI is able to isolate the troposphere, giving measurements of total column NO_2 from the surface to the height of the tropopause, about 15 km above ground level. NO_2 measurements do not give the complete picture of NO_x, since they do not include NO concentrations. However, except for fresh emissions (i.e., very close to the emissions source,) NO_2 usually has a much higher concentration than NO. Therefore, NO_2 is an appropriate surrogate for NO_x in aged air masses.

Comparing OMI satellite images for June 23, 2008 with comparable images from June 16, 2008 shows dramatically increased column NO_2 downwind of the major wildfire areas and throughout the Sacramento Valley (see Figure 13). A column measurement includes surface NO_2 in the boundary layer, but the magnitude of the increase is significantly greater for the column measurement than for the surface NO_x measurement discussed earlier. This observation, combined with the fact that wildfire plumes are known to be buoyant, suggests that a good portion of this NO_2 may have been above the surface. It is likely that the wildfire-related NO_x above the surface also intermingled with wildfire-related NO_x at the surface as the mixed layer deepened from approximately 150 meters in the morning, to 600 meters by early afternoon on June 23. Evidence that additional wildfire emissions from aloft may have mixed downward during the deepening of the mixed layer is suggested by the large increase in hourly $PM_{2.5}$ concentrations during mid-day at a number of sites in the Sacramento region, including Folsom (see Figure 14).

Figure 13

Tropospheric NO_2 Concentrations on Surrogate and Fire Days

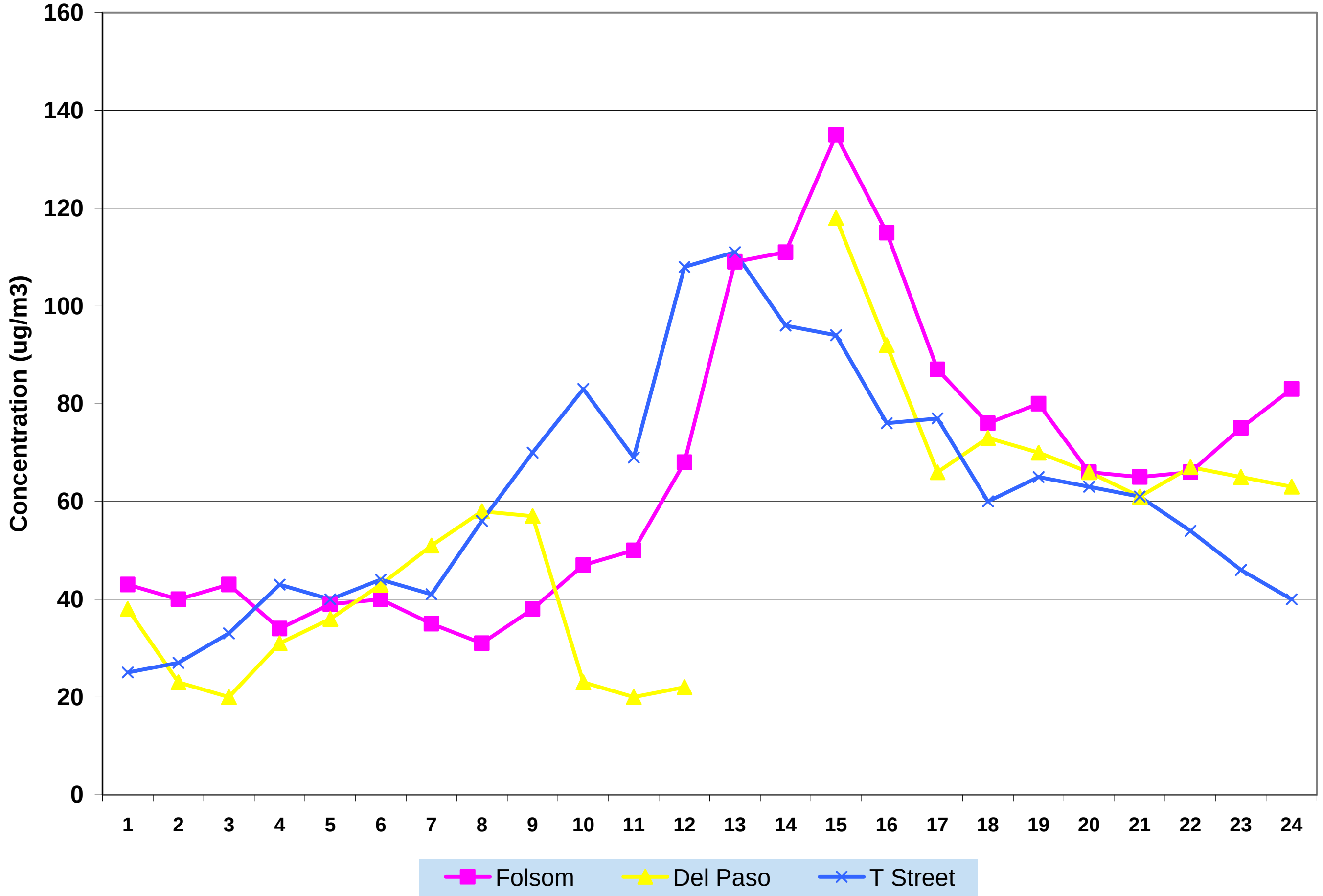




(Represents satellite data, tropospheric NO_2 column)

Figure 14

Hourly $PM_{2.5}$ Concentrations on June 23, 2008



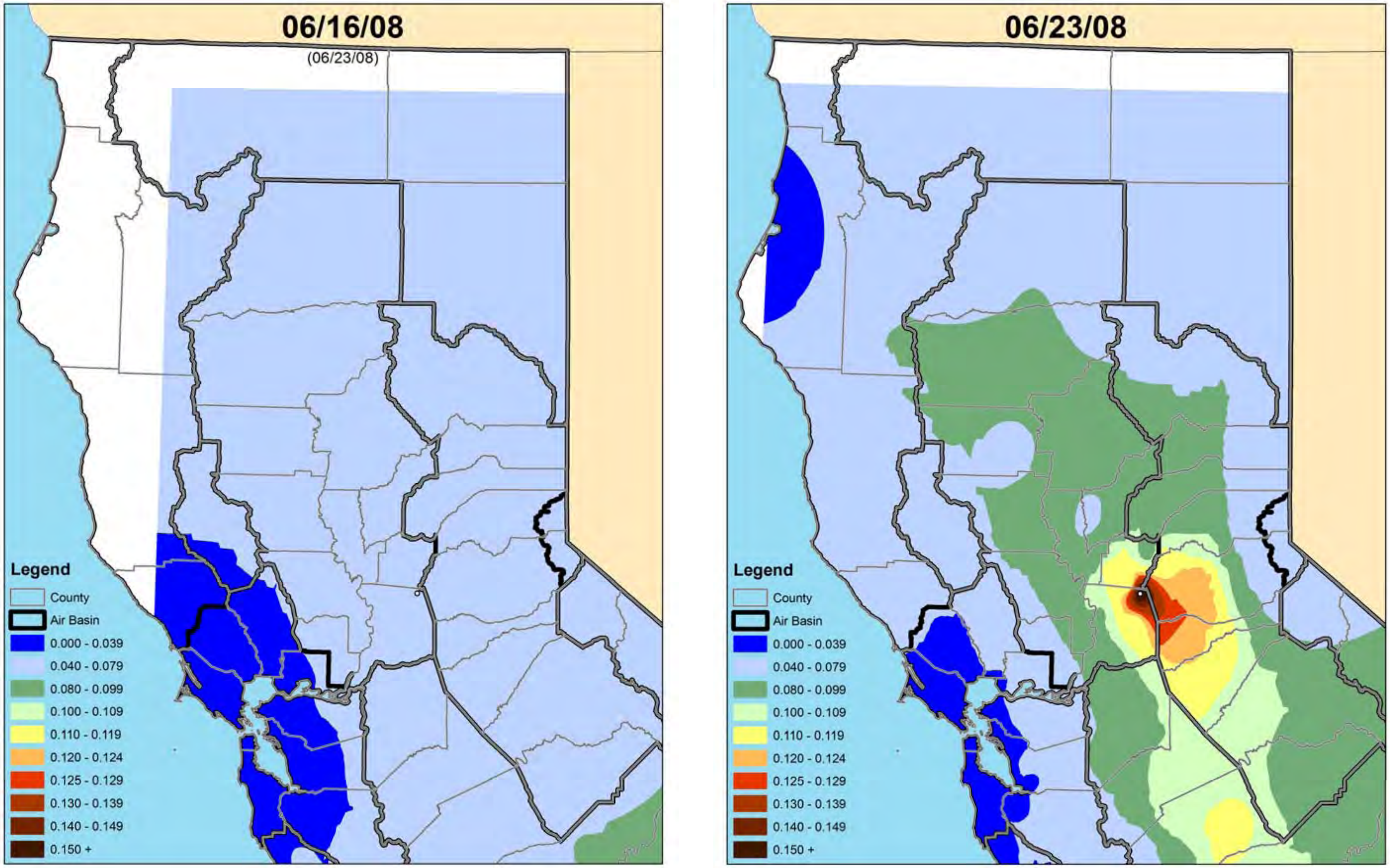
5. Ozone Chemistry and Concentrations

The increased precursor emissions from the fires throughout the Sacramento Valley resulted in substantial amounts of ozone formation, leading to the 1-hour ozone exceedance at Folsom on June 23, 2008. Folsom was sufficiently downwind of the fires that their primary impact was to increase ozone due to the large amount of wildfire-related precursors, rather than decrease ozone due to either near-source NO_x titration or reduced solar insolation from the smoke. Section 2 summarizes the key mechanisms by which emissions from wildfires can increase ozone, as well as past research which has documented increases in ozone formation downwind of wildfires.

On June 23, 2008 the Folsom monitor had the highest ozone concentration in the region, with a 1-hour maximum of 161 ppb. As shown in Figure 15 below, comparison of June 23, 2008 with the surrogate day of June 16, 2008 illustrates the impact of the wildfires on ozone concentrations at Folsom and the surrounding monitors. The maximum 1-hour ozone concentration on the June 16, 2008 surrogate day of 79 ppb was nearly one-half that on June 23, 2008 and far below the standard. In addition to the exceedance at Folsom, ozone was elevated throughout much of the Sacramento Valley and Sierra foothill region on June 23, 2008. Roseville had a maximum 1-hour ozone concentration of 111 ppb, and Sloughhouse had a maximum of 115 ppb, both of which were more than 40 percent higher than the surrogate day. In comparison, on the surrogate day Roseville reached a maximum 1-hour ozone concentration of only 77 ppb, and Sloughhouse reached 69 ppb.

Figure 15

Maximum 1-hour Ozone Concentrations on Surrogate and Fire Days



(Represents monitored data, surface Ozone)

6. Summary

Hundreds of wildfires were burning out of control and surrounded the Sacramento Valley prior to the 1-hour exceedance at Folsom on June 23, 2008. This summary documents the transport of emissions from fires burning in the Coast Range and Sierra Nevada Mountains to the Sacramento Valley. Wildfire emissions transported both at the surface and above the surface intermingled as the mixed layer deepened on June 23, overwhelming the region and causing the 1-hour ozone exceedance at Folsom.

This section has therefore demonstrated a clear causal relationship based on the following evidence:

- Meteorological observations and analyses document the transport of smoke and emissions from fires burning in the Coast Range and Sierra Nevada Mountains, demonstrating that these emissions reached the Folsom area.

- Satellite data show evidence of thick smoke covering the Sacramento Valley. Airport observations document smoke and limited visibility, indicating that smoke reached the ground.

- Evidence of broad surface level impacts of the wildfires is further demonstrated by observed $PM_{2.5}$ concentrations in Sacramento. Prior to the start of the fires, $PM_{2.5}$ levels were at typical low summer levels. After the start of the fires, $PM_{2.5}$ concentrations were two to four times higher than normal summer levels and organic carbon and levoglucosan, markers for biomass burning, were significantly elevated. These measurements confirm a broad regional impact from the wildfires at surface monitors throughout the Sacramento Valley.

- Surface data and satellite imagery show increased NO_x, both at the surface and above the surface. NO_x is an important precursor to ozone formation.

- Pollution in the plume increased ozone consistent with the science of the conceptual model for the event. Ozone levels were anomalously elevated throughout the Sacramento region, including the exceedance at Folsom. This regional increase in ozone, consistent with the extent and timing of increase in $PM_{2.5}$, indicates that it is more likely that the fire emissions increased ozone due to increased precursors, rather than decreased ozone due to decreased solar insolation or increased ozone titration.

- The exceedance of 161 ppb at Folsom is well above normal historical levels. It is among the highest concentration ever recorded for this site and greater than the 99th percentile of frequency of occurrence for 1-hour maximum ozone concentrations from May through October, 2004 through 2008, demonstrating that it is beyond normal historical fluctuations (see Section F).

D. June 27, 2008

1. Transport Patterns

From June 24 to June 27, the wildfires that began during the June 20 – 21 storm continued to burn in the Coast Range and Sierra Nevada Mountains surrounding the Sacramento Valley. By June 27 tens of thousands of acres had burned within 100 miles of Folsom, adversely impacting $PM_{2.5}$ and ozone air quality. A detailed analysis of the transport patterns leading to the 1-hour ozone exceedance at Folsom on June 27 is provided in Appendix C, Meteorological Analysis for June 27, 2008. In summary, the weather-related factors responsible for bringing fire emissions to Folsom were the drainage flow from the Coast Range and Sierra Nevada Mountains, and the sea breeze flow from the Bay Area. In addition, the eddy circulation pattern and the negative pressure gradient further trapped wildfire emissions within the southern Sacramento Valley, and the increase in the height of the mixed layer allowed wildfire emissions aloft to reach the surface.

Overall, the weather patterns causing the ozone exceedance on June 27 were very similar to those of June 23. Overnight surface drainage winds transported additional wildfire emissions and smoke from both the Coast Range and the Sierra Nevada Mountains to the southern Sacramento Valley. The sea breeze flow from the Bay Area also brought emissions from fires in the Coast Range to the southern Sacramento Valley. The eddy circulation pattern then trapped and accumulated these emissions in the southern Sacramento Valley. Figure 16 provides a satellite view on June 27 at 1109 PST illustrating that the Sacramento Valley was covered with smoke. Surface weather observations also noted smoke and haze starting with hour 0300 and continuing throughout the day, as well as reduced visibility of 2 to 4 miles throughout the Sacramento Valley and at Folsom (see Appendix C for detailed discussion).

During the late morning/early afternoon of June 27, the eddy pattern weakened and a portion of the wildfire emissions were subsequently transported to the Sacramento urban area, including Folsom. Similar to June 23, the height of the mixed layer also increased throughout the late morning and afternoon, from approximately 150 meters in the morning to more than 500 meters in the afternoon, allowing fire emissions above the surface (but below the inversion) to reach the ground. In contrast, the dispersion of wildfire emissions was more limited on June 27 due to the negative pressure gradient (Sacramento to Reno) that kept wildfire emissions from moving out of the southern Sacramento Valley (refer to Appendix C for more information).

Figure 16
June 27, 2008 1109 PST Visible Satellite Image

NASA Visible Terra MODIS Bands 1, 4, and 3 True Color Satellite Image (250 meter resolution)
http://activefiremaps.fs.fed.us/data/imagery/2008179/ca-north-000/crefl1_A2008179190901-2008179192011_250m_ca-north-000_143.jpg

2. $PM_{2.5}$ Concentrations

$PM_{2.5}$ is directly emitted during combustion, and elevated concentrations are an important indicator that emissions from the wildfires reached ground level monitors in the Sacramento region. Prior to the start of the fires, the $PM_{2.5}$ filter-based sites in northern and central California had typical concentrations far below the 24-hour NAAQS of 35 $\mu g/m^3$ and even below the annual average NAAQS of 15 $\mu g/m^3$. Based on historical data for 2005 through 2007 in June and July, 24-hour average $PM_{2.5}$ concentrations at sites in the Sacramento area ranged from an average of 7.3 to 9.9 $\mu g/m^3$, and 98th percentile concentrations for the three-year period ranged from 14.5 to 25.5 $\mu g/m^3$. For more information, please refer to the $PM_{2.5}$ Natural Events document submitted to U.S. EPA on July 20, 2009.

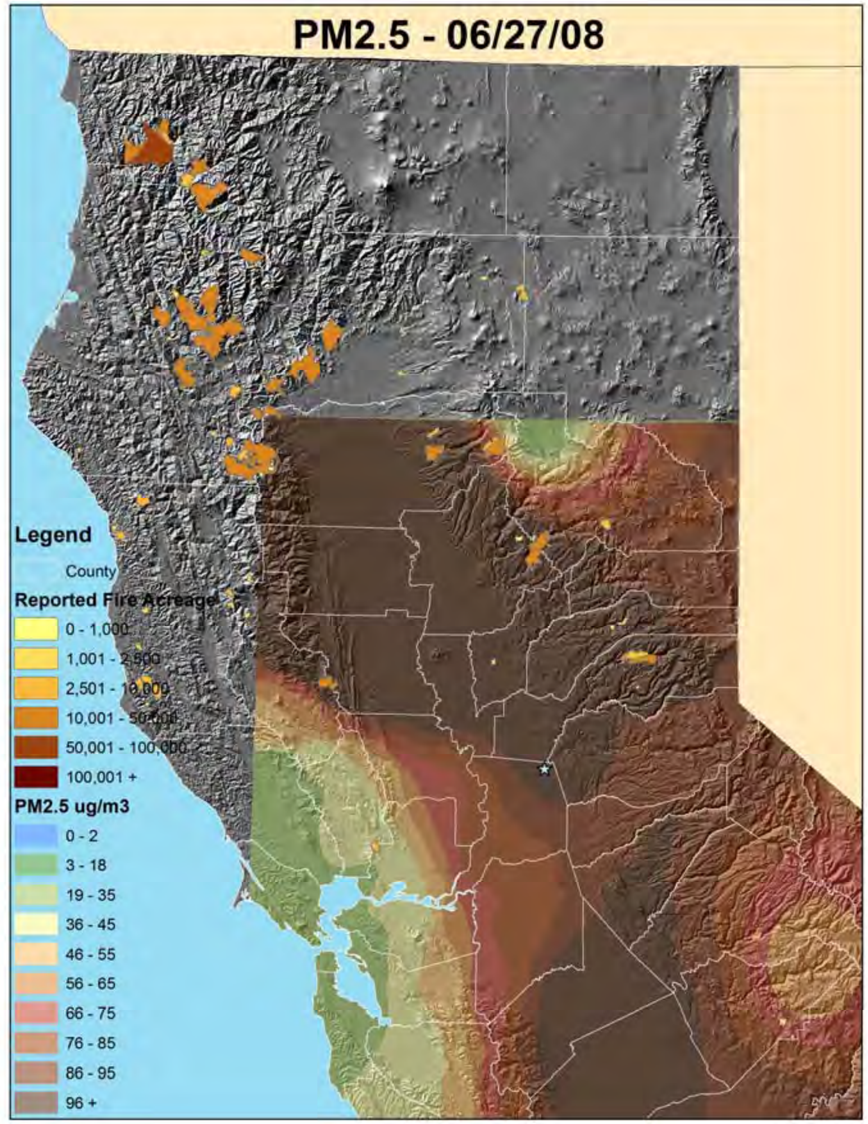
This changed after the fires started, when $PM_{2.5}$ concentrations rose from typical low summer, seasonal levels to daily average that exceeded the 24-hour NAAQS at many sites. Although there are no $PM_{2.5}$ filter based measurements for Sacramento County on June 27, data is available for June 26. In the Sacramento region, 24-hour average $PM_{2.5}$ concentrations ranged from 64 to 70 $\mu g/m^3$. Continuous $PM_{2.5}$ measurements on June 27 show 24-hour average concentrations ranging from 66 to 125 $\mu g/m^3$, five to nearly ten times higher than the typical summer levels.

STI identified July 9, 2007 as a day with similar meteorological conditions (referred to as the surrogate day.) STI's analysis is detailed in Appendix Y. Figure 17 compares 24-hour average $PM_{2.5}$ concentrations on the surrogate day to June 27, 2008. The peak 24-hour average $PM_{2.5}$ concentration in the Sacramento region on June 27 was 125 $\mu g/m^3$, more than eight times the peak 24-hour concentration of 14.1 $\mu g/m^3$ on the surrogate day.

ARB staff evaluated June 27, 2008 and the surrogate day and found there was no evidence to suggest that anthropogenic emission-generating activities differed significantly between the two days. Therefore, the most likely difference between the $PM_{2.5}$ concentrations measured on the two days, given the similarity in key meteorological parameters, was the presence of wildfire emissions on June 27.

Figure 17

24-hour Average $PM_{2.5}$ Concentrations on Surrogate and Fire Days



(Represents monitored data, surface $PM_{2.5}$)

3. $PM_{2.5}$ Speciation

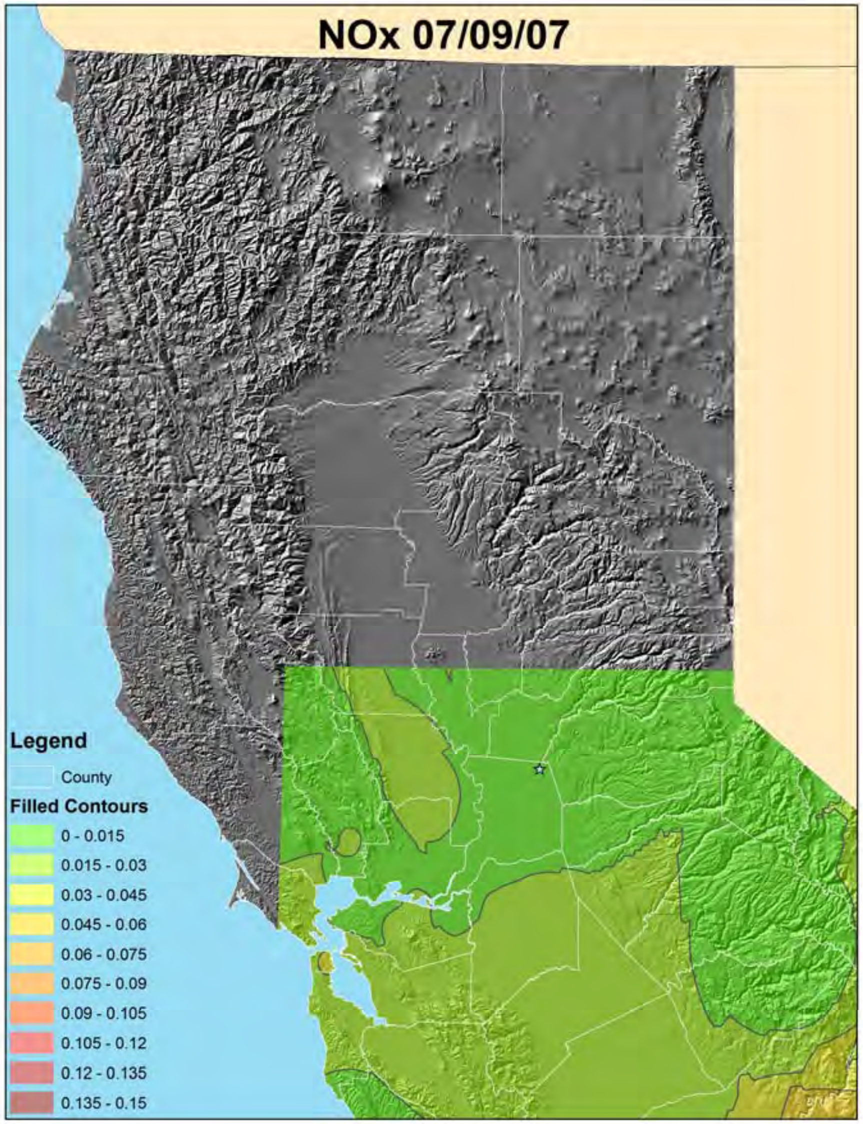
Evaluation of $PM_{2.5}$ speciation data provides further evidence that the elevated $PM_{2.5}$ concentrations can be attributed to impacts from the wildfires. As shown in Figures 3 and 4 previously, 24-hour average organic carbon levels on the day prior to the June 27 exceedance were extremely high and monthly average levoglucosan levels were much higher in June of 2008, compared to 2007. 24-hour average organic carbon levels on June 20 were 7.7 µg/m^3 but increased on June 26 to 54 µg/m^3, a six-fold increase (refer to Figure 3). In addition, monthly average levoglucosan levels (refer to Figure 4) were 0.01 µg/m^3 in June 2007 compared to 0.208 µg/m^3 in June 2008, a 20-fold increase. Both of these species are markers for biomass burning.

4. Ozone Precursor Concentrations

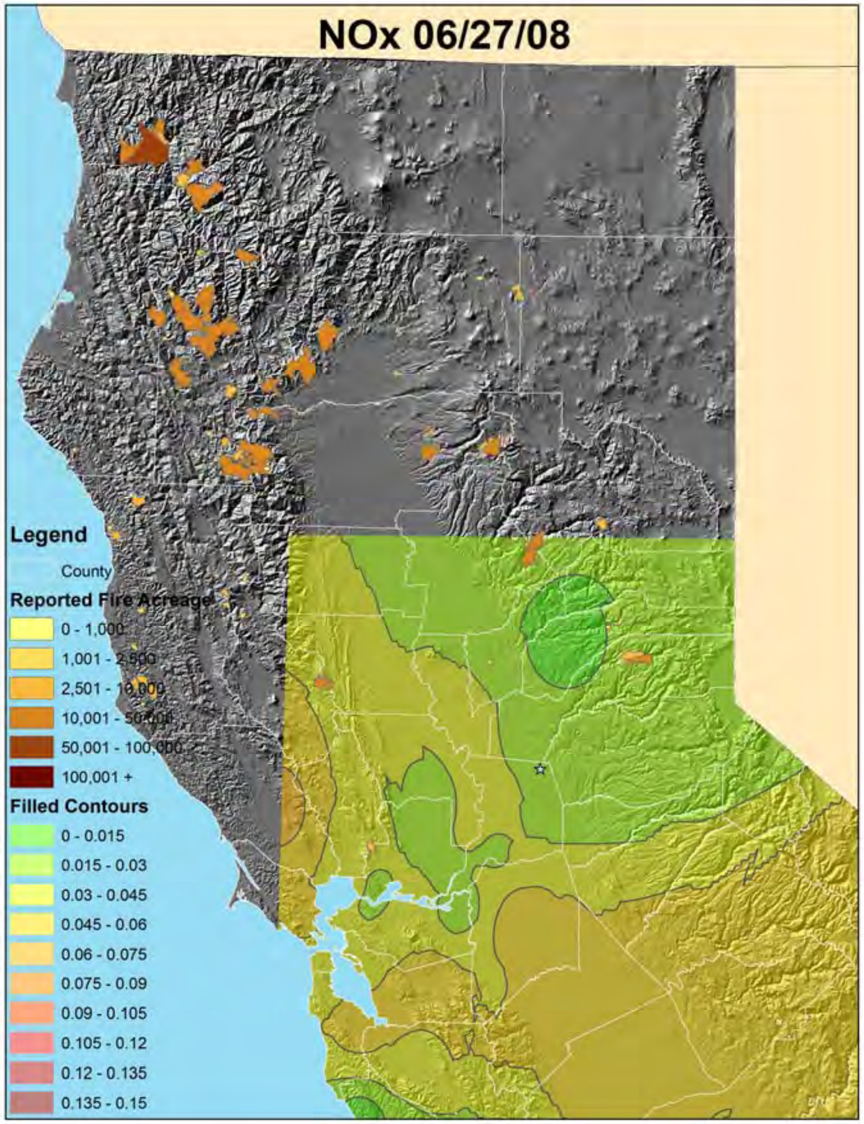
The previous sections have demonstrated that significant smoke and elevated $PM_{2.5}$ concentrations were observed throughout the Sacramento Valley on June 27, 2008. Evaluation of satellite data and comparison to concentrations on the surrogate day further indicate that there were also elevated levels of NO_x, a key precursor to ozone, both at the surface and aloft on June 27, 2008. As shown in Figure 18, on the July 9, 2007 surrogate day, most of the Sacramento region had maximum 1-hour NO_x concentrations below 19 ppb. In contrast, surface NO_x was significantly elevated throughout the region on June 27, 2008, compared with the July 9, 2007 surrogate day. Maximum 1-hour NO_x concentrations at Folsom reached 19 ppb compared to 10 ppb, indicating the presence of additional precursors for ozone formation in the vicinity of Folsom. In addition, maximum 1-hour NO_x concentrations at Sacramento T Street reached 49 ppb compared to 12 ppb on the surrogate day, and Sacramento Airport Road reached 43 ppb compared to 16 ppb. Both of these sites are upwind of Folsom during the morning eddy circulation and daytime sea breeze flow from the west, providing additional evidence of higher levels of ozone precursors along several of the key transport pathways to Folsom. As noted previously, there were no known differences in anthropogenic NO_x emissions. Thus, the most likely difference in measured NO_x concentrations was the presence of wildfire emissions on June 27.

Figure 18

Maximum 1-hour Surface NO_x Concentrations on Surrogate and Fire Days



(Represents monitored data, surface NO_x)

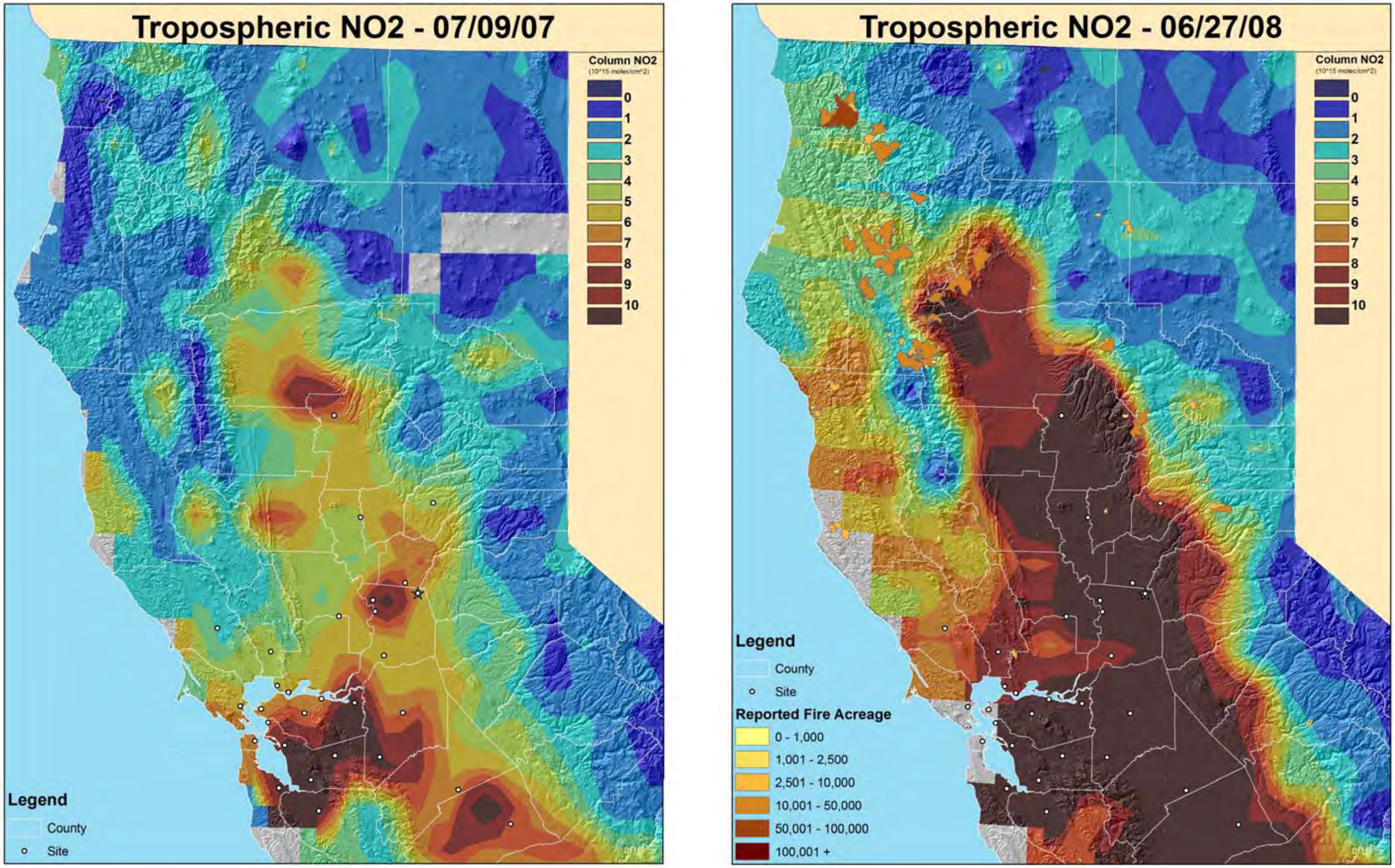


In addition to elevated NO_x at the surface, transport of NO_x above the surface layer can also be inferred from satellite images taken by NASA's Ozone Monitoring Instrument (OMI). These satellite images derive from snapshots of the atmosphere as the satellite passes over northern California. OMI is able to isolate the troposphere, giving measurements of total column NO_2 from the surface to the height of the tropopause, about 15 km above ground level. NO_2 measurements do not give the complete picture of NO_x, since they do not include NO concentrations. However, except for fresh emissions (i.e., very close to the emissions source,) NO_2 usually has a much higher concentration than NO. Therefore, NO_2 is an appropriate surrogate for NO_x in aged air masses.

OMI satellite data show that tropospheric NO_2 was markedly elevated throughout the Sacramento Valley on June 27, 2008 in comparison with the July 9, 2007 surrogate day (see Figure 19). The increase over the surrogate day is more dramatic for the column NO_2 measurement than for the surface NO_x measurement. This observation, combined with the fact that wildfire plumes are known to be buoyant, suggests that the greatest portion of the NO_2 increase measured by OMI may have been above the surface. However, it is likely that this increased NO_x above the surface intermingled with wildfire pollutants at the surface as the mixed layer deepened from approximately 150 meters to 500 meters in the afternoon of June 27, 2008. While hourly $PM_{2.5}$ concentrations remained elevated throughout the day at Folsom, the increase in hourly $PM_{2.5}$ concentrations during the morning into early afternoon at Sacramento T Street provide evidence that wildfire emissions from aloft may have mixed downward as the mixed layer increased (see Figure 20).

Figure 19

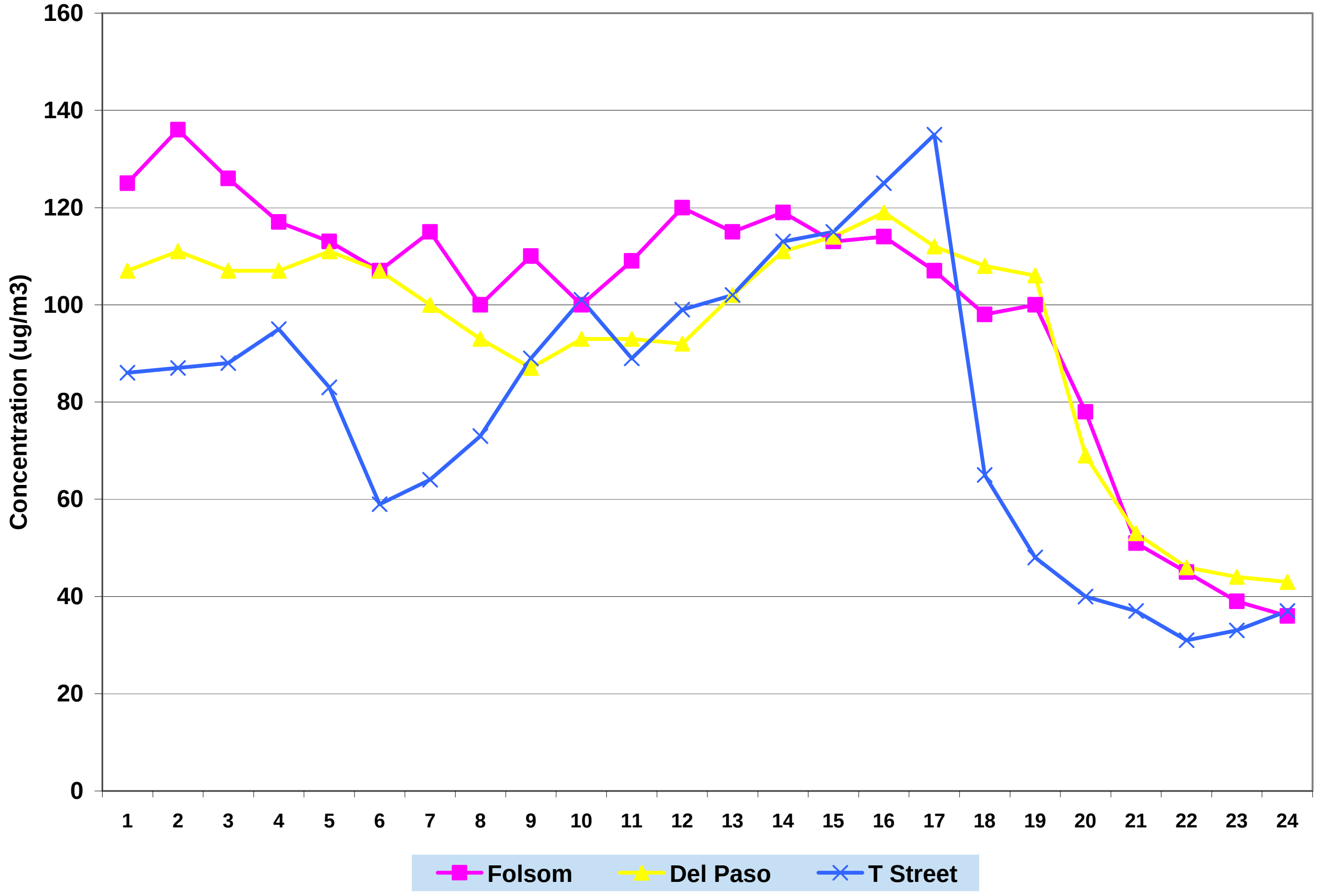
Tropospheric NO_2 Concentrations on Surrogate and Fire Days



(Represents satellite data, tropospheric NO_2 column)

Figure 20

Hourly $PM_{2.5}$ Concentrations on June 27, 2008



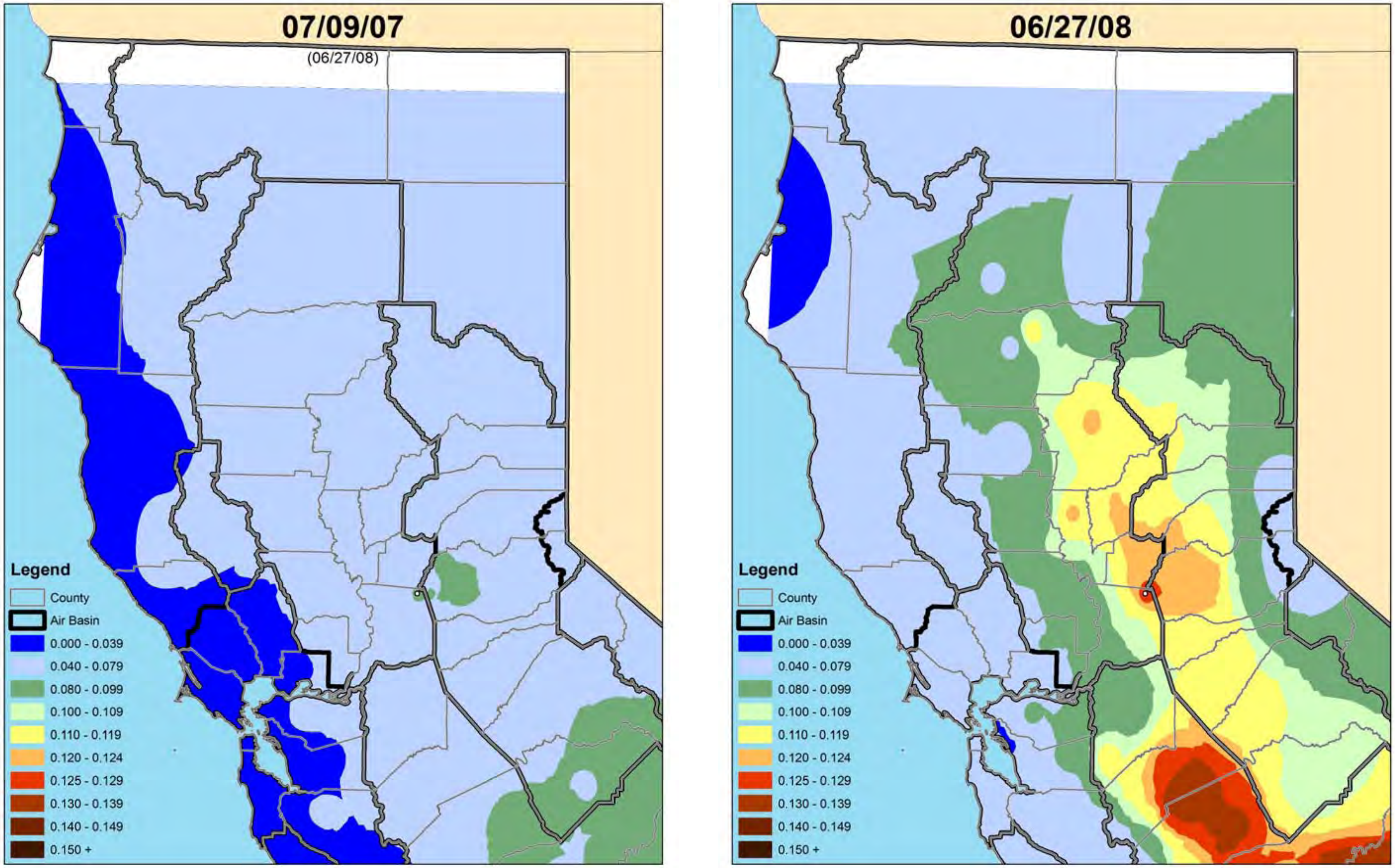
5. Ozone Chemistry and Concentrations

The increased precursor emissions from the fires throughout the Sacramento Valley resulted in substantial amounts of ozone formation, leading to the 1-hour ozone exceedance at Folsom on June 27. Folsom was sufficiently downwind of the fires that their primary impact was to increase ozone due to the large amount of wildfire-related precursors, rather than decrease ozone due to either near-source NO_x titration or reduced solar insolation from the smoke. Section 2 summarizes the key mechanisms by which emissions from wildfires can increase ozone, as well as past research which has documented increases in ozone formation downwind of wildfires.

On June 27, 2008, the Folsom monitor had the highest ozone concentration in the region, with a 1-hour maximum of 129 ppb. As shown in Figure 21, comparison of June 27, 2008 with the July 9, 2007 surrogate day illustrates the impact of the wildfires on ozone concentrations at Folsom and the surrounding monitors. The maximum 1-hour ozone concentration on the July 9, 2007 surrogate day was 84 ppb, approximately two-thirds that of June 27, 2008 and far below the standard. In addition to the exceedance at Folsom, ozone was elevated throughout much of the Sacramento Valley and Sierra foothill region on June 27, 2008. Roseville had a maximum 1-hour ozone concentration of 122 ppb, and Sloughhouse had a maximum of 107 ppb, both of which were 67 percent higher than the surrogate day. On the surrogate day, Roseville reached a maximum 1-hour ozone concentration of only 73 ppb, and Sloughhouse reached 64 ppb.

Figure 21

Maximum 1-hour Ozone Concentrations on Surrogate and Fire Days



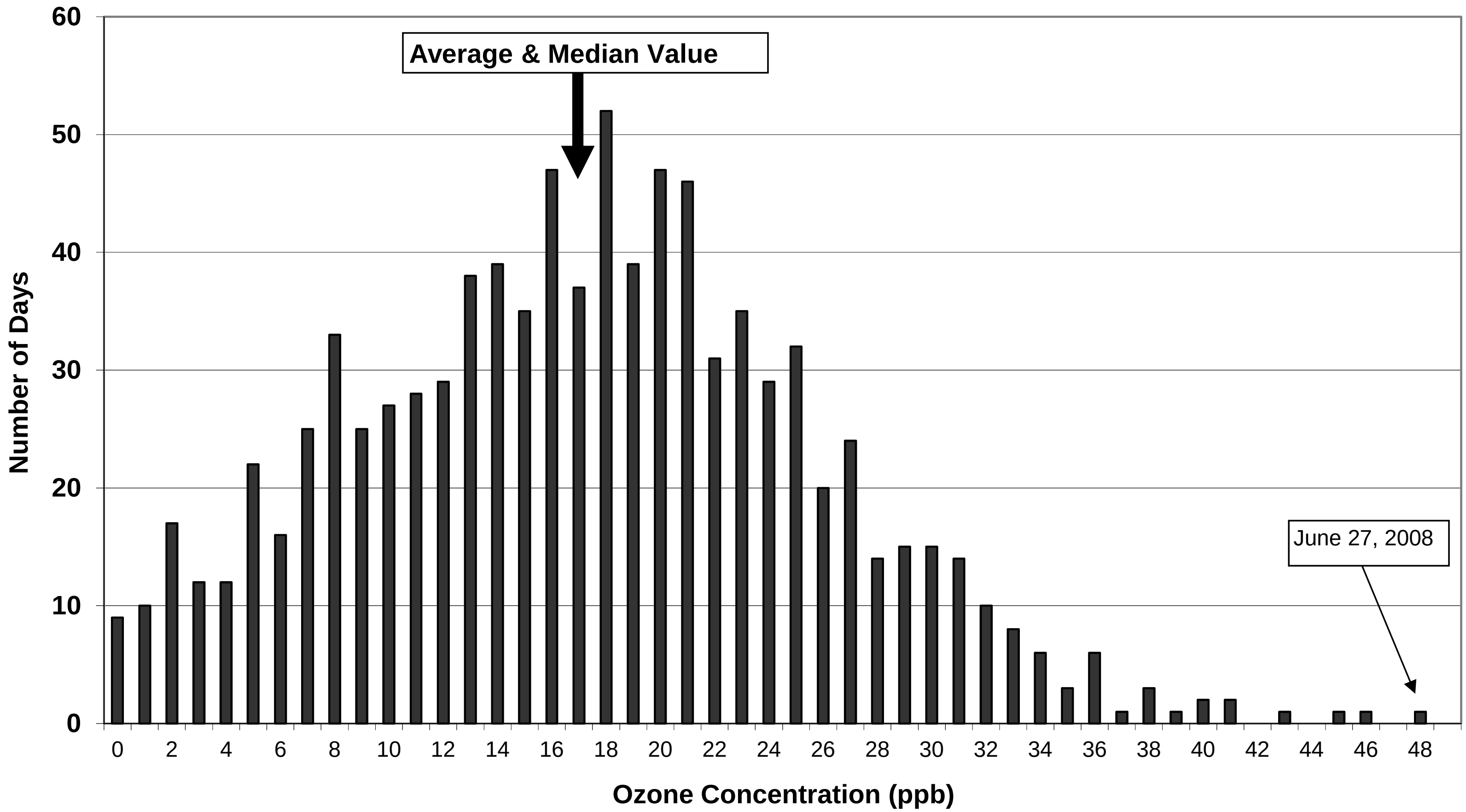
(Represents monitored data, surface ozone)

There is also evidence for a substantial amount of wildfire-related ozone carryover from the prior day. During the night of June 26 and into the early morning of June 27, downslope winds transported emissions from the wildfires to the southern Sacramento Valley (see previous section and Appendix C for detailed discussion). Associated with this wind pattern was the carryover of ozone from June 26 to June 27. Although the federal 1-hour ozone standard was not exceeded on June 26, concentrations remained higher than normal throughout the night and early morning hours of June 27.

The level of carryover was nearly three times what it was the day before, and much higher than normal for the Folsom site, as shown on Figure 22. The minimum 1-hour ozone concentration measured at Folsom on June 27 was 48 ppb at 5 a.m. (the daily minimum typically occurs between 4 a.m. and 6 a.m.). Based on data for the 2004 through 2008 May through October ozone seasons, both the average and the median minimum 1-hour ozone carryover concentrations are 17 ppb. The carryover concentration on June 27 was the highest minimum measured during the 5-year period. Other downwind sites also had carryover ozone concentrations at or near their highest on June 27, 2008 for the period May-October 2004-2008.

Figure 22

Folsom
Number of Days that a Daily Minimum 1-hour Ozone Concentration Equals a Specified Value
(May-October 2004-2008)



6. Summary

Nearly 200 wildfires surrounded the Sacramento Valley prior to the 1-hour ozone exceedance at Folsom on June 27, 2008. This summary documents the transport of emissions from these fires burning in the Coast Range and Sierra Nevada Mountains to the Sacramento Valley, as well as significant wildfire related ozone carried over from the previous day. The wildfire emissions transported both at the surface and above the surface intermingled with the wildfire related ozone carried over from the previous day and surface ozone transported from the fires as the mixed layer deepened on June 27, overwhelming the region and causing the 1-hour ozone exceedance at Folsom.

This section has therefore demonstrated a clear causal relationship based on the following evidence:

- Meteorological observations and analyses document the transport of smoke and emissions from fires burning in the Coast Range and Sierra Nevada Mountains, demonstrating that these emissions reached the Folsom area.

- Satellite data show evidence of thick smoke covering the Sacramento Valley. Airport observations document smoke and limited visibility, indicating that smoke reached the ground.

- Evidence of broad surface level impacts of the wildfires is further demonstrated by observed $PM_{2.5}$ concentrations in Sacramento. Prior to the start of the fires, $PM_{2.5}$ levels were at typical low summer levels. By June 27, $PM_{2.5}$ concentrations were five to ten times higher than normal summer levels and organic carbon and levoglucosan, markers for biomass burning, were significantly elevated. These measurements confirm a broad regional impact from the wildfires at surface monitors throughout the Sacramento Valley.

- Surface data and satellite imagery show increased NO_x, both at the surface and above the surface. NO_x is an important precursor to ozone formation.

- Analyses also document the significant amount of wildfire related ozone carried over from the previous day.

- Pollution in the plume increased ozone consistent with the science of the conceptual model for the event. Ozone levels were anomalously elevated throughout the Sacramento region, including the exceedance at Folsom. This regional increase in ozone, consistent with the extent and magnitude of elevated $PM_{2.5}$ concentrations, indicates that it is more likely that the fire emissions increased ozone due to increased precursors, rather than decreased ozone due to decreased solar insolation or increased ozone titration.

- The exceedance of 129 ppb at Folsom is well above normal historical levels. It is among the highest concentration ever recorded for this site and greater than the 99^{th} percentile of frequency of occurrence for 1-hour maximum ozone concentrations from May through October, 2004 through 2008, demonstrating that it is beyond normal historical fluctuations (see Section F).

E. July 10, 2008

1. Transport Patterns

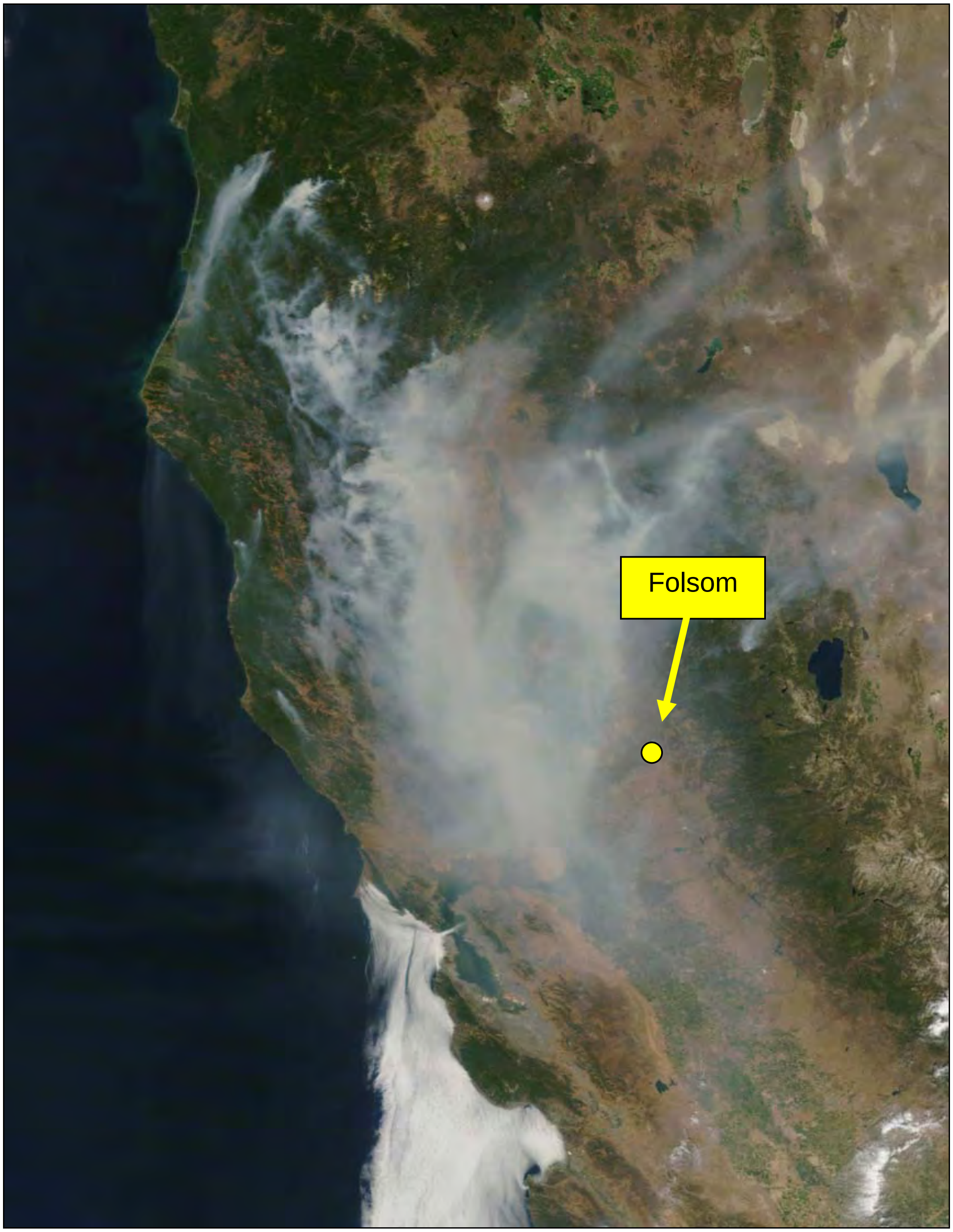
The hundreds of wildfires started by the lightning strikes during the June 20-21, 2008, storm system continued to burn into July. The days leading up to the ozone exceedance on July 10 were characterized by heavy smoke and haze throughout the southern Sacramento Valley. By July 10, wildfires had been burning for 20 days and as a result the Sacramento region was shrouded in smoke. The satellite image in Figure 23, taken at 1038 PST shows the extent of the smoke impact in the entire region. In addition, weather observations taken at Sacramento Executive Airport, Sacramento International Airport, and Mather Field demonstrate the increasing presence of smoke in the Sacramento area. As shown on Table 5 below, by July 8 and 9, smoke and haze were observed for nearly the entire day, persisting until the hour of the highest 1-hour ozone concentration on July 10 (12 p.m.).

Table 5
Summary of Smoke and Haze Observations at
Southern Sacramento Valley Airports* during June 8 through 10, 2008

Date	Number of Hours with Haze and/or Smoke Observations	Percent of Hours in Day with Haze and/or Smoke
July 8, 2008	24	100
July 9, 2008	23	96
July 10, 2008 (00-1200 PST)	13	100

* Hour counted as having haze or smoke if at least one of the three southern Sacramento Valley airports (Mather Field, Sacramento Executive, or Sacramento International) reported such. Hours for July 10 are only counted up to 12:00-13:00 hours, as the highest 1-hour concentration at Folsom occurred at 12:00.

Figure 23
July 10, 2008 1038 PST Visible Satellite Image



NASA Visible Terra MODIS Bands 1, 4, and 3 True Color Satellite Image (250 meter resolution)
http://activefiremaps.fs.fed.us/data/imagery/2008192/ca-north-000/crefl1_A2008192183811-2008192185022_250m_ca-north-000_143.jpg

A detailed analysis of the transport patterns leading up to the 1-hour ozone exceedance at Folsom on July 10 is provided in Appendix D, Meteorological Analysis for July 10, 2008. Overall, the weather-related factors responsible for bringing fire emissions to Folsom were the drainage flow from the Coast Range and Sierra Nevada Mountains, the sea breeze flow from the Bay Area, wind flow from the northwest, and the eddy circulation pattern in the southern Sacramento Valley coupled with a negative pressure gradient which trapped wildfire emissions within the region. In addition, the midday increase in the height of the mixed layer in the hours prior to the exceedance allowed wildfire emissions aloft to reach the ground.

Many of the weather patterns which caused the 1-hour ozone exceedances on June 23 and 27 were repeated on July 9 and 10. Overnight surface drainage winds transported wildfire emissions and smoke from both the Coast Range and the Sierra Nevada Mountains to the southern Sacramento Valley. The sea breeze from the Bay Area brought emissions from fires in the Coast Range to the southern Sacramento Valley. Surface winds from the northwest also brought additional wildfire emissions from the northern portion of the Coast Range (where some of the largest fires continued to burn) into the southern Sacramento Valley. The early morning eddy circulation pattern trapped and accumulated these emissions in the southern Sacramento Valley.

During the late morning, the eddy pattern weakened and a portion of the wildfire emissions were subsequently transported to the Sacramento urban area, including Folsom. Similar to June 27, the morning surface pressure gradient (Reno to Sacramento) helped keep the wildfire emissions confined to the Valley. The height of the mixed layer also increased throughout the late morning and early afternoon (from approximately 150 meters to 330 meters), though to a lesser extent than on June 23 and 27, allowing fire emissions above the surface (but below the inversion), to reach the ground (refer to Appendix D for more information).

2. $PM_{2.5}$ Concentrations

$PM_{2.5}$ is directly emitted during combustion, and elevated concentrations are an important indicator that emissions from the wildfires reached ground level monitors in the Sacramento region. Prior to the start of the fires, the $PM_{2.5}$ filter-based sites in northern and central California had typical concentrations far below the 24-hour NAAQS of 35 µg/m^3 and even below the annual average NAAQS of 15 µg/m^3. Based on historical data for 2005 through 2007 in June and July, 24-hour average $PM_{2.5}$ concentrations at sites in the Sacramento area ranged from an average of 7.3 to 9.9 µg/m^3, and 98th percentile concentrations for the three-year period ranged from 14.5 to 25.5 µg/m^3. For more information, please refer to the $PM_{2.5}$ Natural Events document submitted to U.S. EPA on July 20, 2009.

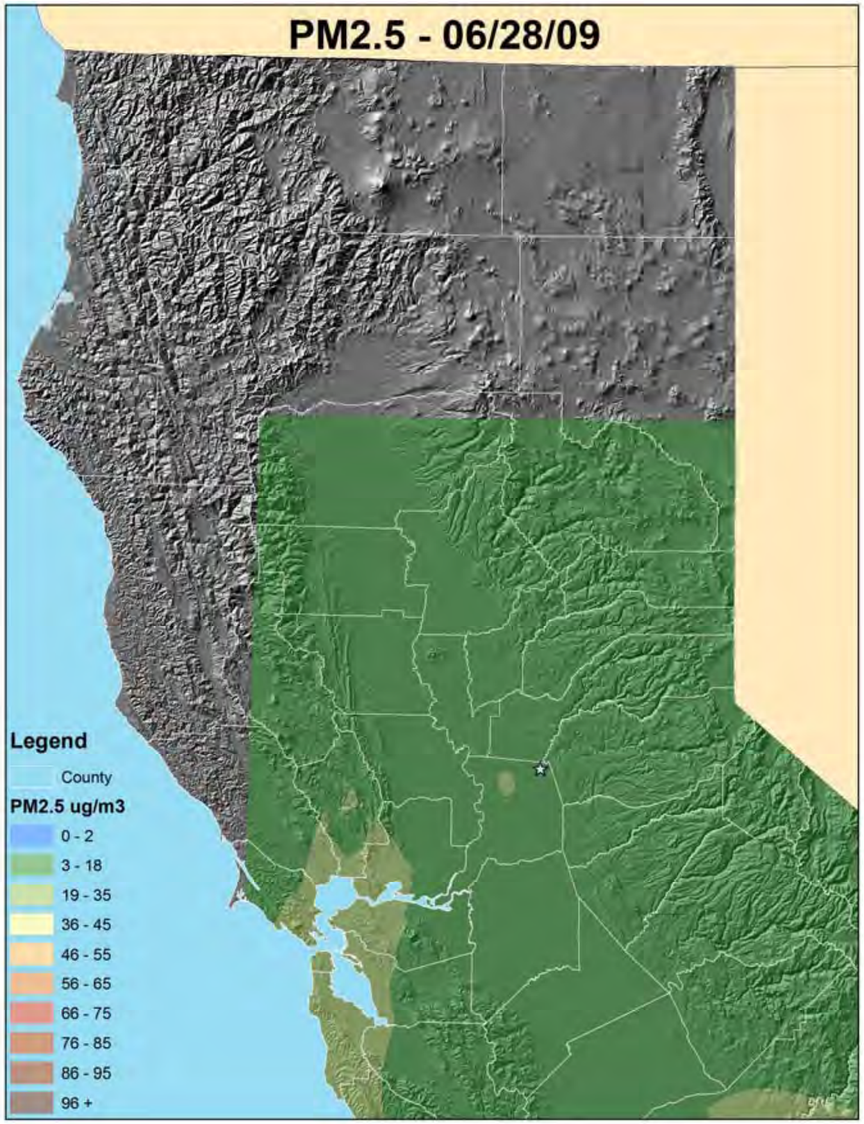
This changed after the fires started, and $PM_{2.5}$ concentrations rose from typical low summer, seasonal levels to daily averages that exceeded the 24-hour NAAQS at many sites. There were no 24-hour average $PM_{2.5}$ filter measurements on July 10 except for Yuba City, which measured a concentration of 147 $\mu g/m^3$. However, continuous $PM_{2.5}$ measurements on July 10 recorded 24-hour averages which ranged from 65 to 191 $\mu g/m^3$ in the Sacramento Valley. These 24-hour average $PM_{2.5}$ concentrations were from five to fourteen times higher than typical summer levels.

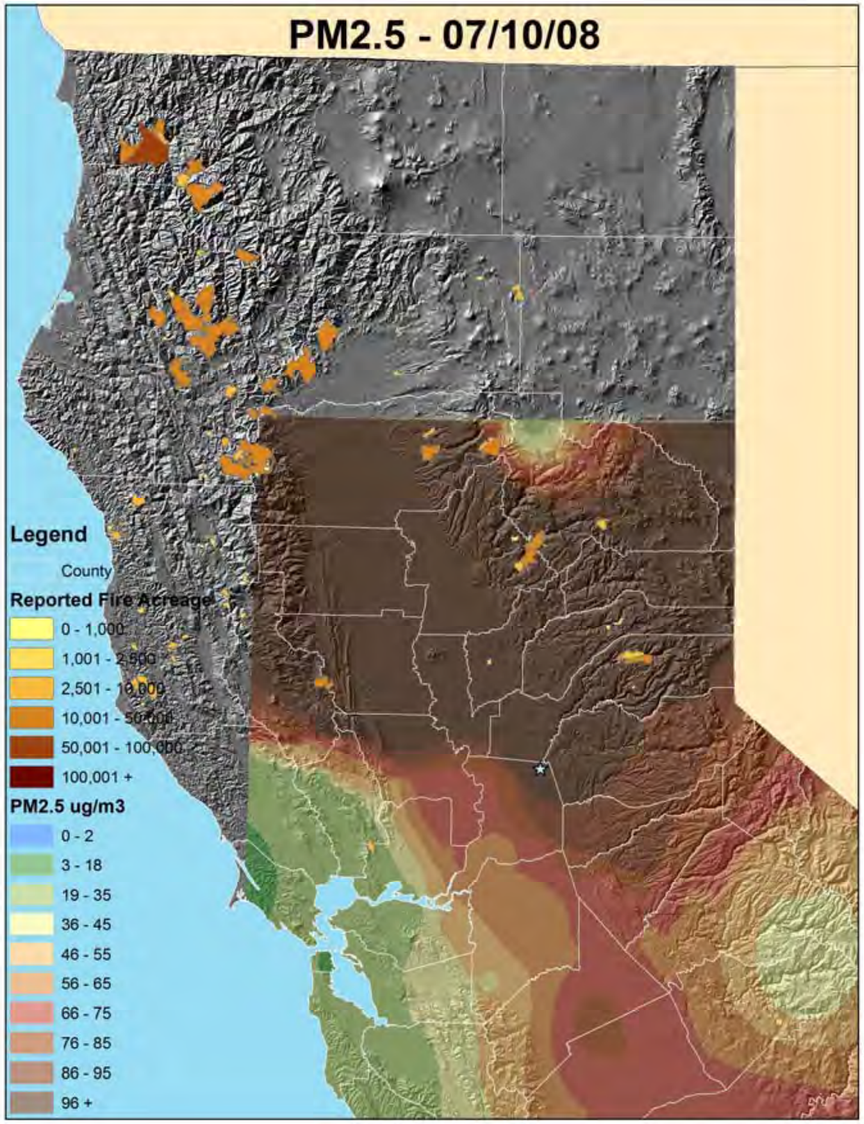
STI identified June 28, 2009, as a day with similar meteorological conditions (referred to as the surrogate day). STI's analysis is detailed in Appendix Y. Figure 24 compares 24-hour average $PM_{2.5}$ concentrations on the June 28, 2009 surrogate day to the July 10, 2008 fire day. On July 10, 2008, the Folsom monitor had a maximum 24-hour average $PM_{2.5}$ concentration of 100 $\mu g/m^3$, more than five times the Sacramento region peak 24-hour average concentration of 20.5 $\mu g/m^3$ on the surrogate day.

ARB staff evaluated July 10, 2008 and the surrogate day and found there was no evidence to suggest that anthropogenic emission-generating activities differed significantly between the two days. Therefore, the most likely difference between the $PM_{2.5}$ concentrations measured on the two days, given the similarity in key meteorological parameters, was the presence of wildfire emissions on July 10, 2008.

Figure 24

24-hour Average $PM_{2.5}$ Concentrations on Surrogate and Fire Days





(Represents monitored data, surface $PM_{2.5}$)

3. $PM_{2.5}$ Speciation

Evaluation of $PM_{2.5}$ speciation data provides further evidence that the elevated $PM_{2.5}$ concentrations can be attributed to impacts from the wildfires. As shown in Figures 3 and 4 previously, 24-hour average organic carbon levels were extremely elevated on the days immediately preceding the fires (no 24-hour average $PM_{2.5}$ filter data is available for July 10) and average monthly levoglucosan levels were much higher in July of 2008, compared to 2007. 24-hour average organic carbon levels at Sacramento-Del Paso Manor, prior to the fires (June 20) were 7.7 $\mu g/m^3$; by July 8 24-hour average organic carbon increased to 39.9 $\mu g/m^3$. In addition, monthly average levoglucosan levels were four times higher in July 2008 (0.048 $\mu g/m^3$) than in July 2007 (0.01 $\mu g/m^3$). Both of these are markers for biomass burning.

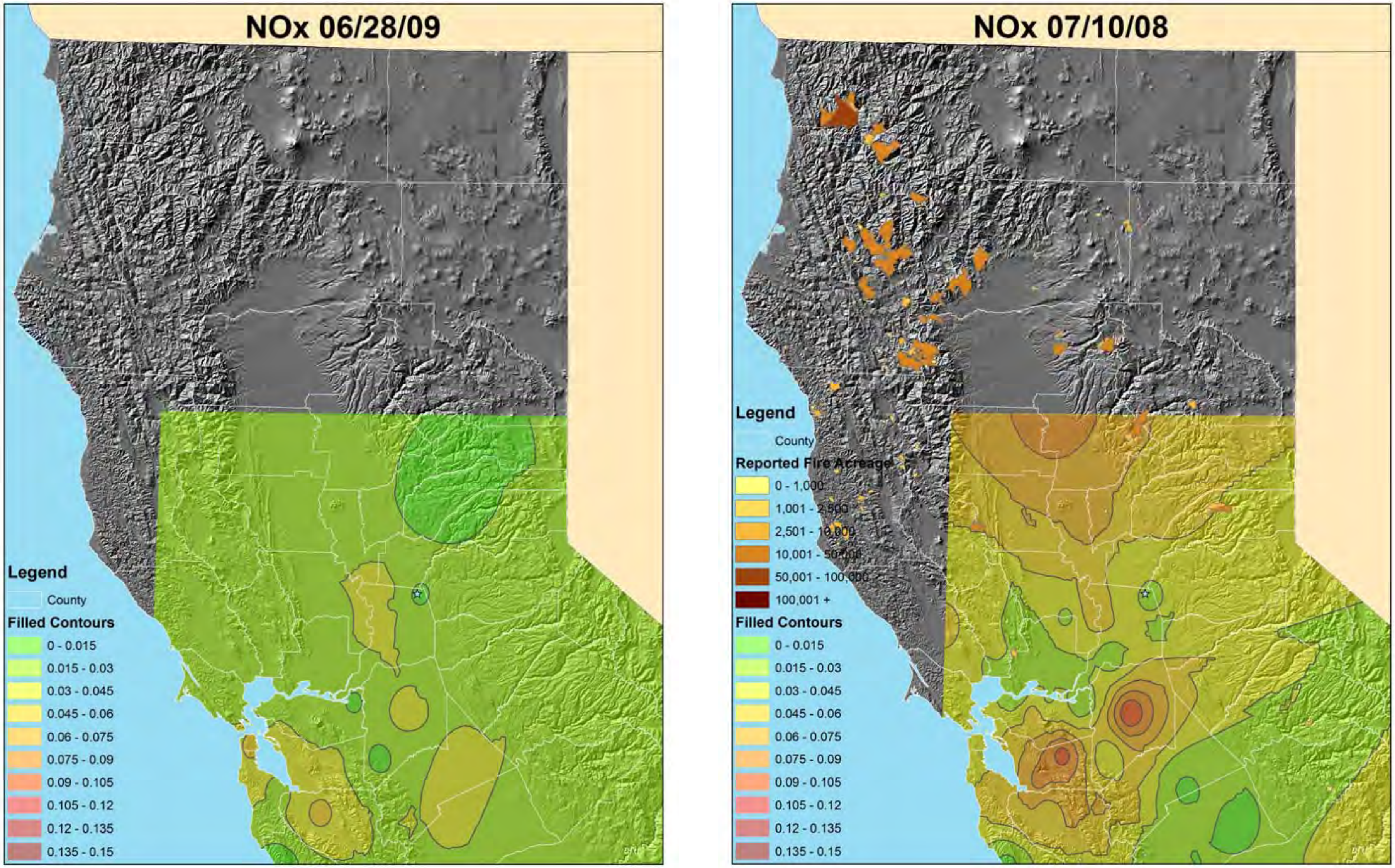
4. Ozone Precursor Concentrations

The previous sections have demonstrated that significant smoke and elevated $PM_{2.5}$ concentrations were observed throughout the Sacramento Valley on July 10. As discussed earlier, by the time of the July 10 exceedance, the fires had been burning for 20 days and the region was inundated with smoke. Evaluation of satellite data and comparison to concentrations on the surrogate day further indicate that there were also elevated levels of NO_x, a key precursor to ozone, both at the surface and aloft on July 10.

As shown in Figure 25, surface NO_x was significantly elevated throughout the region on July 10, 2008 compared with the surrogate day (June 28, 2009). On the surrogate day most maximum 1-hour NO_x concentrations ranged between 5 to 39 ppb. In contrast, on July 10, 2008 maximum 1-hour NO_x concentrations in much of the Sacramento Valley ranged from 21 to 67 ppb, with an average of 47 ppb. At Folsom, the maximum 1-hour NO_x concentration on the July 10, 2008 fire day was 21 ppb. This is 133 percent greater than on the surrogate day which had a maximum 1-hour NO_x concentration of only 9 ppb, and indicates the presence of additional precursors for ozone formation in the vicinity of Folsom. In addition, the maximum 1-hour NO_x concentration at the Sacramento T street monitoring site on July 10, 2008 was 59 ppb, compared to 39 ppb on the surrogate day and maximum 1-hour NO_x at Yuba City was 67 ppb compared to 18 ppb. These sites were upwind of Folsom during the morning eddy circulation and daytime sea breeze flow from the west and the overnight/morning wind flow from the northwest, providing additional evidence of higher levels of ozone precursors along several of the key transport pathways to Folsom. As noted previously, there were no known differences in anthropogenic NO_x emissions. Thus, the most likely difference in measured NO_x concentrations was the presence of wildfire emissions on June 27, 2008.

Figure 25

Maximum 1-hour Surface NO_x Concentrations on Surrogate and Fire Days



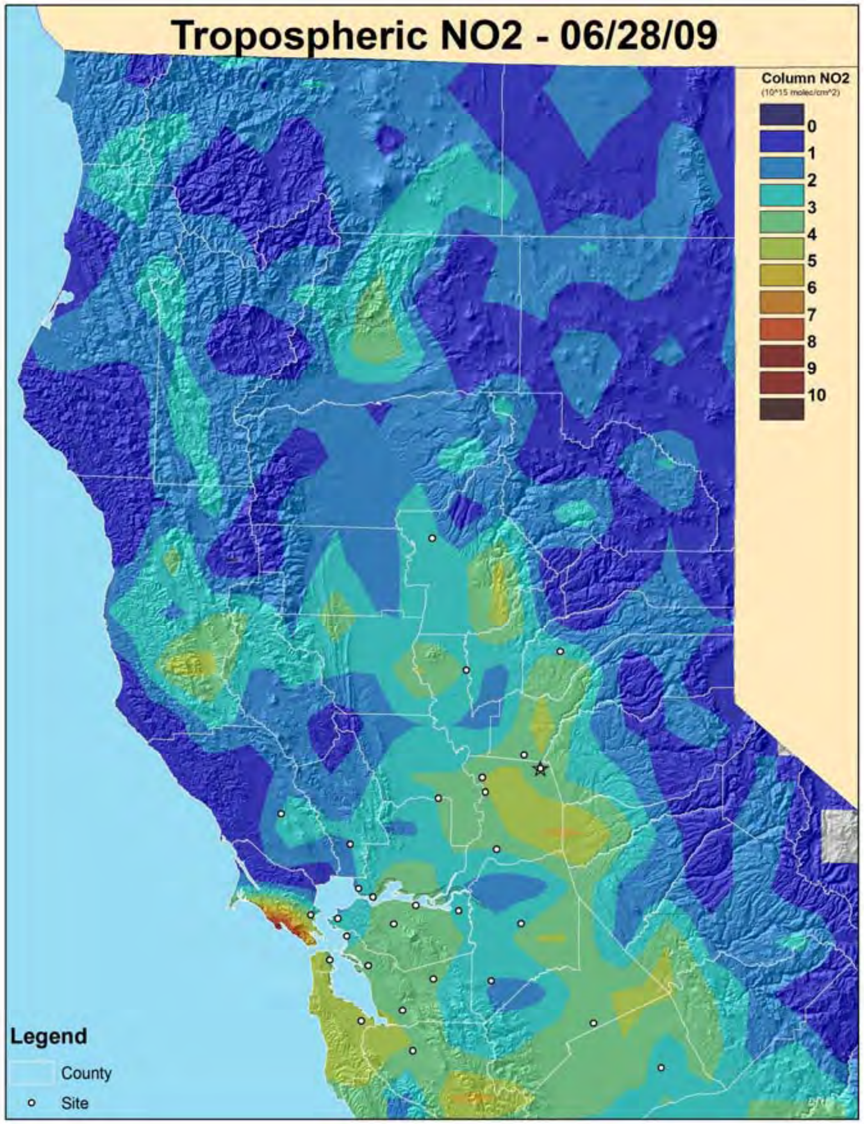
(Represents monitored data, surface NO_x)

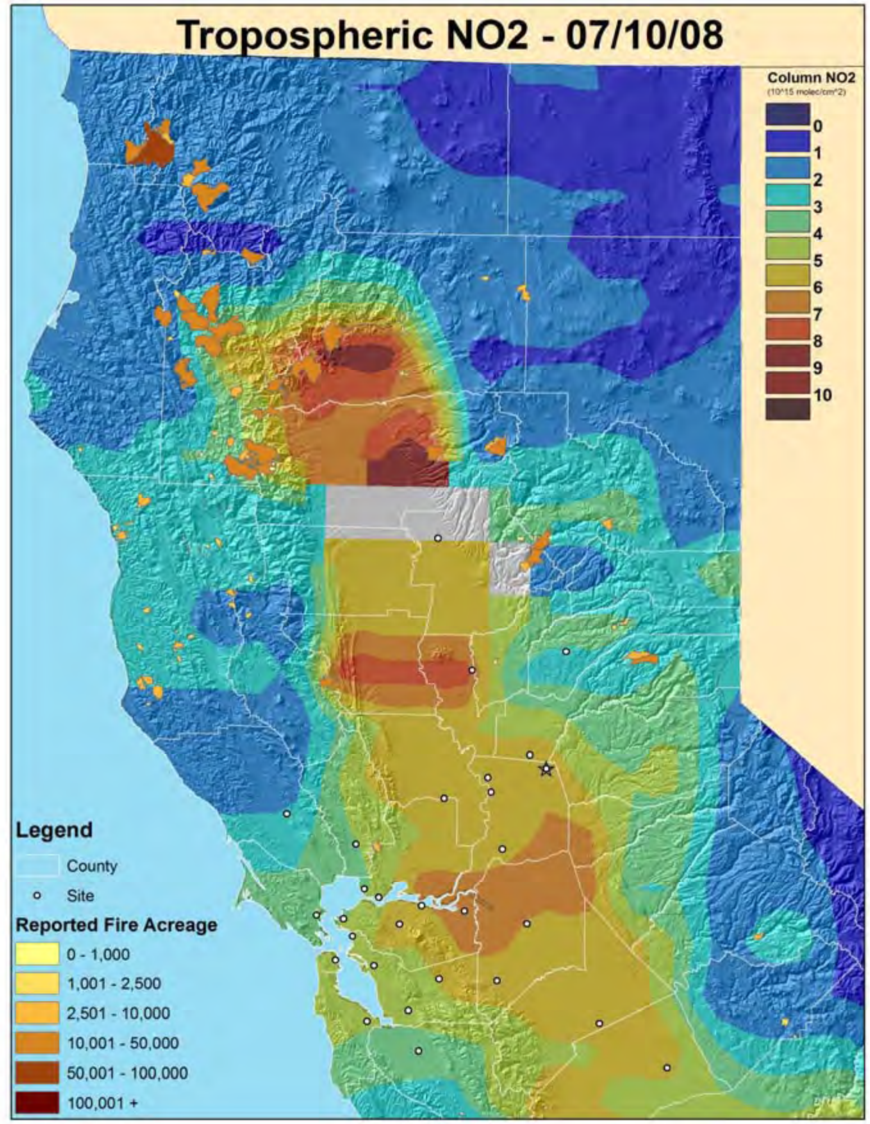
In addition to elevated NO_x at the surface, transport of NO_x above the surface layer can also be inferred from satellite images taken by NASA's Ozone Monitoring Instrument (OMI). These satellite images derive from snapshots of the atmosphere as the satellite passes over northern California. OMI is able to isolate the troposphere, giving measurements of total column NO_2 from the surface to the height of the tropopause, about 15 km above ground level. NO_2 measurements do not give the complete picture of NO_x, since they do not include NO concentrations. However, except for fresh emissions (i.e., very close to the emissions source,) NO_2 usually has a much higher concentration than NO. Therefore, NO_2 is an appropriate surrogate for NO_x in aged air masses.

OMI satellite data (see Figure 26) show that tropospheric NO_2 on July 10, 2008 was elevated throughout the Sacramento Valley, in comparison with the June 28, 2009 surrogate day. It is likely that some of the NO_x above the surface intermingled with wildfire related surface NO_x as the height of the mixed layer doubled from 0800 PST and 1200 PST, increasing to about 330 meters. Evidence that additional wildfire emissions from aloft may have mixed downward during the deepening of the mixed layer is suggested by the large increase in hourly $PM_{2.5}$ concentrations during mid-day at Del Paso and Sacramento T Street in Sacramento (see Figure 27). However, because the mixing depth was lower on July 10 than on June 23 or June 27 (see earlier discussion), the impact of additional NO_x from aloft was likely somewhat lessened, on July 10 as compared to June 23 and 27.

Figure 26

Tropospheric NO_2 Concentrations on Surrogate and Fire Days

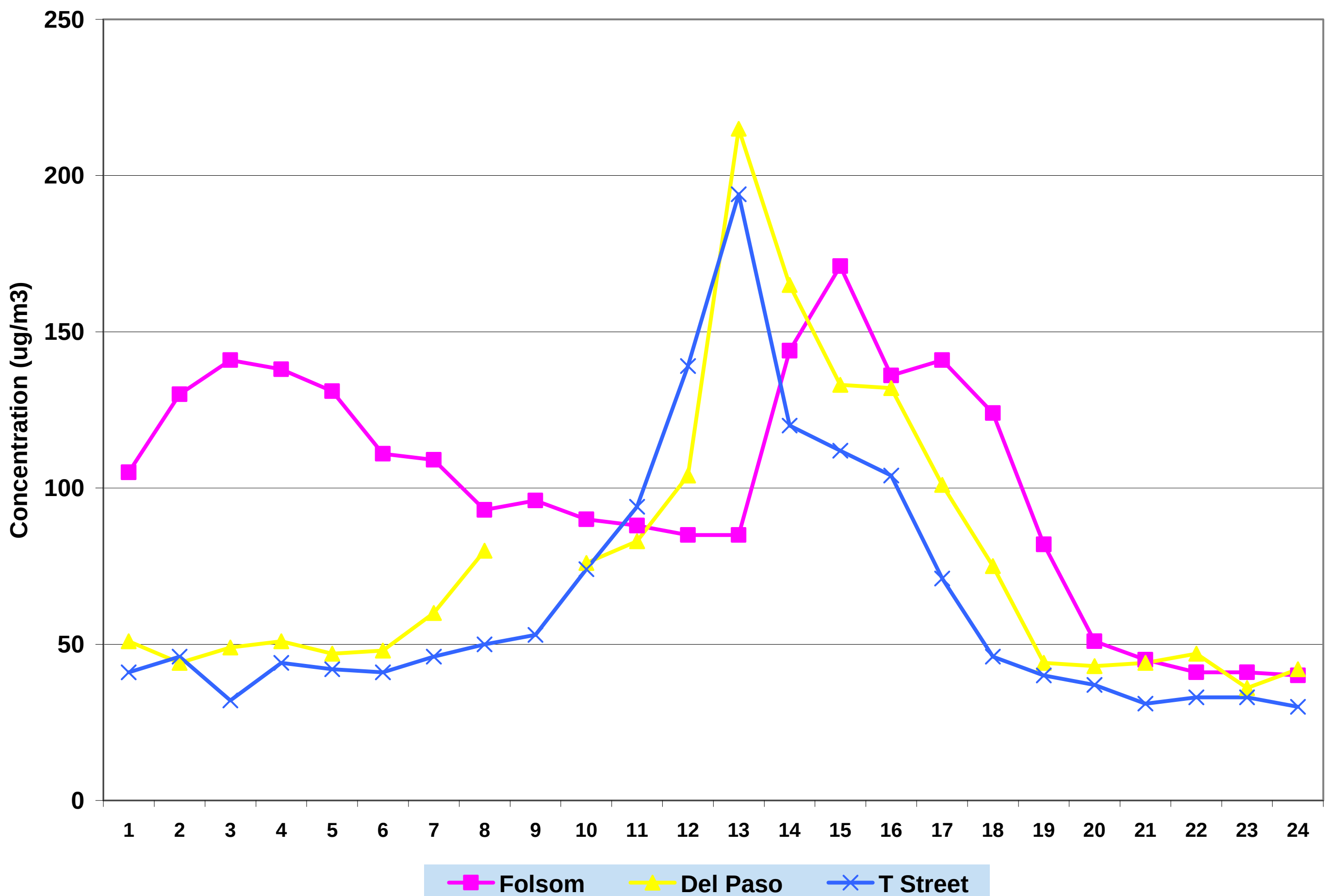




(Represents satellite data, tropospheric NO_2 column)

Figure 27

Hourly $PM_{2.5}$ Concentrations on July 10, 2008



5. Ozone Chemistry and Concentrations

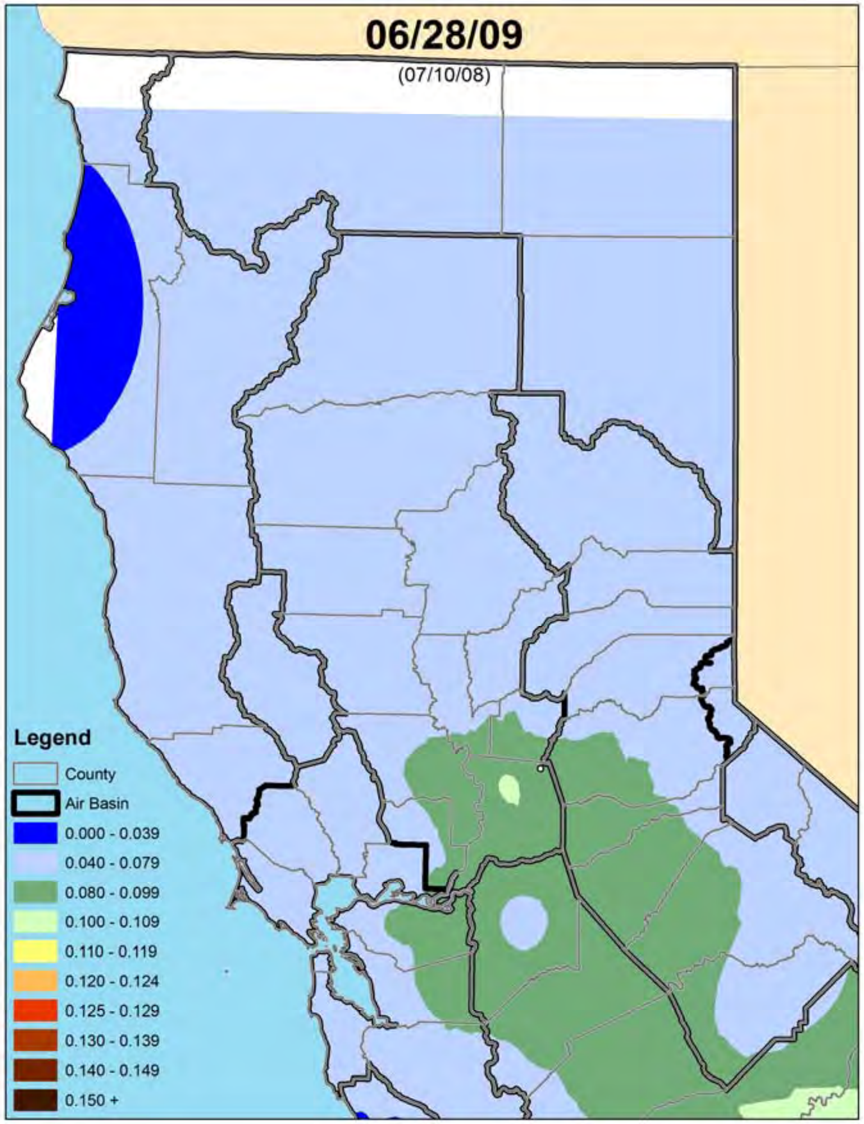
The increased precursor emissions from the fires throughout the Sacramento Valley resulted in substantial amounts of ozone formation, leading to the 1-hour ozone exceedance at Folsom on July 10. Folsom was sufficiently downwind of the fires that their primary impact was to increase ozone due to the large amount of wildfire-related precursors, rather than decrease ozone due to either near-source NO_x titration or reduced solar insolation from the smoke. Section 2 summarizes the key mechanisms by which emissions from wildfires can increase ozone, as well as past research which has documented increases in ozone formation downwind of wildfires.

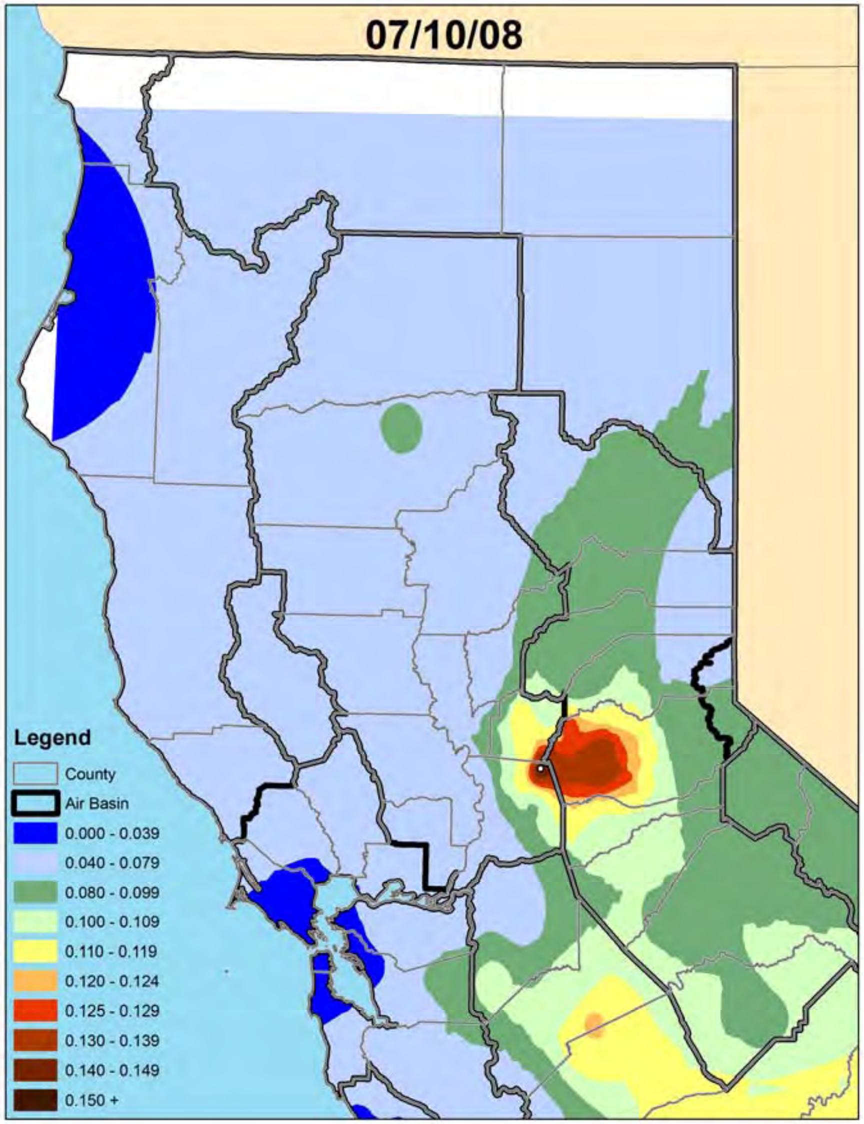
On July 10, 2008 the Folsom monitor had the highest ozone concentration in the region, with a 1-hour maximum concentration of 150 ppb. As shown in Figure 28, comparison of July 10, 2008 with the surrogate day illustrates the impact of the wildfires on ozone concentrations at Folsom and the surrounding monitors. The maximum 1-hour ozone concentration on June 28, 2009, the surrogate day, was 91 ppb, which is well below the standard. In addition to the exceedance at Folsom, ozone was elevated throughout much of the Sacramento Valley and Sierra foothill region on July 10, 2008. 1-hour ozone exceedances also occurred at Cool with a maximum 1-hour ozone concentration of 129 ppb, and Placerville with a peak of 137 ppb. On the surrogate day, Cool reached a maximum 1-hour ozone concentration of only 80 ppb, and Placerville reached a maximum of 82 ppb.

There is also evidence for a substantial amount of wildfire-related ozone carryover from the prior day. Ozone generated on the day(s) prior to the exceedance remained in the area overnight, resulting in a higher than average level of wildfire-generated ozone carryover. The amount of wildfire-related ozone carryover from July 9 to July 10 was quite significant. Although the federal 1-hour ozone standard was not exceeded on July 9, concentrations remained higher than normal throughout the night and early morning hours of July 10. The minimum 1-hour ozone concentration measured at Folsom on July 10 was 31 ppb at 5 a.m. (the minimum typically occurs between 4 a.m. and 6 a.m.). This is nearly twice the average level for Folsom and is about one-quarter of the federal 1-hour standard (see Figure 29).

Figure 28

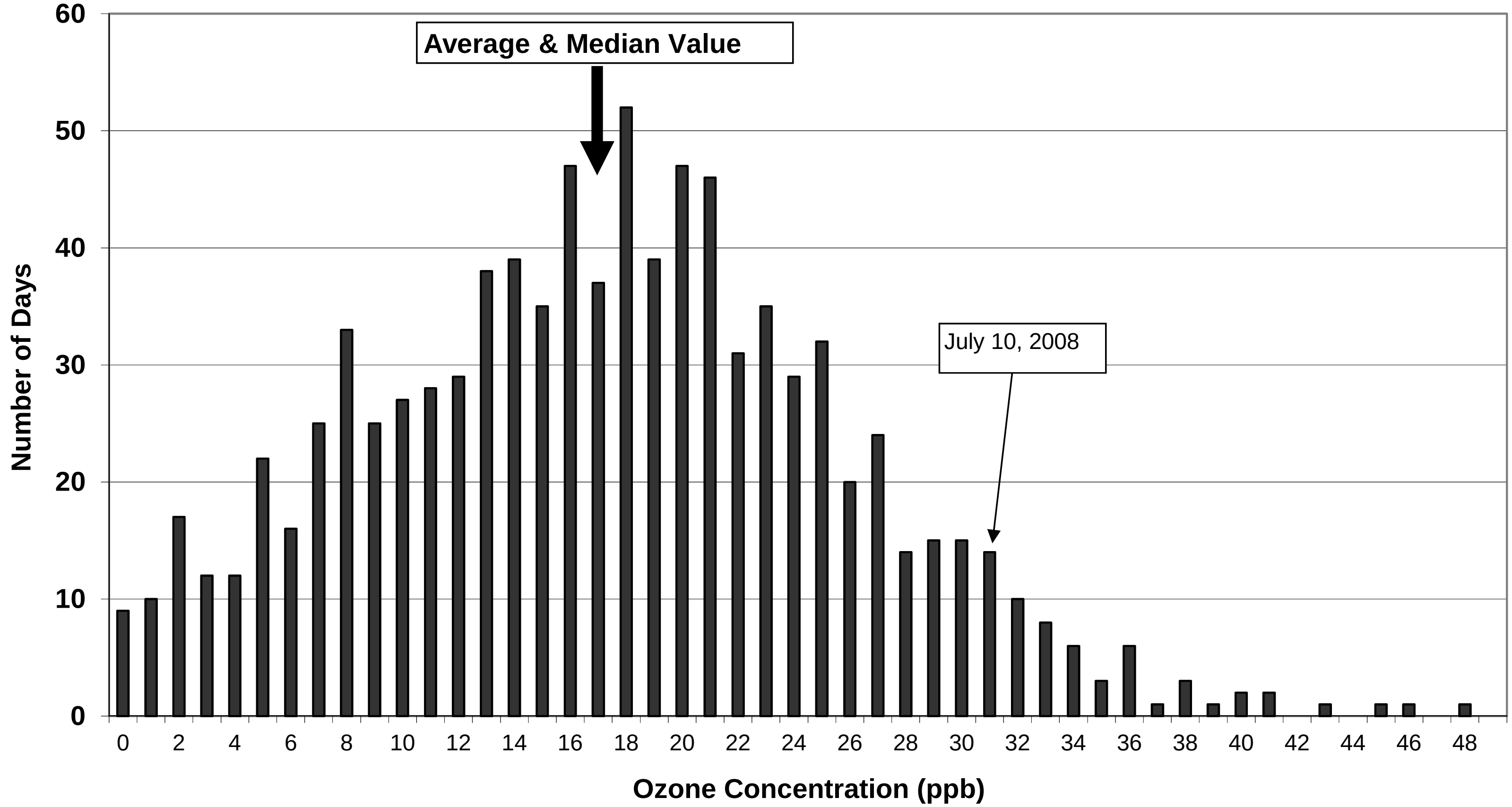
Maximum 1-hour Ozone Concentrations on Surrogate and Fire Days





(Represents monitored data, surface ozone)

Figure 29
Number of Days that a Daily Minimum 1-hour Ozone Concentration Equals a Specified Value at Folsom (May-October 2004-2008)



6. Summary

Hundreds of wildfires were buring out of control and surrounded the Sacramento Valley prior to the 1-hour exceedance at Folsom on July 10. By July 10, fires had been burning for 20 days, and over 1,000,000 acres had burned within 300 miles of Folsom. This summary documents the transport of emissions from these fires burning in the Coast Range and Sierra Nevada Mountains to the Sacramento Valley, as well as significant wildfire related ozone carried over from the previous day. The wildfire emissions transported both at the surface and above the surface intermingled witht he wildfire related ozone carried over from the previous day as well as surface ozone transported from the fires as the mixed layer deepened on July 10, overwhelming the region and causing the 1-hour ozone exceedance at Folsom.

This section has therefore demonstrated a clear causal relationship based on the following evidence:

- Meteorological observations and analyses document the transport of smoke and emissions from fires burning in the Coast Range and Sierra Nevada Mountains, demonstrating that these emissions reached the Folsom area.

- Satellite data show evidence of thick smoke covering the Sacramento Valley. Airport observations document smoke and limited visibility, indicating that smoke reached the ground.

- Evidence of broad surface level impacts of the wildfires is further demonstrated by observed $PM_{2.5}$ concentrations in Sacramento. Prior to the start of the fires, $PM_{2.5}$ levels were at typical low summer levels. By July 10, $PM_{2.5}$ concentrations were 5 to 14 times higher than normal summer levels, and organic carbon and levoglucosan, markers for biomass burning, were significantly elevated. These measurements confirm a broad regional impact at surface monitors throughout the Sacramento Valley.

- Surface data and satellite imagery show increased NO_x, both at the surface and above the surface. NO_x is an important precursor to ozone formation.

- Analyses also document the significant amount of wildfire related ozone carried over from the previous day.

- Pollution in the plume increased ozone consistent with the science of the conceptual model for the event. Ozone levels were anomalously elevated throughout the Sacramento region, including the exceedance at Folsom. This regional increase in ozone, consistent with the extent and magnitude of elevated $PM_{2.5}$ concentrations, indicates that it is more likely that the fire emissions increased ozone due to increased precursors, rather than decreased ozone due to decreased solar insolation or increased ozone titration.

- The exceedance of 150 ppb at Folsom is well above normal historical levels. It is among the highest concentration ever recorded for this site and greater than the 99th percentile of frequency of occurrence for 1-hour maximum ozone concentrations from May through October, 2004 through 2008, demonstrating that it is beyond normal historical fluctuations (see Section F).

F. Beyond Historical Fluctuations

Further evidence that the added emissions from the wildfires were the cause of the 1-hour ozone exceedances at Folsom on June 23, June 27, and July 10, 2008 is the relative rarity of 1-hour ozone exceedances at Folsom, as well as the severity of the observed concentrations on the wildfire impacted days. ARB staff analyzed the 1-hour daily maximum ozone frequency distribution data for a five-year period (2004 – 2008) at the Folsom Street monitor. As a very conservative approach, this evaluation is limited to the ozone season, May through October, when the highest ozone concentrations occur.

Figure 30 below shows the number of days over the five-year period where the maximum 1-hour ozone concentration fell within established concentration bins of five parts per billion (ppb). The curve on the graph represents the cumulative percentage for days that fall within or below each concentration bin. All three of the wildfire events (June 23, June 27, and July 10, 2008) exceed the 99^{th} percentile.

Figure 30

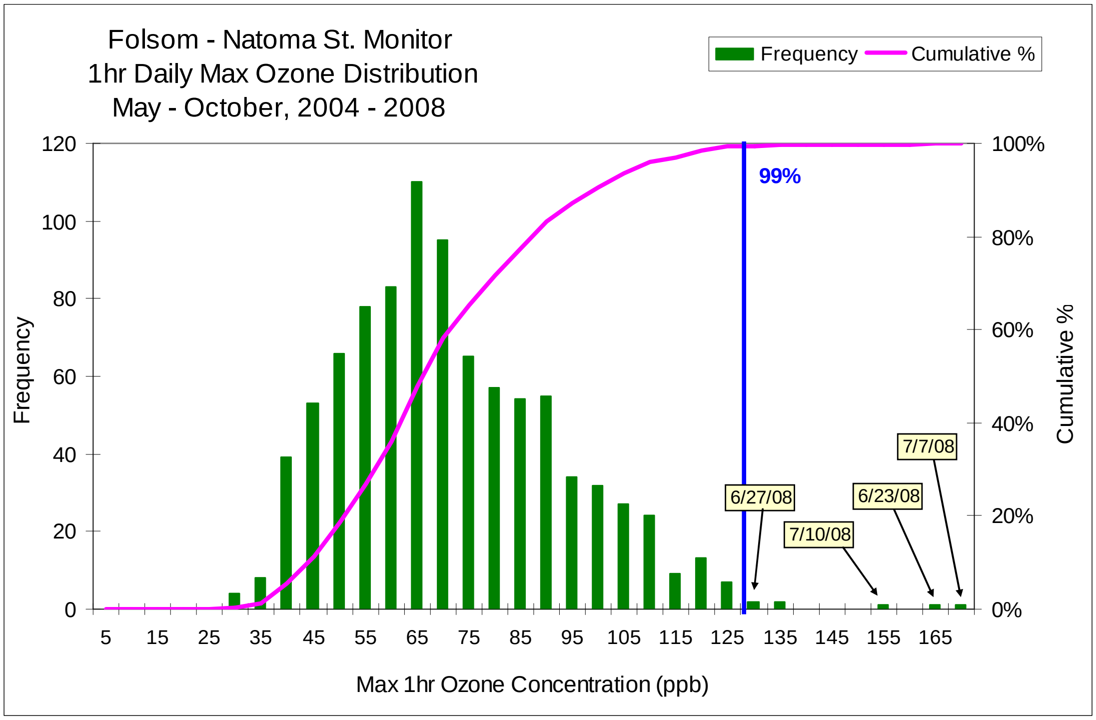


Table 6 below further summarizes the number of exceedances of the federal 1-hour ozone standard for the last seven years at the Folsom site. Six of the seven years had no more than one exceedance. In 2008, there were five exceedances, four of which occurred during the peak wildfire impacted period, providing further evidence of the extreme nature of the wildfire impacted ozone concentrations. It should be noted that occasional exceedances of the 1-hour standard can occur in attainment areas. The form of the standard takes this into account by allowing three or less exceedances in any three year period.

Table 6
Number of Exceedance Days of the Federal 1-Hour Standard at the Folsom-Natoma Site

2004	2005	2006	2007	2008	2009	2010
0	1	1	1	5	0	0

4: <u>But For Demonstration</u>

A. Introduction

The analyses described below provide a comprehensive weight of evidence approach demonstrating that in the absence of the catastrophic 2008 wildfires, there would have been no exceedances of the federal 1-hour ozone standard on June 23, 2008, June 27, 2008, and July 10, 2008, at the Folsom-Natoma Street monitoring site in Sacramento County. The analyses summarized include regression and related additional statistical evaluation, surrogate day and rule of thumb analysis, and evaluation of the frequency of high ozone concentrations at the Folsom monitoring site.

B. Regression Analysis

1. Results

Estimates of the 1-hour ozone contribution from the 2008 wildfires were determined using a complex regression method developed by STI (see Appendix X). These estimates were provided to U.S. EPA in ARB's original 2009 submittal and are summarized in Table 7, below. Using four sets of meteorological conditions (from National Weather Service forecast models), the regression program provided four different ozone estimates for each day. The estimated wildfire contribution is the difference between the observed 1-hour ozone concentration and the 1-hour ozone concentration estimated to occur in the absence of wildfires. To rely on the most conservative estimate, only the minimum wildfire contribution for each day was used.

Based on the regression analysis, in the absence of wildfires the 1-hour ozone concentrations would only have reached 76 to 95 ppb on the three fire-impacted days. The 1-hour ozone contribution from the wildfires therefore ranged from 53 to 84 parts per billion (ppb).

Table 7
Estimated Wildfire Contribution
Regression Equation Analysis
Folsom Monitoring Site

Day	Observed Daily Max Concentration (ppb)	Estimated Concentration w/o Wildfire Impact (ppb)	Estimated Wildfire Impact (ppb)
6/23/08	161	77	84
6/27/08	129	76	53
7/10/08	150	95	55

Developed by SonomaTechnology, Inc. This table summarizes regression results for the Folsom monitoring site previously submitted to U.S. EPA on July 8, 2009.

2. Method Description

Regression analysis is a statistical method for developing an equation or series of equations to quantify the relationship among different variables, such as how air quality is affected by meteorology. This allows the use of one or more meteorological variables to predict air quality concentrations. Because the regression equations used in forecasting ozone air quality are generally developed using several years of air quality data, they represent the relationship between air quality and meteorology under the typical spectrum of emission patterns that occurred during those years. As a result, the differences between predicted and observed values can be used to help detect excess air pollution caused by unanticipated emissions from sources such as wildfires.

In developing regression equations, several years of air quality data are typically used, and there is often a lag of five years or more between program development and application. Although this lag time does not change the general nature of how meteorology affects air quality, substantial emission reductions can alter some aspects of the relationship between predicted and observed values. So, the effects of emission reductions need to be accounted for when providing regression estimates for a year that was not used to develop the regression equation(s).

In 2004, STI developed regression equations that were subsequently used to forecast daily 1-hour ozone concentrations in Sacramento County (see Appendix X for details about the development, application, and evaluation of the regression equations). These regression equations were developed using data for the years 1997 to 2003. Because ozone precursor emissions in Sacramento County have decreased about 15 percent since 2003, STI evaluated the performance of the regression equations in the 2007 ozone season to evaluate their continued applicability. STI determined the daily difference between the 1-hour ozone predictions and the observed 1-hour ozone concentrations for each day. The average of these daily differences characterized the current 2007 bias between observed and predicted values. There was a positive bias of 8 to 13 ppb depending on the meteorological forecast model output used. The regression estimates were adjusted, or corrected, to reflect this bias and are referred to as bias corrected regression estimates in this document (see following section for further information).

As discussed on pages 6 and 7 of Appendix X, modeled weather data (National Weather Service Eta model), rather than observed weather data, were used to estimate ozone concentrations in the absence of wildfires. This is because the modeled weather data are free of any potential influence of the wildfires on meteorology and therefore, represent conditions expected in the absence of wildfires. Wildfires can impact weather conditions in several ways. Fires can produce thick smoke that can accumulate downwind and decrease solar radiation. This decrease in solar radiation can result in a decrease in temperature near the surface. In addition, convective updrafts in fire areas can cause localized, strong surface winds within a few miles of the fire location

3. Method Uncertainty and Error

As described in the previous section, the appropriate average bias value was subtracted from the regression estimates for the fire days in 2008 to account for changes in emissions which have occurred since development of the equations. A discussion of the overall regression model performance and a summary of the distribution of errors associated with the regression equation are provided in Appendix X.

While the potential bias may be smaller and have greater uncertainty at very high concentrations due to model performance and the more limited number of measurements, the use of the average bias is appropriate under moderate ozone conditions where the bulk of measurements occur. In general, this reflects conditions when predicted 1-hour ozone values do not exceed 110 ppb. Because the predicted 1-hour ozone concentrations on June 23, June 27, and July 10, 2008 fall into this range, it is appropriate to use the average difference to characterize the bias for this application.

The regression program provides an estimate of the maximum 1-hour ozone concentration expected each day in Sacramento County. Although the program was not designed to make site-specific estimates, Folsom is typically the high site in the region. Therefore, the regression program usually forecasts the 1-hour ozone concentrations likely to occur at Folsom. There are occasional days when a distinct meteorological scenario occurs that causes the region's maximum 1-hour ozone concentration to occur at other sites such as Sloughhouse. However, meteorological conditions on the three fire days were such that Folsom was likely to be the high site.

~~4.~~ Addendum to Appendix X

To further evaluate the performance of the regression program and associated uncertainties, ARB staff prepared an Addendum to Appendix X (Addendum). Building on the data assembled for Appendix X, ARB staff added conservative approaches that account for both method uncertainty and prediction errors.

Figure 1 in the Addendum compares the bias-corrected maximum 1-hour ozone concentration estimates with the observed estimates for the May through October 2007 ozone season in Sacramento County. This ozone season was largely unaffected by wildfires. As shown in the graph (Figure 1 in Addendum), the regression program does a reasonable job of estimating 1-hour ozone concentrations on most days. Some days show a positive difference because the measured ozone concentration was higher than predicted, while other days show a negative difference because the measured ozone concentration was lower than predicted.

The distribution of daily differences for 2007 and portions of 2008 is represented by the histogram shown in Figure 3 of the Addendum. Figure 3 also identifies the 95th percentile of the daily differences, which is 27.6 ppb. A conservative statistical threshold of the maximum predicted concentration can be calculated by adding this 95th percentile of 27.6 ppb to each of the daily bias-adjusted estimates from the regression model. This provides an extremely conservative approach for bounding the uncertainties and errors inherent in this application of the regression program. Figures 10 through 14 in the Addendum show this conservative statistical threshold, or "regular upper limit" plotted with the observed concentrations.

The figures in the Addendum present a clear contrast between the irregular behavior in ozone concentrations from June 23 through July 26, 2008, and the regular behavior during the surrounding months of 2008, as well as the May through September period of 2007 (note that August 2008, when some fires continued to burn, is borderline). During the irregular period, 16 of the 34 days (47 percent), instead of an expected 2 of 34 days (5 percent) exceeded the regular upper limit.

The three dates under consideration (June 23, June 27, and July 10, 2008) occurred during the highly irregular period, when emissions from wildfires enhanced the ozone concentrations. In addition, on these three days, the measured ozone concentrations exceeded the federal 1-hour ozone standard, while the conservative “regular upper limit” concentration did not exceed the standard. The broader time period of May through September 2007, along with the surrounding months of 2008, show that measured ozone concentrations rarely exceed the regular upper limits (4.2 percent of the time or 10 out of 246 days in a five month period).

These analyses establish a broad context of typical high-ozone events, so that irregular, exceptional events can be identified with confidence. Therefore, the regression analysis provides compelling evidence that in the absence of wildfires, an exceedance of the 1-hour ozone standard would not have occurred on June 23, June 27, or July 10, 2008.

C. Surrogate Day and Rules of Thumb Analysis

1. Results

Independent of the regression analysis described above, STI identified key meteorological parameters that are important to understanding ozone formation in Sacramento County (refer to Appendix Y). STI calls these parameters “rules of thumb.” Using these rules of thumb, STI identified surrogate days with meteorology similar to the fire-impacted days. STI also identified thresholds for these key parameters, thereby identifying conditions under which high 8-hour ozone concentrations would be likely to occur. The meteorological parameters on the fire-impacted days were compared with the thresholds to assess whether 1-hour ozone concentrations on June 23, June 27, and July 10, 2008 would likely have exceeded the federal 1-hour standard, in the absence of wildfire emissions.

The 1-hour ozone concentrations on the surrogate days are shown in Table 8. These 1-hour concentrations range from 79 to 91 ppb, well below the level of the standard. In addition, measured concentrations on the surrogate days are quite close to the regression estimates (< 10 ppb difference). Given the similarity in key meteorological parameters between the surrogate day and the wildfire-impacted day, these results corroborate the regression estimates discussed earlier. Based on the rules of thumb and additional evaluation of large-scale weather patterns, STI also concluded that a 1-hour ozone concentration exceeding the federal 1-hour ozone standard would likely not have occurred on June 23, June 27, or July 10, 2008.

Table 8
1-Hour Daily Maximum Ozone
Regression Estimate Compared with
Surrogate Day Measured Concentrations
Folsom Monitoring Site

Day	Regression Estimate (ppb)	Surrogate Day Concentration (ppb)	Difference (ppb)
6/23/08	77	79	2
6/27/08	76	84	8
7/10/08	95	91	4

2. Method Description

In developing the rules of thumb, STI reviewed surface and upper level weather maps, daily ozone data, and surface and upper air data from the National Oceanic and Atmospheric Administration. STI identified 12 parameters and associated threshold values under which elevated ozone concentrations are likely to occur. The rules of thumb are listed in Appendix Y and include average morning and afternoon surface winds and temperatures at various locations. These parameters are used to represent processes, including transport and dispersion.

The 12 parameters are associated with 8-hour ozone concentrations expected to exceed 95 ppb. To apply the rules of thumb to 1-hour ozone concentrations, STI analyzed the 1-hour concentrations on days when the 8-hour ozone concentration was greater than 95 ppb. They found that on average, an 8-hour concentration of 95 ppb or greater corresponded with an average 1-hour concentration of 118 ppb.

3. Method Uncertainty and Error

As noted previously, the parameter thresholds STI specified in their rules of thumb were used to assess the likelihood of elevated 8-hour ozone concentrations in the Sacramento region. Although: 1) these parameter thresholds were not specifically developed for 1-hour ozone concentrations, and 2) there can be difficulty in selecting exact meteorological matches to wildfire-influenced days, these rules of thumb appropriately capture many primary factors influencing both 8-hour and 1-hour ozone levels, and as such, are useful and appropriate for predicting higher versus lower ozone concentrations, as well as for selecting matching surrogate days.

However, even under conditions that meet all the rules of thumb for 8-hour ozone concentrations above 95 ppb, a corresponding 1-hour ozone exceedance is very rare. As shown in Table 9, of the 46 days during 2004 through 2010 with 8-hour ozone concentrations greater than 95 ppb, only seven days had corresponding exceedances of the 1-hour standard. Of these seven days, three were the days included in this request (June 23, June 27 and July 10, 2008). In addition, a fourth exceedance occurred on July 7, 2008, which was also during the peak 2008 wildfire period. Finally, it is worth noting that of the remaining three days, two were also likely impacted by wildfires, as wildfires continued to burn on August 13, 2008, and also were burning in the region on September 13, 2006 (refer to satellite images, Figures 31 and 32). This further supports the conceptual model that the meteorological conditions present on June 23, June 27, and July 10, 2008 were not sufficient to result in an exceedance of the 1-hour ozone standard in the absence of wildfire emissions.

The outcomes of these analyses (comparisons of surrogate days to wildfire-influenced days and the assessment of whether the met thresholds were met on wildfire-influenced days) provide additional information of what was likely to have occurred without the impacts of the wildfire. Therefore, the information they provide increases the overall weight of evidence presented elsewhere in support of the clear causal relationship criteria and the “but-for” criteria.

Figure 31

MODIS Satellite Image – September 13, 2006

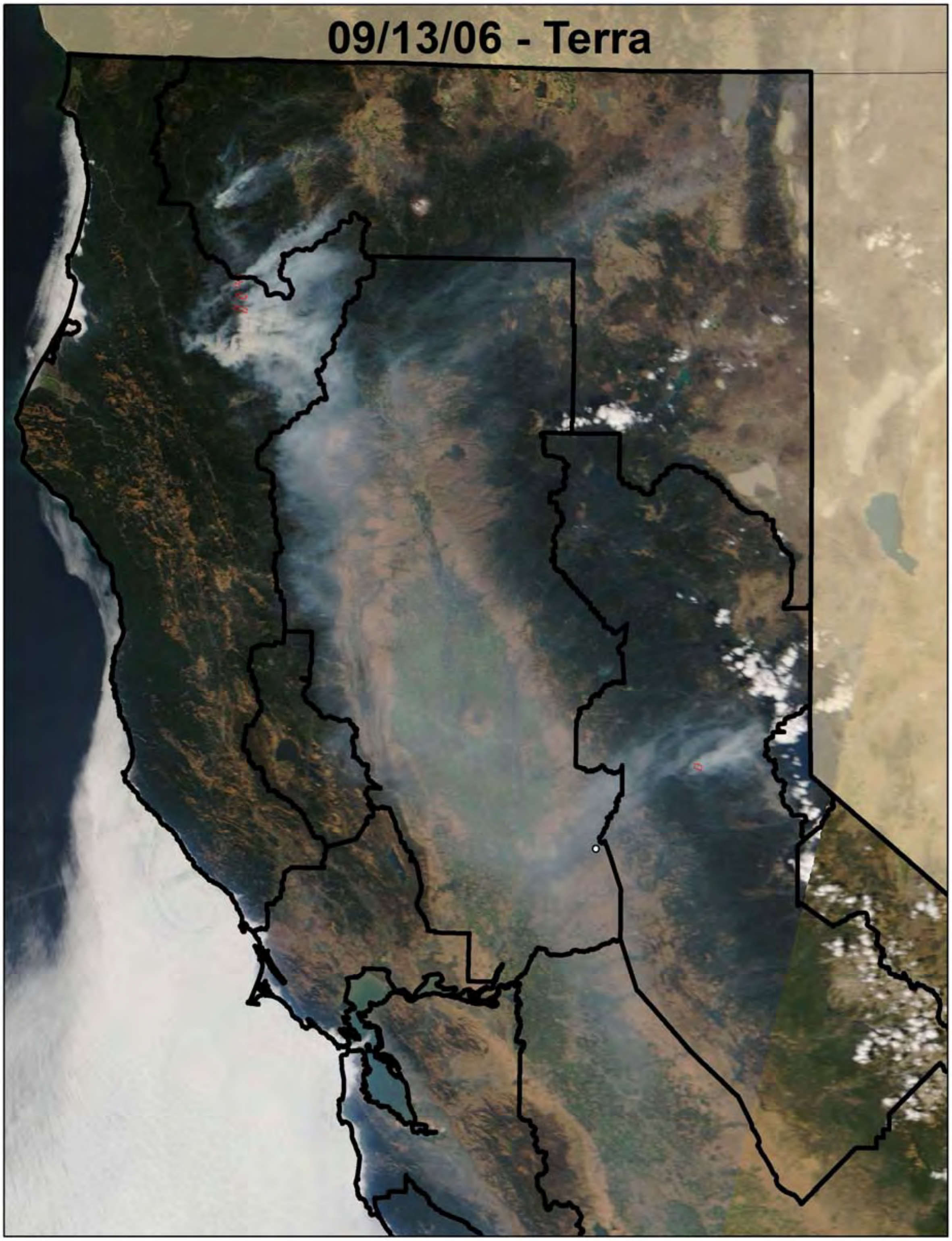
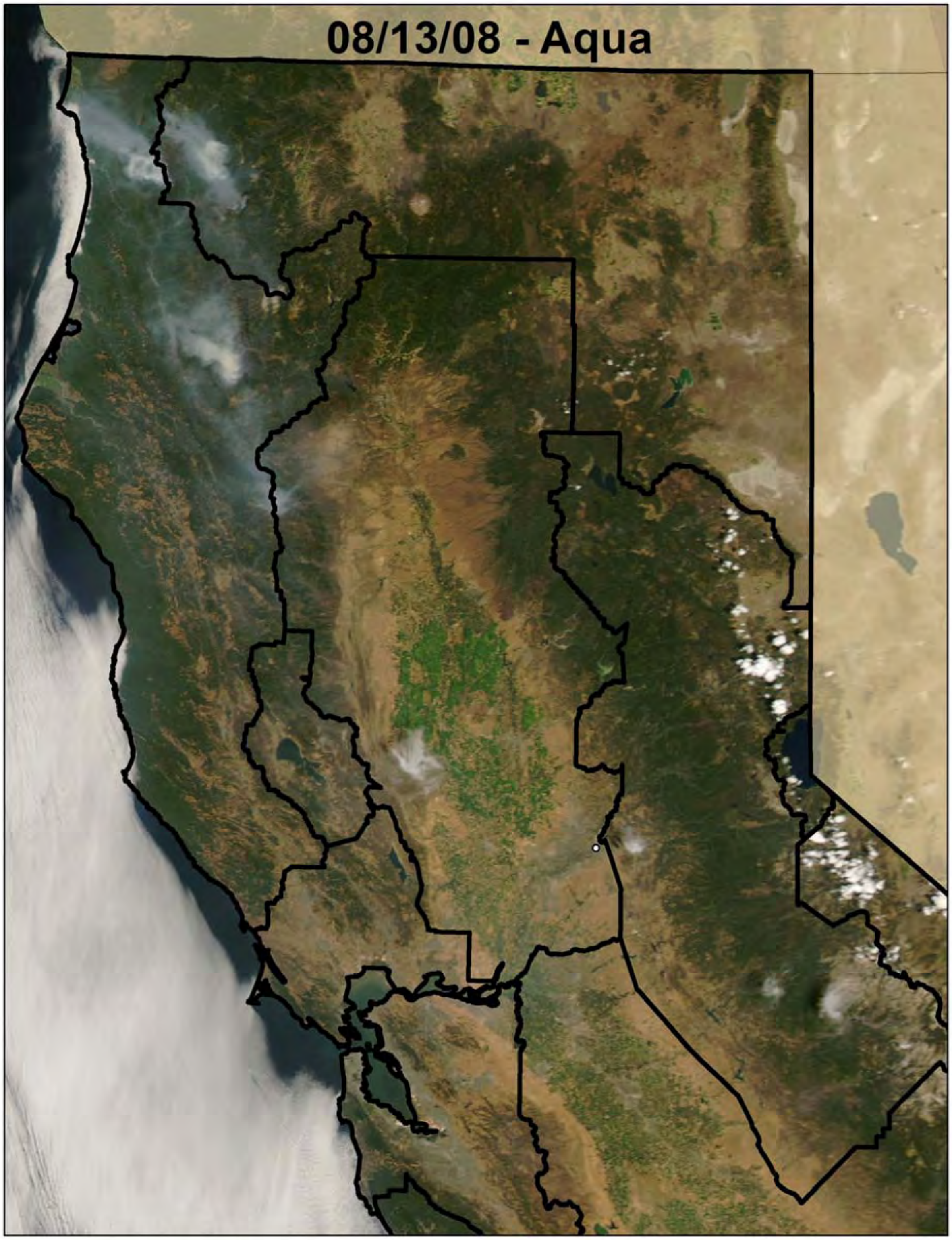


Figure 32

MODIS Satellite Image – August 13, 2008



D. Infrequency of 1-Hour Ozone Exceedances

The 1-hour ozone concentrations on June 23, June 27 and July 10, 2008, are greater than the 99th percentile of concentrations during the May through October ozone seasons of 2004 through 2008, as described elsewhere in this document (see Section 3.F, Beyond Historical Fluctuations). In addition, Table 6 of Section 3.F shows that except for 2008, the frequency of occurrence for 1-hour ozone concentrations exceeding the federal standard from 2004 to 2010 is no more than one per year at the Folsom site.

E. No Unusual Local Emissions

ARB staff evaluated the surrogate days and the wildfire-impacted days, and staff found no evidence to suggest that anthropogenic emission-generating activities differed significantly between the surrogate days and wildfire-impacted days. Sacramento District staff responds to complaints, perform surveillance, and conduct inspections for violations of District air quality rules and regulations, including prohibitive burning and commercial and industrial source compliance. In-field observations reported no violations that could be considered to significantly contribute to widespread air quality degradation or potentially be responsible for triggering a violation of the federal 1-hour ozone standard. Significant violations are reported to U.S. EPA's Air Facility Database. No significant violations were reported to this database for June 23, June 27, and July 10, 2008. The ARB meteorology staff also makes daily "burn" or "no burn" decisions for air basins in California. The three days in question were "no burn" days for Sacramento County. Thus, the only difference from the typical emissions pattern was the presence of the wildfire emissions.

Table 9
1-Hour Ozone Concentrations on Days when 8-Hour Ozone Concentrations were 95 ppb or Greater (2004-2010)
Folsom – Natoma Street Monitoring Site

Date	Max8HrOzone	Max1HrOzone
9/26/2009	0.096	0.104
9/1/2006	0.095	0.105
7/13/2005	0.098	0.106
7/13/2006	0.096	0.106
7/23/2005	0.098	0.107
6/20/2008	0.096	0.107
9/2/2010	0.095	0.107
7/24/2008	0.097	0.108
7/25/2008	0.105	0.108
7/18/2009	0.096	0.108
8/9/2006	0.095	0.109
7/21/2006	0.103	0.11
7/16/2005	0.098	0.111
9/7/2006	0.102	0.111
7/4/2007	0.097	0.114
7/15/2005	0.103	0.115
7/19/2008	0.095	0.115
8/17/2009	0.096	0.115
7/26/2005	0.1	0.116
8/15/2008	0.097	0.116
9/6/2008	0.099	0.116
6/28/2010	0.096	0.116
6/13/2008	0.103	0.117
7/20/2005	0.102	0.118
7/9/2008	0.107	0.118
8/21/2009	0.101	0.118
9/27/2010	0.1	0.118
6/30/2005	0.101	0.119
7/14/2005	0.108	0.12
7/17/2005	0.106	0.12
7/8/2008	0.105	0.12
8/18/2009	0.103	0.12
9/27/2009	0.104	0.12
6/24/2008	0.102	0.121
9/3/2010	0.103	0.121
9/12/2006	0.102	0.122
8/14/2008	0.105	0.122
6/25/2008	0.106	0.123
8/25/2010	0.112	0.124
7/5/2007	**0.122**	**0.129**
6/27/2008	**0.112**	**0.129**
8/13/2008	**0.116**	**0.132**
9/13/2006	**0.11**	**0.133**
7/10/2008	**0.115**	**0.15**
6/23/2008	**0.123**	**0.161**
7/7/2008	**0.114**	**0.166**
Exceedance Day / **Fire Day**		

F. Summary

In summary, the exceedances of the federal 1-hour ozone standard on June 23, June 27, and July 10, 2008, would not have occurred but for the wildfires, based on the following weight of evidence:

- In the absence of wildfires, the predicted 1-hour ozone concentrations would have been below the 1-hour federal standard, ranging from 76 to 95 ppb using the regression equation;

- The fact that nearly half the days (16 of 34 days) between June 24 and July 26, 2008, instead of the expected 5 percent of days (2 of 34 days), exceeded statistically conservative regular upper limits applied to the regression equation output clearly supports the cause-and-effect relationship between the 2008 wildfires and enhanced ozone levels (refer to the Addendum to Appendix X);

- On each of the three fire-impacted days, a conservative regular upper limit applied to the regression equation prediction shows 1-hour ozone concentrations below the federal 1-hour standard, (refer to the Addendum to Appendix X);

- Based on measured ozone concentrations for days with similar meteorology, but no wildfires,1-hour ozone concentrations on the 2008 wildfire-impacted days would have been expected to range from 79 to 91 ppb;

- Based on the rules of thumb for predicting the likelihood of elevated ozone concentrations, the meteorological conditions on the three fire-impacted days were not sufficient to cause an exceedance of the federal 1-hour ozone standard in the absence of the wildfires;

- Exceedances of the federal 1-hour ozone standard are rare at Folsom, and the 1-hour concentrations on the three 2008 fire-impacted days are greater than the 99th percentile of ozone concentrations (based on 2004 through 2008 May through October data);

Therefore, each piece of evidence supports the same conclusion - the 1-hour ozone exceedances on June 23, June 27, and July 10, 2008, would not have occurred but for the wildfire emissions:

(1) the regression analysis (including an assessment of the bias/error in the regression equations),

(2) the failure of the regular upper limit to reach a 1-hour ozone concentration of 125 ppb (an exceedance of the federal 1-hour ozone standard),

(3) the surrogate day analysis,

(4) meteorological thresholds for high 8-hour ozone (rules of thumb), and

(5) the infrequency of 1-hour exceedances,

5. <u>Criteria for the Definition of an Exceptional Event</u>

The criteria in 40 CFR §50.1(j) for an event to meet the definition of an exceptional event need to be met for the measured exceedances to qualify for exclusion. These criteria are:

- The event affects air quality.
- The event is not reasonably controllable or preventable.
- The event is unlikely to reoccur at a particular location or [is] a natural event.

A. Affects Air Quality

As stated in the preamble to the Exceptional Events Rule, the event in question is considered to have affected air quality if it can be shown that there is a clear causal relationship between the monitored exceedance and the event, and that the event is associated with a measured concentration in excess of normal historical fluctuations. These criteria are demonstrated previously in detail in Section 3. The public health notices discussed in Section 6 and Appendix E also provide evidence that the wildfires affected air quality in the vicinity of the Folsom monitor. Given the information presented in Sections 3 and 6, we can reasonably conclude that the event in question affected air quality.

B. Not Reasonably Controllable or Preventable

The Exceptional Events Rule defines a wildfire as an unplanned, unwanted wildland fire "such as fires caused by lightning…" The fires discussed in Section 2 that caused the exceedances in this request (see Sections 3 and 4) were caused by lightning, and therefore qualify as wildfires. The cause of these fires is supported by news reports (see Appendix F). One example of the many articles in the appendix is the article from the Davis Enterprise of June 24, 2008 that reported that as of June 24, 2008 840 fires had been started by an unprecedented lightning storm.

A determination of whether a particular event was reasonably controllable or preventable depends on the specific facts and circumstances surrounding the event and must be determined on a case by case basis. The evidence presented in Section 2 demonstrates that the events in question were unplanned, lightning-ignited wildfires that directly emit ozone precursors. Therefore, the emissions from the wildfires were not reasonably controllable or preventable.

C. Natural Event

As discussed above and in Section 3, the events shown to cause these exceedances were direct emissions of ozone precursors from unplanned lightning-ignited wildfires in June and July of 2008. The events therefore qualify as natural events.

6: Public Mitigation

A. Requirements

The Sacramento Metropolitan Air Quality Management District (Sacramento District), ARB, and the other four air districts in the Sacramento ozone nonattainment area met all of the requirements for mitigating the impacts of these catastrophic wildfires on the public. The public mitigation requirements specified in 40 CFR 51.930 include the following:

- Provide for prompt public notification whenever air quality concentrations exceed or are expected to exceed an applicable ambient air quality standard.

- Provide for public education concerning actions that individuals may take to reduce exposure to unhealthy levels of air quality during and following an exceptional event.

- Provide for the implementation of appropriate measures to protect public health from exceedances or violations of ambient air quality standards caused by exceptional events.

B. Public Notification

ARB and the northern California air districts provided prompt notification when air quality concentrations were expected to exceed the level of federal and State air quality standards. Numerous health and smoke advisories were issued by ARB, the regional air districts, the U.S. Forest Service, the National Parks Service, the California Department of Forestry and Fire Protection, and the State of California. In addition, the Sacramento District issued numerous health advisories through the "Spare the Air" program during the period spanning the fires, notifying the public that ozone and particulate pollution levels were expected to exceed the levels of the standards. The Sacramento District also provided a free "Air Alerts" service, which notified subscribers when air quality in the Sacramento region was forecast to be unhealthy. These advisories are included in Appendix E.

A prior version of this documentation was made available for public review from July 31, 2009 to August 31, 2009 and two comments were received. The Sacramento District responded to these comments. The prior version of this documentation has been modified and incorporated into this final documentation package. Public comments and the Sacramento District's response to these comments are included in Appendix G.

C. Public Education

Health advisories issued by the Sacramento District, in conjunction with the Sacramento County Public Health Department, urged residents to take precautions to minimize their exposure to the unhealthy air. Advisories issued by the regional air districts and ARB included media interviews intended to educate the public on the hazardous air quality conditions.

ARB, the air districts, the U.S. Forest Service, the National Parks Service, the California Department of Forestry and Fire Protection, and the State of California, all have active community outreach programs, as well as easily accessible information on numerous websites. These various forums aid in educating the public about the hazards posed by smoke from wildfires and how to minimize exposure. For example, an ARB publication titled "Wildfire Smoke: A Guide for Public Health Officials," is readily available on-line and in hard-copy format, to aid local officials, as well as the general public, in understanding the health impacts of wildfire smoke. In addition, the California Air Pollution Control Officers' Association (CAPCOA) Public Outreach Committee, comprising representatives of all California's air districts, maintains an up-to-date webpage to consolidate and disseminate consistent information on the impacts of smoke on public health.

D. Implementation of Mitigation Measures

The Districts in the Sacramento region participate in the California Air Resources Board (CARB) Smoke Management Program which uses adopted guidelines that provide for enhanced smoke management planning and improved communication in conducting and scheduling agricultural and prescribed burning. This program was actively employed during the 2008 wildfires, resulting in numerous "no-burn" day decisions made for the region. Records maintained with the Deputy Agriculture Commissioner for Sacramento County and the ARB Meteorology Section, show that for June 23, June 27, and July 10, 2008, "no-burn" days were called throughout the region due to the high Air Quality Index.

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