Louisiana Exceptional Event of September 14, 2017

Analysis of Atmospheric Processes Associated with the Ozone Exceedance and Supporting Data

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Submitted to:

US EPA Region 6
1445 Ross Avenue, Suite 1200
Dallas, Texas 75202-2733

March 1, 2018

Acknowledgments

The Louisiana Department of Environmental Quality would like to thank Sonoma Technology, Inc. (STI) for extensive contributions to Section 2 and Appendices 2 and 4. STI contributors include Nathan Pavlovic, Bryan Penfold, Patrick Zahn, Ken Craig, ShihMing Huang, Theresa O'Brien, and Steve Brown.

The Louisiana Department of Environmental Quality would also like to thank Dan Jaffe for his contributions to Appendix 3.

Executive Summary

This report will present evidence that the transport of smoke and pollutant precursors from fires burning in the Pacific Northwest caused ozone exceedances and an exceptional event to occur on September 14, 2017 in areas of southern Louisiana. Fires in the Pacific Northwest were particularly extensive in the month of September. The smoke that was transported from the fires on these days contributed to ozone formation and an exceedance of the 2015 National Ambient Air Quality Standard (NAAQS) for 8-hour ozone at several air quality monitors in the Baton Rouge area. While many monitors recorded high levels of ozone that day, the Dutchtown monitor was pivotal as this exceedance was enough to place the area into the predicament of being designated as nonattainment for the current standard.

The Exceptional Events Rule states in 40 CFR §50.1(j) that an exceptional event is that which:

1. affects air quality;
2. is not reasonably controllable or preventable; and,
3. is caused by human activity that is unlikely to recur at a particular location or is a natural event.

This report will show that the transport of smoke did affect the air quality, was not reasonably controllable or preventable, and was caused by a natural event.

As specified in 40 CFR 50.14(c)(3)(iv), to justify the exclusion of air quality data from NAAQS determination, the following must be included:

1. A narrative conceptual model that describes the event(s) causing the exceedance or violation and a discussion of how emissions from the event(s) led to the exceedance or violation at the affected monitor(s);
2. A demonstration that a clear causal relationship between the specific event and the monitored exceedance or violation exists;
3. Analyses comparing the claimed event-influenced concentrations to concentrations at the same monitoring site at other times;
4. A demonstration that the event was both not reasonably controllable and not reasonably preventable; and,
5. A demonstration that the event was a human activity that is unlikely to recur at a particular location or was a natural event.

Statement of Purpose

On September 14, 2017, the Louisiana Department of Environmental Quality (LDEQ) monitored exceedances of the 2015 8-hour ozone (O3) National Ambient Air Quality Standard (NAAQS) at the Dutchtown air quality monitoring site due to wildfire smoke plume impacts from fires in the Northwest. The LDEQ has determined that these wildfires influenced O3 concentrations exceeding the 2015 NAAQS on September 14, 2017 and qualify as an exceptional event under

Title 40, Part 50 of the Code of Federal Regulations (40 CFR 50), Exceptional Event Rule (EER). The purpose of this document is to petition the Regional Administrator for the Environmental Protection Agency (EPA) Region 6 to exclude air quality monitoring data for O3 from the normal planning and regulatory requirements under the Clean Air Act (CAA) in accordance with the EER. This demonstration package will have a regulatory impact on the 2015 8-hour O3 designation for the Baton Rouge Metropolitan Statistical Area.

This report will provide evidence that the daily peak 8-hour average ozone concentrations in exceedance of the NAAQS at the Dutchtown monitor on September 14, 2018, were the result of smoke generated by fires in the Pacific Northwest that was transported to Louisiana. Specifically, that the event affected air quality by demonstrating that: 1)there was a clear causal relationship between the 8-hour O3 concentrations in Dutchtown, 2)the event was a natural event, and 3) the event was not reasonably controllable or preventable.

An Exceptional Events Initial Notification was sent to EPA Region 6 on November 8, 2017. (See Appendix 1). This exceptional event demonstration will undergo a 30-day public comment concurrent with EPA Region 6's review beginning March 1, 2018 pursuant to 40 CFR 50.14(c)(3)(v). By April 1, 2018, LDEQ will forward any written comments received and provide documentation that the public comment process was followed.

Summary of Event

During the two weeks leading up to September 14, 2017 large wildfires were active in the northwestern United States as well as in Saskatchewan, Canada. Wildfire smoke was transported to Baton Rouge from the large wildfires burning in the northwestern United States, including Washington, Oregon, Idaho, and Montana, and in California. Significant quantities of smoke were released from these fires and transported across the northern and central United States. Air mass transport patterns leading up to September 14, 2017 brought smoke from the northwestern United States to Louisiana. That smoke was present at ground level and impacted local air quality.

Summary of Findings

This report demonstrates that the smoke events in question were not reasonably preventable/unlikely to recur; there is a clear causal relationship between the fires and the 8-hour ozone exceedances; ozone concentrations during the event were in excess of historical norms; and the ozone exceedances would not have occurred but for the smoke from the fires. Therefore, the findings strongly suggest that all of the 8-hour ozone concentrations above 0.070 ppm at the Dutchtown monitor on September 14, 2017 meet the requirements for exclusion as an Exceptional Event.

1.0 Narrative Conceptual Model and Exceptional Event Summary

1.1 Regional Description

The area impacted is the historical Baton Rouge 5-Parish metropolitan statistical area (MSA), consisting of Ascension, East Baton Rouge, Iberville, Livingston, and West Baton Rouge Parishes. Over the last 30 plus years, this area has been designated nonattainment/redesignated attainment for both the 1-hour and 8-hour ozone NAAQS. The area was most currently redesignated attainment for the 2008 Ozone NAAQS on December 15, 2016. Prior to this event, the MSA was in attainment for the 2015 Ozone NAAQS.

1.2 Overview of Monitoring Network

LDEQ maintains its ambient air monitoring network in accordance with the quality assurance requirements of 40 CFR Part 58, Appendix A and B, utilizes the methodology provided for each monitor in accordance with Appendix C, designs its network in accordance with Appendix D, and locates its sites to meet all requirements of Appendix E. Each year LDEQ prepares a monitoring network plan that is public noticed and reviewed by EPA. The current monitoring network plan can be found at http://deq.louisiana.gov/page/ambient-air-monitoring-data-reports.

1.3 Characteristics of Pacific Northwest Wildfires Ozone Formation and Related Concentrations

Wildfire smoke can contribute to an increase in ground level O3. These increases are observed in comparison to seasonal, monthly, daily, and hourly historic normals. The September 2016 "Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations" (Wildfire Ozone Guidance) uses emissions and distance as a screening criterion for the level of documentation needed for an event demonstration. It is important to point out that academic research on the behavior of O3 production from a wildfire generally concludes that O3 production may increase with plume age and distance from the wildfire.[1]

1.4 Meteorological Conditions

During the days of the 13th and 14th of September 2017, air composition detection sites in Southern Louisiana identified unusually elevated levels of the ozone molecule near the surface. Several days before this occurred, wildfires in the Pacific Northwest and Central Canadian

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[1] 1 Jaffe, D.A., and Wigder, N.L., 2012. Ozone production from wildfires: A critical review. Atmospheric Environment 51, 1-10, doi:10.1016/j.atmosenv.2011.11.063.

regions violently burned vegetation and produced an immense amount of smoke material which contained pollutants such as hydrocarbons and other particulate matter. Light wind allowed the smoke and pollutants to build up near the source over the course of a few days before moving eastward and diverging. One track moved north and the other moved to the south. As the northern track progressed, it combined with smoke from wildfires in Saskatchewan, Canada, which were at near peak intensity for the month, and traveled clockwise around the Great Lakes region on the outskirts of a high pressure center until reaching the Mid-Atlantic region. There it became involved with the outer edge of Hurricane Irma currents and reconnected with the southern track, which up until this point had stalled out in the Midwest. The two smoke masses traveled together counterclockwise around the Irma system and its remnants as it advanced and pulled the material through Texas, the Northwestern Gulf of Mexico, and onshore to Louisiana. Moisture from the Gulf and a relative high pressure, indicated by clear skies, would both result in vertical mixing and bring the polluted air from higher altitudes down to the surface.

On arrival, dominant air currents for the Southeast region shifted from the Irma remnants back to upper level currents. During this shift, airflow at the surface, in the majority of the Southeast region, became mostly stagnant and allowed for the pollutants delivered from wildfires nearly 2,000 miles away to remain in Southern Louisiana until sufficient airflow to move the pollutants occurred and the ozone concentration returned to average levels. This series of events led to the tropospheric ozone levels in Southern Louisiana on the 13th and 14th of September 2017 being elevated above the concentration that, otherwise, would have been detected. These elevated levels were consequence of atmospheric transportation of wildfire pollutants which originated in the Pacific Northwest and Central Canadian regions, mixed with surface air as it reached the Central Gulf Coast and was detected by air monitoring sites in the area.

Wildfires have a detrimental impact on local regions as they consume nearly any combustible material in their path, but the effects of the smoke, although less severe, are significantly more widespread and can have influences on areas the size of entire continents while also traversing multiple landmasses. The wildfires that plague the Pacific Northwest and Central Canada are affecting atmospheric conditions on nearly all of North America as prevailing currents bring air onshore from the Pacific Ocean and disperse it across the continent. For the first half of September 2017, those wildfires were particularly intense while predominantly clear skies, for weeks before, allowed plenty of sunshine to dry out the region. Several days of still winds over the Pacific Northwest allowed the smoke and other pollutants to accumulate near the source until westerly winds gradually began to increase (Fig. A, B, C; Sonoma Technology, Inc. (STI) Fig. 9).

As the westerly winds became more prominent, the smoke and particulates were introduced to currents that would set them on their path. This eastward movement continued until the air flow diverged into distinct northern and southern paths over Eastern Montana (Fig. D, E). The southeasterly portion was pushed to the east-southeast towards the central Midwest due to influence from upper tropospheric currents (Fig. F). The northeasterly track became trapped in the anticyclonic system centered over the Great Lakes region and moved clockwise around this center until it reached far enough to the south to be affected by Hurricane Irma (Fig. E, G, H, I). Both of these tracks taken by the smoke and particulates produced by wildfires are pulled into the cyclonic low pressure system produced by Hurricane Irma and, later, its remnants (STI Fig. 13; Fig. J).

Hurricane Irma was a major hurricane at landfall, and as it moved into the Southeastern continental United States, it remained powerful and dominated the airflow from the surface to the upper troposphere in the Southeast and parts of the adjacent regions (2017 AHC; Fig. J). Smoke and particulates from both the northern track, which were moving southwest out of the anticyclonic flow, and the southern track, which were lingering in the Midwest, became caught in Hurricane Irma's current (STI Fig. 13). As the low pressure center moved northwestward, the airflows that contained the pollutant material were combined and concentrated as they moved around the center of low pressure in a counter-clockwise direction through Oklahoma, Eastern Texas and the Northwestern Gulf (STI Fig. 8; Fig. K). In the Gulf, the dry parcel of continental air had the opportunity to acquire moisture. During the morning of September the 13th, the center of low pressure that was Hurricane Irma, now sitting over Western Tennessee, was in a position that pulled the polluted air and other wildfire material from the Northwestern Gulf of Mexico onshore to Louisiana (STI Fig. D-1).

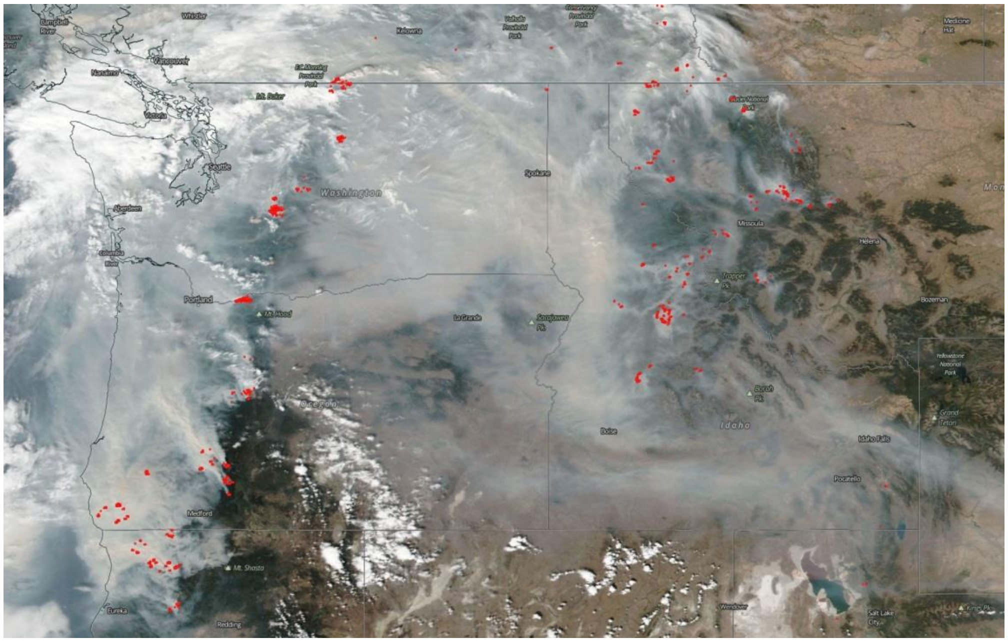
During its nine day journey, these particulates had been exposed to mostly clear skies and plenty of material that contributed to tropospheric ozone development (NASA Worldview). By the time this air reached Southern Louisiana, the smoke and pollutants had abundant opportunities for forming ozone. Pollutants that form ozone were also brought to the state where they mixed with local pollutants, added to the typical ozone levels and produced an exceptional concentration. Throughout its travel time, there were few opportunities for these air parcels to gather moisture, allowing them to be relatively dry and stable and to remain aloft throughout the course of their journey. Roaming through mostly continental areas, the air would have had a high potential for moisture absorption, and after drifting over the Gulf, surface air would have obtained enough moisture to create unstable conditions, induce vertical mixing, displace the pollutants and ozone aloft and bring them to the surface. Furthermore, predominantly clear skies locally in the days before and during the event indicate a relative high pressure present in the region which would generate sinking air (Fig. L, M). This would provide any air aloft with an opportunity to descend, potentially all the way to the surface. Also, areas with a well-defined relative high pressure tend to have light wind and somewhat stagnant wind conditions.

Transportation of ozone and pollutants were not the only contributing factors to the exceptionally high ozone concentration; lack of air transport caused the unusually elevated levels to persist. As the low pressure system that was Hurricane Irma weakened to the point that upper level air currents could regain control of the region, a noticeable hesitation in the surface air currents can be observed. Surface pressures stabilized and, as was the case in the Southeast region, were generally not strong enough to create wind speeds above 5 knots (Fig. M). Stagnant winds and clear skies created conditions that allowed the smoke and pollutants to linger (STI Fig. 8). These circumstances, combined with the surplus of ozone and pollutants, were favorable for an exceedance event in the Southern Louisiana region. Late in the afternoon of the 14th through to the morning of the 15th, light southern winds began and produced adequate airflow to move the excess of pollutants far enough out of the region (Fig. N).

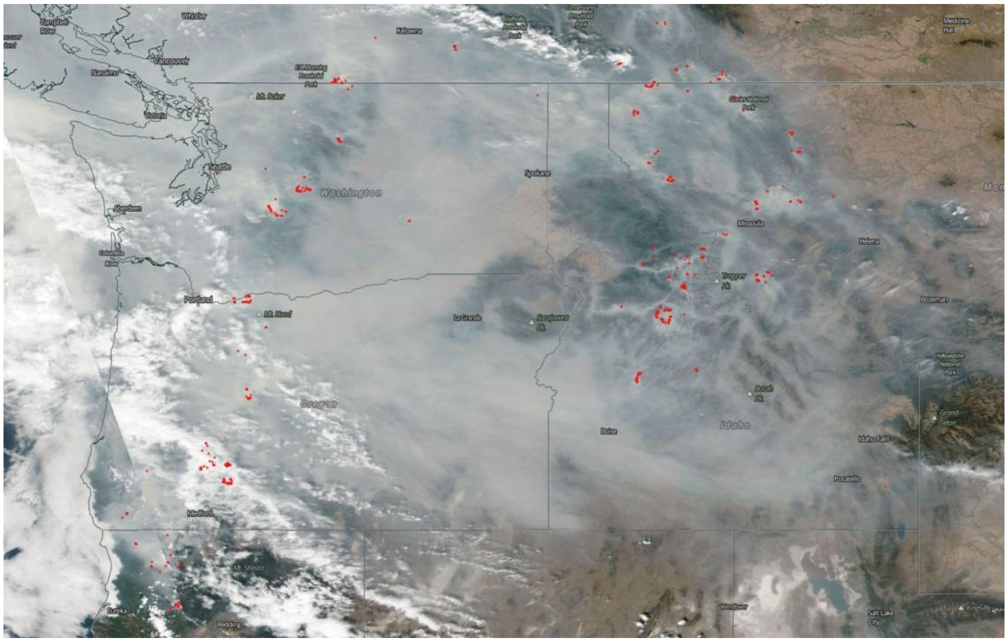
Over the course of nearly two weeks, the smoke and pollutants produced by the Pacific Northwest and Canadian wildfires circulated around much of the North American continent collecting additional pollutants and forming ozone as it journeyed. This material was transported by air currents through the Midwest, Central and Eastern Canada and Northern and Mid-Atlantic regions where mostly clear skies provided opportunity for mid-flight ozone formation. This air was then caught in the Irma low pressure system and delivered to the Northwestern Gulf of Mexico. There with moisture acquired from the Gulf, southwesterly winds pushed the pollutants onshore to Louisiana and produced the unstable atmospheric conditions that promote vertical mixing. Stagnant airflow during the following day further exacerbated the situation by allowing the pollutants to remain in the area. The next day, wind in the area became strong enough to adequately displace the pollutants and end the series of occurrences related to the exceedance.

These phenomena were a demonstration of how events causing massive amounts of air pollution, such as large scale wildfires, have the potential to be carried thousands of miles and influence areas contents away. The dynamic nature and worldwide effect that wind currents can produce give instances, like the one discussed, the potential to have material that has been released into the air impact any location on the planet.

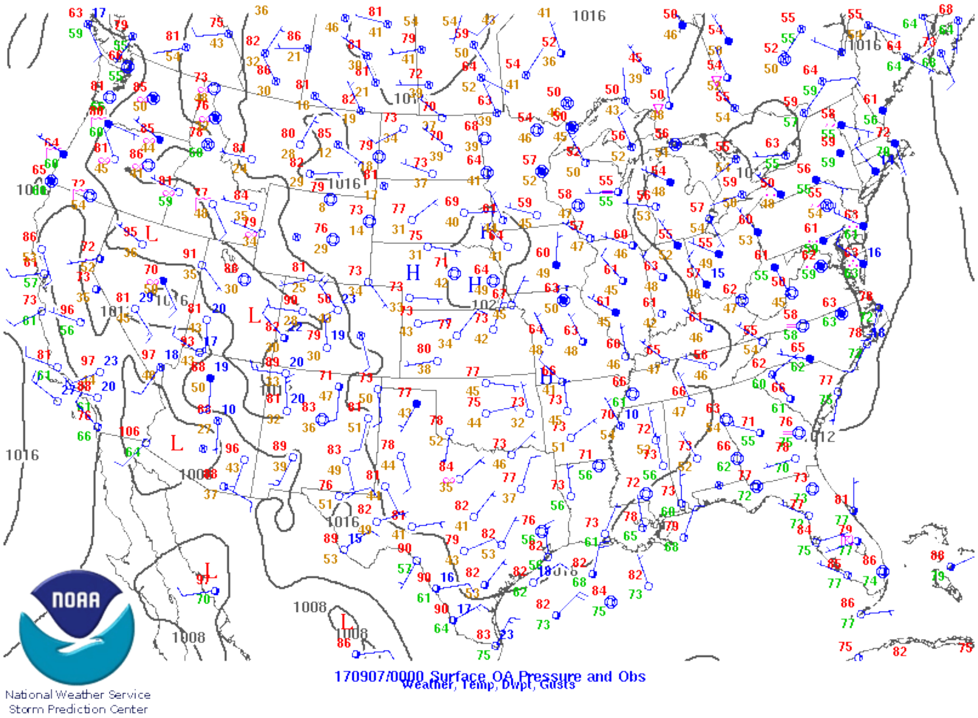
Figures A-N:



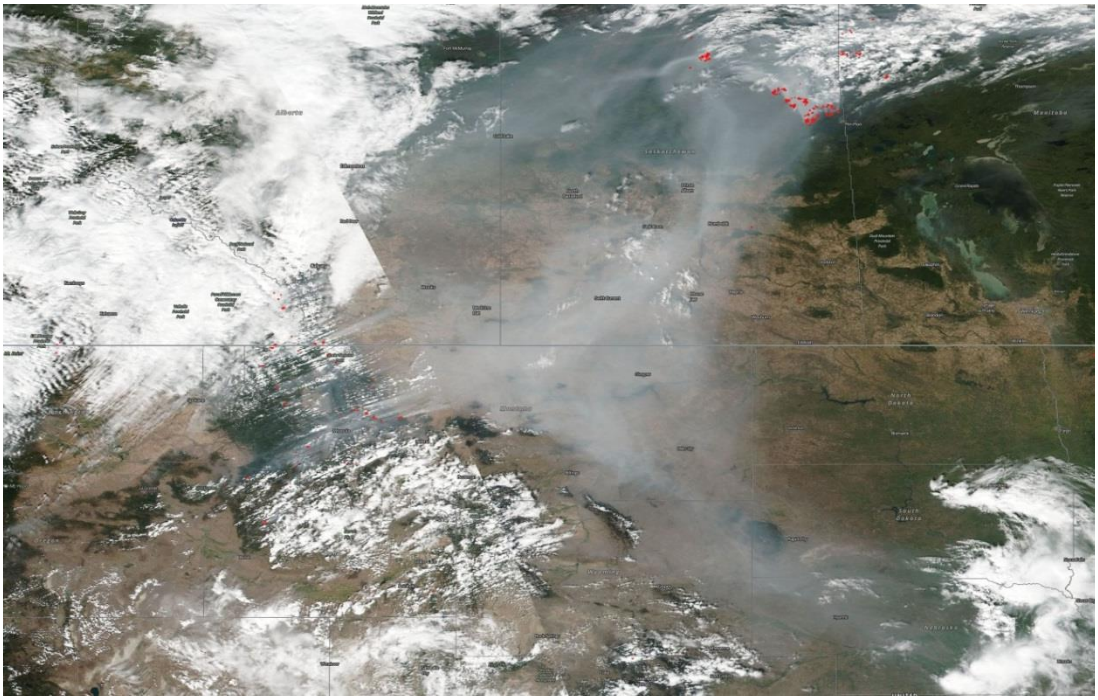
(Figure A) Sept 5, 2017: Red dots indicate the location of fires in the Pacific Northwest**.** Smoke is gathered in the areas near the fires**.** (NASA Worldview)



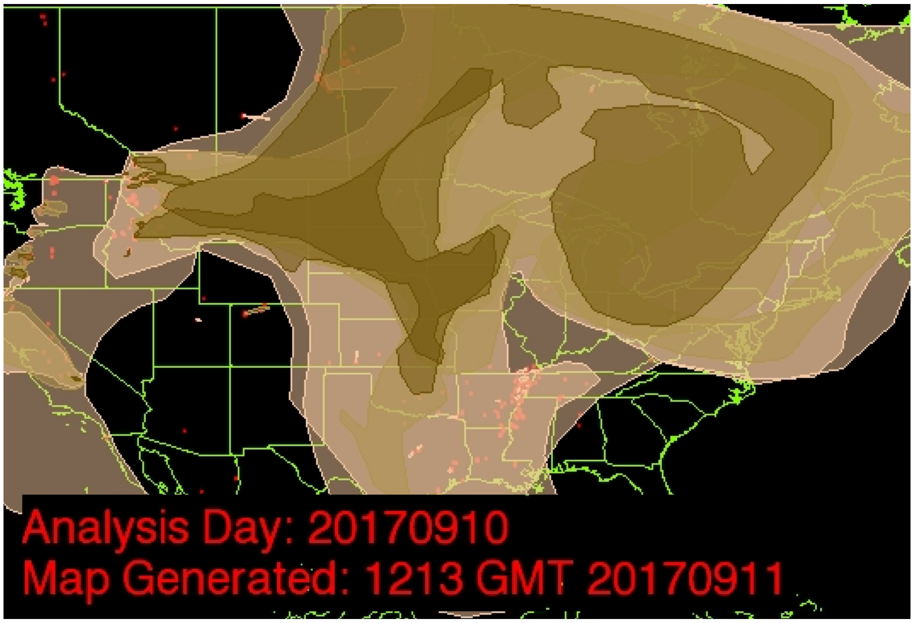
(Figure B) Sept 6, 2017: Faint winds allow the smoke to accumulate further. Light cloud cover allows sunlight to provide energy for ozone formation. (NASA Worldview)



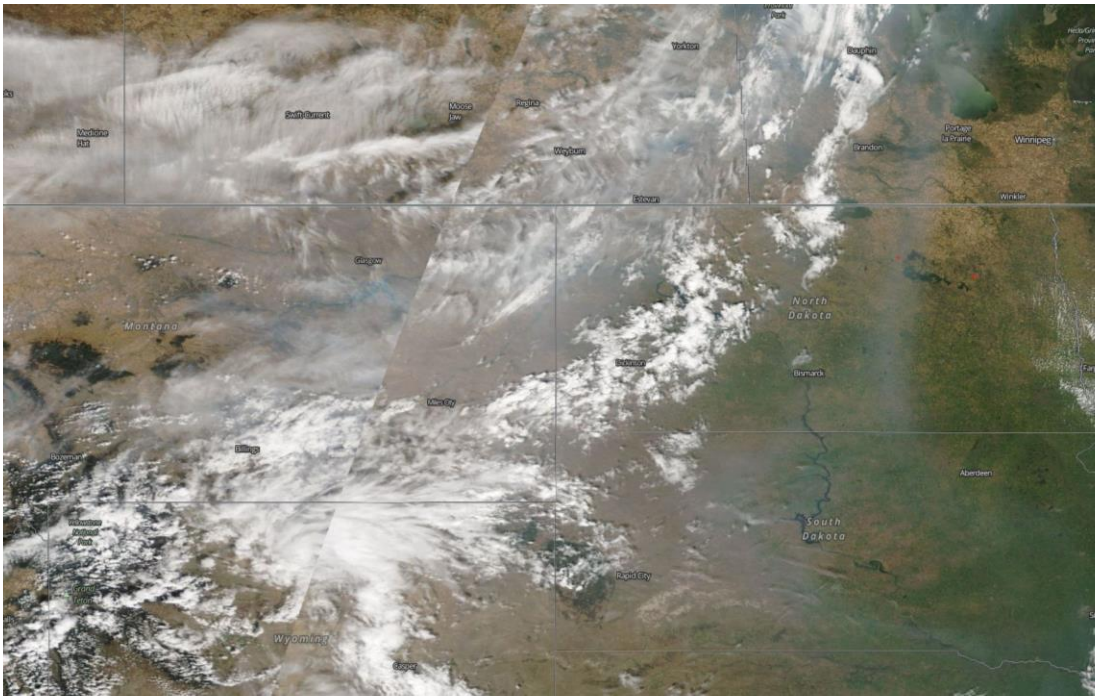
(Figure C) Sept 6, 2017 19:00 CDT, surface; Map of surface conditions for the U.S. Wind barbs in the area of the wildfires indicate light wind activity that translates to stagnant air and a buildup of pollutants. (SPC)



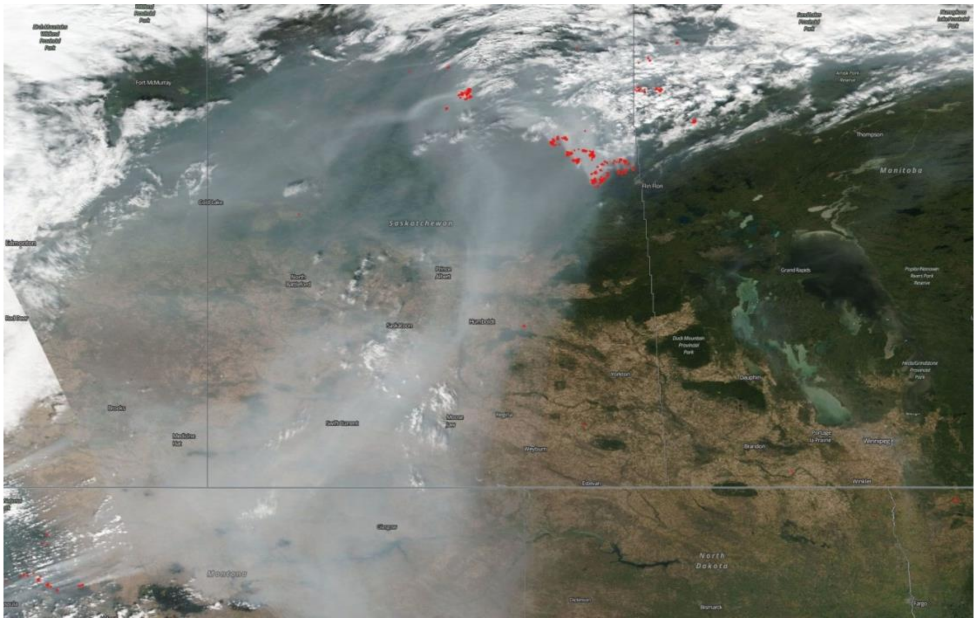
(Figure D) Sept 9, 2017; Smoke from the wildfires continues eastward until it diverges over Eastern Montana. (NASA Worldview)



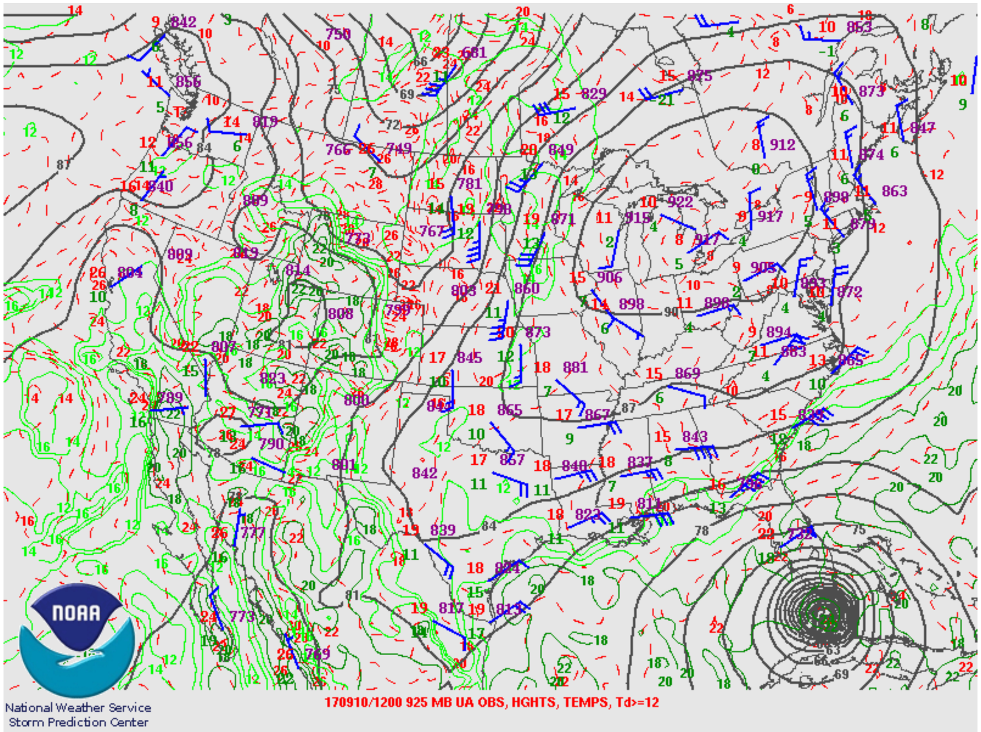
(Figure E) September 10, 2017 7:13 CDT; Smoke plumes from the wildfires diverge into distinct northern and southern tracks. The southern track stalls in the Midwest, and the northern track circles through Canada and moves into the Northeast U.S. (Hazard Map)



(Figure F) Sept 10, 2017; Smoke from the wildfires move into South Dakota. (NASA Worldview)

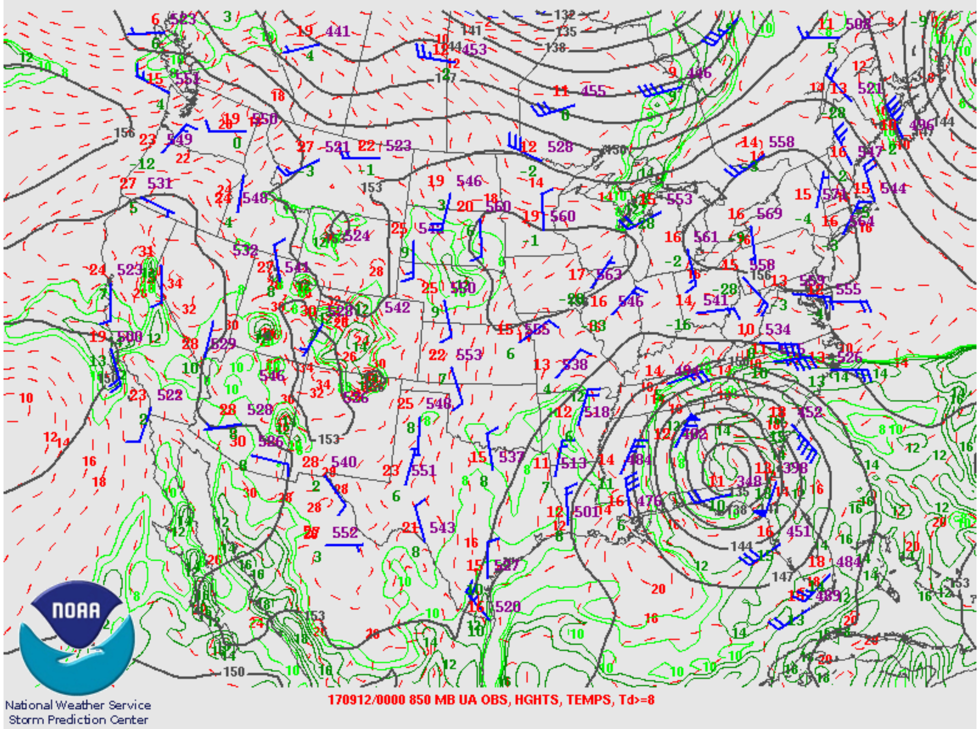


(Figure G) Sept 9, 2017; Smoke from the wildfires continues traveling north through Saskatchewan, Canada and merging with smoke from wildfires in that area. (NASA Worldview)

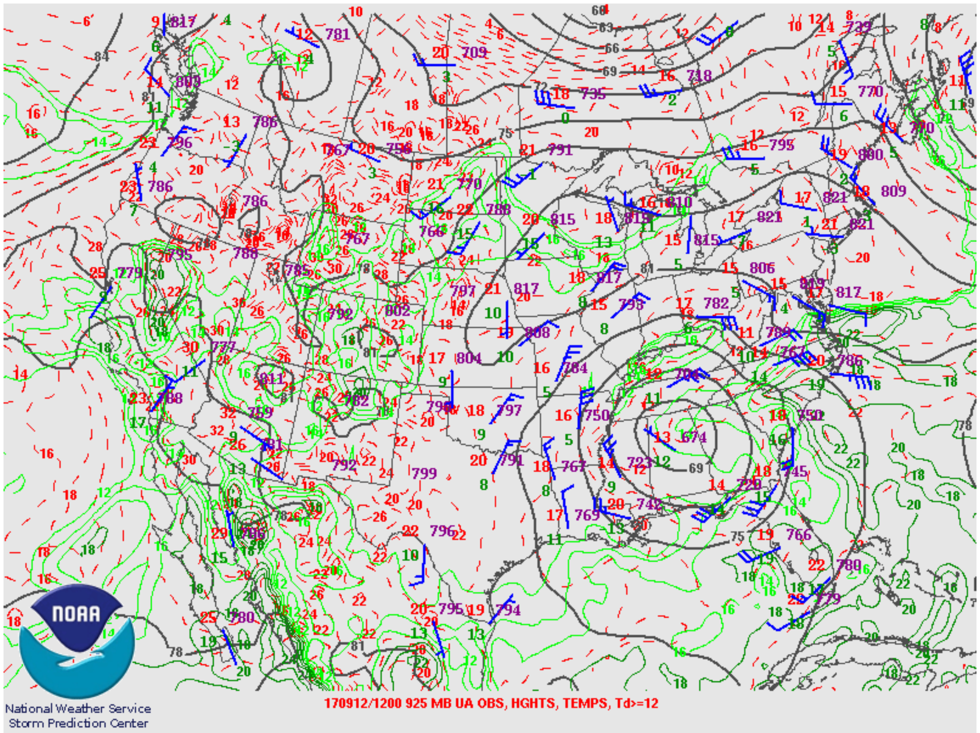


(Figure H) September 10, 2017 7:00 CDT, 925 mbar; Clockwise airflow moves around the center of high pressure positioned over the Great Lakes. (SPC)

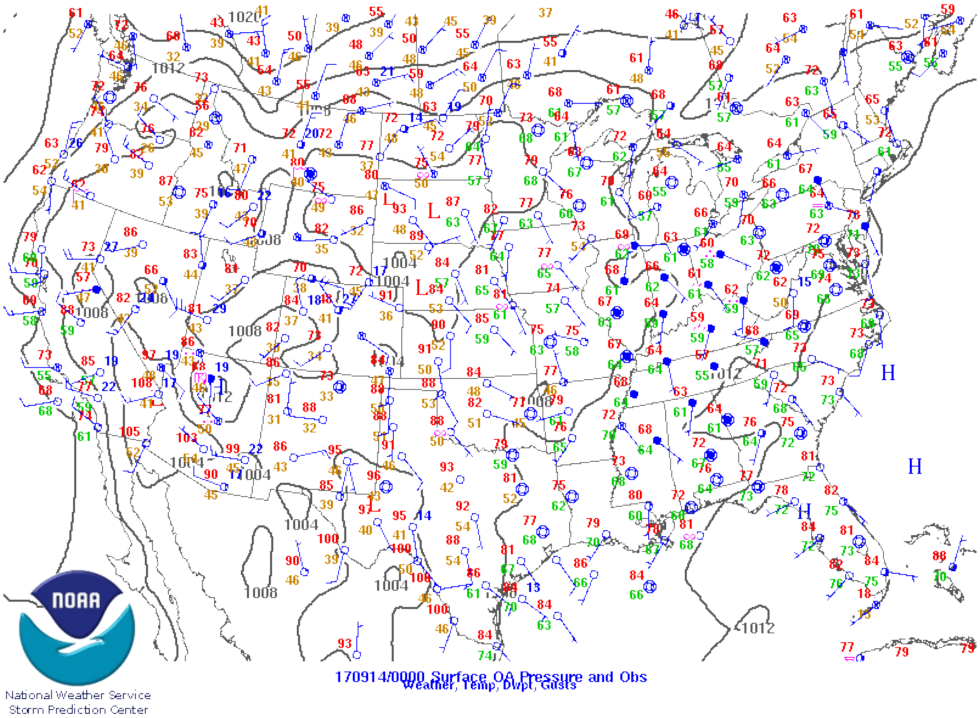
(Figure I) September 10, 2017; Wildfire smoke and pollutants move southwest through the Northeast region before becoming part of Hurricane Irma’s current. (NASA Worldview)



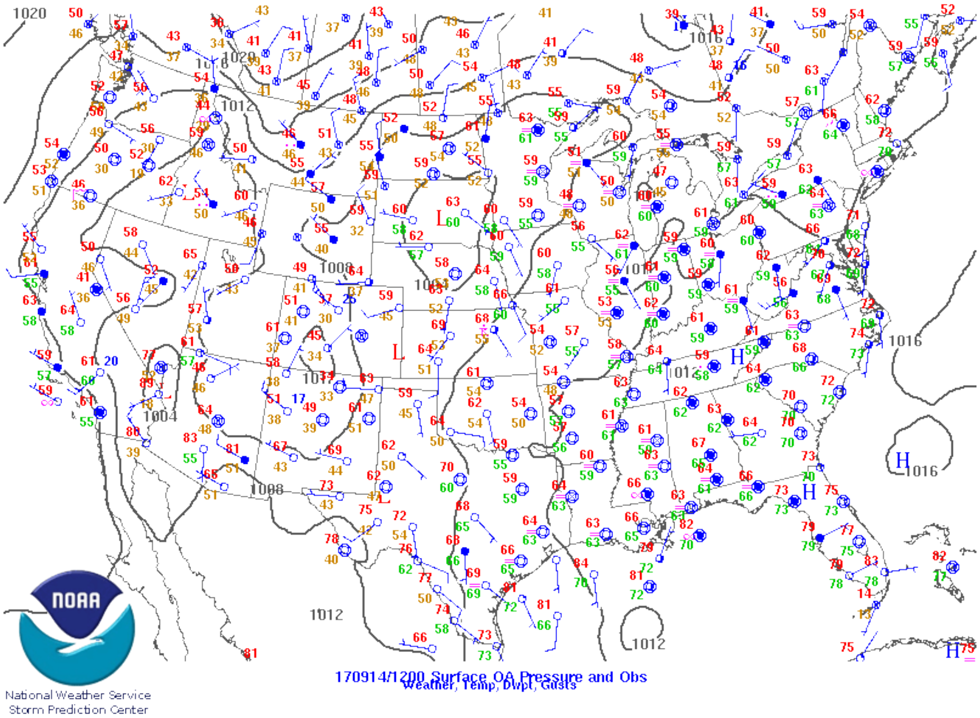
(Figure J) September 11, 2017 17:00 CDT, 850 mbar; Hurricane Irma dominates airflow currents in the Southeastern United States. (SPC)



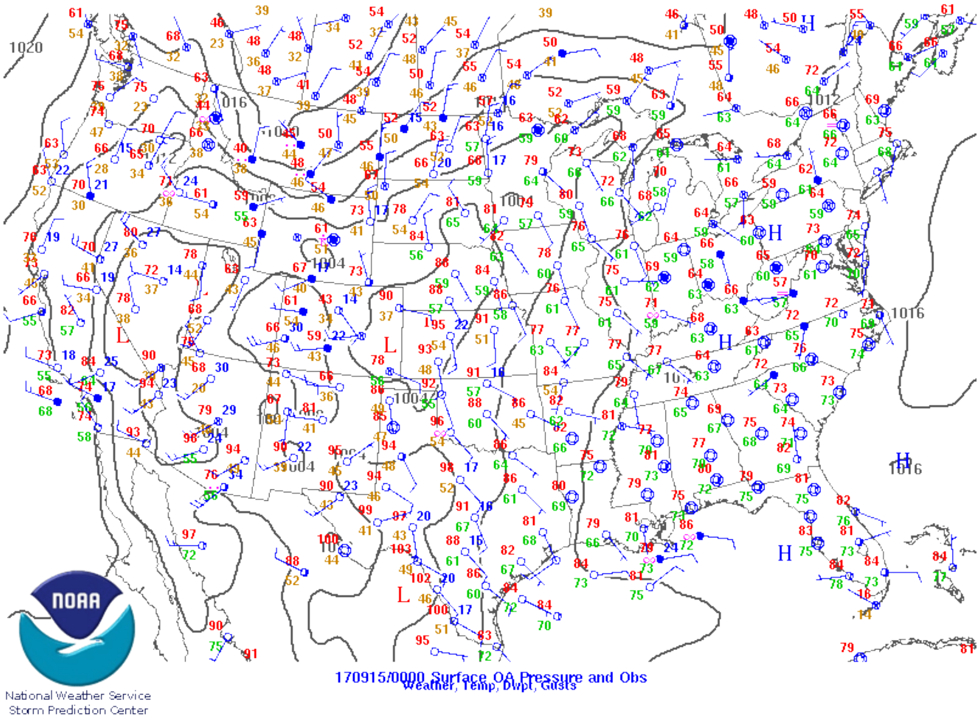
(Figure K) September 12, 2017 7:00 CDT, 925 mbar; Hurricane Irma is located in Northern Alabama and directing air currents from the Northeast and Midwest towards the Western Gulf Coast region. (SPC)



(Figure L) September 13, 2017 19:00 CDT, surface; Station plots surrounding the Baton Rouge area indicate clear skies. (SPC)



(Figure M) September 14, 2017 7:00 CDT, surface; Station plots surrounding the Baton Rouge area continue to indicate clear skies and stagnant wind conditions. (SPC)



(Figure N) September 14, 2017 19:00 CDT, surface; Wind returning to the Central Gulf Coast region restores air flow and displaces the stagnant air.

1.5 Media Coverage

LDEQ collaborates with the local media to provide air quality information to the public each day. Air Quality Index (AQI) forecasts and air alerts are updated daily, or more frequently, on the LDEQ website, and via EnviroFlash. Members of the public can also subscribe to receive alerts directly from the service. This allows the public to receive timely information about precautions they can take to reduce exposure to the high levels of air pollution. In addition, other air quality information and data was available from the LDEQ website (deq.louisiana.gov).

2.0 Clear Causal Relationship

2.1 Introduction

This section of the demonstration addresses the technical element presenting evidence that a clear causal relationship between the wildfire event and the monitored exceedance exists, while further providing evidence that the event affected air quality. In this section, per the EPA's 2016 EER revision and the Wildfire Ozone Guidance, demonstrations that support the clear causal relationship include:

1) a comparison of the O3 data requested for exclusion against historical O3 concentrations at the monitor,
2) evidence that the fire's emissions were transported to the monitor,
3) evidence that emissions from the wildfire influenced the monitored concentrations, and;
4) quantification of the wildfire's emissions contributing to the monitored O3 exceedance.

The Wildfire Ozone Guidance defines a tiered strategy for demonstrations based on the event's potential for ozone formation and the level of evidence required to demonstrate a clear causal relationship between the event and the exceedance. This demonstration meets the purpose of the Wildfire Ozone Guidance and provides the evidence needed for EPA Region 6 to concur that an exceptional event occurred on September 14, 2017.

2.2 Tier 1 Analysis

2.2.1 Comparison of Fire-Influenced Exceedance with Historical Concentrations

Analysis by Sonoma concluded that the exceedance on September 14, 2017, does not satisfy the key factor for a Tier 1 event because it occurred during the normal ozone season (April-October) and because it was not 5-10 ppb higher than non-event-related concentrations. However, it substantially exceeds the 5-year 99th percentile of ozone concentrations measured at the Dutchtown site, satisfying Key Factor #2 for Tier 2 exceptional event demonstrations. This analysis is detailed in Section 3.1 of the report prepared by Sonoma entitled "Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017" and included in Appendix 2.

2.2.2 Evidence of Transport of Fire Emissions to the Dutchtown Monitor

Smoke maps, HYSPLIT trajectories, visible satellite imagery, and satellite retrievals of Aerosol Optical Depth (AOD) and carbon monoxide (CO) show strong evidence of smoke transport from fires burning in the northwestern United States to Louisiana. Furthermore, vertical aerosol profiles from satellite and mixing height information suggest that smoke was present over the site prior to the day of September 14, and that downward vertical mixing occurred from the altitude at which the smoke was observed. Details of this analysis can be found in Section 3.2-3.5 of the report prepared by Sonoma.

2.3 Tier 2 Analysis

2.3.1 Key Factor #1 – Fire Emissions and Distance of Fires

For September 14 in Baton Rouge, the largest calculated Q/d value for an individual fire was 0.79. The aggregate Q/d for all fires on September 14 was 5.36. These Q/d values fall far below the threshold of 100 set by the exceptional event guidance for a Tier 2 exceptional event. Q/d calculations, because they rely on only 24-hr back trajectories, generally reflect the impact of local fires. The low Q/d values calculated for Baton Rouge on September 14, 2017, suggest that local fires likely played only a small role, if any, in the high ozone measurements on September 14 in Baton Rouge. Instead, as the other analyses show, long-range transport of smoke from fires burning in the northwestern United States was likely to have contributed significantly to the ozone exceedance on September 14. Details of this analysis are contained in the Sonoma report.

2.3.2 Key Factor # 2 – Comparison of the Event-Related Ozone Concentration with the Non-Event-Related High Ozone Concentrations

As discussed in the section 2.2.1, the exceedance on September 14, 2017 exceeds the 5-year 99th percentile of ozone concentrations measured at the Dutchtown site thus satisfying the requirements of Key Factor #2.

2.3.3 Evidence that Fire Emissions Affected the Dutchtown Monitor

Ground measurements of wildfire plume components (e.g., PM2.5, CO, NOx and VOCs) can be used to further demonstrate that smoke impacted ground-level air quality if elevated concentrations or unusual diurnal patterns are observed. Analyses done by Sonoma show unusual patterns in PM2.5 and also shows elevation in NO2 and CO that are likely to be attributable to wildfire smoke. These analyses provide additional supporting evidence that wildfire smoke contributed to ozone concentrations at the Dutchtown site on September 14, 2017.

2.4 Tier 3 Analysis – Additional Weight of Evidence to Support the Clear Causal Relationship

2.4.1 Evidence of Fire Emissions Effects on Dutchtown Monitor

A statistical regression model was prepared by Dr. Dan Jaffe to compare the concentrations at Baton Rouge area monitors during the months of September. This model concluded that the minimum contribution from wildfires at the Dutchtown monitor on September 14, 2018 was 7 ppb. This report is attached in Appendix 3.

2.4.2 Additional Wind Trajectories

Additional trajectories were performed that further confirm the observations that (1) smoke from northwestern wildfires traveled to Louisiana and surrounding states on September 13 and 14, 2017, and (2) transported smoke traveled to the surface on those days. These trajectories are included in the "Addendum to "Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017" dated February 20, 2018" prepared by Sonoma. This addendum is included as Appendix 4.

2.4.3 Additional Cloud-Aerosol Transport System (CATS) Data

Additional profiles indicate that the location and altitude of smoke plumes observed over multiple days align with the additional HYSPLIT trajectories discussed above. They also indicate that smoke from northwestern fires arrived at Louisiana on September 14, 2017. These profiles are contained in Appendix 4.

2.4.4 Regional/Upwind Site Supporting Measurements

Upwind sites in Louisiana, Texas, Oklahoma, and Arkansas were selected for additional data analysis by Sonoma. Meteorology and satellite observations indicate smoke transport was likely to occur at these sites and the analysis of ozone concentrations over the past five years shows that ozone was unusually elevated at these sites on September 14, 2017. Details of this analysis are presented in Appendix 4.

2.5 Conclusion

Based upon the completion of the full 3 tiered analyses, it is evident in the demonstration that smoke and ozone precursor pollutants traveled from fires in the northwestern United States to Louisiana and impacted ozone levels at the Dutchtown monitor, as well as other area monitors.

3.0 Natural Event

A wildfire is defined in 40 CFR 50.1(n) as "any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions, or a prescribed fire that has developed into a wildfire." Furthermore, a "wildland" is "an area in which human activity and development are essentially non-existent, except for roads, railroads, power lines, and similar transportation facilities. Structures, if any, are widely scattered." 40 CFR 50.1(o). Finally, "a wildfire that predominantly occurs on wildland is a natural event." 40 CFR 50.1(k).

The Pacific Northwest Wildfires of September 2017 are a natural event under 40 CFR §50.1.

4.0 Not Reasonably Controllable or Preventable

As stated in 40 CFR 50.14(b)(4) Wildfires. "The Administrator shall exclude data from use in determinations of exceedances and violations where a State demonstrates to the Administrator's satisfaction that emissions from wildfires caused a specific air pollution concentration in excess of one or more national ambient air quality standard at a particular air quality monitoring location and otherwise satisfies the requirements of this section. Provided the Administrator determines that there is no compelling evidence to the contrary in the record, the Administrator will determine every wildfire occurring predominantly on wildland to have met the requirements identified in paragraph (c)(3)(iv)(D) of this section regarding the not reasonably controllable or preventable criterion." Thus this event meets the criteria of not reasonably controllable or preventable.

5.0 Mitigation Requirements of 40 CFR §51.930

LDEQ meets the requirements of 40 CFR 51.930, which require that states requesting exceptional events at a minimum:

> "(1) Provide for prompt public notification whenever air quality concentrations exceed or are expected to exceed an applicable ambient air quality standard;
>
> (2) Provide for public education concerning actions that individuals may take to reduce exposures to unhealthy levels of air quality during and following an exceptional event; and
>
> (3) Provide for the implementation of appropriate measures to protect public health from exceedances or violations of ambient air quality standards caused by exceptional events."

LDEQ has a forecast program that provides ozone forecast two days in advance and is updated twice daily. Also when levels are predicted to reach exceedance levels, an ozone alert is issued on our webpage and by notification to persons subscribed to our alert system. LDEQ also provides the appropriate messaging and education to the public about exposure to high levels of pollutants and implements appropriate measures as necessary to protect public health.

6.0 Conclusions and Recommendations

LDEQ recommends that EPA exclude the data from September 14, 2017 at the Dutchtown monitor, as LDEQ has demonstrated that the data was influenced by an exceptional event. As a result of this data exclusion, LDEQ would further recommend an attainment designation for the Baton Rouge MSA.

Appendix 1

JOHN BEL EDWARDS
GOVERNOR

CHUCK CARR BROWN, PH.D.
SECRETARY

State of Louisiana
DEPARTMENT OF ENVIRONMENTAL QUALITY
OFFICE OF THE SECRETARY

Mr. Sam Coleman, Administrator
US EPA Region 6
1445 Ross Avenue, Suite 1200
Dallas, Texas 75202-2733

RE: Initial Notification of Potential Exceptional Event for Ozone on September 13-14, 2017

Dear Mr. Coleman:

Louisiana Department of Environmental Quality (LDEQ) has observed an ozone episode during the period of September 13th through 14th of 2017 which appears to have been influenced by fires in the Pacific Northwest and other fires, and will be flagging all ozone data in the Air Quality System (AQS) as being influenced by fire.

We have concluded that the Pacific Northwest fires influenced the flagged data for the following reasons:

- Visible satellite plumes show smoke transport into the area starting in Lake Charles on September 13th;
- Ozone values were in many cases the highest of the year and are atypical during this period in previous years; and
- Information provided to DEQ by our forecast contractor during the event indicated that ozone and particulate concentrations in the area were being influenced by the wildfires.

In accordance with 40 CFR 50.14(c)(2), discussions are being scheduled between our offices to discuss this episode as it related to regulatory decisions and the scope of any exceptional events demonstration. If you have any questions or need further assistance please contact Vivian Aucoin of my staff at 225-219-3389.

Sincerely,

Chuck Carr Brown, Ph.D.
Secretary

11/8/17
Date

c: Fran Verhalen, EPA R6 Air Monitoring/Grants Section Chief

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Appendix 2

Statistical modeling of Baton Rouge O_3 data for 2008-2017

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Feb. 25th, 2018

Executive Summary

The author of this report was contracted by Alpine Geophysics LLC to do statistical modeling of Baton Rouge O_3 data, focusing on a possible exceptional day in 2017 due to wildfires (Sept 14th, 2017) . For our part, I focused purely on the statistical modeling and left other groups to demonstrate the "smoke/wildfire" impacts in Baton Rouge on that date. Our goal was to examine whether September 14th, 2017 could be considered an outlier and, if so, how much of the MDA8 could be attributed to the wildfire influence.

To build the statistical model I used O_3 and meteorological data from 2008-2017 for four O_3 monitoring sites in the Baton Rouge area: Port Allen, Dutchtown, Louisiana State University (LSU) and Capitol. I used "R" software with the "mgcv" package to compute Generalized Additive Models for the 4 sites. The statistical model predicts MDA8 O_3 based on the meteorology and is able to explain between 65-73% of the variations in daily MDA8 values for the 4 sites. The residual is the part of the MDA8 O_3 that the model cannot explain. On average the residual is zero and has a standard deviation of 7 ppb at all sites. Thus the statistical model performance is generally very good, better than typical Eulerian models used in air quality analysis.

For September 14th, 2017, the model residual is between 22-28 ppb for the 4 sites. This means that there is very likely an additional O_3 source that is not usually present. Using the EPA guidance method for statistical models, we estimate that the minimum wildfire contribution for the 4 sites is 7-14 ppb, depending on the site. Thus I conclude that in the absence of the unusual O_3 source (wildfires) each of these sites would have had an MDA8 value of 69 ppb or less on September 14th, 2017.

1. Introduction to using statistical models for Exceptional Event (EE) analysis

A number of methods have been used to investigate the impacts of meteorology on O_3 concentrations. Camalier et al (2007) developed an approach using Generalized Linear Models to predict O_3 from meteorological variables. Alvarado et al (2015) used Generalized Additive Models (GAMs) to investigate the relationship between O_3 and meteorology for 6 six cities in Texas. Jaffe et al (2004) was the first to use statistical models combined with the “residual” approach to quantify the amount of O_3 due to wildfires. This approach was further developed and compared against Eulerian models in Jaffe et al (2013). The California Air Resources Board applied this method in a successful exceptional events case demonstration for 2008 California wildfires (CARB 2011), and EPA cited this element (statistical models) in its approval documentation. The CARB analysis did not apply the stringent error bounds now recommended by EPA (described below), but their analysis was accepted in any case. More recently, the GAM approach was applied to estimate the wildfire contributions to MDA8 O_3 2015 fires burning in the Pacific Northwest (Gong, Jaffe et al 2017). The approach taken for the present analysis builds on the knowledge from these prior studies.

Generalized Additive Modeling or GAM is a statistical method to model data as a function of various predictor variables (Wood 2006). GAMs can incorporate numerical, ordinal or categorical variables (e.g. weekday/weekend). In our application, we will examine the relationship between the observed maximum daily 8-hour average (MDA8) and meteorological factors. This is a type of “machine learning” using a training dataset of multiple years of data. An example equation for a GAM is:

$$\mathbf{g(O_{3\mathit{i}}) = f_1 (V1_{\mathit{i}}) + f_2 (V2_{\mathit{i}}) + f_3 (V3_i) + \ldots + residual_{\mathit{i}}}$$

Where f_1, f_2, etc are “link” functions which are obtained from spline fits to the observations, V1, V2, etc are the predictor variables and the “*i*” refers to each daily observation. Possible variables to include are daily max temperature, daily min temperature, wind speed, wind direction, relative humidity, etc. For computing the GAMs, we used the “mgcv” package in “R” software. Outliers, or high residuals, represent an additional O_3 source and suggest an unusual or additional source of O_3. However, a statistical model alone cannot identify the cause for a high residual. Possible causes for a significant residual include unusual emissions (e.g. an industrial upset), a stratospheric intrusion or contributions to the MDA8 from a wildfire.

EPA cites the use of statistical regression models in “Guidance on the Preparation of Exceptional Events Demonstration for Wildfire Events that May Influence Ozone Concentrations,” (U.S. EPA 2015), as one of three methods to show that wildfire emissions caused an O_3 exceedance, stating, “the difference between the predictions and observations can provide a reasonable estimate of the air pollution caused by event-related emissions (e.g., emissions from wildfires) provided the analysis accounts for the typical remaining variance of typical days (variability in monitored data not predicted by the model).” Our analysis is consistent with the EPA guidance in all respects.

We note that the EPA guidance document also discusses an analysis called “Q/D” (source emissions divided by distance from the fire). Some caution should be used in applying this method as it appears inconsistent with peer reviewed scientific analyses that clearly demonstrate that for most wildfire plumes, O_3 concentrations increase with distance from the fire (Jaffe and Wigder 2012; Gong et al 2017). It is also based on Eulerian modeling, which is known to have significant challenges in accurately modeling O_3 production in wildfire plumes (e.g. Baker et al 2016).

Methodology

For this analysis I considered 30 meteorological variables from the following sources: NCEP North American Regional Reanalysis (NCEP-NARR), the NWS data from the Ryan Airport (NWS-Ryan), NWS data from the Lake Charles, LA morning and afternoon radiosondes (LCLA). After examining the relationship between O_3 and each variable, the following 7 variables were found to give the best model fits:

NCEP-NARR daily average relative humidity.
NWS-Ryan observed daily average wind speed,
NWS-Ryan observed daily maximum temperature.
NWS-Ryan observed daily minimum temperature.
LCLA afternoon radiosonde mixed layer potential temperature (theta).
LCLA afternoon radiosonde mixed layer water mixing ratio.
Year.

The model was consistently applied (same 7 variables) to all 4 O_3 monitoring sites in Baton Rouge: Duchtown, Port Allen, Capitol and LSU. Data was obtained for 2008-2017. After examining preliminary results for the entire O_3 season and individual months, we found slightly better model performance was obtained using individual months. Thus all results reported here use data for all September data for 2008-2017.

Results

For each site, we run the GAM using the 7 predictors mentioned above. The results show that these 7 predictors have good ability to predict the MDA8 O_3, with R^2 values between 0.65 and 0.73 Table 1 shows a summary of the model results for each site and Figure 1 shows an example of the observed vs predicted MDA8 O_3 for the Capitol site. The input data and all results are given in the included Excel file. The GAM correlations are significantly better than most Eulerian photochemical models, which typically have R^2 values in the range of 0.4 to 0.5 for MDA8 O_3 (Simon et al 2012).

	Port Allen	**Dutchtown**	**LSU**	**Capitol**
Slope (observed/predicted)	1.02	1.03	1.03	1.02
R^2	0.65	0.66	0.68	0.73
Average residual (ppm)	0.000	0.000	0.000	0.000
Residual S.D. (ppm)	0.007	0.007	0.007	0.007
Residual 97.5th percentile (ppm)	0.014	0.016	0.014	0.012

Table 1. Summary of the GAM results for each site.

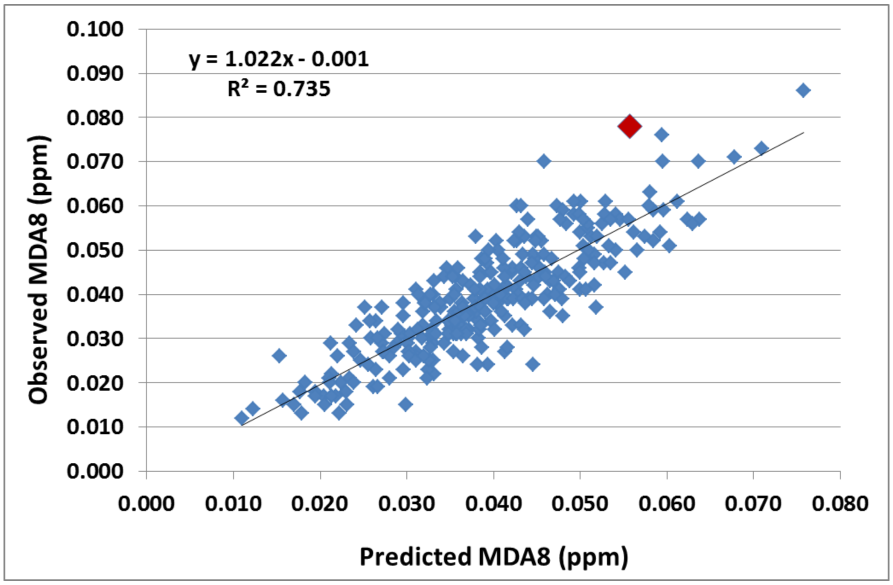


Figure 1. Observed vs predicted MDA8 (ppm) for the Capitol site. The predicted MDA8 values come from the GAM. The point for Sept. 14th, 2017 is highlighted in red. The residual for Sept. 14th, 2017 is 0.022 ppm.

Model validation

It is good practice to evaluate the results of a statistical models using “cross-validation”. In this method, the model is trained with one dataset and then used to predict values that were not part of the original training set. For this, I redid the calculations for the 4 sites, but excluded data from 2016 from the training set. Then based on the training dataset using the predictor variables for 2007-2017, except 2016, we then predict MDA8 O_3 for 2016 from the same variables. Table 2 shows the cross validation results for each site for 2016, keeping in mind this is only the results for 30 days for each site (September 2016). Figure 2 shows the model predicted values for the LSU site for 2016, when the 2016 data were not included in the training set. Given these results, we are confident the model is performing satisfactorily for these sites.

	PA	**Dutch**	**LSU**	**Cap**
Slope	**1.19**	**1.21**	**1.11**	**0.83**
R^2	**0.678**	**0.692**	**0.649**	**0.626**

Table 2. Slope and R^2 for each site for 2016 predicteed MDA8 (n=30 points each) when the 2016 are excluded from the training set.

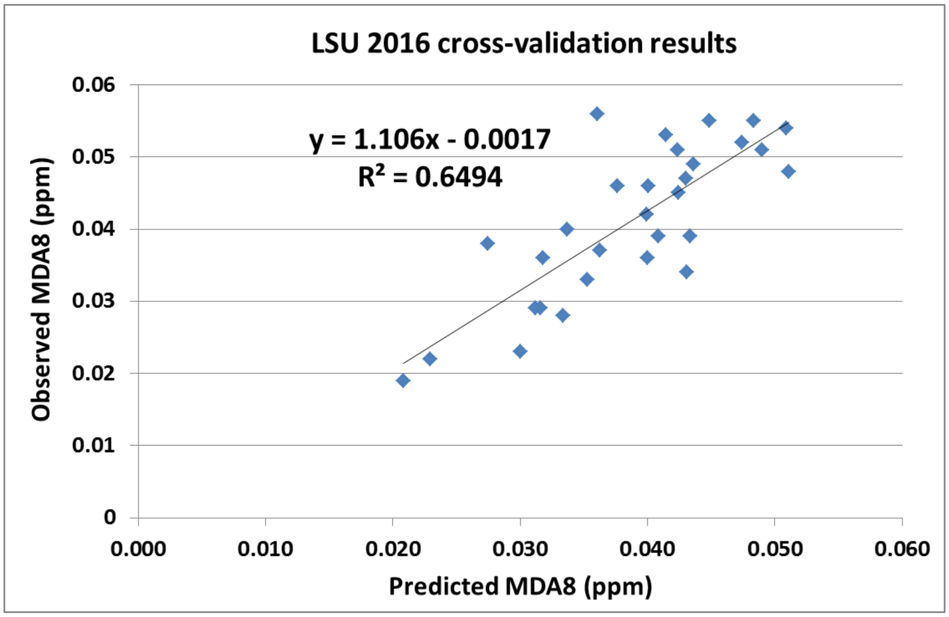


Figure 2. Cross-validation for the LSU site. Here we show the GAM predictions for 2016, when 2016 data were not included in the original training set.

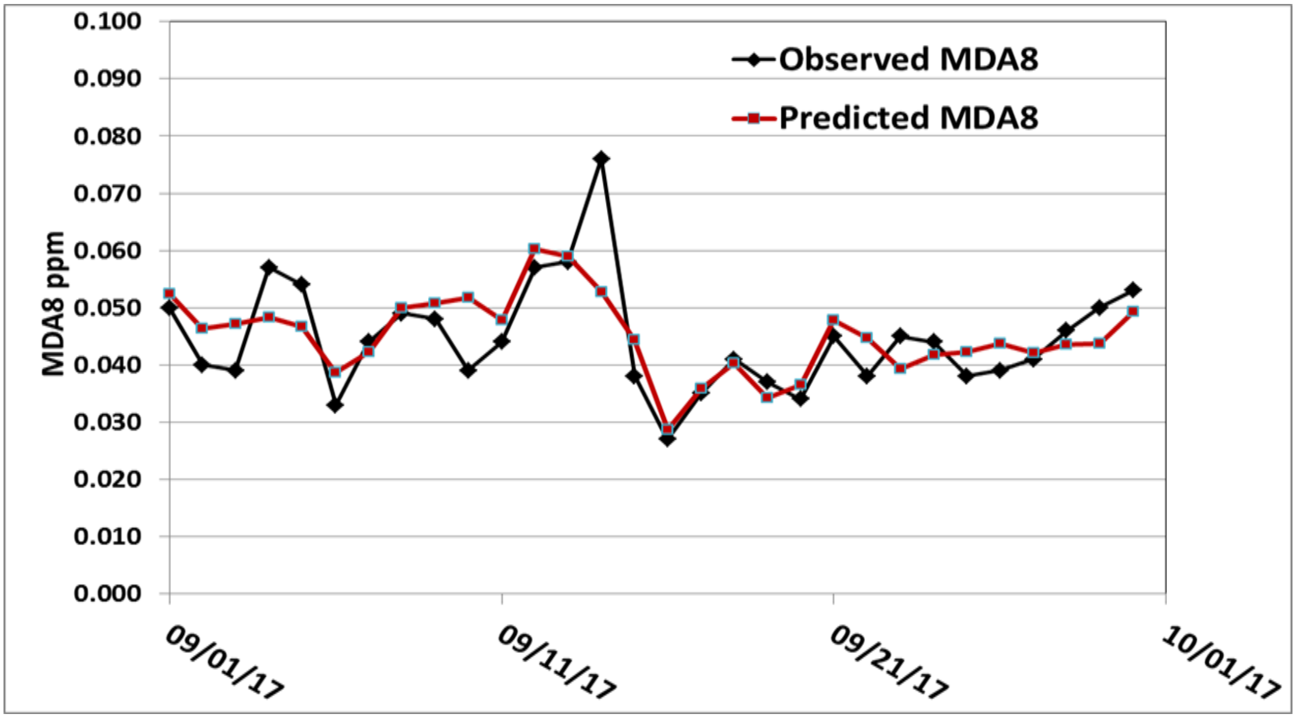
Model results for September 14, 2017 and estimation of "no fire" MDA8

As shown in Figure 1, September 14th, 2017 is not well predicted by the model for the Capitol site. Table 3 shows the predictions for this date, along with other data on the residuals for each site (all values in ppm). The most likely contribution to the MDA8 from the fires on September 14th, 2017 is given by the model residual. Thus we estimate the fires enhanced the MDA8 by 0.022-0.028 ppm. However the EPA suggests use of a more conservative method to estimate this contribution. The EPA guidance states *"The difference between the predicted values and the measured values are analyzed, and the 95th percentile of those positive differences (observed* O_3 *is greater than predicted) is recorded. This 95 percent error bound is added to the* O_3 *value predicted by the regression equation for the flagged days, and any difference between this sum and the observed* O_3 *for the flagged day may be considered an estimate of the* O_3 *contribution from the fire…"* Since the 95th percentile of positive values is equivalent to the 97.5th percentile of all values we refer to this error limit as the "97.5 percentile error limit", which are given in Table 3 for each site. Using the EPA guidance method, we estimate the minimum fire contribution to the MDA8 for these sites to be 0.007 – 0.014 ppm. Therefore in the absence of the fires, the MDA8 values for these sites would have all been below 70 ppb.

	Port Allen	**Dutchtown**	**LSU**	**Capitol**
Sept 14th observed MDA8	0.082	0.076	0.073	0.078
September 14th GAM prediction	0.054	0.053	0.051	0.056
Sept 14th GAM residual	0.028	0.023	0.022	0.022
GAM 97.5th percentile	0.014	0.016	0.014	0.012
GAM prediction + 97.5th percentile	0.068	0.069	0.065	0.068
Minimum fire contribution	0.014	0.007	0.008	0.010
“No fire” MDA8 (ppm)	0.068	0.069	0.065	0.068

Table 3. GAM parameters and estimate “no fire” MDA8 for September 14th, 2017. All values are in ppm.

As a final reality check, it is useful to compare the 2017 high O_3 day with other high days. But there are very few high O_3 dates for Baton Rouge in September. The last time there were multiple monitors which exceeded 0.070 ppm was in September 2011. The meteorological conditions on these dates were very different and the GAM predicted significantly higher O_3 (and lower residual values) for the 2011 episodes. Thus these 2011 dates are not matching days, but do demonstrate the value of the GAMs for predicting usual high O_3 days. Figures 3-6 compare the model performance for the 2011 episodes with the 2017 episodes for each site.



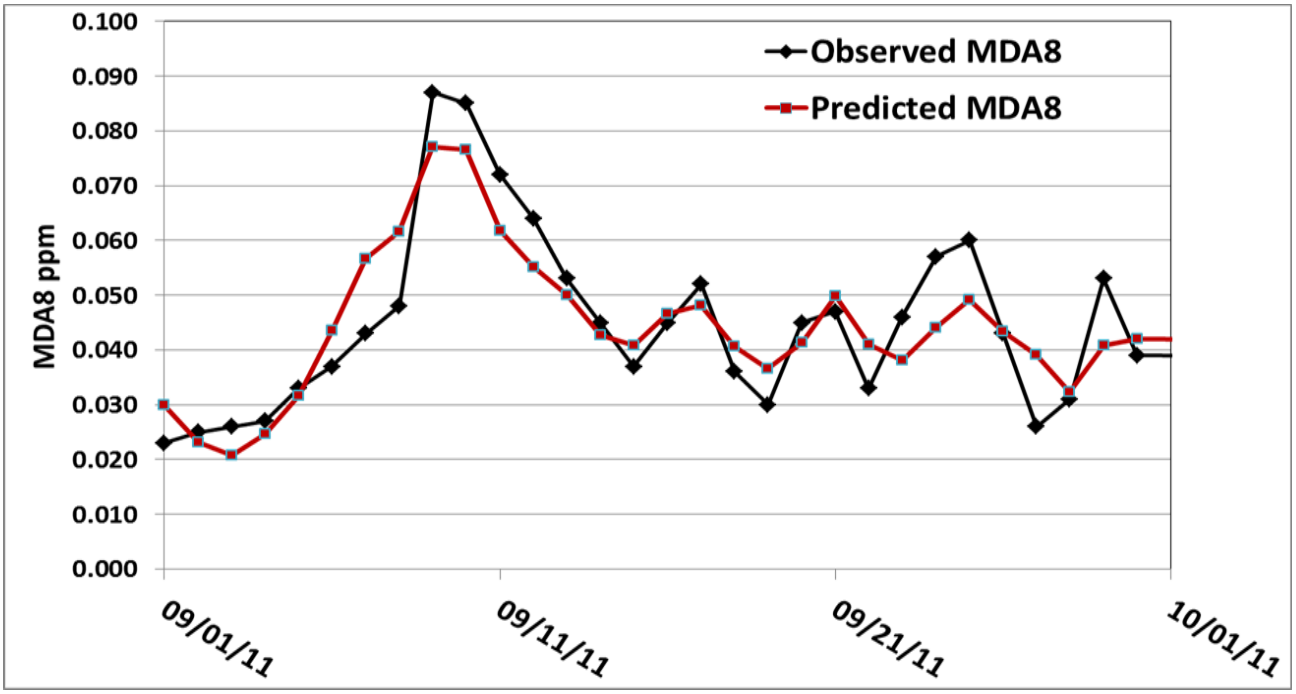


Figure 3. Comparison of GAM predicted and observed MDA8 O_3 for Duchtown for September 2017 (top) and September 2011 (bottom).

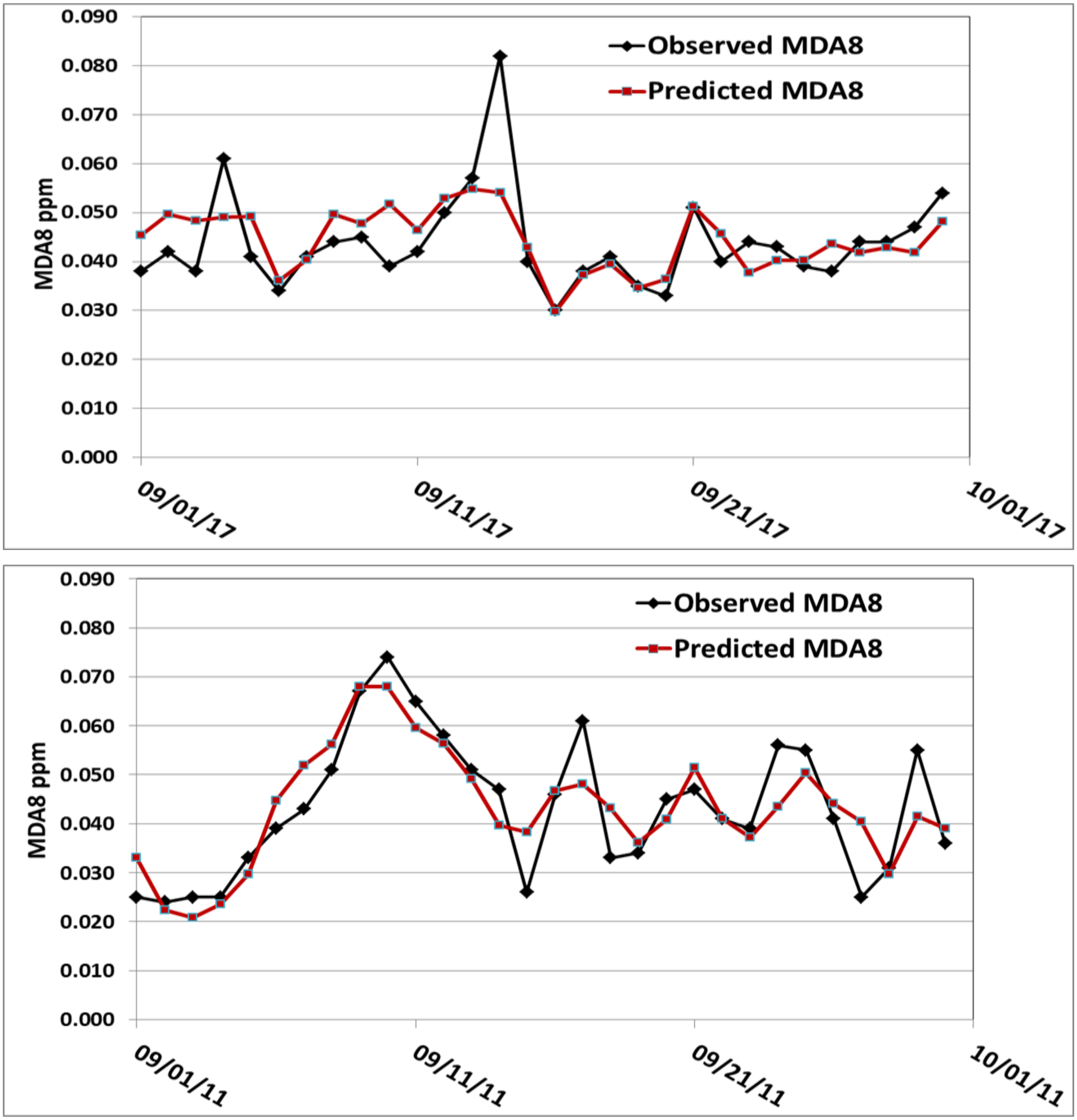
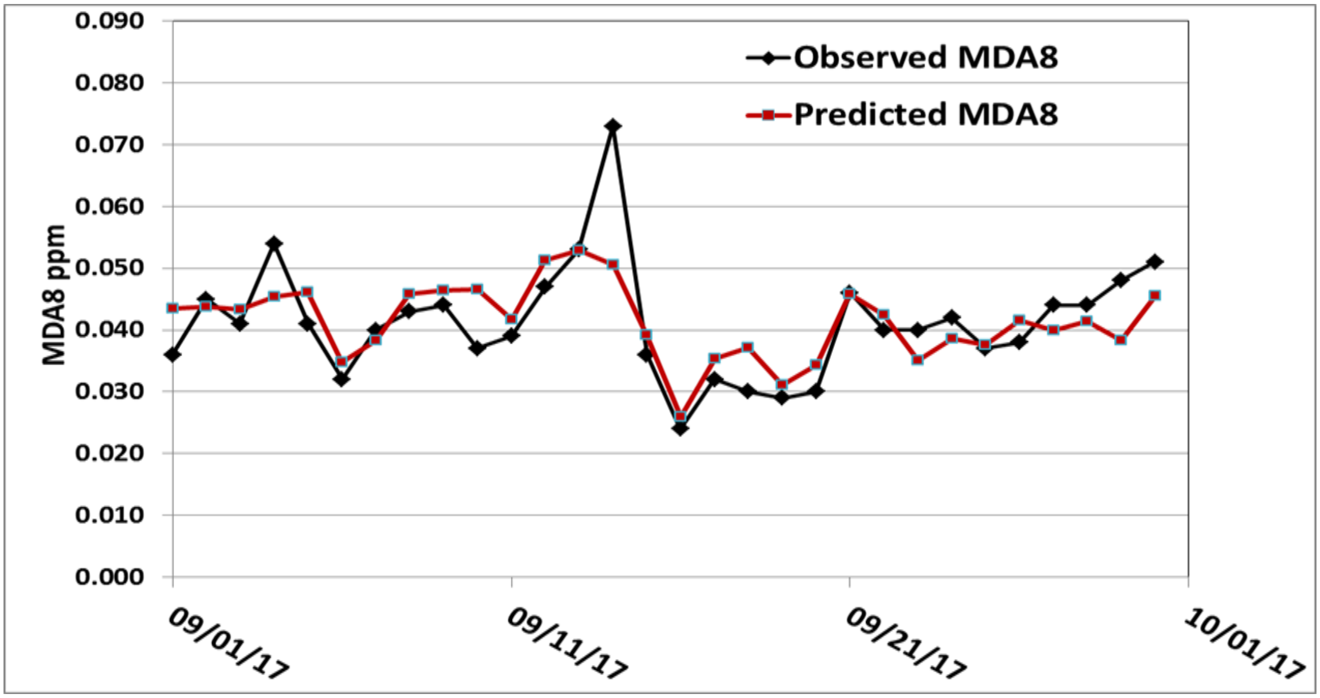


Figure 4. Comparison of GAM predicted and observed MDA8 O_3 for Port Allen for September 2017 (top) and September 2011 (bottom).



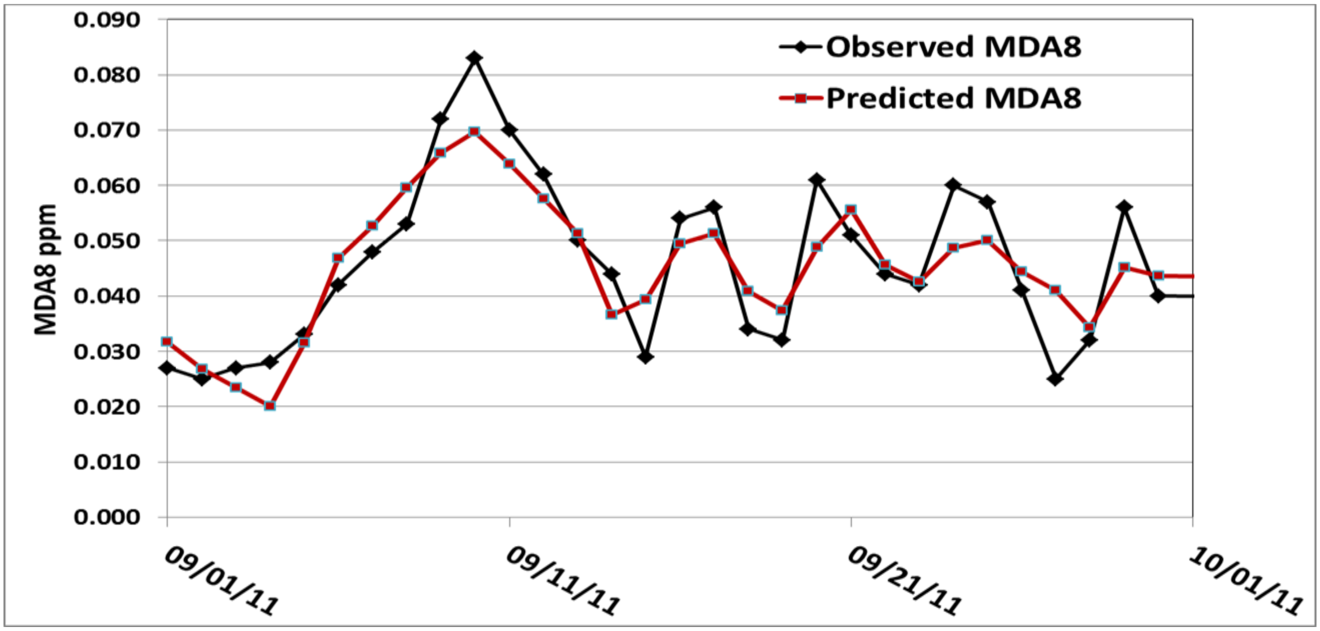
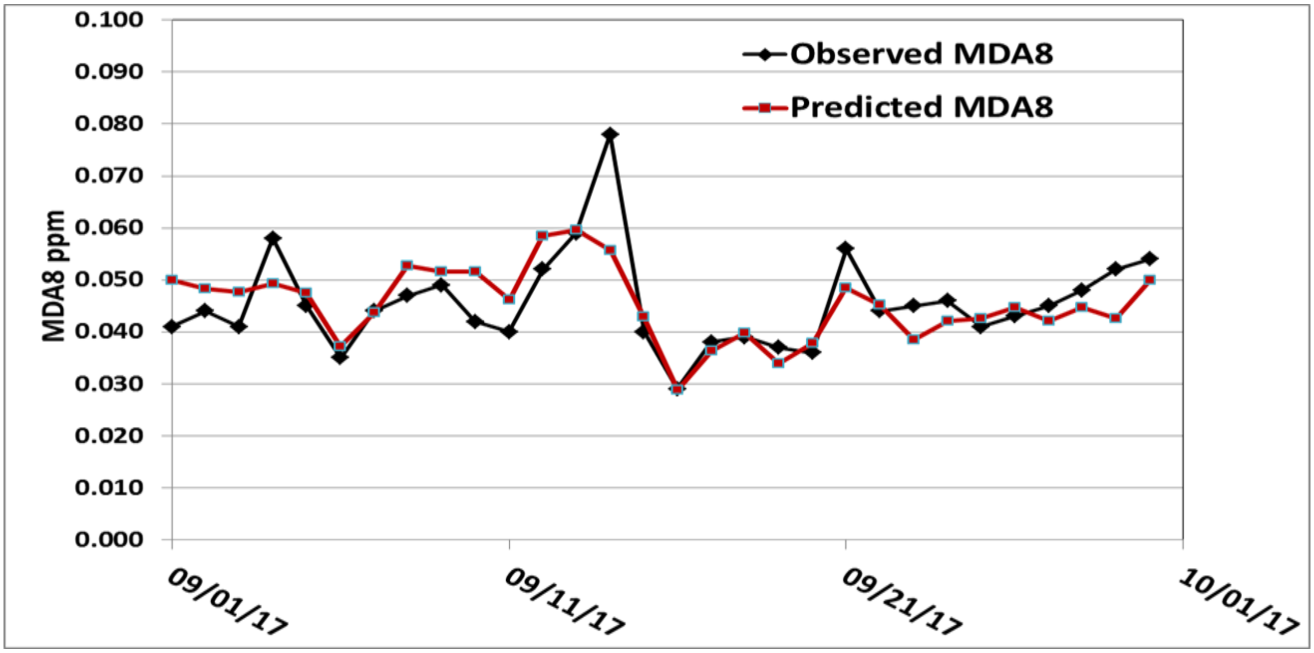


Figure 5. Comparison of GAM predicted and observed MDA8 O_3 for LSU for September 2017 (top) and September 2011 (bottom).



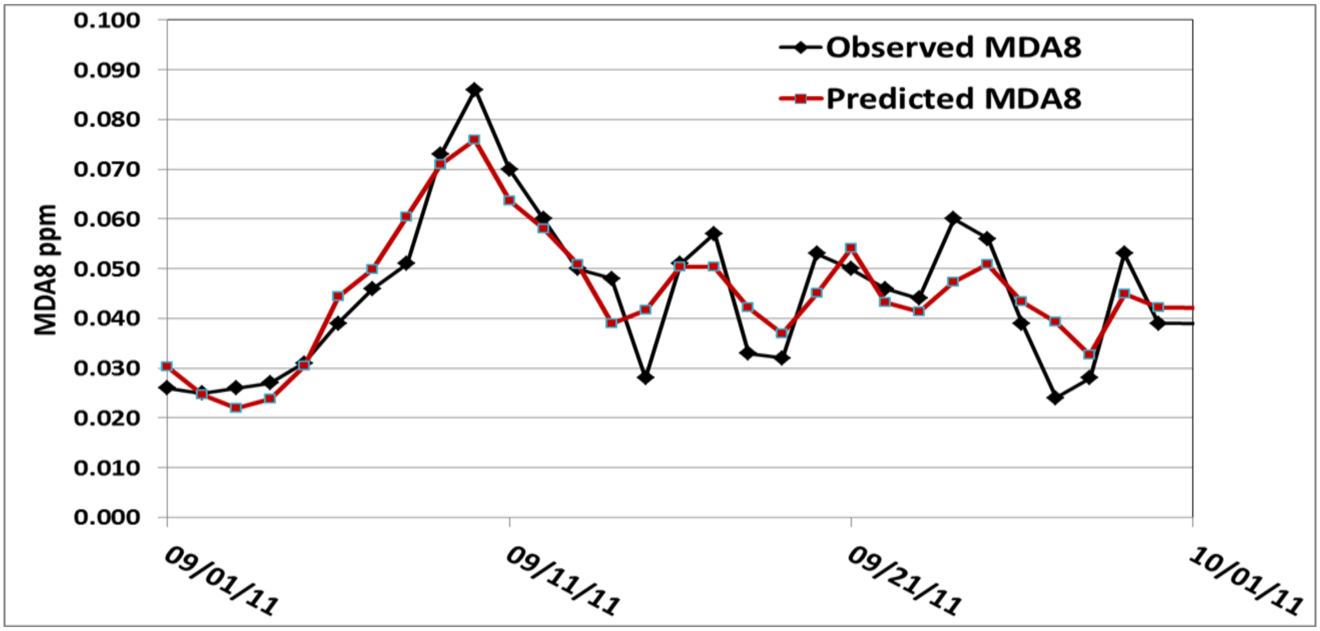


Figure 6. Comparison of GAM predicted and observed MDA8 O_3 for Capitol for September 2017 (top) and September 2011 (bottom).

For all 4 sites, the model does an excellent job of predicting the MDA8 for the September 2011 high O_3 episodes, but a poor job at predicting the September 14th, 2017 high O_3 event. This strongly argues for an unusual source of O_3 and is consistent with impacts from wildfires.

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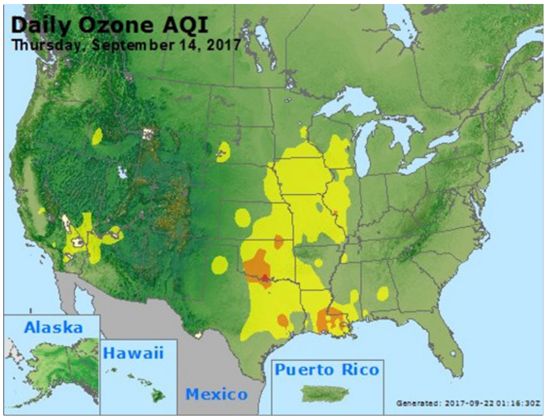
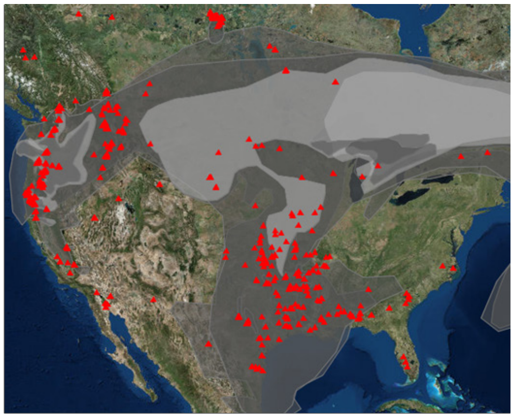
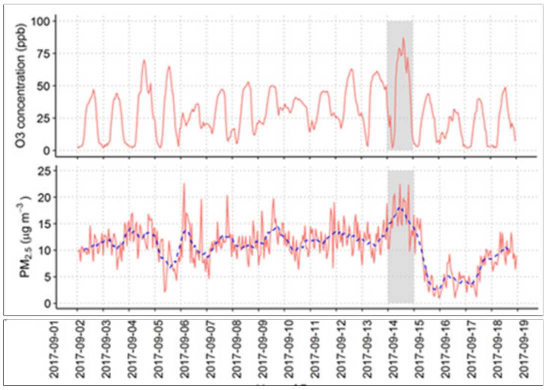
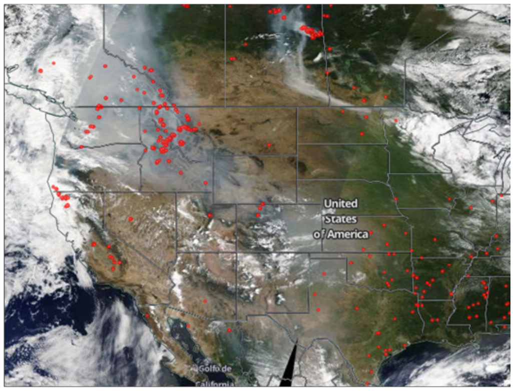
Appendix 3

Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017









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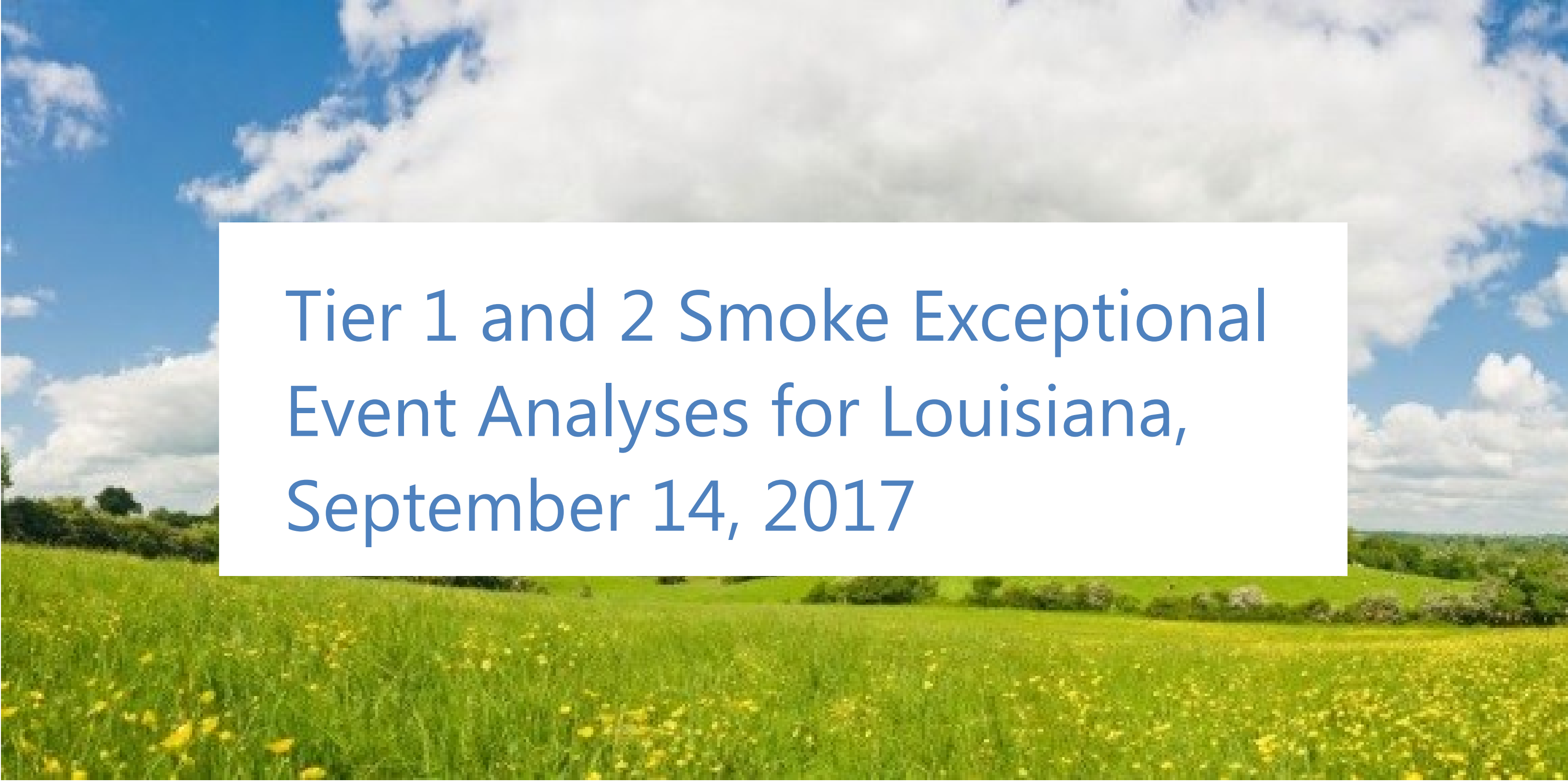
Innovative Environmental Solutions



Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017

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List of Terms

Term	Definition
AGL	Above ground level
AIRS	Atmospheric Infrared Sounder
AOD	Aerosol Optical Depth
AQI	Air Quality Index
AQS	Air Quality System
AVHRR	Advanced Very High Resolution Radiometer
CATS	Cloud-Aerosol Transport System
EPA	U.S. Environmental Protection Agency
FACTS	Forest Service Activity Tracking System
GeoMAC	Geospatial Multi-Agency Coordination
GOES	Geostationary Operational Environmental Satellite system
HMS	NOAA's Hazard Mapping System
HRRR	NOAA's High-Resolution Rapid Refresh model
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
ISS	International Space Station
LIDAR	Light Detection and Ranging
m	meters
MODIS	Moderate Resolution Imaging Spectroradiometer
NAAQS	National Ambient Air Quality Standards
NAM	North American Mesoscale Forecast System
NOAA	National Oceanic and Atmospheric Administration
OMI	Ozone Monitoring Instrument
NASF	National Association of State Foresters
NEI	National Emissions Inventory
NOAA	National Oceanic and Atmospheric Administration
PAMS	Photochemical Assessment Monitoring Stations
Q/d	Emissions/distance ratio
TNMOC	Total non-methane organic compounds
UTC	Coordinated Universal Time
VIIRS	Visible Infrared Imaging Radiometer Suite
VOC	Volatile organic compounds

Executive Summary

On September 14, 2017, Baton Rouge experienced an unusual, area-wide episode of elevated ambient ozone; during this episode, the 2015 8-hr ozone National Ambient Air Quality Standards (NAAQS) thresholds were exceeded at multiple sites, including the Dutchtown monitoring site. The exceedance at Dutchtown could lead to an ozone nonattainment designation for the Baton Rouge area. Satellite observations and air quality modeling suggest that this ozone exceedance was influenced by wildfire smoke that was transported to Baton Rouge from large wildfires burning in the northwestern United States, including Washington, Oregon, Idaho, and Montana, and in California. The EPA Exceptional Event Rule (U.S. Environmental Protection Agency, 2016a) allows air agencies to omit air quality data from the design value calculation if it can be demonstrated that the measurement in question was caused by an exceptional event. This report describes analyses that help to establish a clear causal relationship between wildfire smoke and the September 14, 2017, ozone exceedance at the Dutchtown Monitoring Site.

The analyses we conducted provide evidence supportive of smoke impacts on ozone concentrations in Baton Rouge. We show that (1) substantial amounts of smoke were transported from wildfires in the northwestern United States across the central United States to Louisiana in the days leading up to September 14, 2017, (2) smoke aloft was transported to the surface on September 14, 2017, and (3) smoke impacted ground-level pollution measurements in the Baton Rouge area on September 14, 2017. Sources of evidence used in these analyses include air quality monitor data, satellite data, air trajectory analysis, and agency fire reports.

EPA guidance for exceptional event demonstrations (U.S. Environmental Protection Agency, 2016b) provides a three-tiered approach; depending on the complexity of the event, increasingly involved information may be required to demonstrate a causal relationship between wildfire smoke and an exceedance. Here, we provide the results of analyses conducted to address Tier 1 and Tier 2 exceptional event demonstration requirements. Our findings from these analyses are summarized in Table ES-1. The results are supportive of a Tier 3 exceptional event demonstration.

These analyses show that smoke was transported from wildfires in the northwestern United States to Louisiana over the days leading up to September 14. They additionally show that air quality at the Dutchtown monitor was impacted by wildfire smoke on that day. Combined with additional evidence, such as meteorological regression modeling, our results provide key evidence to support smoke impacts on ozone concentrations in Baton Rouge on September 14, 2017.

Table ES-1. Summary of tier-specific analyses for smoke/ozone exceptional events and the analysis findings.

Tier	Requirements	Finding
1	• Comparison of fire-influenced exceedance with historical concentrations • Key factor: Evidence that fire and monitor meet one of the following criteria: – Seasonality differs from typical season, or – Ozone concentrations are 5-10 ppb higher than non-event-related concentrations • Evidence of transport of fire emissions to monitor: – Trajectories of fire emissions, or – Satellite images and supporting evidence from surface measurements	• The September 14. 2017, ozone exceedance occurred during typical ozone season. • Trajectories and satellite images and data support long-range smoke transport into the area. • Trajectories, ceilometer mixing height measurements, and radiosonde data indicate vertical mixing and transport to the surface from the elevation at which smoke was present.
2	• All Tier 1 requirements • Key Factor #1: Fire emissions and distance of fires (Q/d > 100) • Key Factor #2: Comparison of the event-related ozone concentration with non-event-related high ozone concentrations (>99th percentile over five years or top four highest daily ozone measurement) • Evidence that fire emissions affected the monitor (at least one of the following): – Visibility impacts – Changes in supporting measurements – Satellite NO_x enhancements – Differences in spatial/temporal patterns	• The Q/d was well below 100. • Ozone concentration was >99th percentile over five years and was the top measurement for the year. • Surface $PM_{2.5}$, NO_x, and CO concentrations showed elevated concentrations and/or changes in diurnal profile consistent with smoke impacts.

1. Introduction

On September 14, 2017, the Baton Rouge area of Louisiana experienced area-wide elevated ozone measurements. Six out of nine monitors measured concentrations that exceeded the daily maximum 8-hr average ozone standard of 70 ppb on that day, and the other three monitors in the area also showed evidence of higher than usual ozone. With the September 14 exceedance, the ozone design value for the Dutchtown site in Baton Rouge for 2015–2017 exceeded the national standard of 70 ppb. Had ozone concentrations at the site not exceeded the standard on September 14, the design value would have been within the standard. Therefore, the September 14 exceedance is of regulatory significance.

Under EPA rules, data for which exceptional event impacts have been demonstrated may be omitted from design value calculations. Evidence presented in this report suggests that smoke from wildfires contributed to the exceedance observed on September 14. During the two weeks leading up to September 14, large wildfires were active in the northwestern United States as well as in Saskatchewan, Canada. Significant quantities of smoke were released from these fires and transported across the northern and central United States. Air mass transport patterns leading up to September 14 brought smoke from the northwestern United States to Louisiana. That smoke was present at ground level on September 14, and it impacted local air quality.

This report describes the results of analyses by Sonoma Technology, Inc., that support a causal relationship between wildfire smoke and the Dutchtown exceedance on September 14. In Section 2, we summarize the EPA guidance for demonstrating a wildfire smoke-related exceptional event and describe the analyses conducted in accordance with that guidance. Section 3 describes the analytical approach used for each analysis as well as the results. Section 4 summarizes the findings from this work. The appendices provide additional supporting information. Appendix A contains historical context plots for ozone measurements made at all monitor locations in Baton Rouge. Appendix B provides additional supporting measurement plots, including depictions of ratios of VOC/NO_x and CO/NO_x, and timeseries plots for speciated VOC measurements. Appendix C describes the results of coarse resolution photochemical modeling that provide qualitative evidence that wildfire smoke impacted air quality in Louisiana. Appendix D summarizes the meteorological conditions leading up to the September 14 event.

2. Analysis Approach

EPA exceptional event guidance includes a three-tiered approach for exceptional events demonstrations due to wildfire(s); see **Table 1** for a summary. Tier 1 and Tier 2 analyses are provided for cases where there is a clear or obvious relationship between a fire (or multiple fires) and an ozone exceedance. Tier 1 analyses can be used when an exceedance occurred during a time of year when ozone concentrations are typically low or when the concentration measured during an event is substantially higher in magnitude (5-10 ppb) than observed non-event concentrations. Tier 2 analyses are appropriate for cases when a high-emitting fire occurred near the impacted monitor, and smoke transport from the fire to the monitor can be clearly shown. Tier 3 analyses are used when the relationship between smoke from a wildfire(s) and an ozone exceedance is more complicated, or is more difficult to demonstrate using Tier 1 and Tier 2 data analysis tools and methods. Table 1 summarizes the analyses required in each tier. Within the scope of the work described here, we conducted Tier 1 and Tier 2 exceptional event analyses.

Table 1. Summary of tier-specific analyses for smoke/ozone exceptional events.

Tier	Requirements
1	• Comparison of fire-influenced exceedance with historical concentrations • Key factor: Evidence that fire and monitor meet one of the following criteria: – Seasonality differs from typical season, or – Ozone concentrations are 5-10 ppb higher than non-event-related concentrations • Evidence of transport of fire emissions to monitor: – Trajectories of fire emissions, or – Satellite images and supporting evidence from surface measurements
2	• All Tier 1 requirements • Key Factor #1: Fire emissions and distance of fires • Key Factor #2: Comparison of the event-related ozone concentration with non-event-related high ozone concentrations (>99th percentile over five years or top four highest daily ozone measurements) • Evidence that fire emissions affected the monitor (at least one of the following): – Visibility impacts – Changes in supporting measurements – Satellite NO_x enhancements – Differences in spatial/temporal patterns
3	• All Tier 2 requirements • Evidence of fire emissions effects on monitor: – Multiple analyses from those listed for Tier 2 • Evidence of fire emissions transport to the monitor: – Trajectory or satellite plume analysis, and – Additional discussion of meteorological conditions • Additional evidence such as: – Comparison to ozone concentrations on matching (meteorologically similar) days – Statistical regression modeling – Photochemical modeling of smoke contributions to ozone concentrations

Within the tiered approach for wildfire exceptional event analysis, each tier has one or more key factors and additional supporting evidence that must be addressed by an exceptional event demonstration (Table 2). For Tier 1 analyses, the key factor recommended is to provide evidence of the unusual seasonality and/or higher magnitude of the monitored ozone concentration. In addition, Tier 1 analyses should provide evidence, using Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) trajectories and/or satellite imagery, that the wildfire emissions were transported to the affected monitor. We address the Tier 1 key factor in Section 3.1 of this report, and we provide evidence of smoke transport to the monitor in Sections 3.2, 3.3, and 3.4.

Tier 2 exceptional event analyses must provide evidence of two key factors, including assessment of the fire emissions and distance of fires to the affected monitoring site (Tier 2 Key Factor #1) and a comparison of the event-related ozone concentration with non-event-related high ozone concentrations (Tier 2 Key Factor #2). A Tier 2 exceptional event analysis should also provide evidence of transport of fire emissions from the monitor and evidence that the fire emissions affected the monitor. We address Tier 2 Key Factor #1 in Section 3.7 and Key Factor #2 in Section 3.1. We provide evidence that the smoke was transported to the site in Sections 3.2, 3.3, 3.4, and 3.5, and we show that the monitor was affected by fire emissions in Section 3.6.

We conducted Tier 1 and Tier 2 analyses following EPA's exceptional event guidance. These analyses focused on characterizing the meteorology, smoke, and air quality on the days/weeks leading up to September 14, 2017. The following specific analyses were performed:

- Developed figures that show the September 14 ozone concentrations in historical context for 2017 and for the past five years
- Compiled maps of ozone concentrations in the area, smoke plumes, and fire locations from satellite data
- Showed the air flow patterns via HYSPLIT modeling, and identified where the air flow intersected with smoke plumes or passed over or near fires
- Provided maps showing satellite retrievals of NO_x, Aerosol Optical Depth (AOD), and CO
- Assessed vertical transport of smoke using satellite-observed aerosol vertical profiles and ceilometer mixing height retrievals
- Developed a figure showing whether the diurnal pattern of NO_x, ozone, and volatile organic compound (VOC)/NO_x ratios on September 14 were different from typical patterns in August-September
- Acquired and analyzed local $PM_{2.5}$, VOC, CO, NO_x, and reactive oxides of nitrogen (NO_y) to identify whether there were unusual concentrations of species or of CO/NO_x ratios that would indicate smoke influences
- Quantified total fire emissions and calculate emissions/distance ratio (Q/d) for nearby fires

In Section 3 of this report, we provide the results of the Tier 1 and Tier 2 analyses described above.

Table 2. Evidence for Tier 1 and Tier 2 analyses provided in this report.

Tier	Element	Section of This Report (Analysis Type)
Tier 1	Key factor: Seasonality and/or distinctive level of the monitored ozone concentration compared to non-event-related concentrations	Section 3.1 (Ozone historical context)
	Evidence of smoke transport to the monitor	Sections 3.2 (Maps of ozone, fire, and smoke), 3.3 (HYSPLIT Trajectories), 3.4 (Satellite data), 3.5 (Evidence of vertical transport), and Appendix D
Tier 2	Key Factor #1: fire emissions and distance of fires to the site	Section 3.7 (Q/d)
	Key Factor #2: comparison of event-related ozone with non-event related high ozone	Section 3.1 (Ozone historical context)
	Evidence that the smoke was transported to the site	Sections 3.2 (Maps of ozone, fire, and smoke), 3.3 (HYSPLIT trajectories), 3.4 (Satellite data), and 3.5 (Evidence of vertical transport)
	Evidence that the fire emissions affected the monitor	Section 3.6 (Other supporting pollutant trends and diurnal patterns) and Appendix B

3. Analysis Results

3.1 Ozone Historical Context

Figure 1 shows the locations of the Baton Rouge area monitoring sites; sites that recorded an ozone exceedance on September 14, 2017, are marked in red. Air quality data collected at these sites were downloaded using the Air Quality System (AQS) Web Application for 2013-2017, which retrieves data directly from the EPA AQS database (www.epa.gov/aqs). Parameters retrieved include hourly CO, NO_x, ozone, and $PM_{2.5}$, 24-hr Photochemical Assessment Monitoring Stations (PAMS) VOC, and 3-hr PAMS VOC. AQS data can be used to meet the Tier 1 and Tier 2 requirements for comparison of a fire-influenced ozone exceedance with historical concentrations.

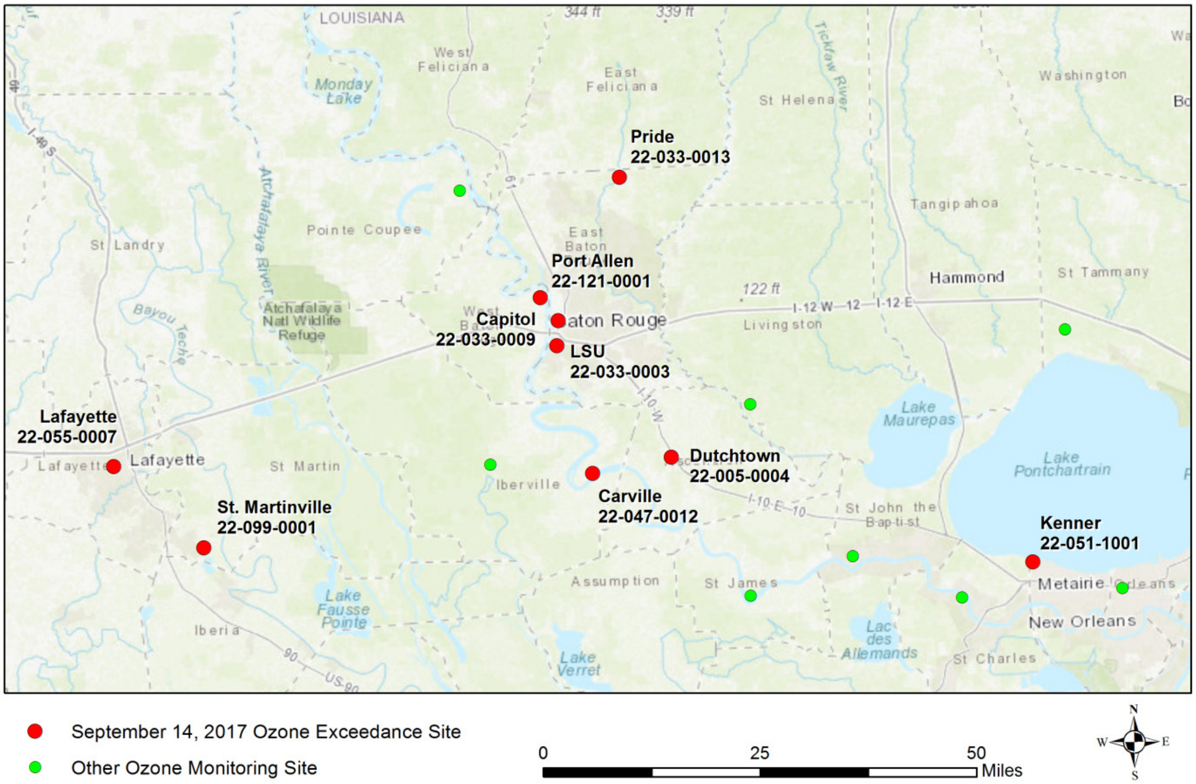

Figure 1. Locations of the Baton Rouge ozone monitoring sites. September 14, 2017, ozone exceedance sites are shown by red circles.

3.1.1 Regulatory Significance

Annual design values are computed by the EPA to reflect a location's air quality status in relation to the National Ambient Air Quality Standards (NAAQS). The 8-hr ozone design value is the three-year average of the fourth-highest daily maximum 8-hr ozone concentration (40 CFR Part 50, Appendix U). The ozone design value for the Dutchtown site is 71 ppb for 2015–2017 when all data are included (Table 3). Table 4 shows that the highest daily maximum 8-hr ozone concentration for Dutchtown in 2017 was on September 14; if the day is omitted, the 2017 ozone design value will drop to 70 ppb and will comply with the NAAQS.

Table 3. Ozone design value in Baton Rouge (N/A indicates that the monitor did not meet the completeness criteria described in 40 CFR Part 50, Appendix U).

AQS Site Code	Site Name	Ozone 4th Highest 2015	Ozone 4th Highest 2016	Ozone 4th Highest 2017	Design Value
22-005-0004	Dutchtown	74	71	68	71
22-047-0012	Carville	75	N/A	62	N/A
22-033-0003	LSU	73	68	70	70
22-033-0009	Capitol	69	61	73	68
22-121-0001	Port Allen	66	66	70	67
22-033-0013	Pride	62	N/A	71	N/A
22-077-0001	New Roads	69	65	68	67
22-047-0009	Bayou Plaquemine	69	64	67	N/A
22-063-0002	French Settlement	70	67	68	68

Table 4. Ozone design value comparison at the Dutchtown monitoring site. The asterisk (*) marks the September 14, 2017, ozone exceedance.

	2015	2016	2017
Highest	82	74	76*
Second Highest	80	73	75
Third Highest	75	72	69
Fourth Highest	74	71	68
Fifth Highest	71	66	67
Design Value Including All Measurements		71	
Design Value Excluding September 14, 2017 Event(*)		70	

3.1.2 Ozone Historical Data Comparisons

The maximum daily 8-hr ozone average concentration of 76 ppb measured at the Dutchtown monitoring site was the highest measured ozone concentration in 2017. **Figure 2** shows the September 14 concentration value of 76, with only one other day in the year exceeding the 70 ppb NAAQS threshold.

Figures 3 and 4 provide historical context of ozone concentrations at the Dutchtown site by showing maximum 8-hr ozone concentration data from 2013 to 2017. Figure 3 shows that the Dutchtown monitoring site measured concentrations of 76 ppb or higher on only four days in the past five years, one of which was September 14, 2017. Figure 4 shows that elevated ozone historically occurs between April (91st day) and the end of October (304th day). Although the September 14, 2017, exceedance occurred during the normal April-October ozone seasons, it ranks above the 99th percentile for the all data collected from 2013 to 2017 at Dutchtown.

The evidence provided by these plots is relevant to key factors for Tier 1 and Tier 2 exceptional event demonstrations. The exceedance on September 14, 2017, does not satisfy the key factor for a Tier 1 event because it occurred during the normal ozone season (April-October) and because it was not 5-10 ppb higher than non-event-related concentrations. However, it substantially exceeds the 5-year 99th percentile of ozone concentrations measured at the Dutchtown site, satisfying Key Factor #2 for Tier 2 exceptional event demonstrations. Key Factor #1 for Tier 2 is discussed in Section 3.7.

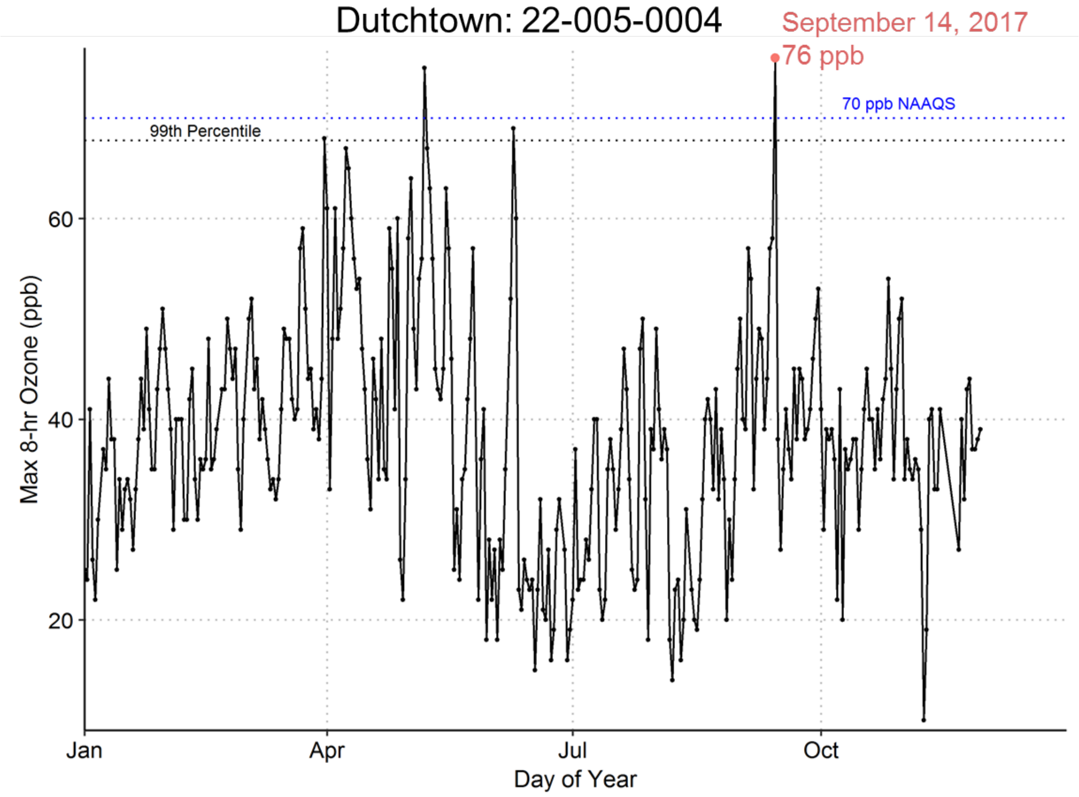

Figure 2. Daily maximum 8-hr ozone concentrations (ppb) at the Dutchtown monitoring site in 2017. The black dotted line indicates the 99th percentile for 2013 through 2017 at the Dutchtown monitoring site.

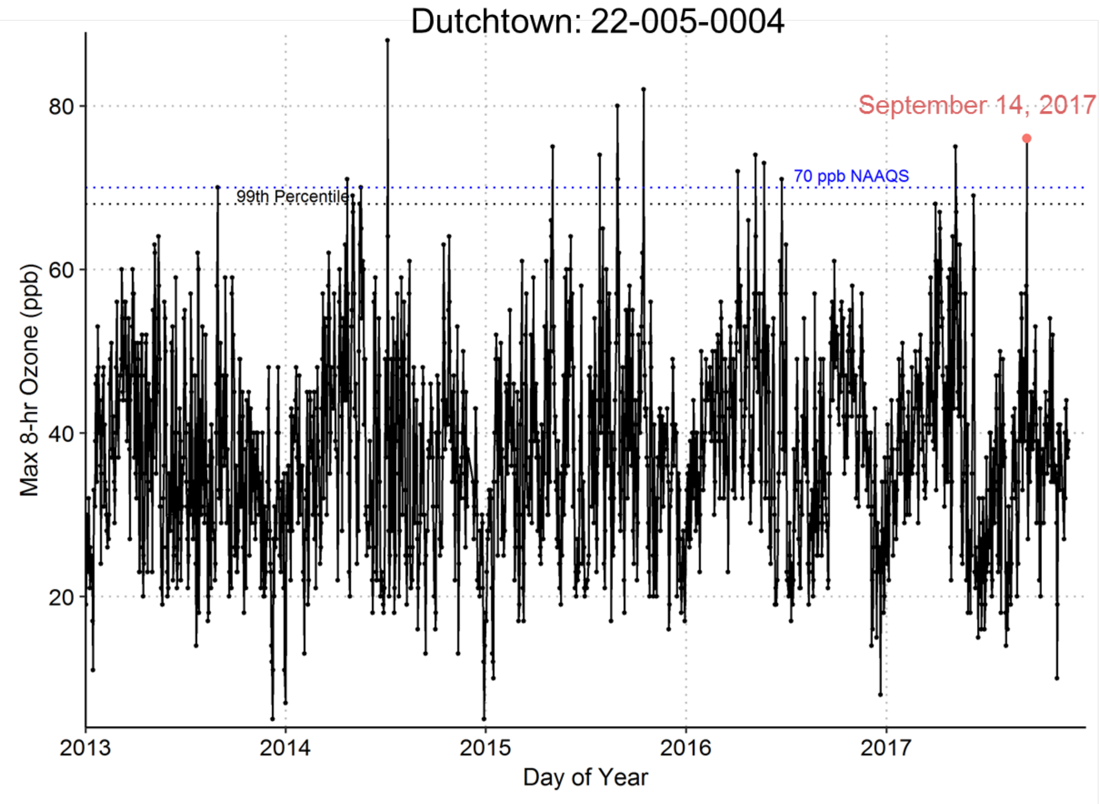

Figure 3. Daily maximum 8-hr ozone concentrations (ppb) at the Dutchtown monitoring site over the past five years (2013-2017).

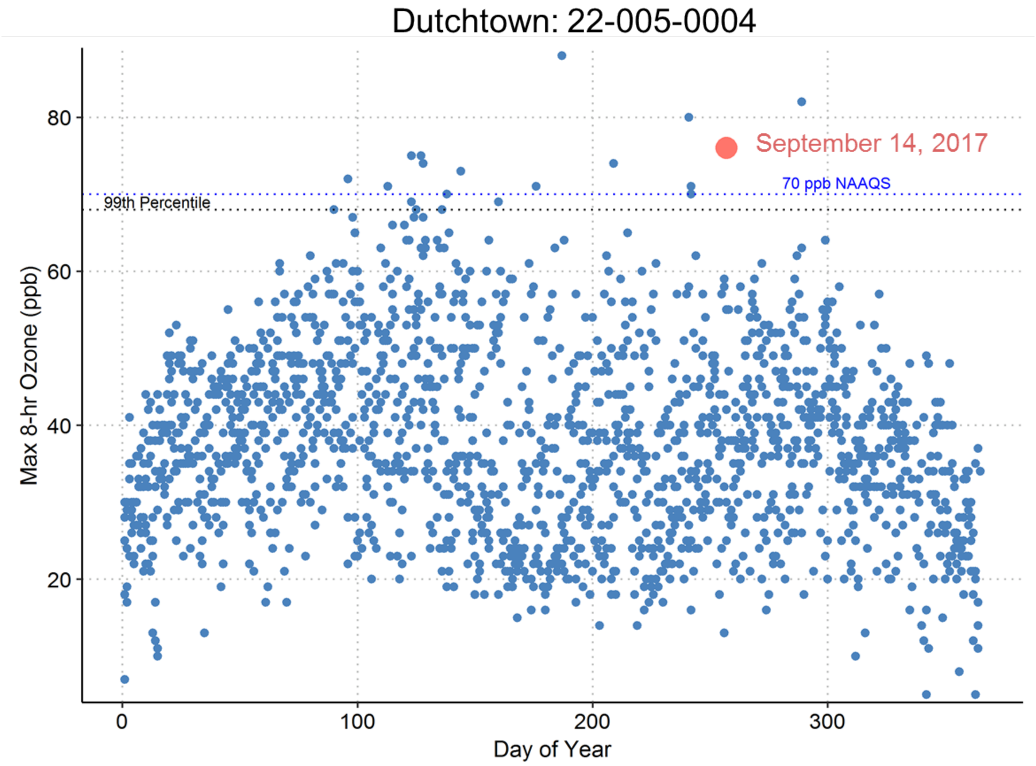

Figure 4. Daily maximum 8-hr ozone concentrations (ppb) by day of year at the Dutchtown monitoring site for 2013 through 2017. The typical ozone season is between the beginning of April (Day 91) and end of October (Day 304).

Ozone concentrations were elevated at sites across Baton Rouge on September 14 (Figure 5), indicating that Baton Rouge was impacted by an area-wide ozone event. Table 5 depicts the 5-year percentile of daily maximum 8-hr ozone concentration on September 14, 2017, for ozone monitors in the Baton Rouge area. Eight out of nine monitors in the Baton Rouge area recorded daily maximum 8-hr ozone concentrations above the 99th percentile on September 14, 2017, indicating a rare ozone event on this date. Between 2013 and 2017, the September 14, 2017, exceedance was the only exceedance recorded at the Pride monitoring site between July and the end of the year, further underscoring the exceptional nature of this ozone exceedance. Historical ozone plots for all other Baton Rouge sites, similar to the Dutchtown plots shown in Figures 3 and 4, can be found in Appendix A.

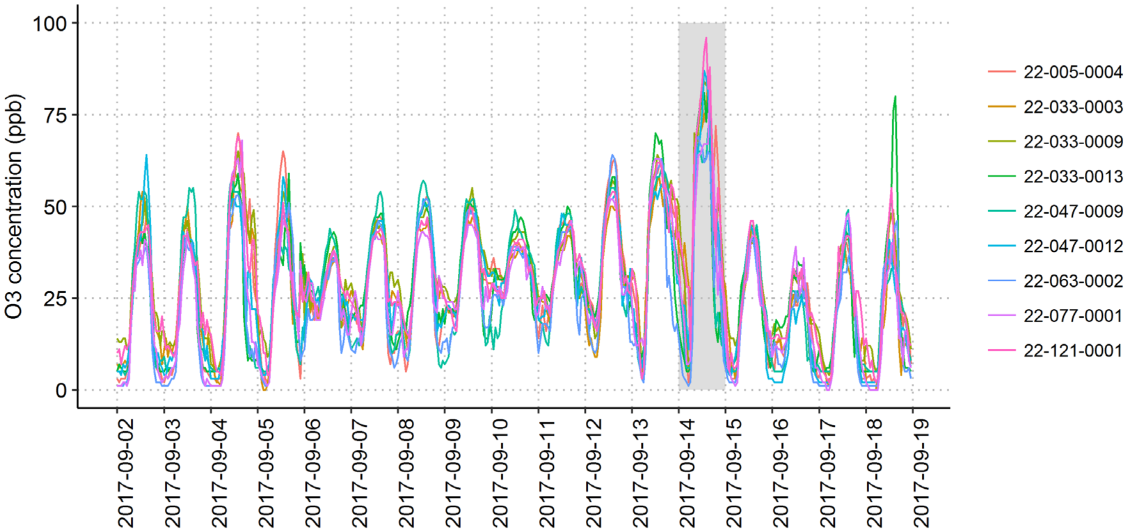

Figure 5. One-hour ozone concentrations (ppb) at all ozone monitoring sites in Baton Rouge, September 2 to September 18, 2017.

Table 5. Five-year percentile of daily maximum 8-hr ozone concentrations on September 14, 2017, for ozone monitors in the Baton Rouge area.

AQS Site Code	Site Name	5-Year Percentile
22-005-0004	Dutchtown	99.8
22-033-0003	LSU	99.3
22-033-0009	Capitol	99.9
22-033-0013	Pride	99.9
22-047-0009	Bayou Plaquemine	99.0*
22-047-0012	Carville	99.5
22-063-0002	French Settlement	97.9*
22-077-0001	New Roads	99.1*
22-121-0001	Port Allen	99.9

* Did not record an ozone exceedance on September 14, 2017.

These analyses show that, while not eligible for Tier 1, ozone concentrations measured on September 14, 2017, were unusually high at sites throughout Baton Rouge. The results also show that the September 14 event satisfies Key Factor #2 for Tier 2 exceptional events.

3.2 Ozone, Fire, and Smoke Maps

We produced maps of ozone AQI, $PM_{2.5}$ AQI, active fire and smoke detections from satellite, and visible satellite imagery that show the transport of smoke to Louisiana on September 14, 2017, and that show that high ozone across multiple states corresponded with the presence of wildfire smoke.

3.2.1 Ozone and $PM_{2.5}$ AQI Maps

From September 11 through September 14, high ground-level ozone concentrations increased in the central and southern United States (**Figure 6**), peaking on September 14 in several locations. On September 11, higher ozone concentrations are seen in Oklahoma and central Texas. This ozone develops and moves southward on September 12. On September 13, the area impacted by high ozone concentrations covers an area from Iowa to Texas and extends eastward into Louisiana from Texas. On September 14, the region of high observed ozone expands over a larger portion of the South and Midwest, and high ozone concentrations are present at Baton Rouge.

The same pattern of expanding pollutant concentrations over the Midwest and South is also seen in air quality index (AQI) plots for $PM_{2.5}$ (**Figure 7**). According to EPA guidance, “if plume arrival at a given location coincides with elevation of wildfire plume components (such as $PM_{2.5}$, CO, or organic and elemental carbon), those two pieces of evidence combined can show that smoke was transported from the event location to the monitor with the elevated O_3 concentration.” In Sections 3.2.2, 3.2.3, and 3.4, we show that the elevated ozone and $PM_{2.5}$ concentrations observed in the Midwest and South, including Louisiana, corresponded with the arrival of a smoke plume from fires in the northwestern United States.

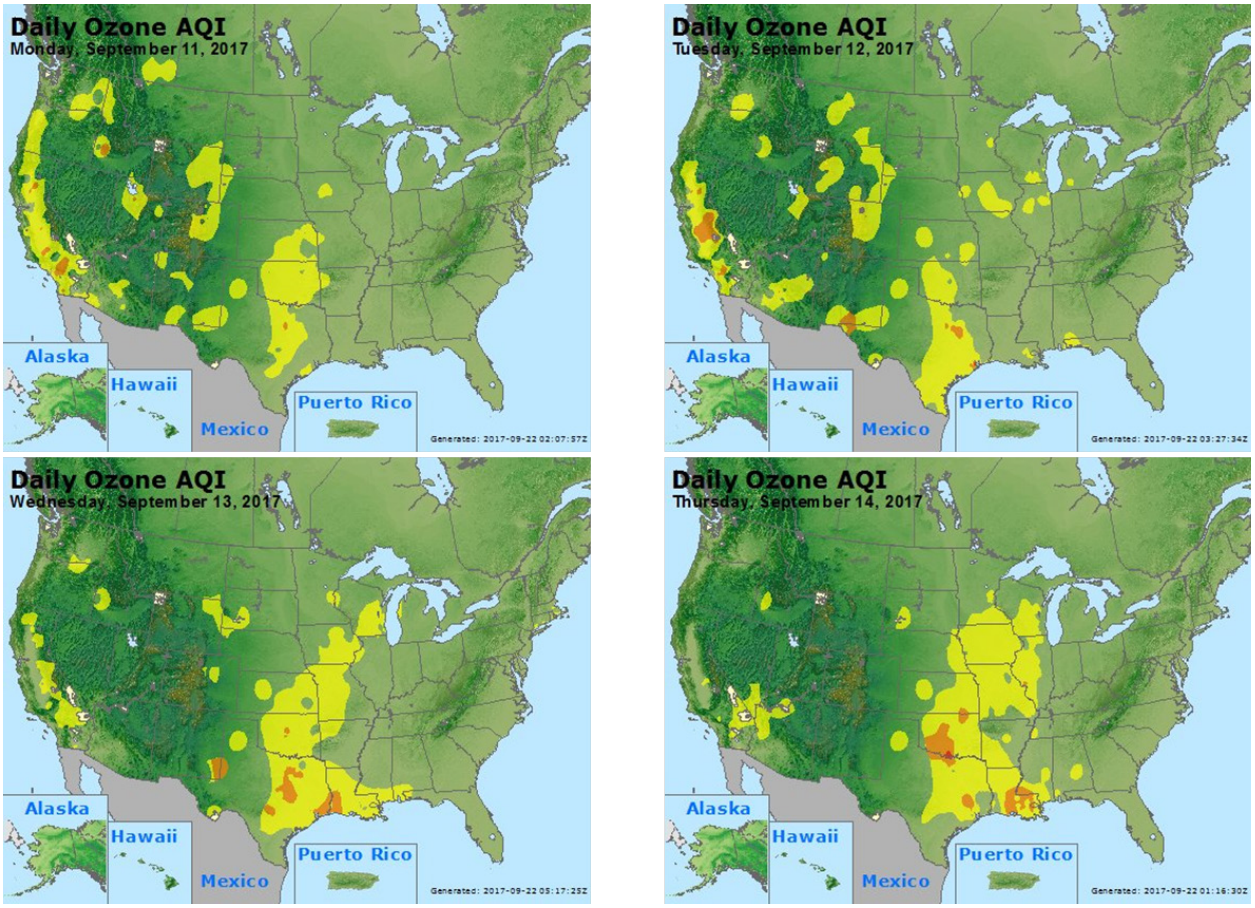

Figure 6. Daily ozone AQI from airnow.gov for September 11-14, 2017. Colors on the map indicate interpolated air quality observations. Yellow indicates Moderate air quality (AQI: 51-100), orange indicates Unhealthy for Sensitive Groups air quality (AQI: 101-150), and red indicates Unhealthy air quality (AQI: 151-200). Image source: EPA AirNow.

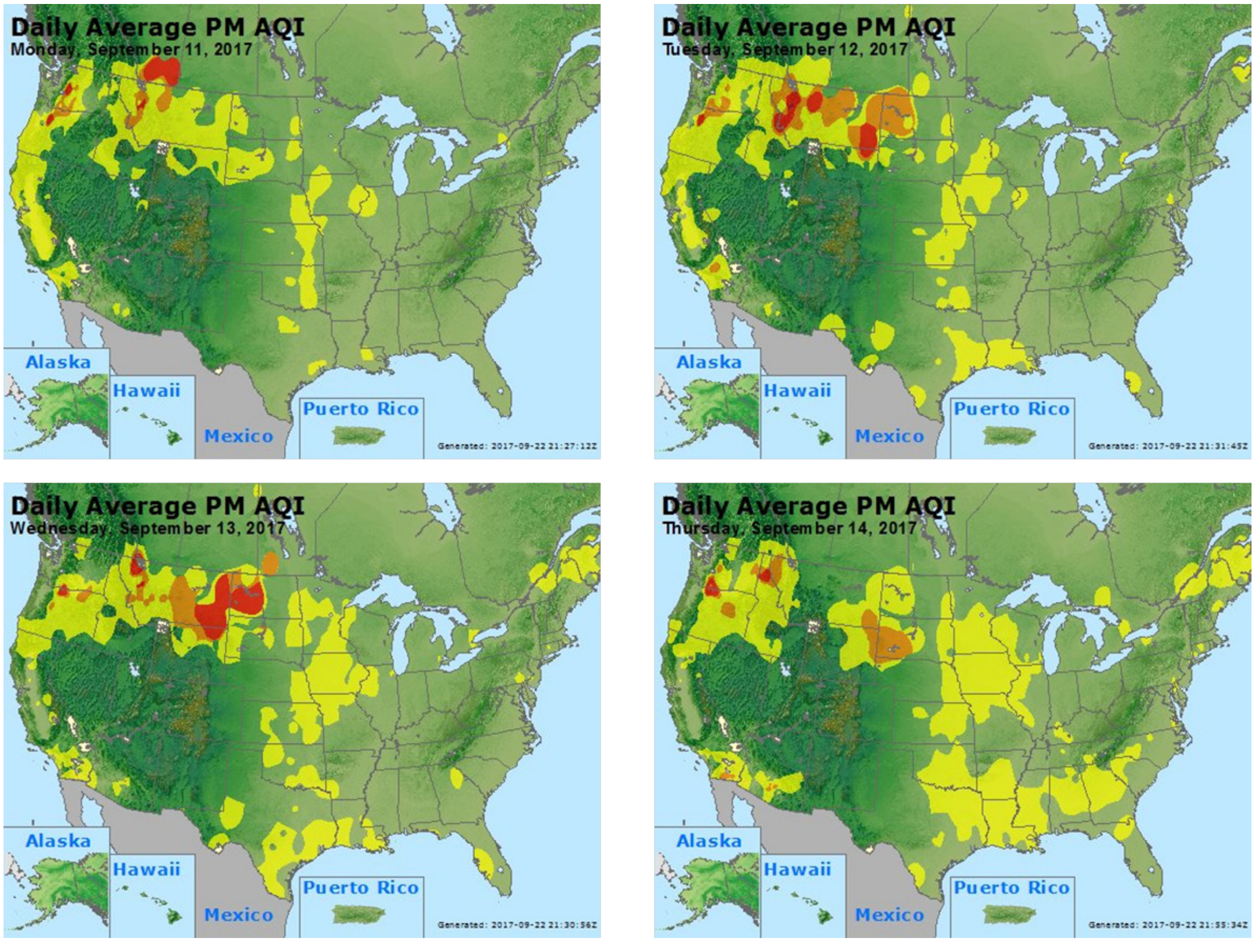

Figure 7. Daily $PM_{2.5}$ AQI from airnow.gov for September 11-14, 2017. Colors on the map indicate interpolated air quality observations. Yellow indicates Moderate air quality (AQI: 51-100), orange indicates Unhealthy for Sensitive Groups air quality (AQI: 101-150), and red indicates Unhealthy air quality (AQI: 151-200). Image source: EPA AirNow.

3.2.2 HMS Fire Detect and Smoke Plume Data

The National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) Fire and Smoke Product consists of

1. A daily fire detection product derived from three satellite data products[1] to spatially and temporally map fire locations at 1-km grid resolution, and
2. A daily smoke product derived from visible satellite imagery[2] that consists of polygons showing regions impacted by smoke.

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[1] The HMS fire detection product is developed using data from the Moderate Resolution Imaging Spectroradiometer (MODIS), Geostationary Operational Environmental Satellite system (GOES), Advanced Very High Resolution Radiometer (AVHRR) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellite instruments.

[2] The HMS smoke product is derived from GOES-EAST and GOES-WEST visible satellite imagery.

HMS can be used to provide evidence of transport of fire emissions to a monitor as part of the Tier 1 analysis requirements discussed in the EPA's guidance. An advantage of HMS smoke plume data over other available satellite data is that HMS incorporates data from several environmental satellites. An additional advantage is that HMS data are created and reviewed by NOAA-trained analysts using animated imagery, allowing the analyst to identify instances where smoke is dispersed by transport, which can be challenging to recognize in a single visible image. Real-time HMS fire detection and smoke products, as well as a six-month archive of the products, are available on the NOAA Satellite and Information Service website (ospo.noaa.gov/products/land/hms.html). Users may download data as a GIS SHP, Google Earth KML, or JPG file. **Figure 8** shows HMS smoke plume and fire detect data for September 11-14, 2017.

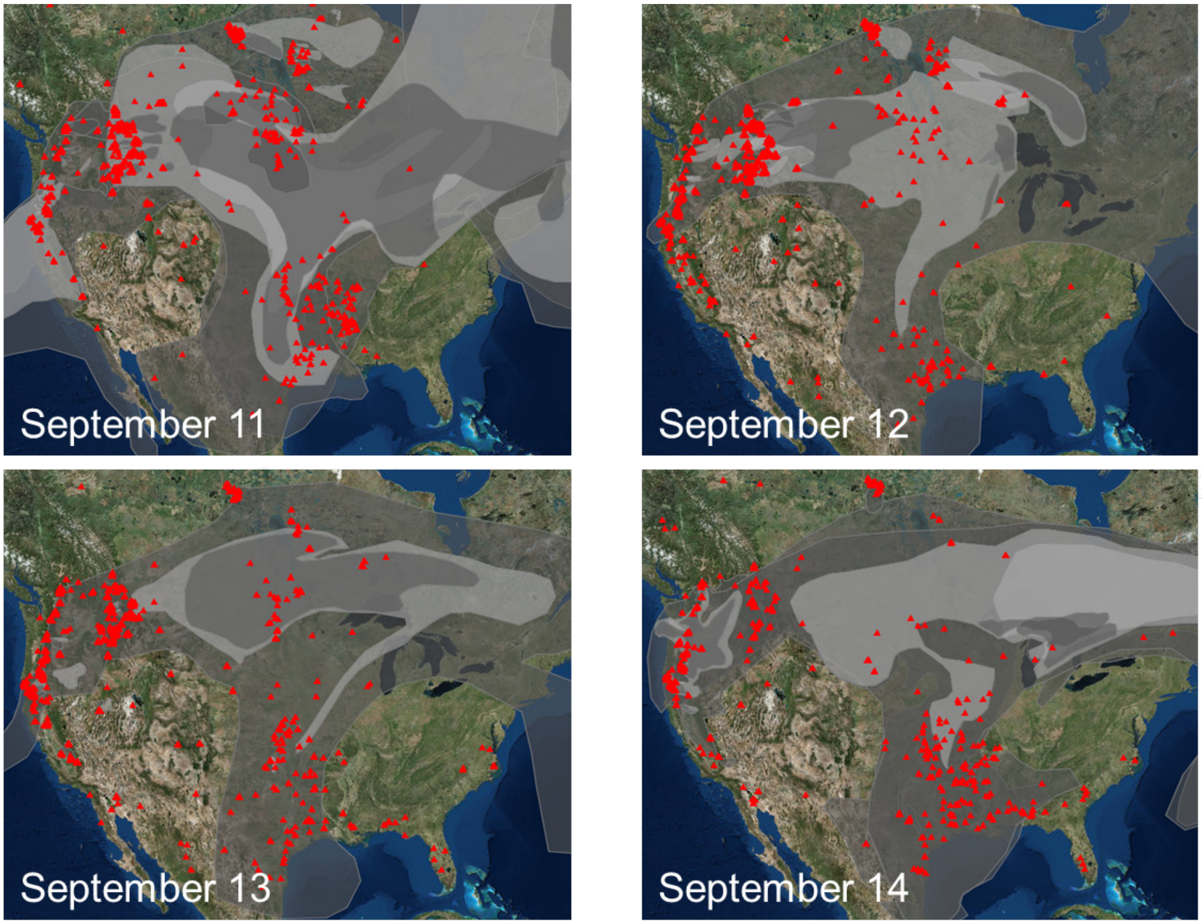


Figure 8. Daily NOAA HMS fire and smoke observations. Red triangles indicate a fire detected by satellite observation. Gray areas indicate the locations of smoke plumes observed in satellite imagery. Image source: EPA AirNow-Tech.

The HMS fire and smoke maps show large, active fires in the northwestern United States on the days leading up to September 14. There is also significant fire activity in Central Canada on those days. Scattered fires in Louisiana and nearby states, including Texas, Arkansas, and Oklahoma, are also apparent. In addition to the fire activity, the maps also show large smoke plumes extending across much of the northern United States and Canada. A substantial smoke plume extends southward through the central United States on each day between September 11 and 14. This plume corresponds to the elevated levels of ozone and $PM_{2.5}$ measured throughout the central United States in the days leading up to September 14.

The HMS smoke plume data for the days leading up to September 14 were obtained and combined with HYSPLIT back trajectories on high ozone concentration days to identify intersections and assess the potential for smoke impacts (Section 3.3). The following sections provide further evidence, based on HYSPLIT trajectories and satellite data, of a large smoke plume that traveled from northwestern fires across the central United States to Louisiana.

3.2.3 Visible Satellite Imagery

Visible satellite imagery from the MODIS Aqua and Terra satellites plainly show transport of smoke from fires burning in the Northwest to the central and southern United States, including Louisiana, between September 7 and September 14 (**Figures 9 through 16**). This evidence corroborates the evidence of smoke over Louisiana demonstrated by the HMS maps (Section 3.2.1). The movement of a dense smoke plume from Texas and the Gulf of Mexico to Louisiana between September 13 and 14 is particularly noteworthy. The movement of this smoke corresponds to the expansion of elevated ozone and $PM_{2.5}$ AQI values in Louisiana noted above. In addition, the transport of smoke northeastward from Texas and the Gulf of Mexico is consistent with transport patterns seen in the HYSPLIT trajectory analysis presented in Section 3.3 and the satellite measurements of smoke-associated species presented in Section 3.4.

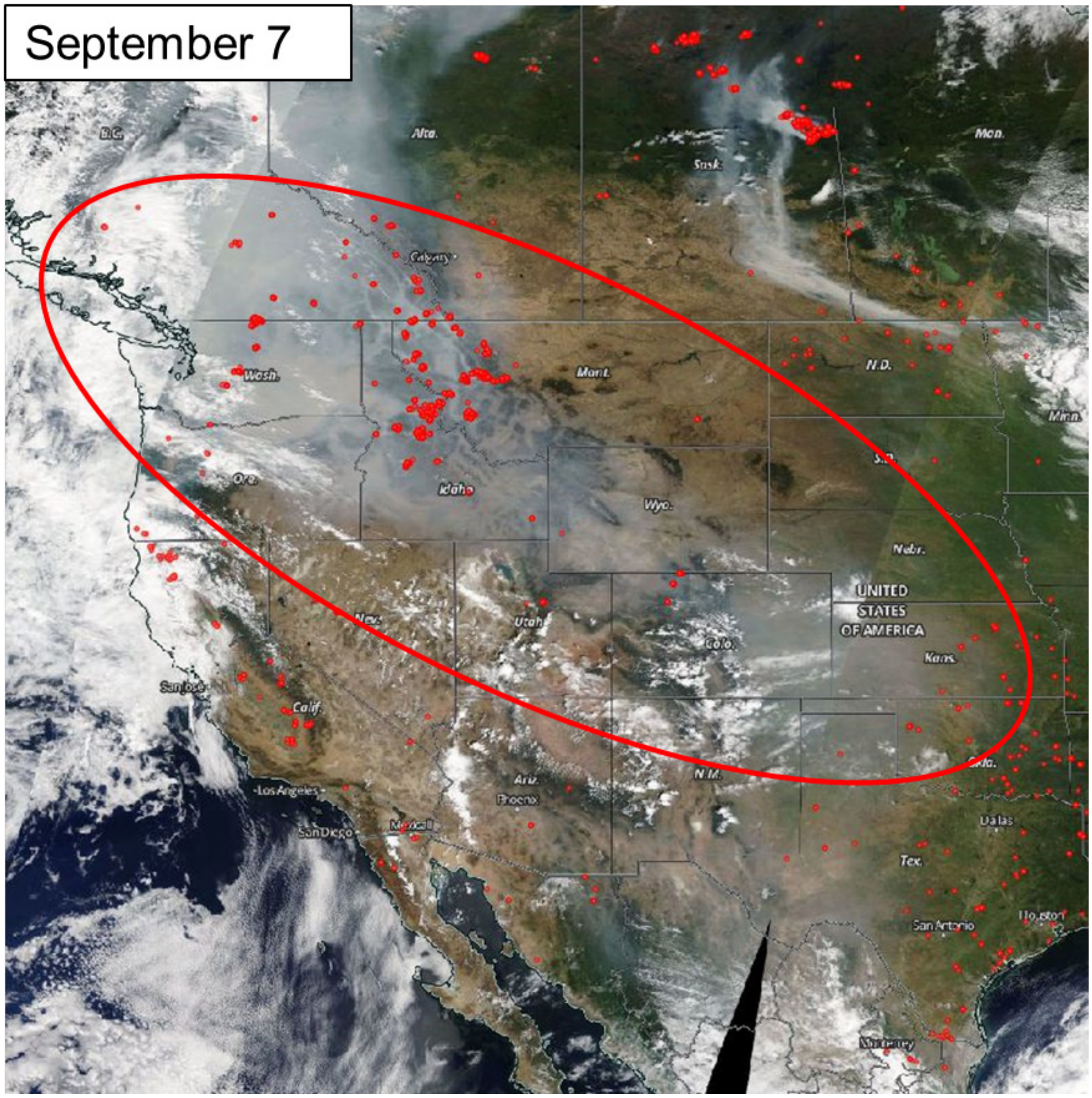


Figure 9. MODIS Terra true color satellite imagery from September 7, 2017, showing clear evidence of a dense smoke plume over Washington, northern Oregon, British Columbia, Idaho, and Montana. The visible smoke extends eastward at least as far as Kansas. Image source: NASA Worldview.

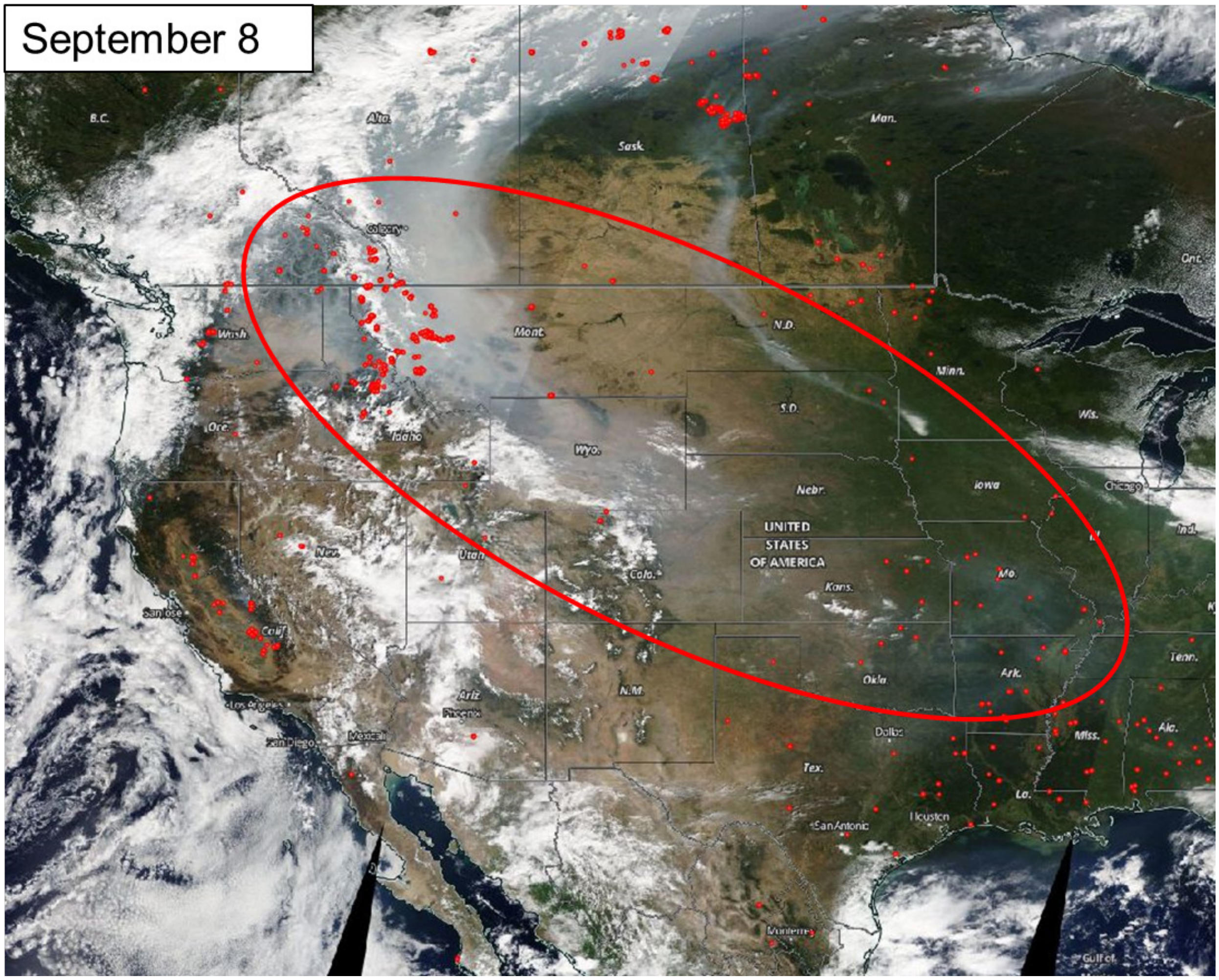


Figure 10. MODIS Terra true color satellite imagery from September 8, 2017, showing clear evidence of a dense smoke plume that extends as far east as Missouri. Image source: NASA Worldview.

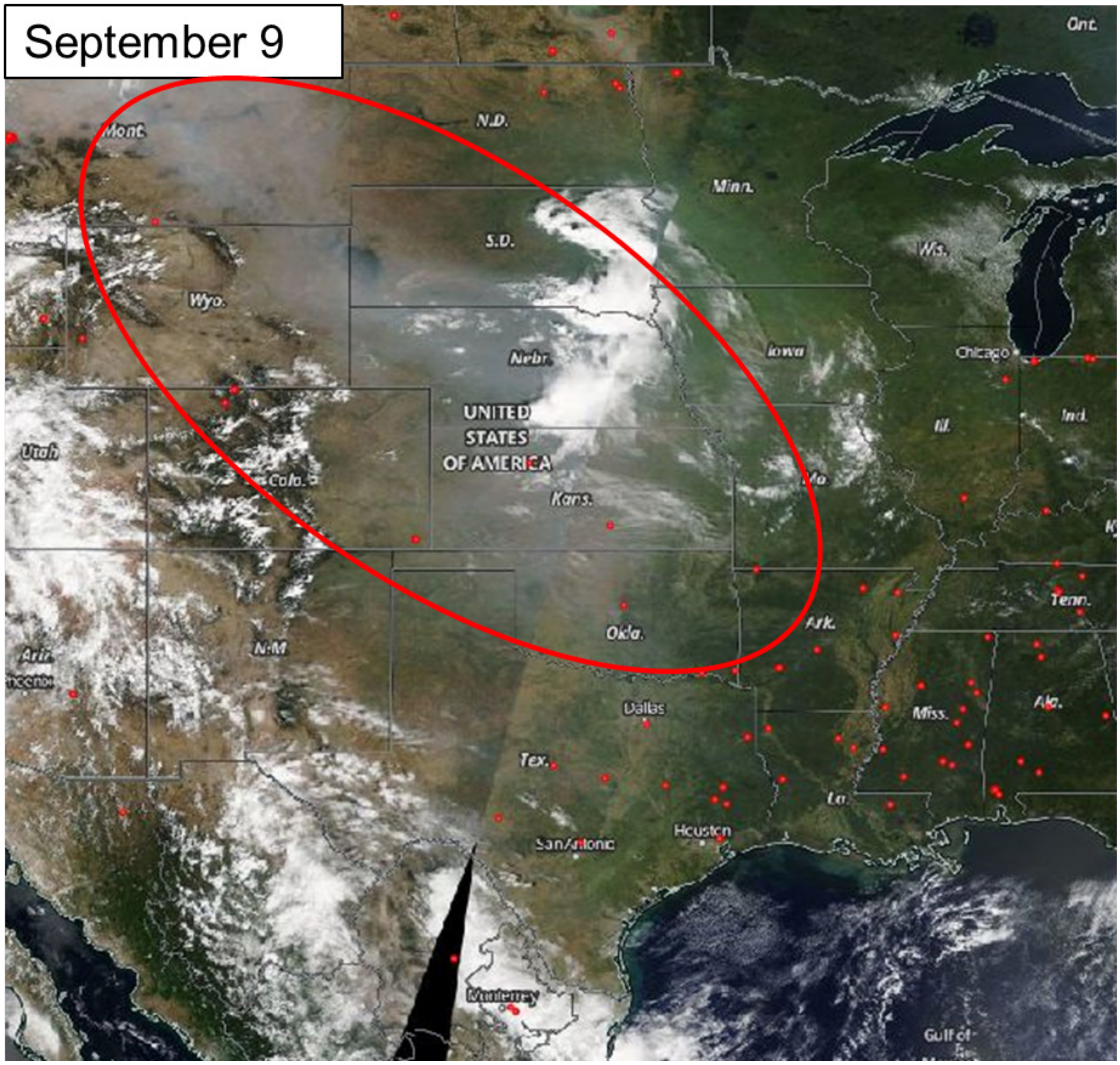


Figure 11. MODIS Terra true color satellite imagery from September 9, 2017, showing clear evidence of a dense smoke plume over the central United States. Image source: NASA Worldview.

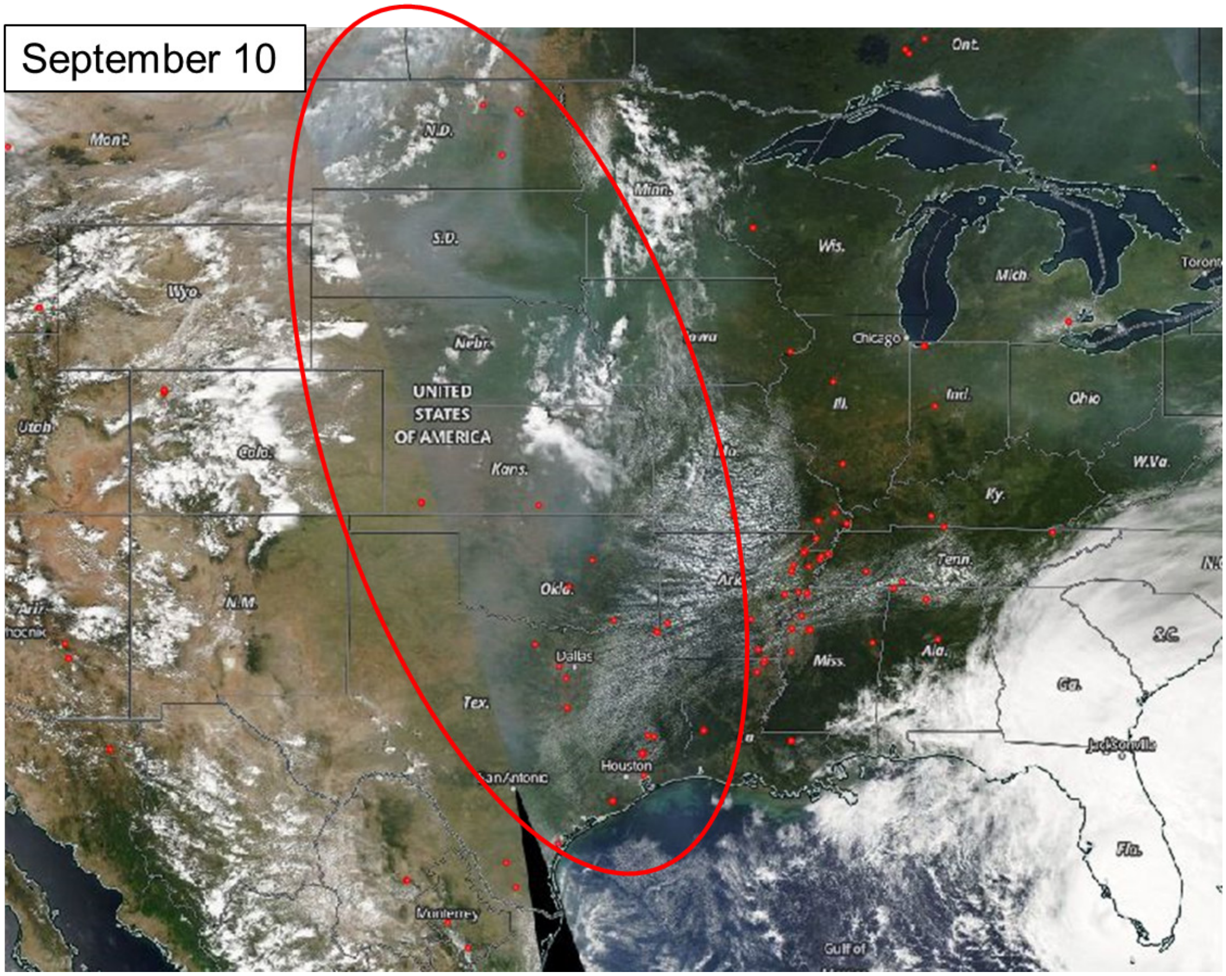


Figure 12. MODIS Aqua true color satellite imagery from September 10, 2017, showing clear evidence of a dense smoke plume that extends north to south over the central United States from North Dakota to Texas. Hurricane Irma is evident in the bottom right corner of the image. The hurricane likely contributed to the north-south distribution of the smoke plume. Image source: NASA Worldview.

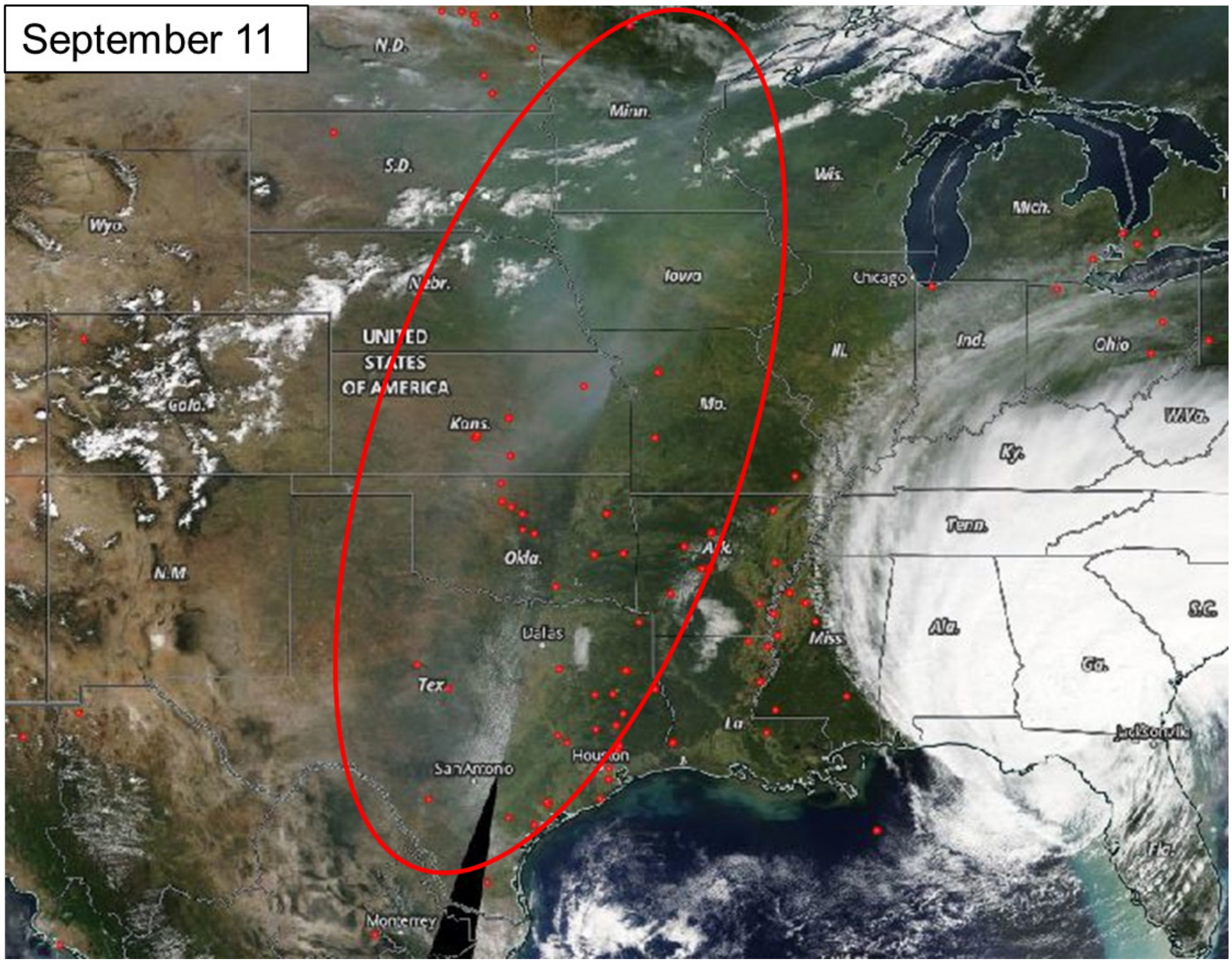


Figure 13. MODIS Terra true color satellite imagery from September 11, 2017, showing evidence of a smoke plume extending from Iowa to Texas. Hurricane Irma has moved northwest since the previous day, contributing to the alignment of the smoke north to south. Image source: NASA Worldview.

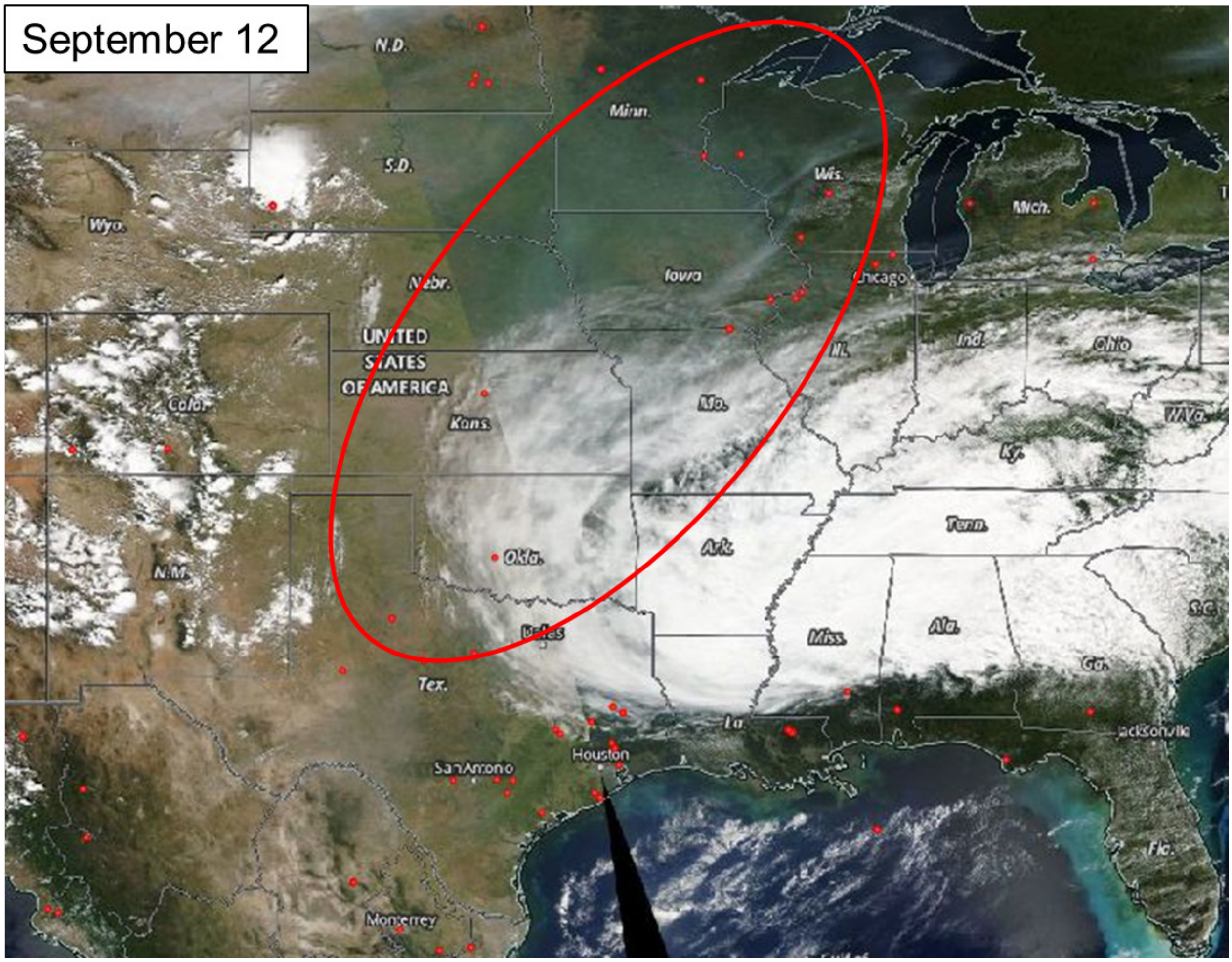


Figure 14. MODIS Aqua true color satellite imagery from September 12, 2017. Smoke is visible in northern Iowa, Nebraska, and Minnesota. Smoke farther south around Kansas and Oklahoma has been obscured by cloud cover associated with Hurricane Irma. Image source: NASA Worldview.

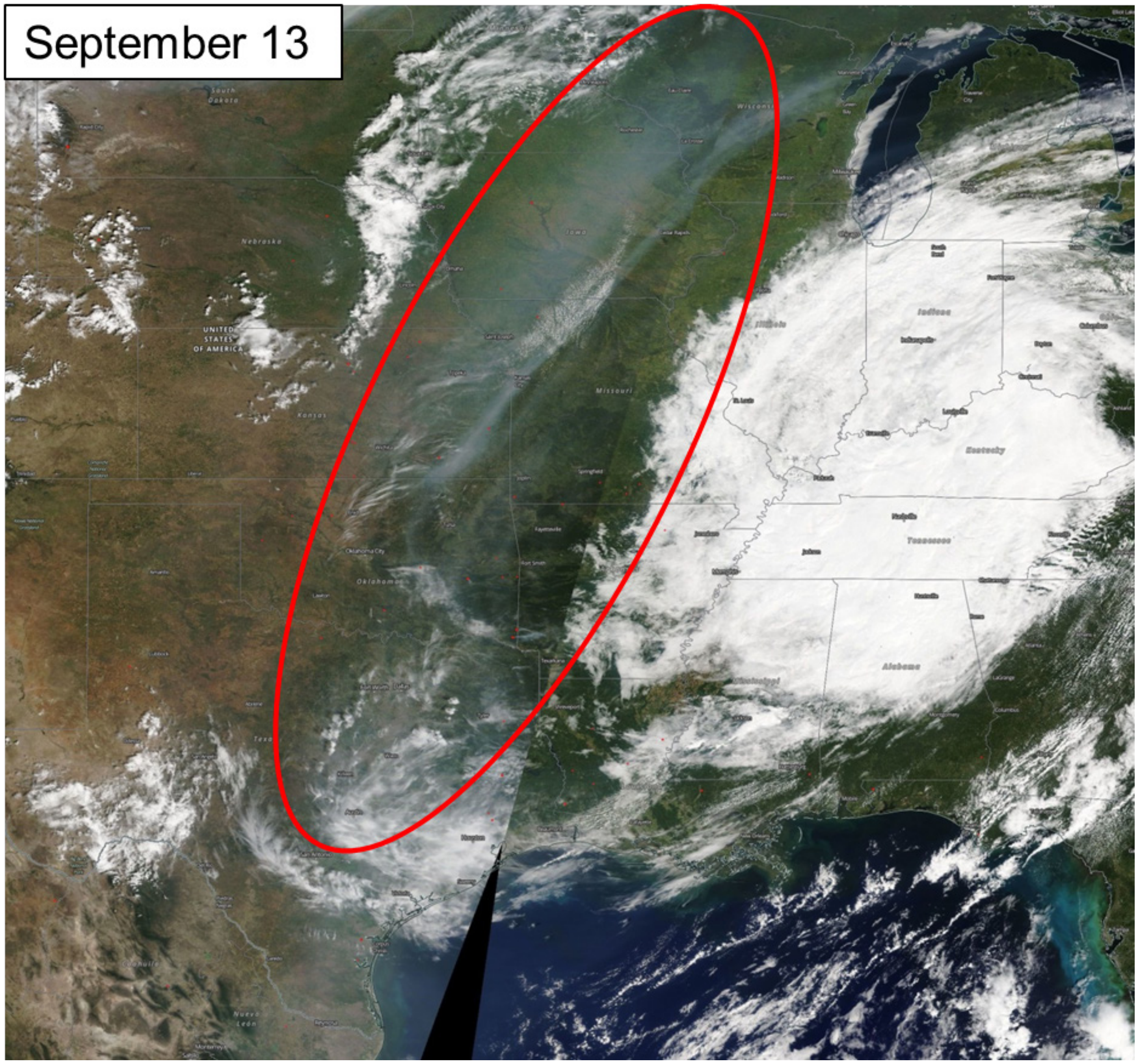


Figure 15. MODIS Terra true color satellite imagery from September 13, 2017, showing evidence of a smoke plume that extends from Texas to Iowa. Smoke that was obscured on the previous day has become apparent as Hurricane Irma moves eastward. Image source: NASA Worldview.

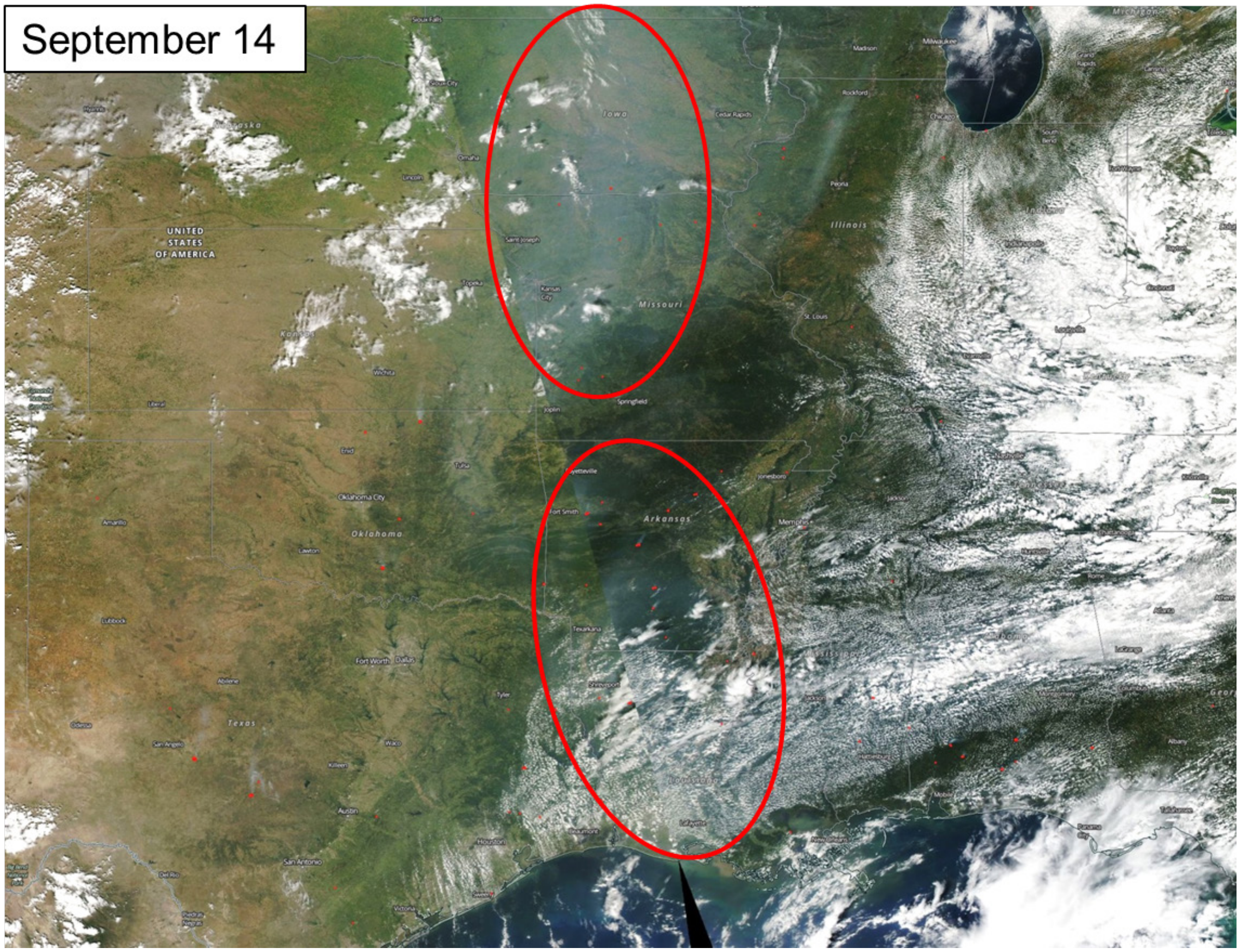


Figure 16. MODIS Aqua true color satellite imagery from September 14, 2017, showing that the smoke plume observed on previous days has moved into a north-south line over Iowa, Missouri, Arkansas, and Louisiana. Image source: NASA Worldview.

3.3 HYSPLIT Trajectories

HYSPLIT trajectories were run to demonstrate the transport of air parcels to Baton Rouge from upwind areas, and to show transport of smoke-containing air parcels from wildfires toward the affected monitor. These trajectories show that air was transported from wildfires in Idaho and Montana to Texas in the days prior to the event and that air from Texas was transported across the Gulf of Mexico to Louisiana between September 12 and 14. Combined with satellite observations described in Sections 3.2 and 3.4, the trajectories demonstrate that smoke was transported from wildfires in the northwestern United States to Baton Rouge.

NOAA's HYSPLIT model was used for the trajectory modeling (http://ready.arl.noaa.gov/HYSPLIT.php). HYSPLIT is a commonly used model that calculates the path of a single air parcel from a specific location and height above the ground over a period of time; this path is the modeled trajectory.

HYSPLIT trajectories can be used as evidence that fire emissions were transported to an air quality monitor; trajectory analysis is one option for meeting the Tier 1 requirement and is required under Tier 3.

The model options used for this study are summarized in **Table 6**. The 12-km resolution meteorological data from the North American Mesoscale Forecast System (NAM) were used (http://www.emc.ncep.noaa.gov/NAM). These data are high-spatial-resolution, are readily available for HYSPLIT modeling over the desired lengths of time, and are expected to capture fine-scale meteorological variability. Backward trajectory start times were selected to coincide with peak 8-hr ozone concentrations on September 14, 2017. As suggested in the EPA's exceptional event guidance, a backward trajectory length of 72 hours was selected to assess whether smoke from the current day or from the previous two days may have been transported over a long distance to the monitoring sites. Trajectories were initiated at 50 m, 500 m, and 1,000 m above ground level to capture transport throughout the mixed boundary layer, as ozone precursors may be transported aloft and influence concentrations at the surface through vertical mixing. Three backward trajectory approaches available in the HYSPLIT model were used in this analysis, including site-specific trajectories, trajectory matrix, and trajectory frequency. Site-specific trajectories are single trajectories run to arrive at a given site, trajectory matrices provide trajectories that arrive at a grid of points covering a specified area, and trajectory frequency analyses show the frequency with which multiple trajectories initiated over multiple hours pass over each location on a map. Together, these trajectory analyses indicate the transport patterns in Baton Rouge on September 14.

Based on trajectories and satellite data, the location at which back trajectories ended was used to initiate additional back trajectories to show long-range air transport over multiple days. Additionally, a forward trajectory matrix was run for fires in the northwestern United State to show transport of air from these fires in the direction of Louisiana. Finally, back trajectories were run for the Dutchtown monitor using higher resolution meteorological data to demonstrate vertical air transport (Section 3.5.2).

Table 6. HYSPLIT trajectory model options used in this study.

	Backward Trajectory Analysis – Site-Specific	Backward Trajectory Analysis – Matrix	Backward Trajectory Analysis – Frequency	Forward Trajectory Analysis – Matrix	Backward Trajectory Analysis – High Resolution (Section 3.5)
Meteorology	12-km NAM	12-km NAM	12-km NAM	12-km NAM	3-km HRRR[a]
Time Period	September 12-14, 2017	September 14, 2017	September 14, 2017	September 8-13, 2017	September 12-14, 2017
Starting Location	Capitol, monitoring site (Site ID: 220330009)	Evenly spaced grid covering Baton Rouge	Capitol, monitoring site (Site ID: 220330009)	Evenly spaced grid covering fires in Idaho and Montana	Dutchtown monitoring site
Trajectory Time Length	72 hours	72 hours	72 hours	120 hours	24 hours
Starting Heights (AGL)	50 m, 500 m, 1,000 m	50 m, 500 m, 1,000 m	50 m, 500 m, 1,000 m	1,000 m	50 m
Starting Times	1600 UTC	1600 UTC	1600 UTC	1600 UTC	Every 3 hours between 0200 UTC Sept. 12 and 2300 UTC Sept. 14
Vertical Motion Method	Model vertical velocity	Model vertical velocity	Model vertical velocity	Model vertical velocity	Model vertical velocity
Top of Model	10,000 m AGL	10,000 m AGL	10,000 m AGL	10,000 m AGL	10,000 m AGL

[a] NOAA's High-Resolution Rapid Refresh model.

Site-specific backward trajectories were calculated from the downtown Baton Rouge Capitol monitoring site on September 14, 2017, at (10:00 a.m. CST/4:00 p.m. UTC, when ozone concentrations were the highest of the day. Figure 17 shows backward trajectories, along with measured ozone (8-hr begin time average) at other monitoring sites and HMS fire detect locations on September 14, 2017. As shown in Figure 17, each trajectory height follows a similar backward path from Baton Rouge and travels over or near several active fire locations. HMS smoke plume data are overlaid and displayed in Figures 18 and 19. As shown in Figure 18, smoke is identified over much of the map on September 14, 2017. Additionally, elevated ozone concentrations are evident at other sites in the area where smoke was present. Previous-day trajectory plots shown in Figure 19 show similar smoke plume coverage over the area; however, backward trajectories originating from Baton Rouge on those days do not intersect with the plumes.

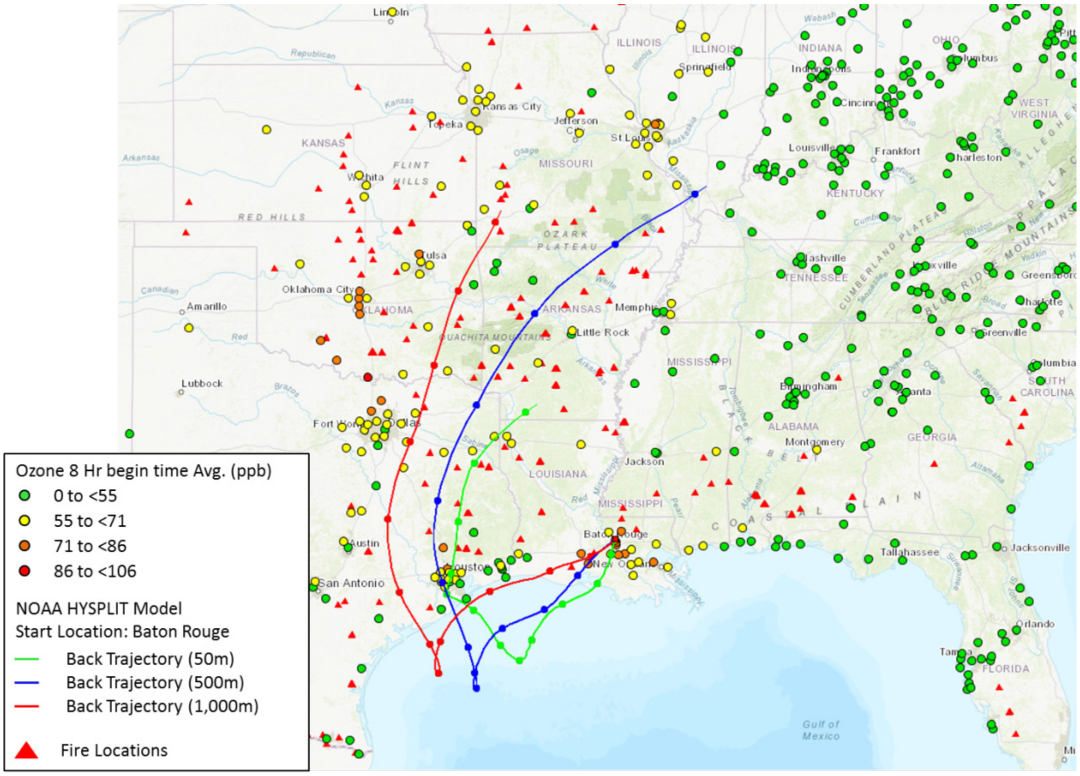


Figure 17. Backward trajectories from Baton Rouge on September 14, 2017.

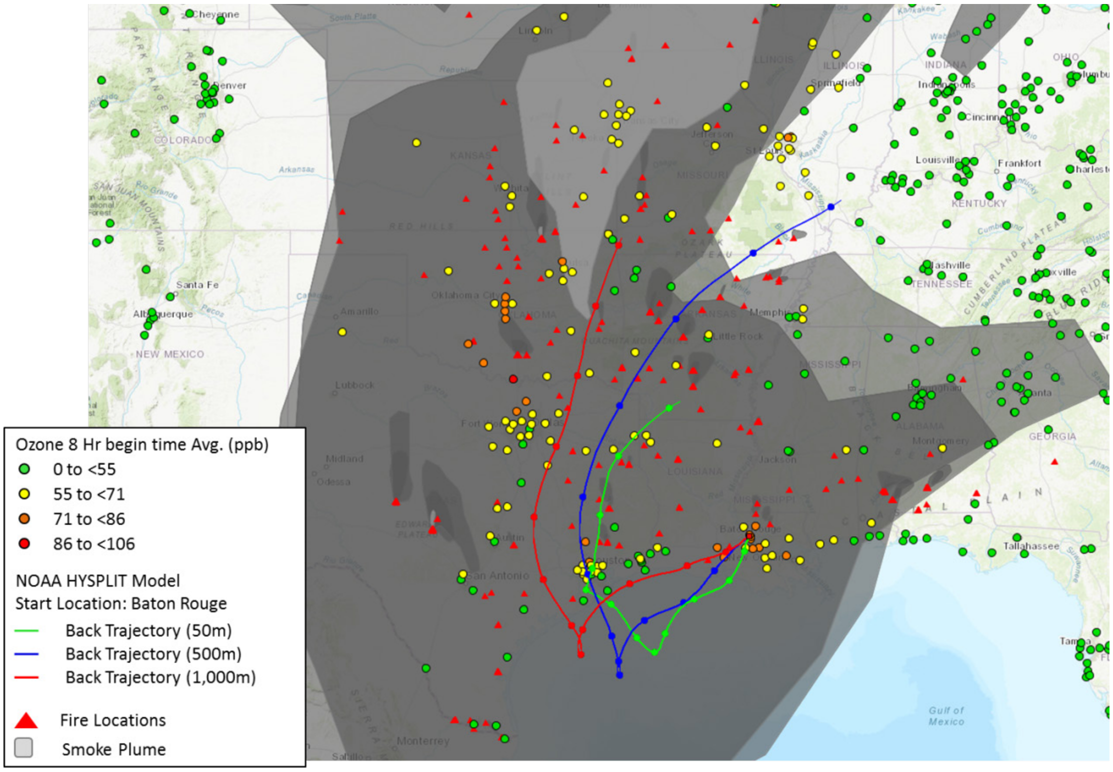
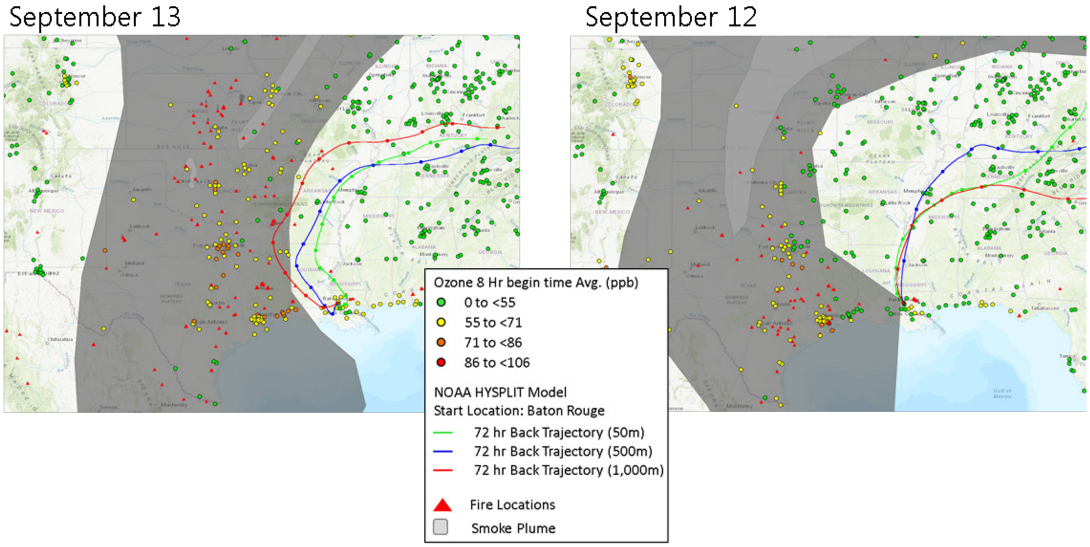


Figure 18. Backward trajectories from Baton Rouge on September 14, 2017, overlaid with HMS fire detect and location smoke plume data.


September 13

September 12

Figure 19. Backward trajectories from Baton Rouge on September 13 and 12, 2017, overlaid with HMS fire detect locations and smoke plumes.

The second trajectory approach used in this analysis was HYSPLIT trajectory matrix. In the trajectory matrix option, trajectories are run in an evenly spaced grid of source locations. The objective of this analysis was to identify variations in meteorological patterns of transported air to the greater Baton Rouge area. Figure 20 shows a 72-hour backward trajectory matrix with source locations encompassing the greater Baton Rouge area. The backward trajectories were initiated on September 14, 2017 (10:00 a.m. CST/4:00 p.m. UTC), when ozone concentrations were the highest of the day, at a starting height of 50 m AGL. As shown in Figure 20, transported air intersecting the greater Baton Rouge area on September 14, 2017, follows a consistent pattern. Much like the trajectories depicted in Figure 17, transported air traveled from Western Texas, over the Houston area, over the Gulf of Mexico, and progressed back to the northeast to intersect Baton Rouge at 50 m AGL.

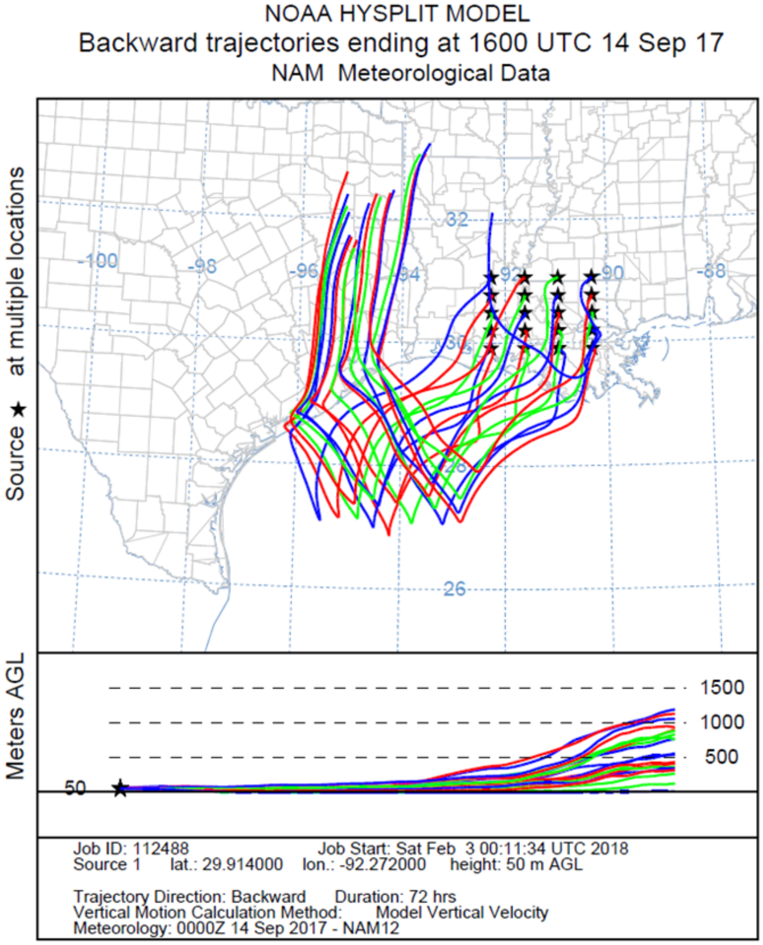
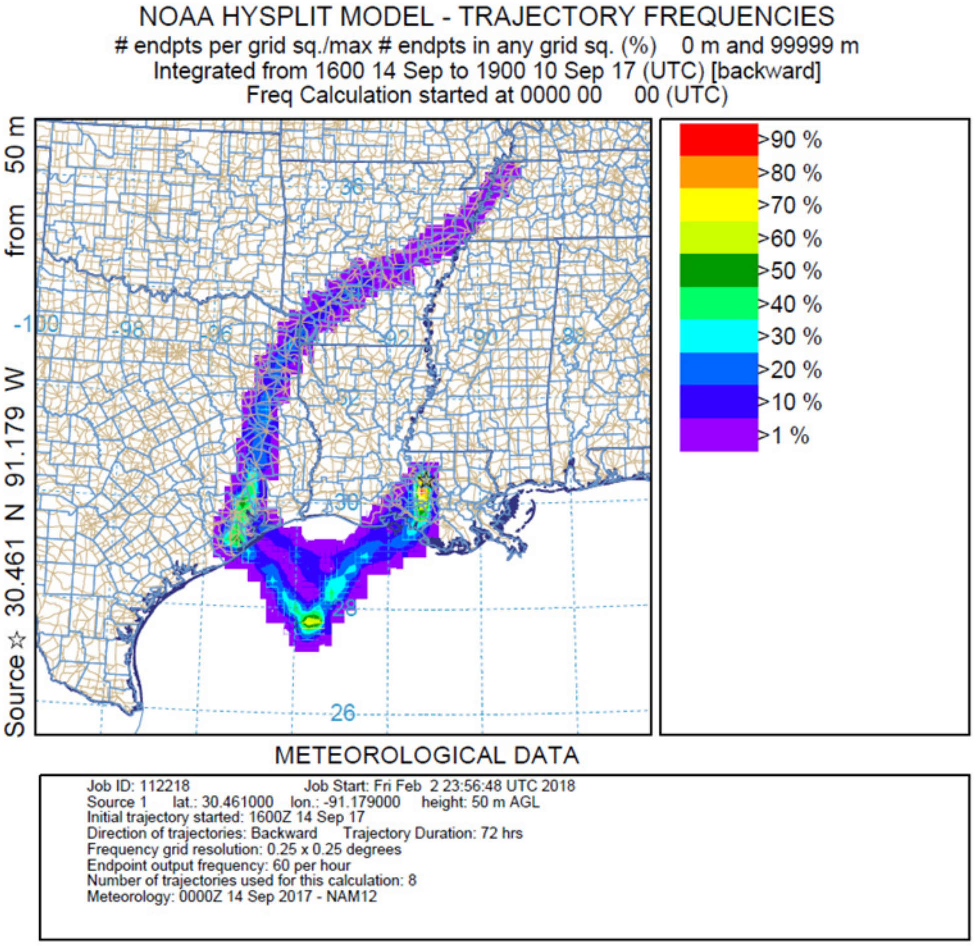


Figure 20. Backward trajectory matrix for the greater Baton Rouge area on September 14, 2017.

The third trajectory approach used in this analysis was HYSPLIT trajectory frequency. The trajectory frequency option starts a trajectory from a single location and height every three hours. Using a continuous 0.25 degree grid, the frequency of trajectories passing through each grid cell is totaled and then normalized by the total number of trajectories. Figure 21 shows a 72-hour backward trajectory frequency plot, using the Capitol monitoring site as the starting location and 50 m AGL as the starting height. The trajectory frequency plot provides similar results as the previous two approaches; transported air impacting Baton Rouge on September 14, 2017, is predominately coming from Western Texas and passing over the Houston area. Backward trajectory frequency plots with starting heights at 500 and 1,000 m AGL show transported air extending to Arkansas and Southern Missouri, as shown in Figure 22.



Job ID: 112218 Job Start: Fri Feb 2 23:56:48 UTC 2018
Source 1 lat.: 30.461000 lon.: -91.179000 height: 50 m AGL
Initial trajectory started: 1600Z 14 Sep 17
Direction of trajectories: Backward Trajectory Duration: 72 hrs
Frequency grid resolution: 0.25 x 0.25 degrees
Endpoint output frequency: 60 per hour
Number of trajectories used for this calculation: 8
Meteorology: 0000Z 14 Sep 2017 - NAM12

Figure 21. Backward trajectory frequency plot for the greater Baton Rouge area originating on September 14, 2017.

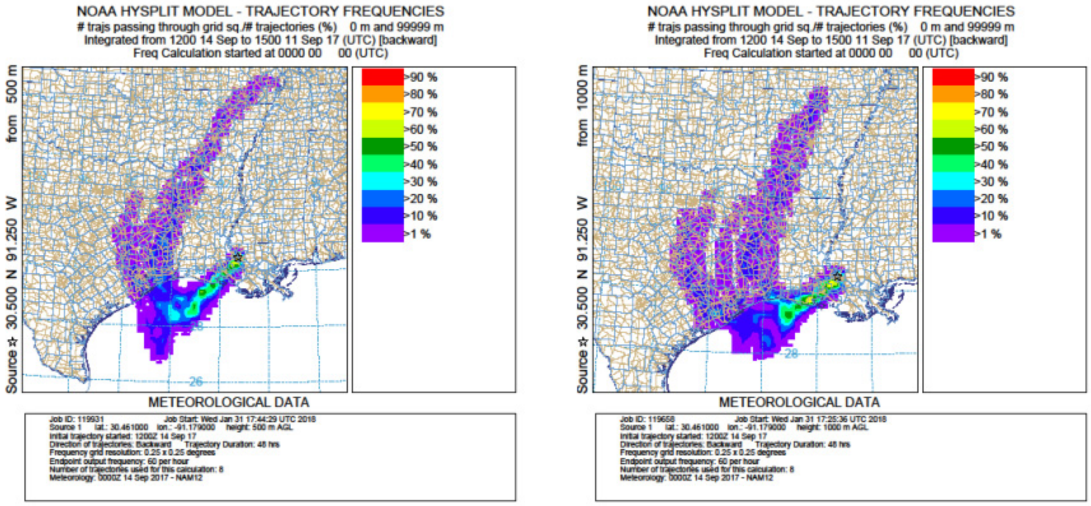


Figure 22. Backward trajectory frequency plots for the greater Baton Rouge area originating on September 14, 2017, at starting heights of 500 and 1,000 m AGL.

Forward trajectories were run from fires in the northwestern United States starting at 1600 UTC on September 8 (**Figure 23**). These trajectories show that smoke was transported from fires in the Northwest in two major transport patterns. Some air parcels traveled northeastward from the fires, while others traveled southeastward to Oklahoma and Texas. These forward trajectories, combined with the back trajectories showing smoke transport from Texas to Louisiana, further support the transport of smoke from northwestern fires to Louisiana.

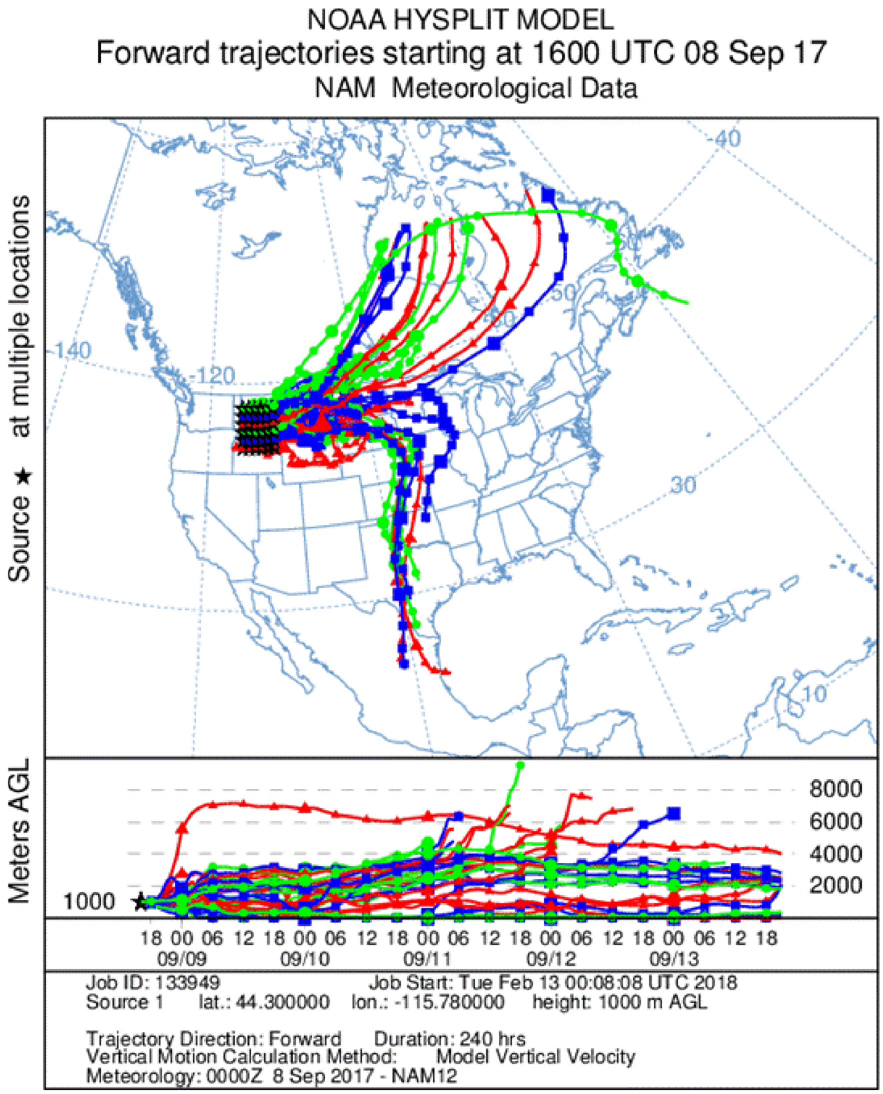


Figure 23. Forward trajectory plots for trajectories originating at 1600 UTC on September 8, 2017, at starting height of 1,000 m AGL.

3.4 Satellite NO_x, AOD, and CO

Satellite retrievals of pollutants associated with wildfire smoke, such as AOD, CO, and NO_x, can provide evidence that smoke was present at the monitoring site. We examined maps of AOD from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Aqua and Terra satellites, CO retrievals from the Atmospheric Infrared Sounder (AIRS) instrument onboard the Aqua satellite, and NO_2 retrievals from the Ozone Monitoring Instrument (OMI). These maps provide evidence to support the transport of smoke from fires in the northwestern United States to Louisiana, as already demonstrated with visual imagery and trajectories.

MODIS AOD measurements indicate the concentration of light-absorbing aerosols, including those emitted by wildfires, in the total atmospheric column. Between September 9 and September 14, AOD measurements show the movement of a dense plume of aerosols originating near fires in the Northwest (**Figure 24**). This plume moves to the central United States between September 9 and September 11. The plume is then transported southward to Texas by weather patterns associated with Hurricane Irma, producing a north-south line of elevated AOD between Texas and Iowa on September 13. On September 14, the aerosol plume moves eastward from Texas to Louisiana. Despite partial obstruction by cloud cover, MODIS Aqua AOD retrievals indicate elevated aerosols in the Baton Rouge area on September 14 (**Figure 25**).

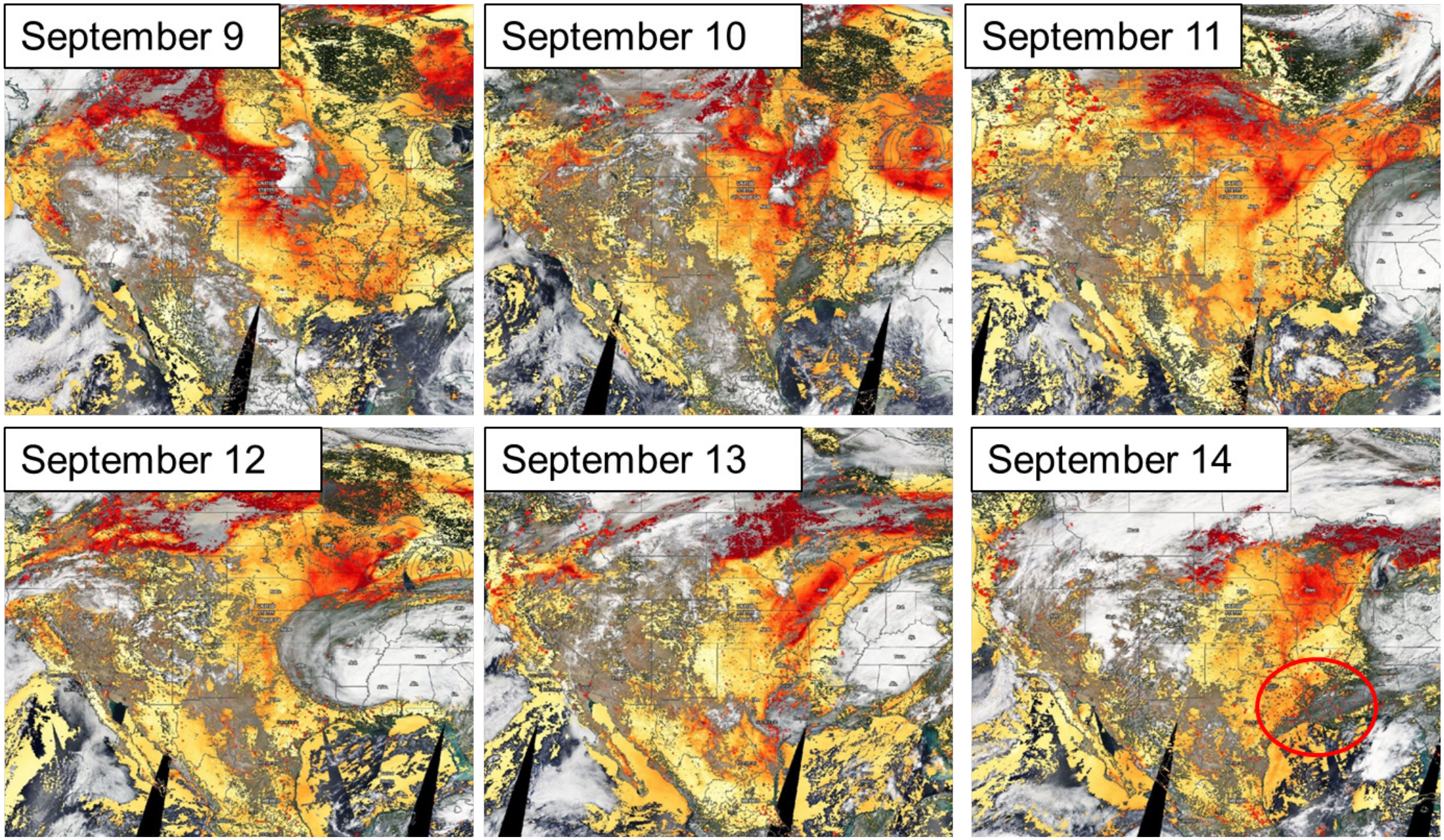


Figure 24. MODIS (Aqua/Terra) aerosol optical depth retrievals from the "Dark Target" algorithm at 3 km spatial resolution for September 9 through September 14, 2017. AOD indicates the concentration of aerosols in the total atmospheric column. Yellow indicates low AOD, while orange and red indicate increasingly higher AOD. Missing data are represented as transparent, with MODIS visible imagery from the indicated day underlying the AOD layer. Scattered aerosol retrievals and missing data due to cloud cover over Louisiana are indicated with a red circle for September 14. Image source: NASA Worldview.

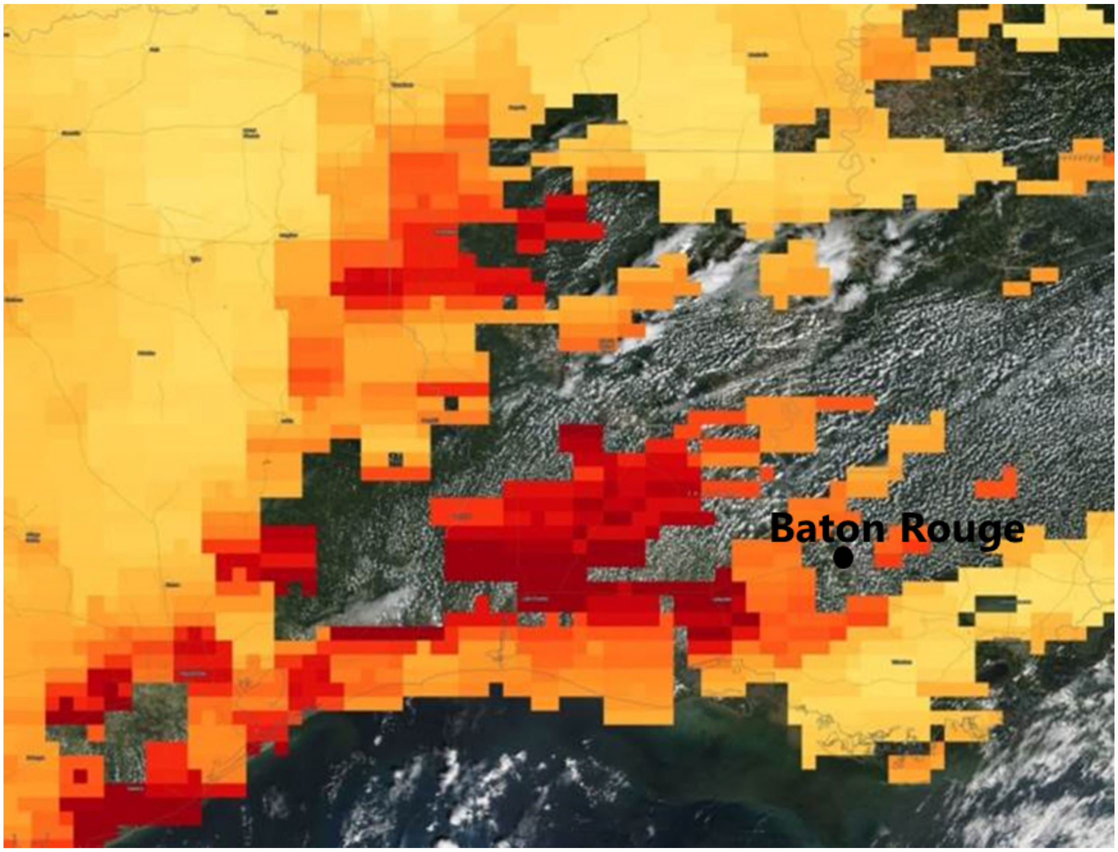


Figure 25. MODIS Aqua aerosol optical depth retrievals from the "Deep Blue" algorithm at 10 km nominal spatial resolution for September 14, 2017, over Baton Rouge. Images were acquired between approximately 12:30 p.m. and 2:15 p.m. CST. AOD indicates the concentration of aerosols in the total atmospheric column. Yellow indicates low AOD, while orange and red indicate increasingly higher AOD. Missing data are represented as transparent, with MODIS visible imagery from the indicated day underlying the AOD layer. Image source: NASA Worldview.

Carbon monoxide measurements from AIRS show the same pattern of smoke plume transport seen in the MODIS AOD data noted above. The maps show smoke transport from the northwest to the central United States between September 9 and September 11 (Figure 26). The north-south line of CO, indicating a smoke plume, between Texas and Iowa on September 13 is particularly clear in this imagery. By slightly after midnight on September 14, the CO plume has been transported eastward from Texas to Louisiana (Figure 27). Total column concentrations of CO observed over Louisiana, up to 120 ppb, on that day are about 50% higher than typical background concentrations of 70-90 ppb. These observations are much higher than those observed elsewhere in the United States on September 14. This imagery clearly indicates the presence of a smoke plume over Louisiana by the beginning of September 14.

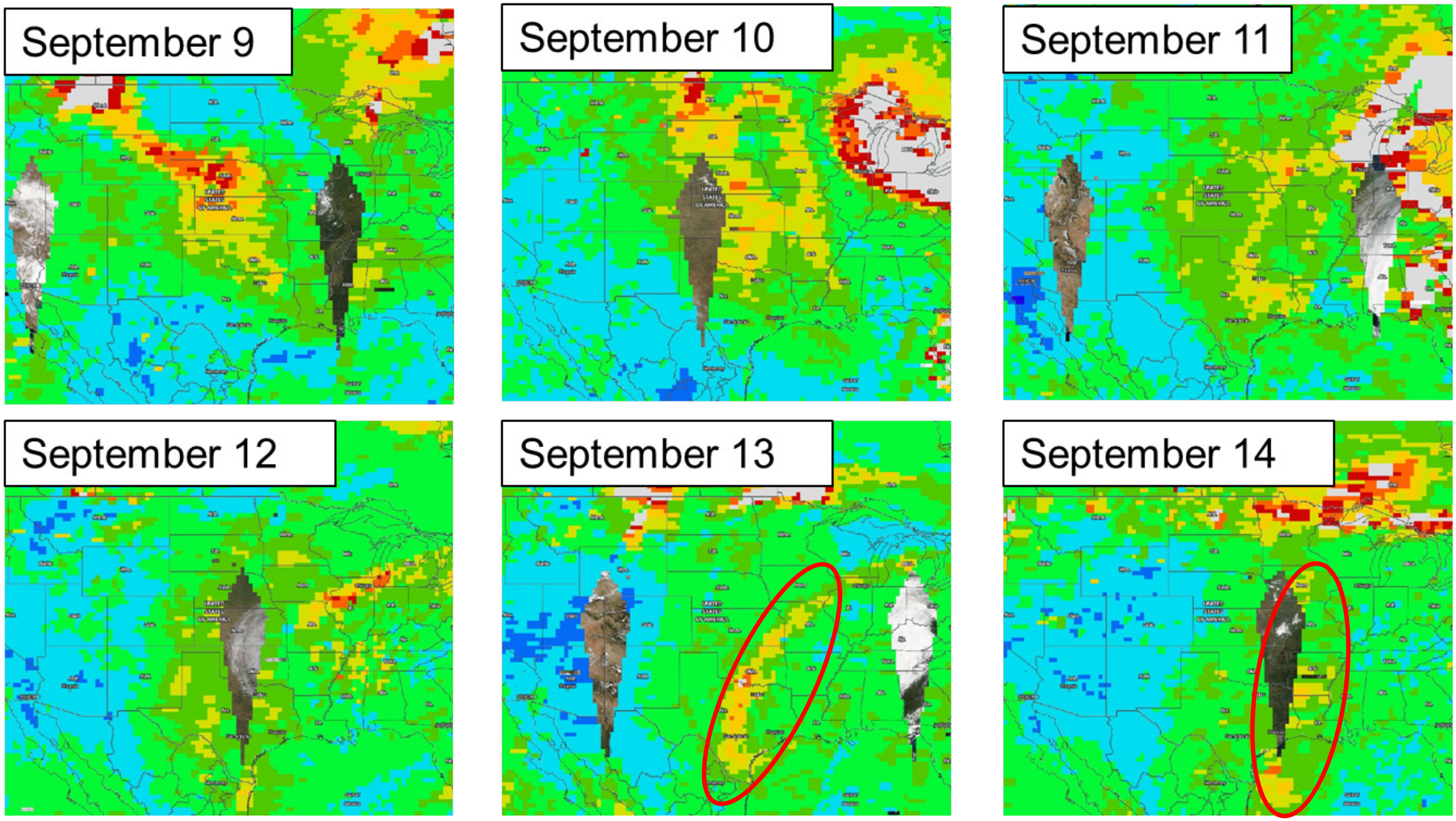


Figure 26. Atmospheric Infrared Sounder (AIRS) carbon monoxide total column retrievals combined for day and night for September 9 through September 14. Cool colors (dark blue: 60-70 ppb, blue: 70-80 ppb) indicate low CO mixing ratios, greens (light green: 80-90 ppb, dark green: 90-100 ppb) indicate moderate to high CO mixing ratios, and warm colors (yellow: 100-110 ppb, orange: 110-120 ppb, dark orange: 120-130 ppb, red: 130-140 ppb, and white: >= 140 ppb) indicate high CO mixing ratios. Plumes on September 13 and 14 are indicated with red circles. Missing data are represented as transparent, with MODIS visible imagery from the indicated day underlying the CO layer. Image source: NASA Worldview.

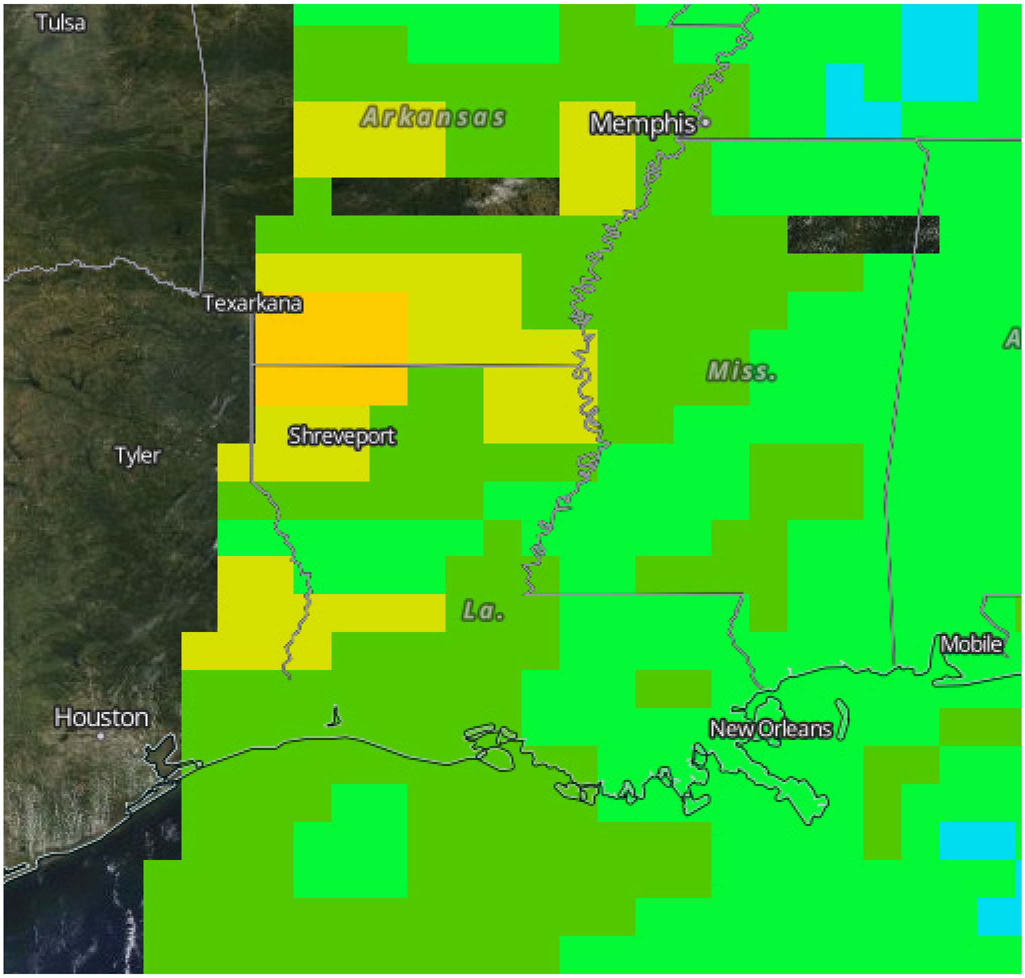


Figure 27. Atmospheric Infrared Sounder (AIRS) carbon monoxide total column nighttime retrievals at approximately 1:35 AM CST on September 14. Cool colors (dark blue: 60-70 ppb, blue: 70-80 ppb) indicate low CO mixing ratios, greens (light green: 80-90 ppb, dark green: 90-100 ppb) indicate moderate to high CO mixing ratios, and warm colors (yellow: 100-110 ppb, orange: 110-120 ppb, dark orange: 120-130 ppb, red: 130-140 ppb, and white: ≥140 ppb) indicate high CO mixing ratios. Missing data are represented as transparent, with MODIS visible imagery from September 14 underlying the CO layer. Image source: NASA Worldview.

We additionally examined OMI retrievals of tropospheric NO_2 (Figure 28). However, the retrievals likely reflect urban sources rather than NO_2 from smoke. Even over areas of dense, visible smoke and near actively burning fires, where significant smoke is present in the troposphere, the measurements show little increase in measured NO_2. Therefore, it was determined that NO_2 does not provide strong evidence for or against smoke impacts in Baton Rouge.

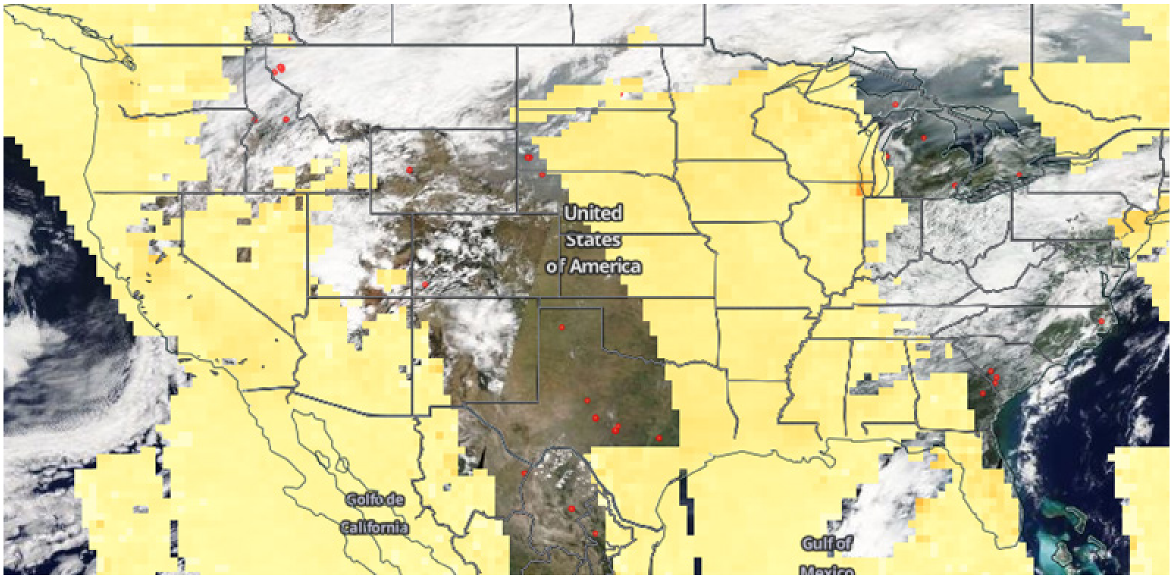


Figure 28. OMI retrievals of the tropospheric component of the total NO_2 column for September 14, 2017. Light yellow indicates low concentrations of NO_2, while darker yellow and orange indicate higher concentrations. Missing data are represented as transparent, with MODIS visible imagery from September 14 underlying the NO_2 layer. Image source: NASA Worldview.

3.5 Vertical Transport of Smoke

3.5.1 Location of Smoke in the Vertical Column

The satellite analyses and HYSPLIT trajectories provided strong evidence that smoke was present over Louisiana at the time of the event on September 14, 2017. However, the visible true color, AOD, and CO satellite data do not provide information about the vertical distribution of visible or measured smoke components. We examined satellite-retrieved aerosol vertical profiles and ceilometer mixing height measurements to determine whether the smoke plume was present at the surface on September 14. We also ran additional high-resolution HYSPLIT trajectories to determine whether transport to the surface was indicated by meteorological models.

The Cloud-Aerosol Transport System (CATS), launched in January 2015, is a Light Detection and Ranging (LIDAR) remote sensing instrument mounted on the International Space Station (ISS) that provides vertical profile measurements of atmospheric aerosols and clouds. Detected aerosols are classified into marine, marine mixture, dust, dust mixture, clean/background, polluted continental, smoke, and volcanic aerosol types.

The best CATS aerosol retrieval over Louisiana for the September 14 ozone event is available at 11:30 p.m. local time on September 13 (Figure 29). The CATS vertical profile shows that a smoke plume was present over Louisiana on the night of September 13 between the altitudes of 1,400 m and approximately 5,000 m (Figures 30 and 31).

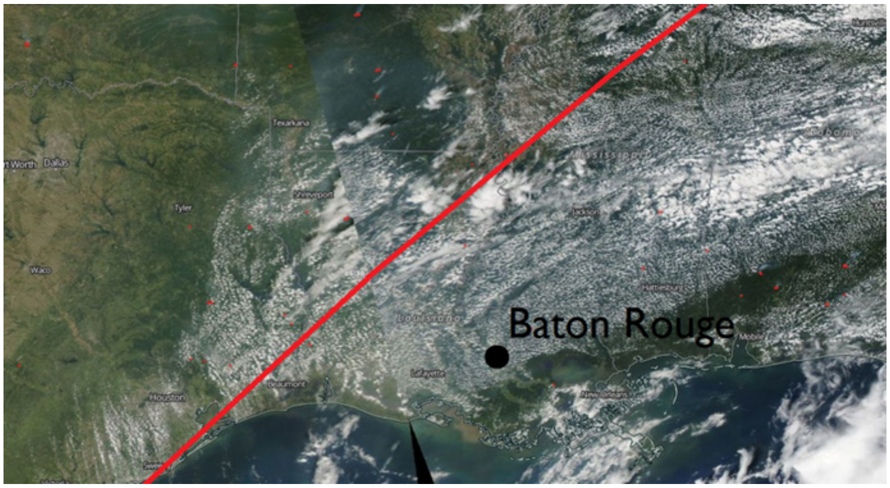


Figure 29. Location of CATS orbital track over Louisiana at approximately 11:30 p.m. CST on September 13, 2017. The center line of the instrument passes about 115 miles northwest of Baton Rouge. Image source: NASA Worldview.

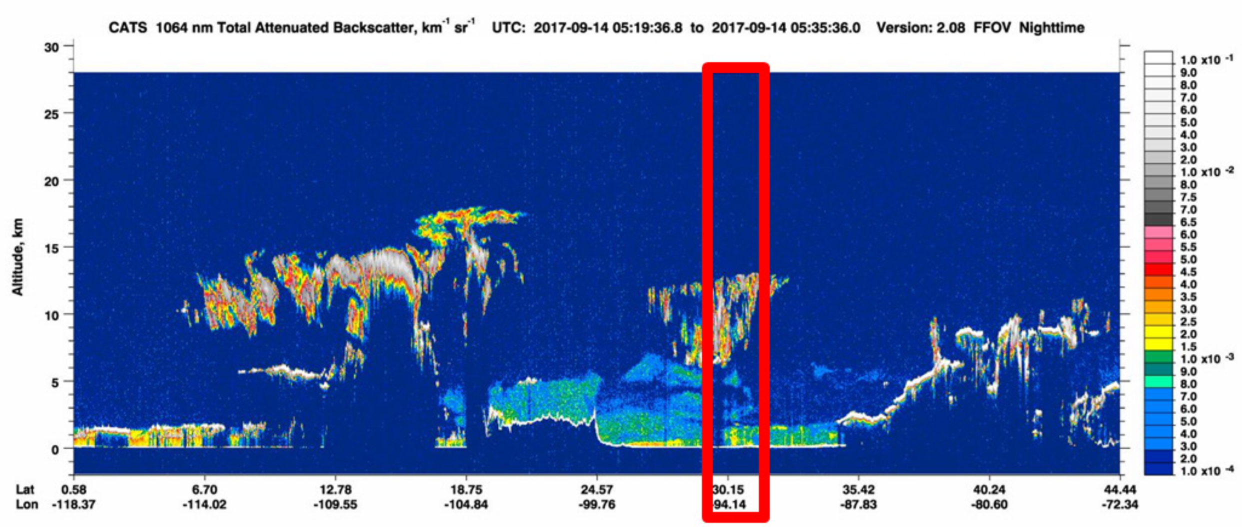


Figure 30. CATS aerosol total attenuated backscatter vertical profile at 1064 nm, collected on September 13, 2017, between 11:18 and 11:33 p.m. over the northern hemisphere. The approximate latitude at which the instrument passed over Louisiana is indicated with a red box. Image source: https://cats.gsfc.nasa.gov.

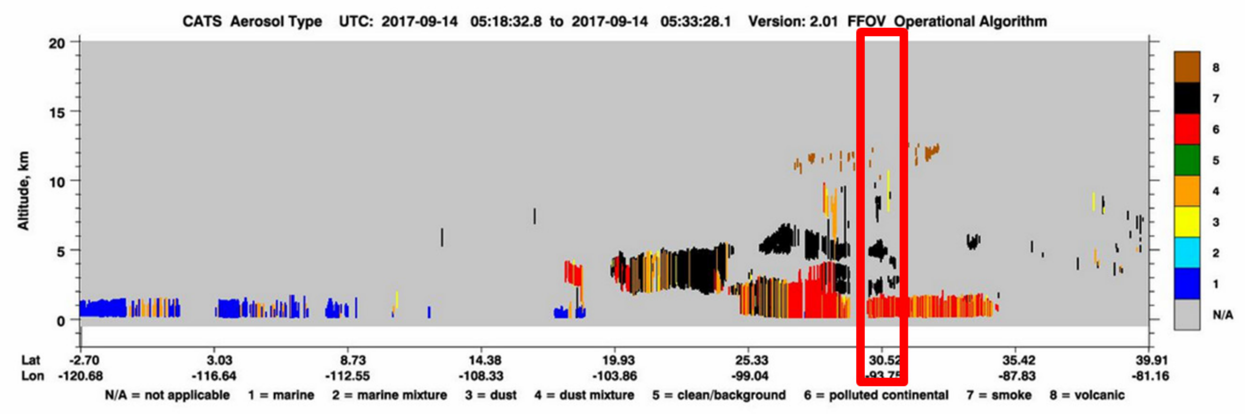


Figure 31. CATS aerosol type vertical profile collected on September 13, 2017, between 11:18 and 11:33 p.m. over the northern hemisphere. The approximate latitude at which the instrument passed over Louisiana is indicated with a red box. Image source: https://cats.gsfc.nasa.gov.

3.5.2 Vertical Mixing

On the day of the event, smoke was present over Louisiana at an altitude of 1,400 m and above. The mesoscale and local meteorological conditions on September 13 provide evidence for vertical mixing of smoke from aloft to the surface in Louisiana. As discussed in further detail in Appendix D, the regional upper-level weather pattern observed on September 13 was dominated by a trough of low pressure (associated with the remnants of Hurricane Irma) over the southeastern United States. Coinciding with this upper-level trough, a band of positive absolute vorticity stretched from the center of an upper-level low pressure system over Indiana and Kentucky across western Tennessee, through northern Alabama and Mississippi, and into Louisiana (indicated by the green, yellow, and orange shading in Figure 32). Upper-level vorticity enhances vertical mixing, allowing for aloft smoke to be mixed vertically toward the surface

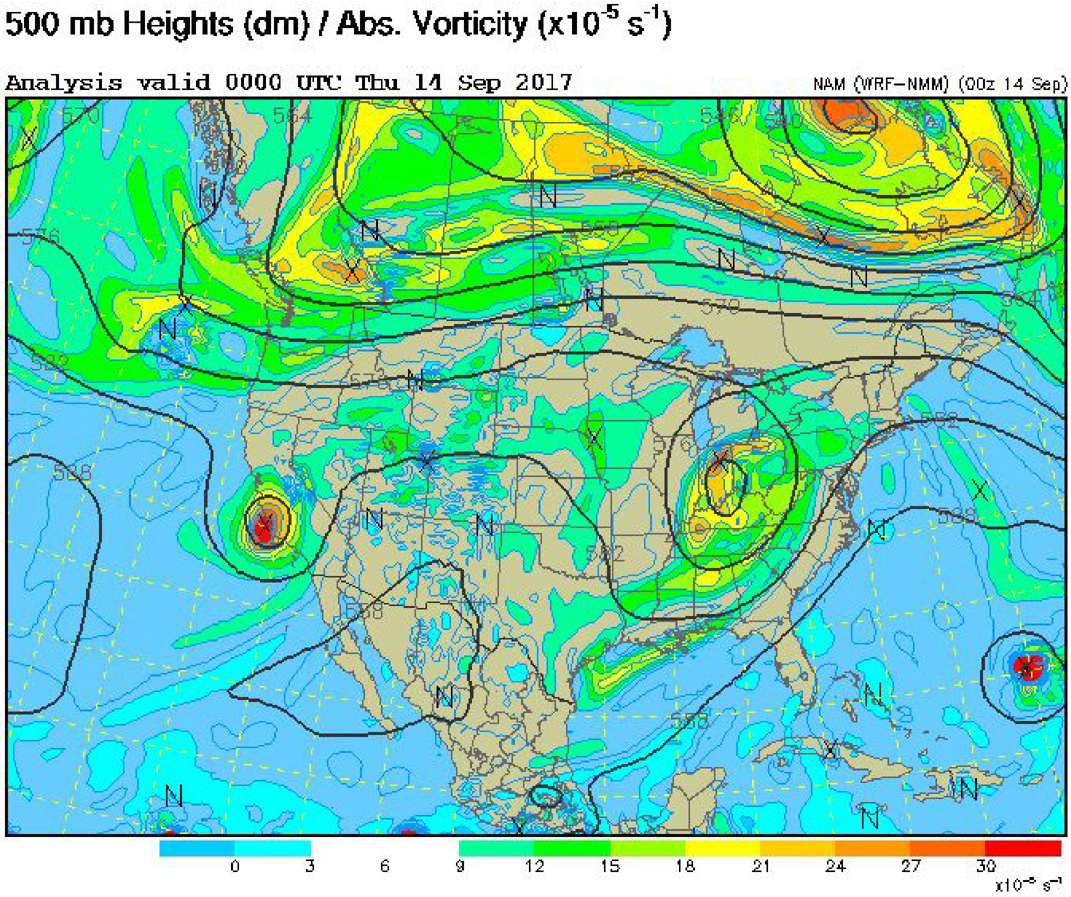


Figure 32. Analysis of 500-mb heights and absolute vorticity on the afternoon of September 13, 2017. Source: http://www2.mmm.ucar.edu/imagearchive/.

Local observations of mixing heights in the Baton Rouge area on September 13 and 14 also suggest that smoke mixed into the lower levels of the atmosphere. Ceilometer data from the Capitol site indicate mixing heights on September 13 and September 14 in excess of 1,700 m for several hours (**Figure 33**). As already noted, CATS detected a smoke plume over the area down to a height of 1,400 m. Because the layer of air below the mixing height is generally well mixed to the surface, this observation provides strong evidence for the existence of smoke in the lower levels of the atmosphere over Baton Rouge on the afternoon of September 13 and on September 14. Satellite data show that the majority of the smoke plume did not arrive over Baton Rouge until September 14. Therefore, although mixing of the smoke plume to the surface was likely to occur on both days, smoke impacts were observed in Baton Rouge primarily on September 14, as smoke at the surface and aloft was transported northeastward from the Gulf to Baton Rouge.

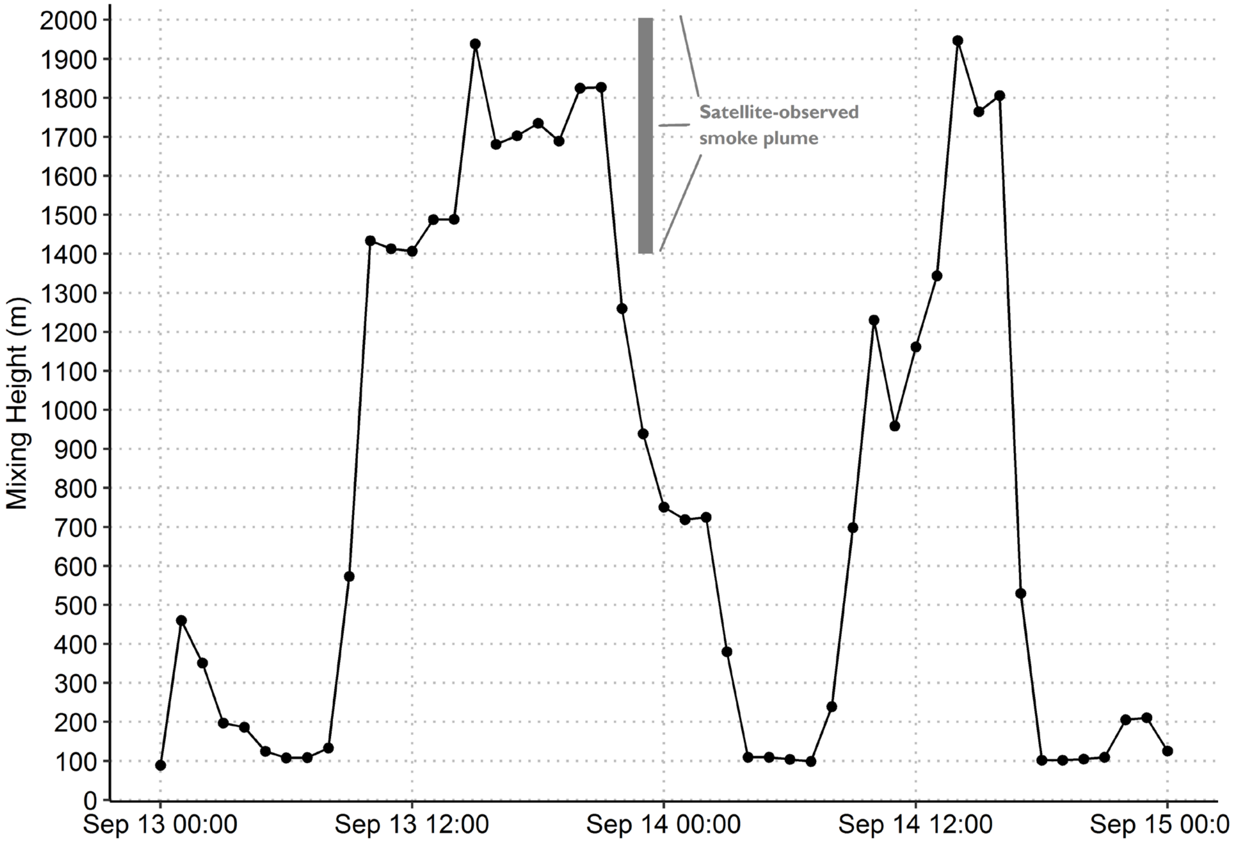


Figure 33. Mixing height in meters measured at the Capitol site using an optical scattering ceilometer on September 13 and 14, 2017. The vertical mixing height measured at each hour is shown with black points. The timing and vertical height of the observed smoke plume are also shown..

In addition to the ceilometer-based measurements of mixing heights, vertical temperature profiles can be used to estimate mixing heights. The vertical temperature profile at Lake Charles on the morning of September 14 (Figure 34) showed a strong temperature inversion (temperature increasing with height) at the same level that the smoke plume was detected by CATS (i.e., approximately 1,500 m). The vertical temperature profile observed on the afternoon of September 14 indicated a mixing height up to at least this height (Figure 35), consistent with the ceilometer mixing heights. This further supports mixing of the smoke plume to the surface.

Downward mixing and transport of air is also demonstrated by HYSPLIT trajectories run using high-resolution meteorology for the Dutchtown site (Figure 36). Trajectories arriving at the monitor site on September 14 show evidence of downward transport from elevations of up to 1,500 m, where a smoke plume had been observed the previous night.

The CATS vertical profile of aerosols over Louisiana in the evening of September 13, the ceilometer data, the vertical temperature profile, and the HYSPLIT trajectories suggest the existence of smoke within the mixed layer on the evening of September 13 and September 14 and support mixing of smoke to the surface on at Baton Rouge on September 14.

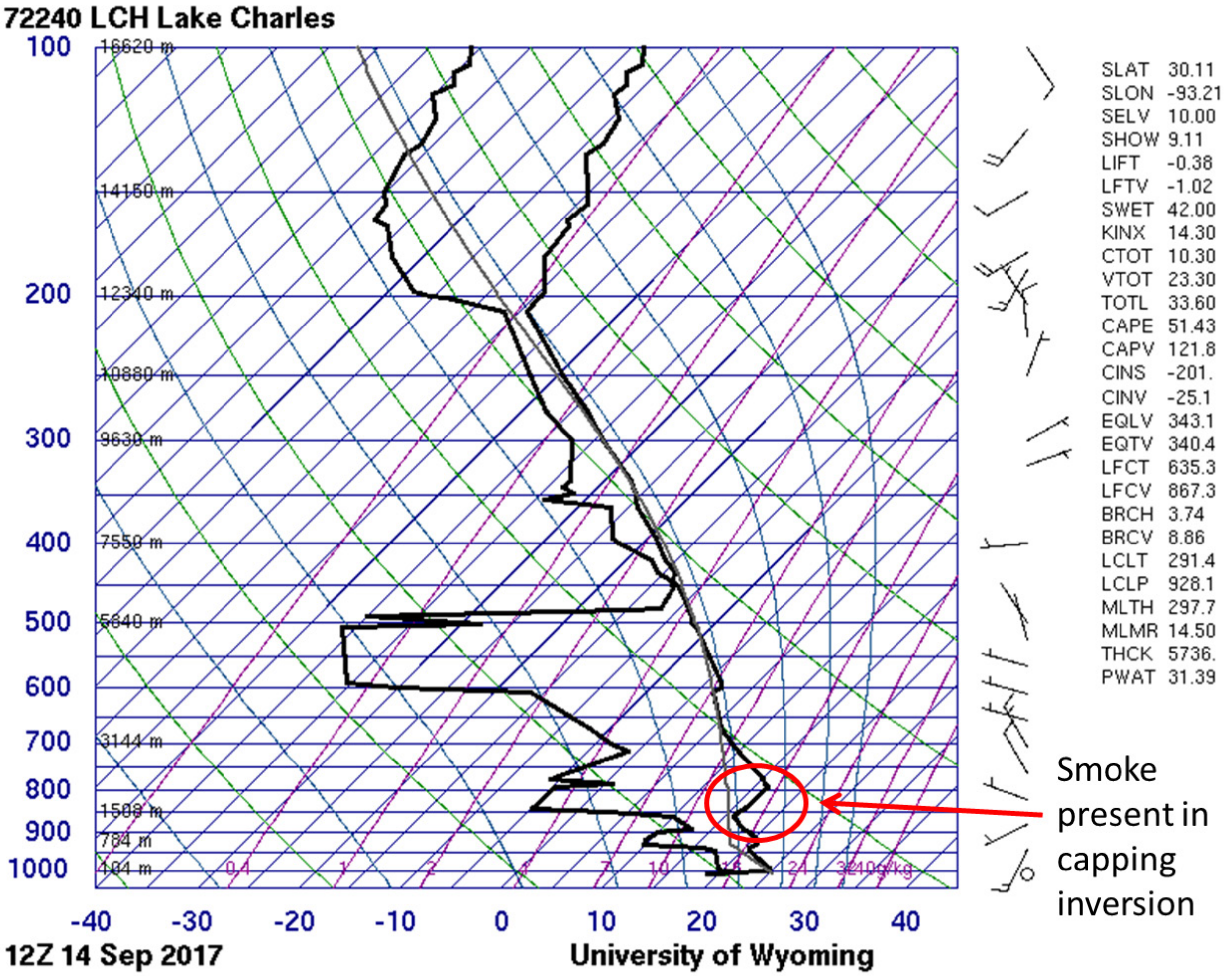
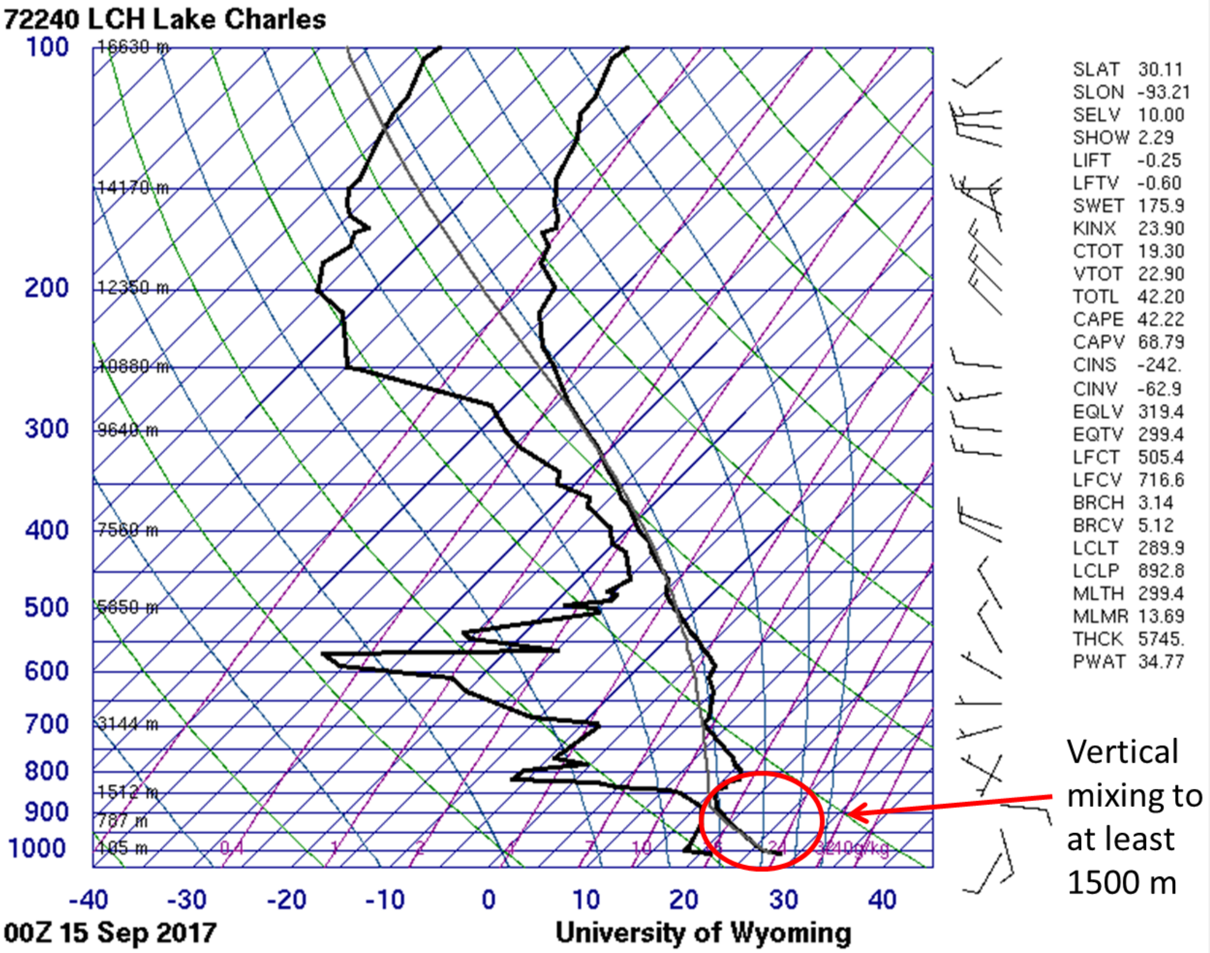


Figure 34. Skew-T plot showing temperature and humidity morning vertical profiles collected at Lake Charles, approximately 125 miles west of Baton Rouge on September 14, 2017, at 6:00 a.m. CST. The approximate vertical location of the smoke plume detected by CATS is indicated by a red circle. The temperature profile indicates the smoke is located in a capping inversion.



SLAT	30.11
SLON	-93.21
SELV	10.00
SHOW	2.29
LIFT	-0.25
LFTV	-0.60
SWET	175.9
KINX	23.90
CTOT	19.30
VTOT	22.90
TOTL	42.20
CAPE	42.22
CAPV	68.79
CINS	-242.
CINV	-62.9
EQLV	319.4
EQTV	299.4
LFCT	505.4
LFCV	716.6
BRCH	3.14
BRCV	5.12
LCLT	289.9
LCLP	892.8
MLTH	299.4
MLMR	13.69
THCK	5745.
PWAT	34.77

Vertical mixing to at least 1500 m

Figure 35. Skew-T plot showing temperature and humidity afternoon vertical profiles collected at Lake Charles, approximately 125 miles west of Baton Rouge on September 14, 2017, at 6:00 p.m. CST. The temperature profile indicates that vertical mixing occurred up to the height at which the smoke plume was present earlier in the day.

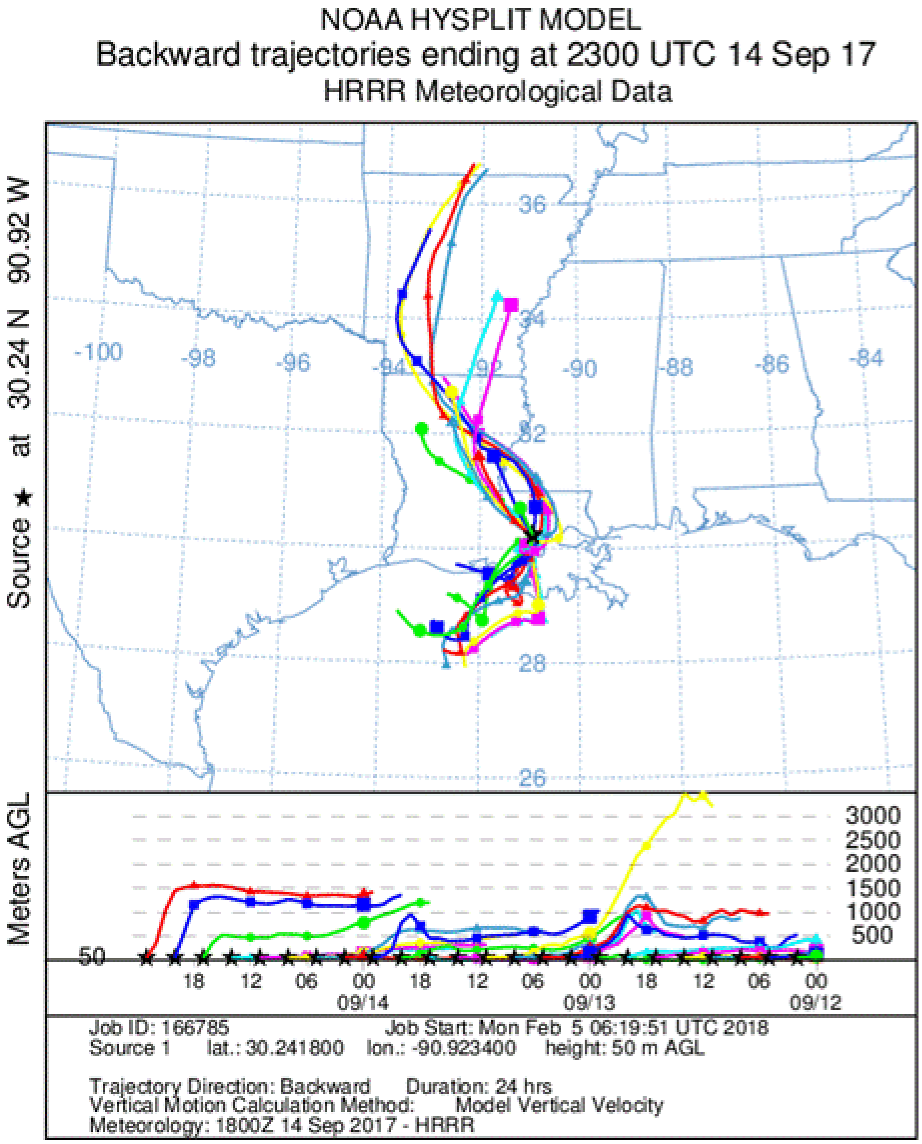


Figure 36. Twenty-four hour backward trajectories from Baton Rouge on September 12-14, 2017.

3.6 Supporting Pollutant Trends and Diurnal Patterns

Smoke maps, HYSPLIT trajectories, visible satellite imagery, and satellite retrievals of AOD and CO show strong evidence of smoke transport from fires burning in the northwestern United States to Louisiana. Furthermore, vertical aerosol profiles from satellite and mixing height information suggest that smoke was present over the site prior to the day of September 14, and that downward vertical mixing occurred from the altitude at which the smoke was observed.

Ground measurements of wildfire plume components (e.g., $PM_{2.5}$, CO, NO_x and VOCs) can be used to further demonstrate that smoke impacted ground-level air quality if elevated concentrations or unusual diurnal patterns are observed. We examined concentrations of $PM_{2.5}$, CO, NO_x, and speciated VOCs measured at the Capitol site in downtown Baton Rouge, approximately 20 miles northwest of Dutchtown. If $PM_{2.5}$, CO, NO_x, and VOCs were elevated at the time the smoke plume arrived in Baton Rouge, these measurements would provide additional supporting evidence of smoke impacts in Baton Rouge.

Twelve-hour average $PM_{2.5}$ concentrations showed a marked increase over the course of the day on September 14 (**Figure 37**), closely following the rise in ozone on that day. This provides support for the presence of smoke at the surface. Unusual spikes are observed in hourly NO_x and CO measurements at the same time of day that $PM_{2.5}$ concentrations increase, providing support for smoke impacts on September 14. Although spikes of total non-methane organic compounds (TNMOCs) also occurred, these increases are similar in magnitutde to increases observed on nearby dates, suggesting that smoke impacts could not be discerned from local sources.

Figure 37. Hourly concentrations of ozone, $PM_{2.5}$, NO_x, CO, and total non-methane organic compound (TNMOC). Ozone is shown for the Dutchtown site, while all other measurements were collected at the Capitol Site. The blue dashed line indicates 12-hr rolling average $PM_{2.5}$ concentrations. The grey bar indicates September 14, 2017.

Unusual diurnal patterns of supporting measurements can provide evidence that smoke impacted Baton Rouge air quality. In Figure 38, average diurnal patterns for five years of ozone and $PM_{2.5}$ data are displayed for the Downtown Baton Rouge Capitol monitoring site. On a typical day, the diurnal profiles of ozone and $PM_{2.5}$ follow different patterns. When ozone concentrations are increasing in midday, $PM_{2.5}$ concentrations show little variation. In contrast, on September 14, 2017, $PM_{2.5}$ rose and fell with ozone. While on average days both $PM_{2.5}$ and ozone concentrations decline between

2:00 p.m. and 7:00 p.m., concentrations of both pollutants remained at elevated levels throughout that period on September 14. Figure 39 shows the measurements of ozone at the Dutchtown monitoring site (22-005-0004) and $PM_{2.5}$ at the Downtown Baton Rouge Capitol monitoring site (22-033-0009) on September 14, 2017. Ozone and $PM_{2.5}$ measurements show the correspondence between the two pollutants and a significant deviation of $PM_{2.5}$ from its average diurnal pattern. This is a clear indication that ozone concentrations, along with concentrations of other pollutants, were impacted by wildfire emissions.

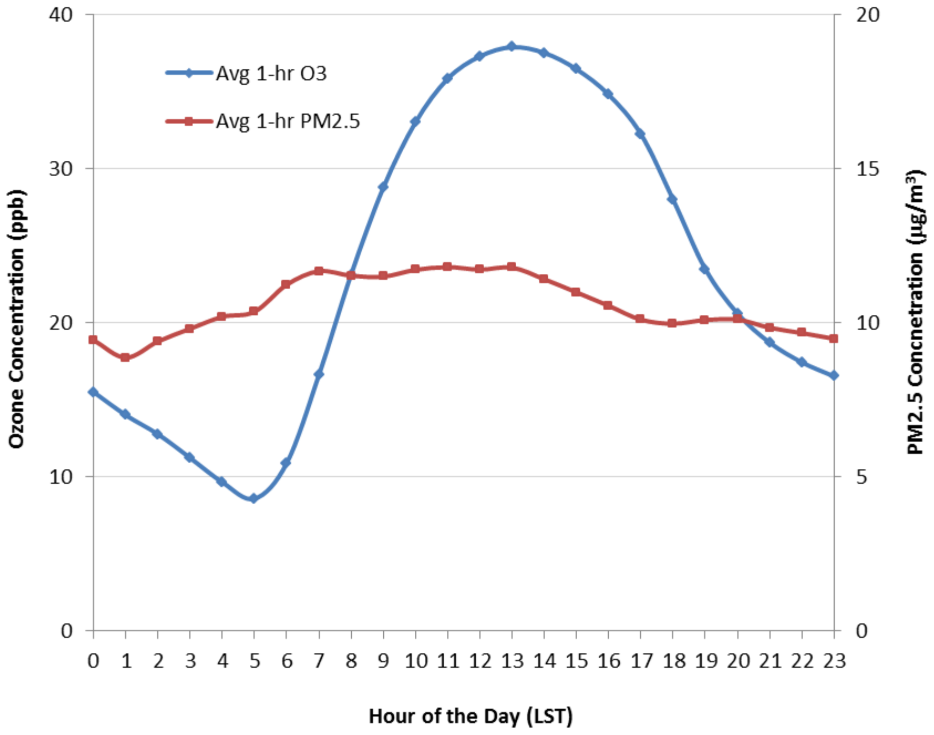


Figure 38. Average diurnal profile for ozone and $PM_{2.5}$ (May-September, 2013-2017) for the Downtown Baton Rouge Capitol monitoring site.

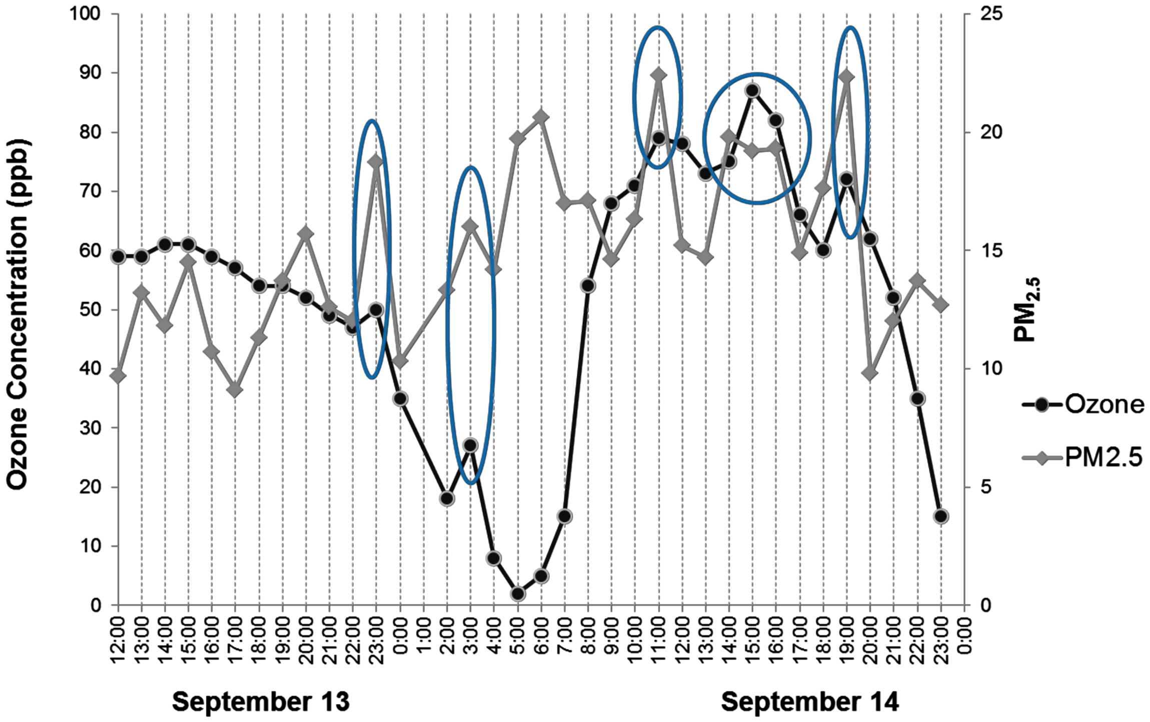


Figure 39. Hourly ozone (Dutchtown) and $PM_{2.5}$ (Capitol) concentrations for September 2017. Circles indicate time-coincident peaks in $PM_{2.5}$ and ozone.

Figure 40 shows the September 14, 2017, diurnal profile for ozone and CO concentrations at the Downtown Baton Rouge Capitol monitoring site. Also provided in this plot is the average diurnal profile for CO (2013-2017). Unlike $PM_{2.5}$, which rose and fell with ozone concentrations on September 14, 2017, CO follows its normal diurnal pattern. However, the level of CO measured on September 14 is higher than average throughout the day, which in part may reflect the impact of smoke. CO mixing ratios greater than 0.3 ppm have been considered as indicative of smoke impacts elsewhere (Lindaas et al., 2017). The CO mixing ratio at the Capitol site on September 14 exceeded 0.5 ppm for two morning hours and remained above 0.25 ppm for most of the day. The value recorded at 6:00 a.m. on September 14 was the highest CO value measured between September 2 and September 19. As with CO, the diurnal pattern of NO_x shows that NO_x concentrations measured in the morning of September 14 were substantially higher than on average days in August and September and higher than average for exceedance days (Figure 41). High CO and NO_x concentrations are consistent with either local emissions or transported smoke.

In addition to patterns for $PM_{2.5}$, CO, and NO_x, other pollutant patterns were investigated for noteworthy changes in pollutant concentrations on September 14. Appendix B provides VOC/NO_x ratios, CO/NO_x ratios, and time series plots surrounding September 14, 2017, for speciated VOC measurements. Ratios of VOC/NO_x can indicate key causes of high ozone. Low VOC/NO_x ratios indicate high relative NO_x concentrations. As seen with Figure 40 and Figure B-1, there were higher-than-normal NO_x concentrations and low/typical VOC concentrations on the episode day.

Reactive VOC species are unlikely to persist aloft over a 10-day transit period in midsummer. High photochemical reaction rates driven by long hours of sunlight will remove any species with a residence time of less than three days. Concentrations of longer-lived species like ethane and propane may be expected to be higher in smoke undergoing long range transport. On September 14, ethane (Figure B-4), n-butane (Figure B-13), and propane (Figure B-24) were slightly elevated relative to background concentrations in the area. This is consistent with higher concentrations of pollution regionally. Concentrations of more reactive species like benzene, alkenes, and other aromatics were low or typical. This indicates that the high concentrations of ethane are not from a local emissions source. The speciated VOC measurements therefore show that the elevated CO and NO_x are more likely to be associated with transported smoke than with local emissions sources.

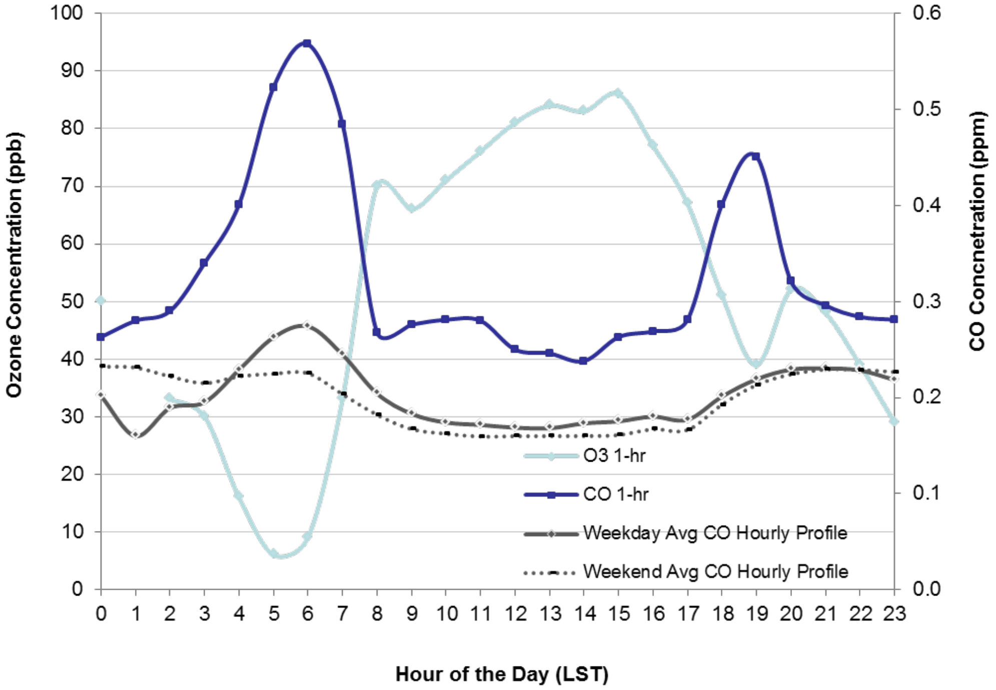


Figure 40. Diurnal profile for ozone and CO on Sept 14, 201,7 for the Downtown Baton Rouge Capitol monitoring site, as well as the average diurnal profile for CO (May-September, 2013-2017).

In addition to $PM_{2.5}$, CO, and NO_x, other pollutant patterns were investigated for noteworthy changes in pollutant concentrations on September 14. Appendix B provides VOC/NO_x ratios, CO/NO_x ratios, and time series plots surrounding September 14, 2017 for speciated VOC measurements. These measurements do not provide strong evidence for or against smoke impacts in Baton Rouge.

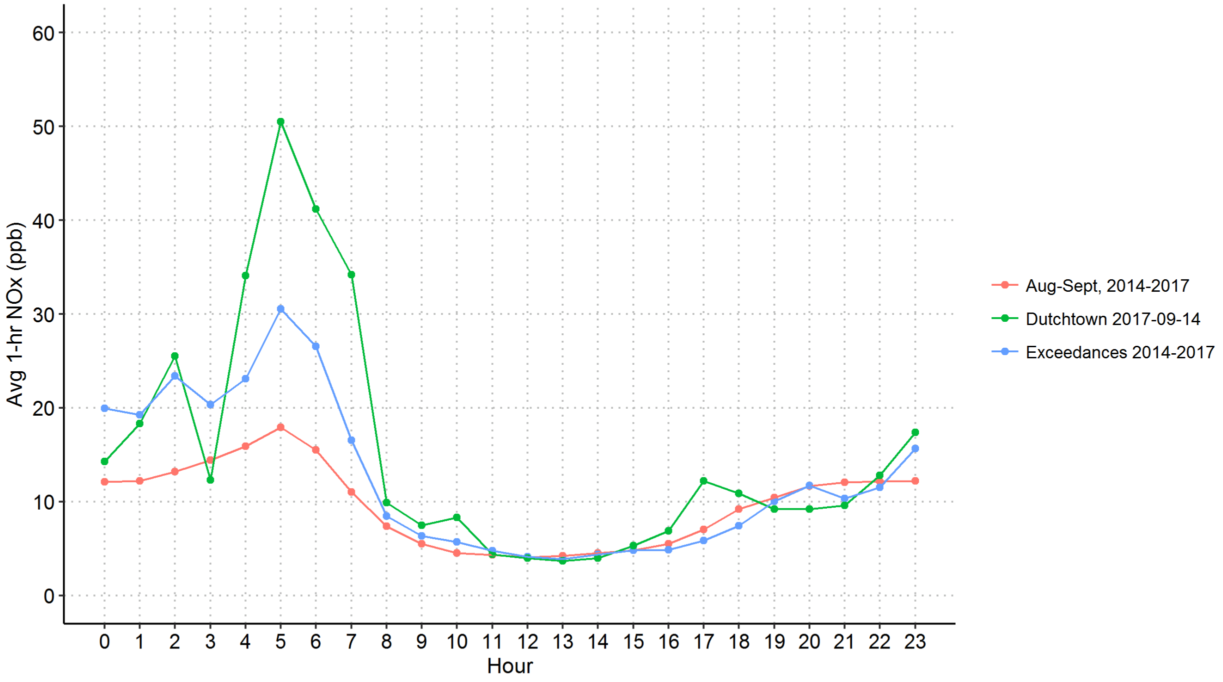


Figure 41. Diurnal profile of 1-hr NO_x measurements at Dutchtown on September 14, 2017 (green), average measurements at Dutchtown in August and September for 2014-2017 (red), and average measurements at Dutchtown on exceedance days for 2014-2017 (blue).

Our analysis shows unusual patterns $PM_{2.5}$ and also shows elevation in NO_2 and CO that are likely to be attributable to wildfire smoke. These analyses provide additional supporting evidence that wildfire smoke contributed to ozone concentrations at the Dutchtown site on September 14, 2017.

3.7 Smoke Emissions from Wildfires

Tier 2 analyses require calculation of the emissions of NO_x and reactive VOCs divided by the distance (Q/d) as the first of two key factors. Sonoma Technology, Inc., is the contractor to EPA for calculating wildland fire emissions for the National Emissions Inventory (NEI). To support the Q/d calculations for the September 14, 2017 smoke event, we prepared wildfire smoke emissions using the same methods normally used for the NEI (Huang et al., 2017), in accordance with the EPA's exceptional event guidance. Specifically, we used the SmartFire/BlueSky Framework approach (U.S. Environmental Protection Agency, 2016c) to prepare emissions for fires based on data available between August 27 and September 16, 2017, for the continental United States only.

We collected fire activity data sets from both satellite detections and agency reports. Data sources included Geospatial Multi-Agency Coordination (GeoMAC) Group wildfire polygons,[3] National

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[3] GeoMAC data were obtained from https://rmgsc.cr.usgs.gov/outgoing/GeoMAC/historic_fire_data/.

Association of State Foresters fire reports,[4] USDA Forest Service prescribed fire data from the Forest Service Activity Tracking System (FACTS),[5] Louisiana state fire data,[6] and NOAA Hazard Mapping System fire detections.[7] We combined these data sets using the SmartFire reconciliation system and calculated emissions from the fires using the BlueSky Framework (Figure 42). Fire emissions included NO_x and total VOCs. Total VOCs were converted to reactive VOCs by multiplying by a factor of 0.6, as recommended in the EPA exceptional event guidance. Fire activity data and emissions were quality-controlled through analyst review and automated control methods.

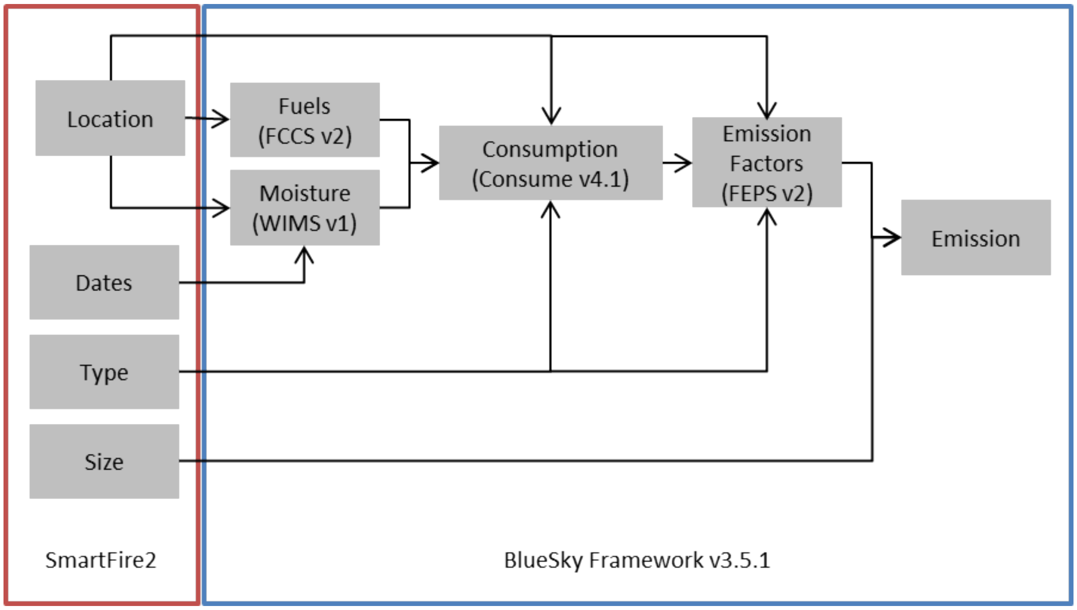

Figure 42. Model chain used to develop emissions for the contiguous United States based on fire activity between August 27 and September 16, 2017.

Fire emissions data were used to calculate the Q/d values for fires that could have impacted air quality in Baton Rouge. We calculated 24-hr HYSPLIT back trajectories from the monitor location starting on each hour of the day of the exceedance as well as the day prior to the exceedance. We then created a buffer of uncertainty around each trajectory based on 25% of the distance traveled by the trajectory, based on the uncertainty reported for HYSPLIT modeling (Draxler, 1991). All fires falling within the uncertainty buffer of one or more trajectories were then used to calculate an individual Q/d value for each day on which emissions occurred. In addition, for each day we calculated the aggregate Q/d value for all fires falling within the uncertainty buffer (Figure 43). For September 14 in Baton Rouge, the largest calculated Q/d value for an individual fire was 0.79. The aggregate Q/d for all fires on September 14 was 5.36. These Q/d values fall far below the threshold of 100 set by the exceptional event guidance for a Tier 2 exceptional event. Q/d calculations, because

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[4] NASF data were obtained from https://fam.nwcg.gov/fam-web/.
[5] FACTS data was obtained from http://data.fs.usda.gov/geodata/edw/datasets.php.
[6] Fire data were obtained from https://www.arcgis.com/home/item.html?id=7df93214bdb84217b7fb6db5cfc6a0a5.
[7] HMS data were obtained from ftp://satepsanone.nesdis.noaa.gov/FIRE/HMS/GIS/ARCHIVE/.

they rely on only 24-hr back trajectories, generally reflect the impact of local fires. The low Q/d values calculated for Baton Rouge on September 14, 2017, suggest that local fires likely played only a small role, if any, in the high ozone measurements on September 14 in Baton Rouge. Instead, as our other analyses show, long-range transport of smoke from fires burning in the northwestern United States was likely to have contributed significantly to the ozone exceedance on September 14.

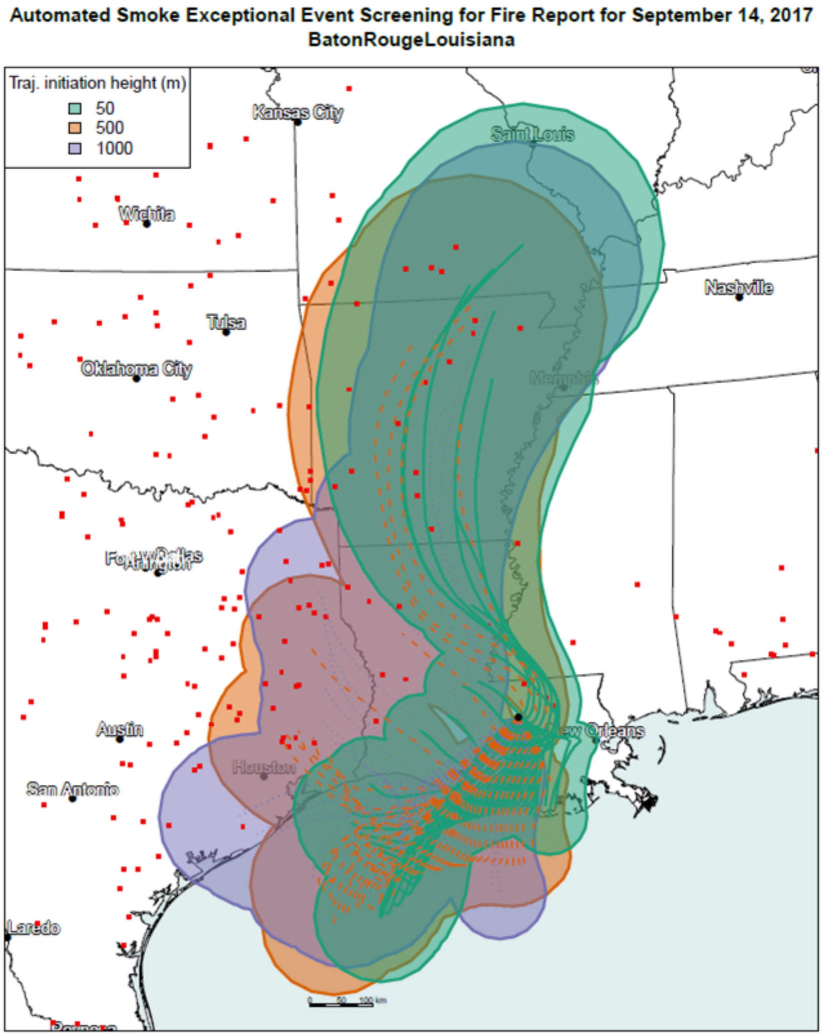
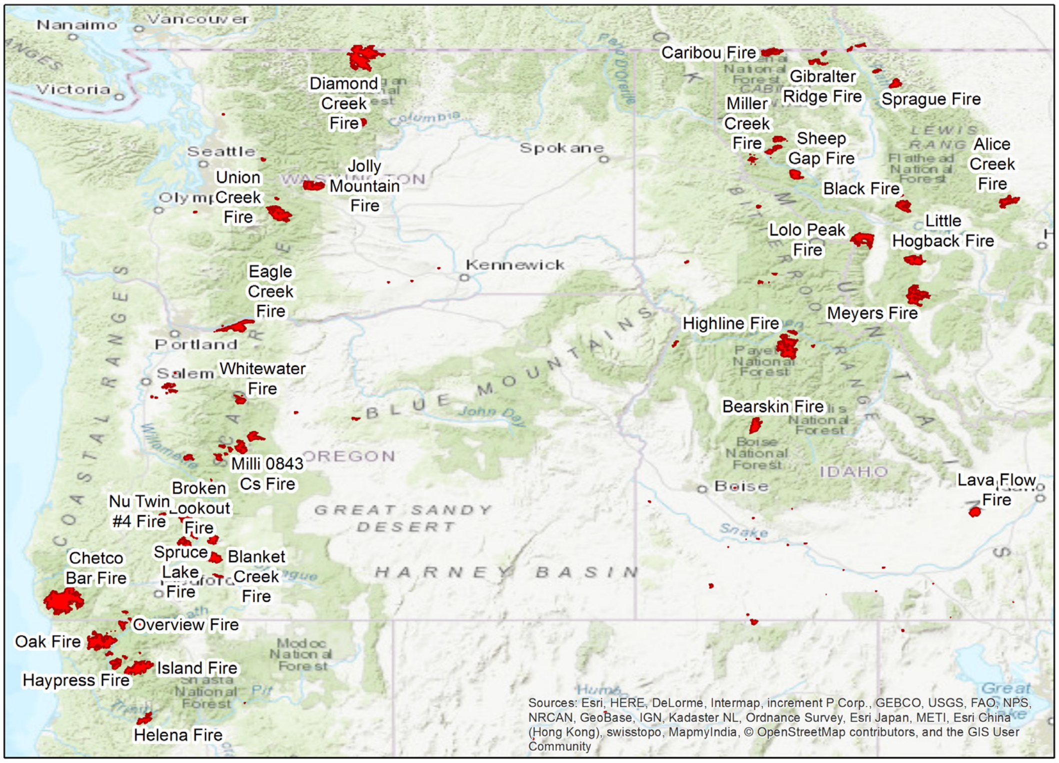


Figure 43. Map showing the approach used to identify fires for the Q/d calculation for September 14. 2017. Fires active on September 13 or September 14 are shown as red squares. Twenty-four hour back trajectories are shown as solid or dotted lines. The starting height of the back trajectory is indicated by the color. Uncertainty buffers, calculated as 25% of the distance traveled by the trajectory, are shown as colored polygons, where the color indicates the starting height of the trajectory at Baton Rouge. Fires falling within one or more uncertainty buffers were used to calculate individual and aggregate Q/d values.

Using the SmartFire-reconciled fire activity data, we identified 24 fires in the northwestern United States that burned areas larger than 10,000 acres[8] and that were active on September 14, 2017 (**Figure 44**). All fires shown in Figure 44 were actively burning on September 14, and the majority started on or before August 27, 2017, burning over multiple days leading up to September 14. In total, these fires accounted for over 1,200,000 acres burned in Washington, Oregon, California, Idaho, and Montana. These fires, in conjunction with smaller fires not named here, produced the large smoke plume that was transported over the United States, as observed via several sources of satellite data.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 44. Map of wildfires active in the northwestern United States on September 14, 2017. The names of fires greater than 10,000 acres are shown.

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[8] Fires starting on or before August 27 as shown in the map above included the Alice Creek, Bearskin, Blac, Blanket Creek, Broken Lookout, Caribou, Chetco Bar, Diamond Creek, Gibralter Ridge, Haypress, Highline, Island, Jolly Mountain, Little Hogback, Lolo Peak, Meyers, Milli 0843 Cs, Nu Twin #4, Oak, Overview, Sprague, Spruce Lake, Union Creek, and Whitewater Fires.

4. Discussion of Findings

The analyses conducted provide evidence supportive of smoke impacts on ozone concentrations in Baton Rouge on September 14, 2017. We show that (1) a substantial amount of smoke was transported from wildfires in the northwestern United States across the central and southern United States to Louisiana in the days leading up to September 14, 2017, (2) smoke aloft was transported to the surface on September 14, 2017, and (3) smoke impacted ground-level pollution measurements in the Baton Rouge area on September 14, 2017. These analyses were conducted to address Tier 1 and Tier 2 exceptional event demonstration requirements, and the results are summarized in **Table 7**. The results are supportive of a Tier 3 exceptional event demonstration.

We identified 24 wildfires that burned over 10,000 acres each during the weeks leading up to September 14 and that remained active until at least September 14. The fires together burned over 1.2 million acres. These wildfires emitted a large plume of smoke that is visible in satellite images and in satellite measurements of AOD and CO. These images and measurements show that the smoke was transported over nearly a week's time to Louisiana. In addition, HYSPLIT trajectories show that the smoke was transported from wildfires in Idaho to the central United States in the days prior to September 14. Additional trajectories show transport of air masses eastward from Texas over the Gulf of Mexico to Louisiana on September 14. In visible imagery, and in CO and AOD measurements from satellite, the eastward movement of smoke from Texas and the Gulf is apparent. These data show that wildfire smoke was present over Louisiana on the day of the event, September 14.

Additional analyses show that vertical mixing and downward transport of smoke aloft to the surface occurred over September 13 and 14. At approximately 11:00 p.m. CST on September 13, CATS aerosol data show that smoke was present over Louisiana at an altitude of 1,400 m to approximately 5,000 m. The approximate elevation of the smoke is additionally supported by meteorological evidence. Ceilometer and radiosonde mixing height measurements show that vertical mixing from the altitude at which the smoke was present occurred on September 13 and 14. Additional evidence supporting this activity is provided by HYSPLIT back trajectories run for September 14, which show downward transport on September 14 from an altitude of approximately 1,500 meters. Evidence is strong that smoke aloft over Baton Rouge was mixed downward to the surface.

The arrival of smoke at the surface on September 14 impacted air quality in Baton Rouge. Exceptionally high area-wide ozone concentrations were observed on that day. The exceedance at the Pride monitoring site represented the only time that monitor showed an ozone exceedance between July and December of 2013 through 2017. In addition, supporting measurements of $PM_{2.5}$, CO, and NO_x concentrations indicate the presence of smoke.

Together, these analyses demonstrate that ozone concentrations in Baton Rouge were impacted on September 14 by wildfire smoke transported from fires in the northwestern United States.

Table 7. Summary of tier-specific analyses for smoke/ozone exceptional events and our findings.

Tier	Requirements	Finding
1	• Comparison of fire-influenced exceedance with historical concentrations • Evidence that fire and monitor meet one of the following key factors: – Key Factor #1: Seasonality differs from typical season, or – Key Factor #2: Ozone concentrations are 5-10 ppb higher than non-event-related concentrations • Evidence of transport of fire emissions to monitor: – Trajectories of fire emissions, or – Satellite images and supporting evidence from surface measurements	• The September 14. 2017 ozone exceedance occurred during typical ozone season. • Trajectories and satellite images and data support long range smoke transport into the area. • Trajectories, ceilometer mixing height measurements, and radiosonde data indicate vertical mixing and transport to the surface from the elevation at which smoke was present.
2	• All Tier 1 requirements • Key Factor #1: Fire emissions and distance of fires (Q/d > 100) • Key Factor #2: Comparison of the event-related ozone concentration with non-event-related high ozone concentrations (> 99th percentile over five years or top four highest daily ozone measurement) • Evidence that fire emissions affected the monitor (at least one of the following): – Visibility impacts – Changes in supporting measurements – Satellite NOx enhancements – Differences in spatial/temporal patterns	• The Q/d was well below 100. • Ozone concentration was >99th percentile over five years and the top measurement for the year • Surface PM2.5, NOx, and CO concentrations showed elevated concentrations and/or changes in diurnal profile consistent with smoke impacts.

5. References

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Appendix A. Historical Context for Ozone Concentrations in Baton Rouge

Historical context for ozone concentrations recorded at eight Baton Rouge ozone monitoring sites is provided in the following figures. Red dots indicate the measurements collected on September 14, 2017. The black dotted line on all plots indicates the 99th percentile at that site for 2013 through 2017. The plots show daily maximum 8-hr ozone concentrations in 2017, in 2013 through 2017, and in 2013 through 2017 by day of year.

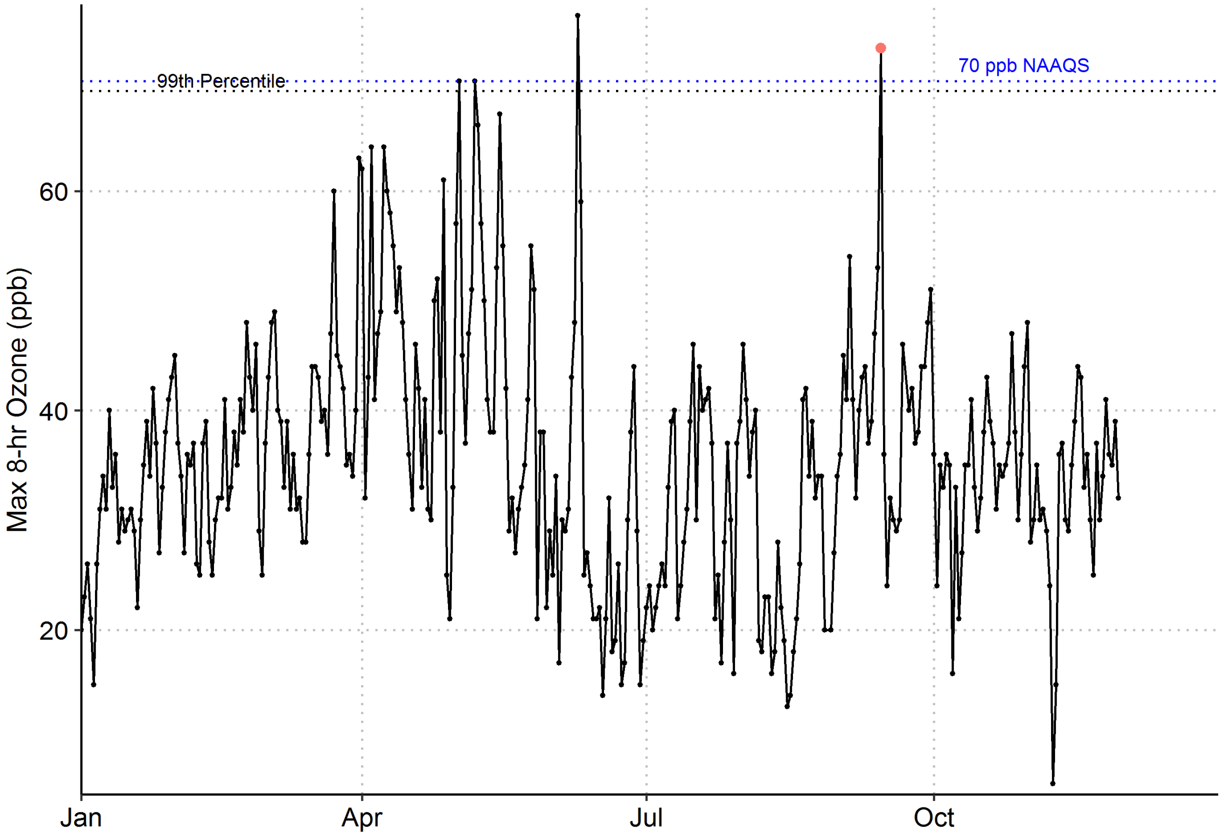

Figure A-1. Daily maximum 8-hr ozone concentrations at the LSU monitoring site (AQS ID 22-033-0003) in 2017.

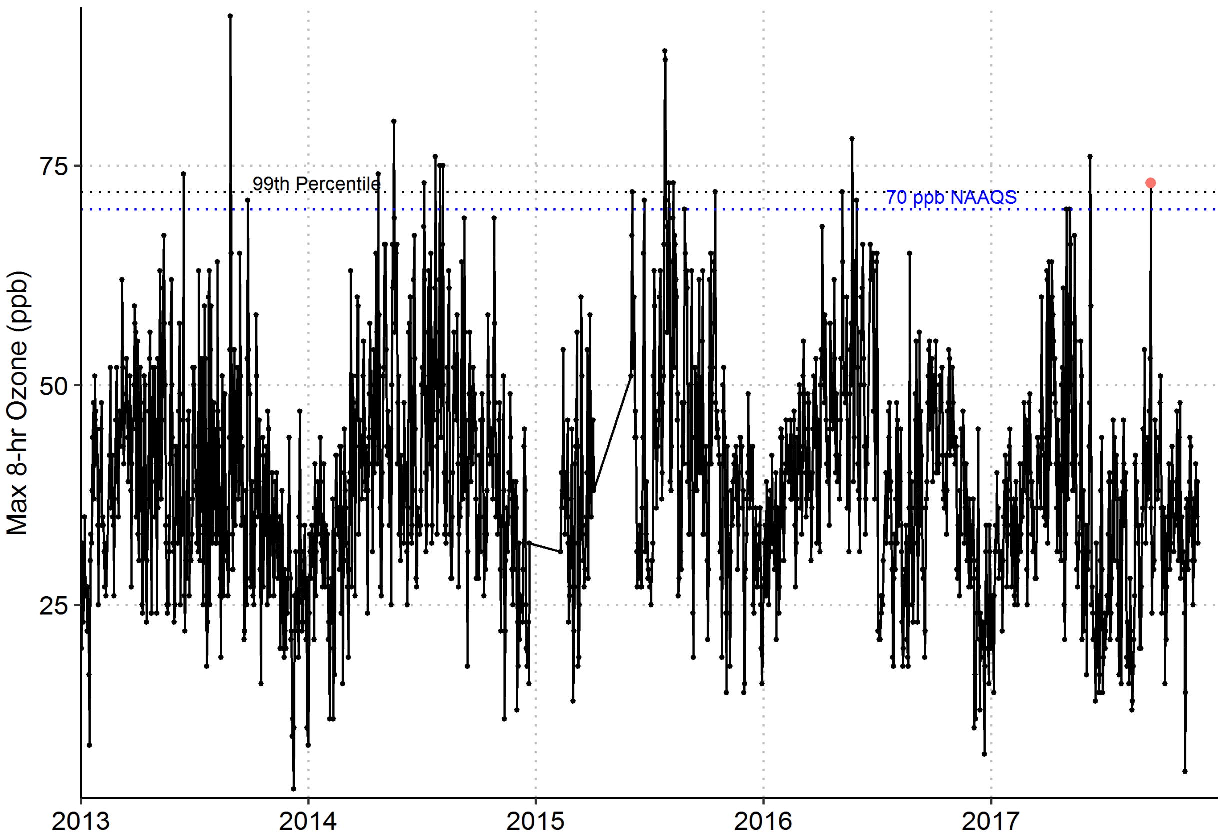

Figure A-2. Daily maximum 8-hr ozone concentrations at the LSU monitoring site (AQS ID 22-033-0003) from 2013 through 2017.

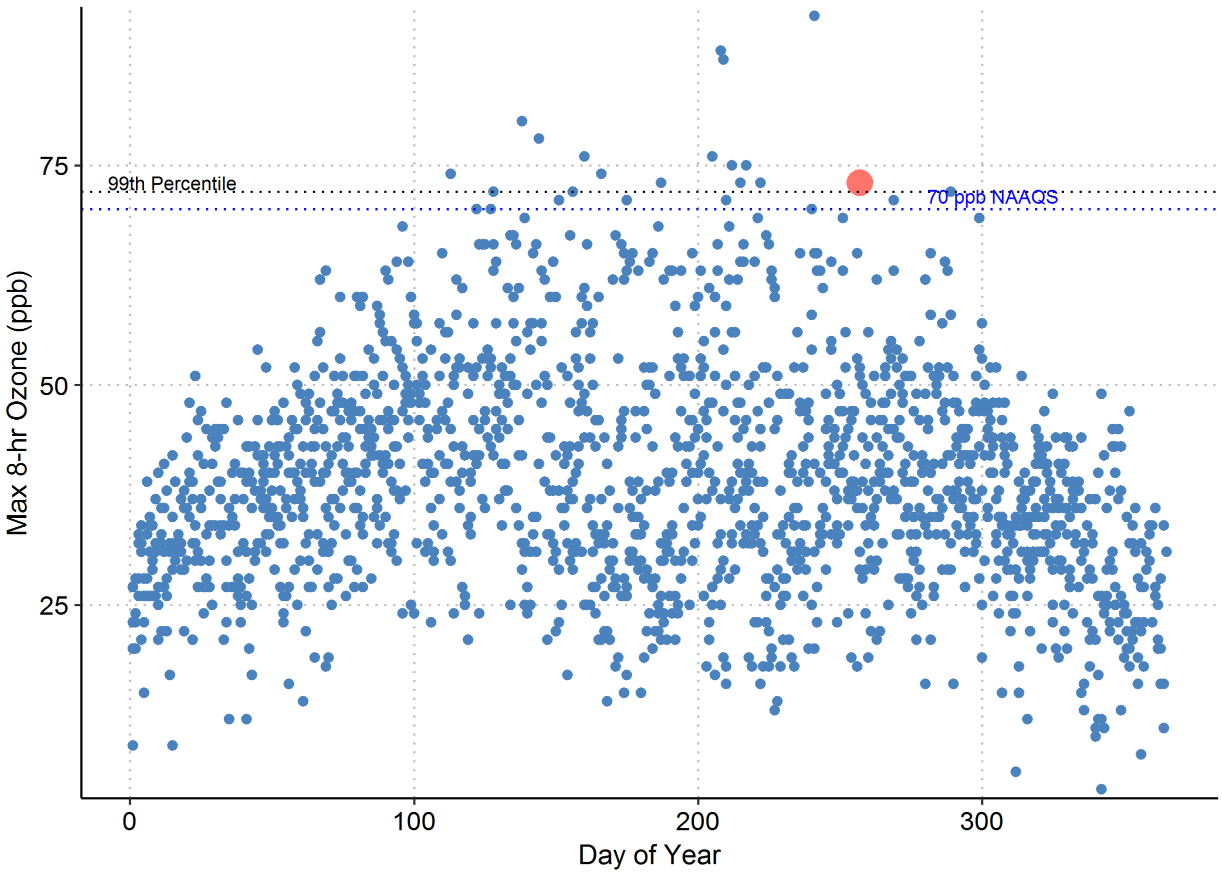

Figure A-3. Daily maximum 8-hr ozone concentrations at the LSU monitoring site (AQS ID 22-033-0003) from 2013 through 2017 by day of year.

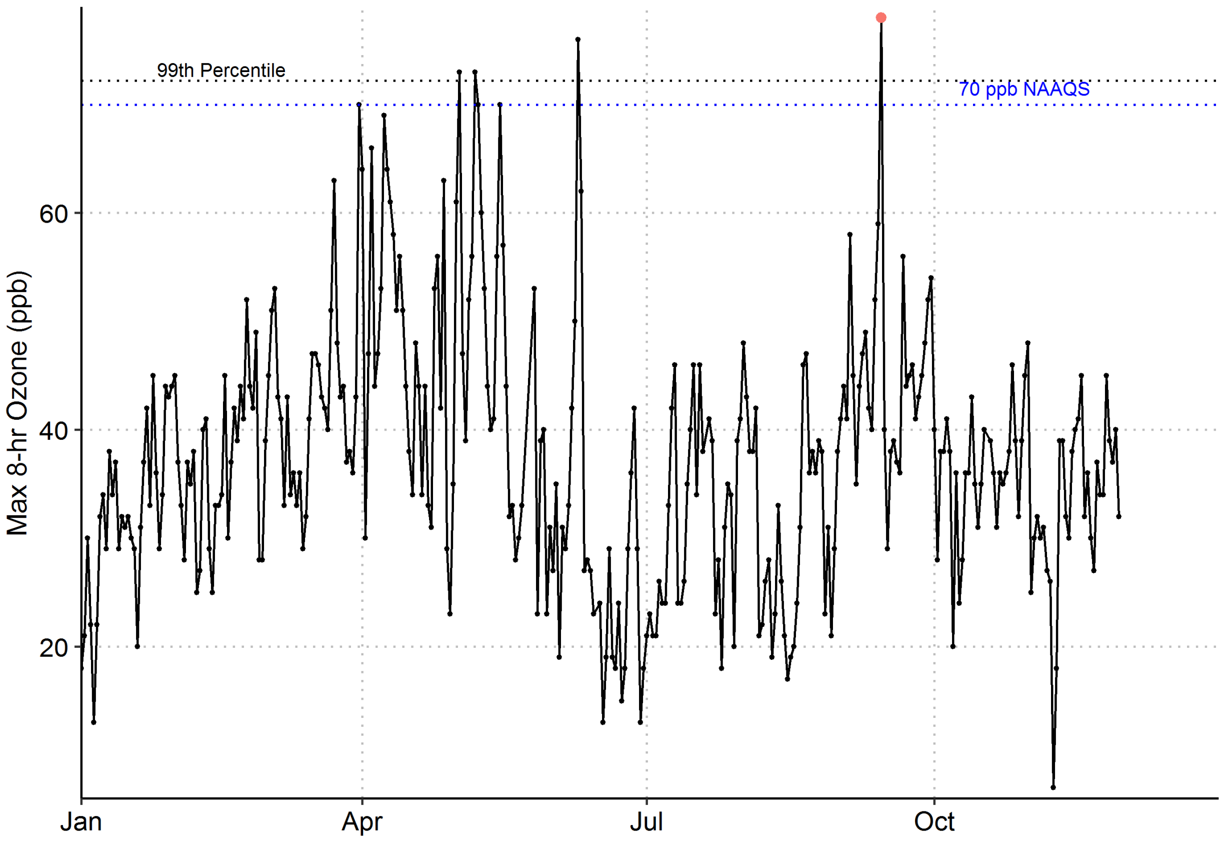

Figure A-4. Daily maximum 8-hr ozone concentrations at the Capitol monitoring site (AQS ID 22-033-0009) in 2017.

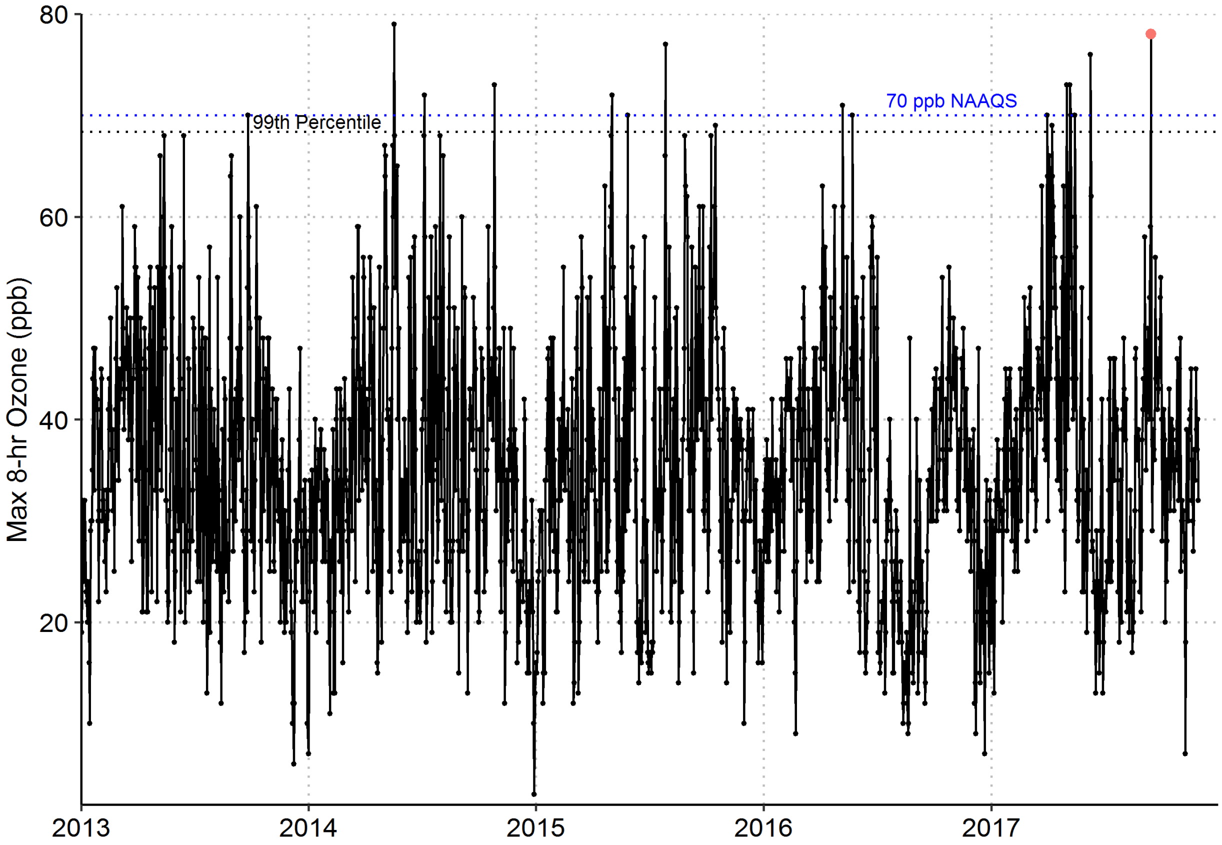

Figure A-5. Daily maximum 8-hr ozone concentrations at the Capitol monitoring site (AQS ID 22-033-0009) from 2013 through 2017.

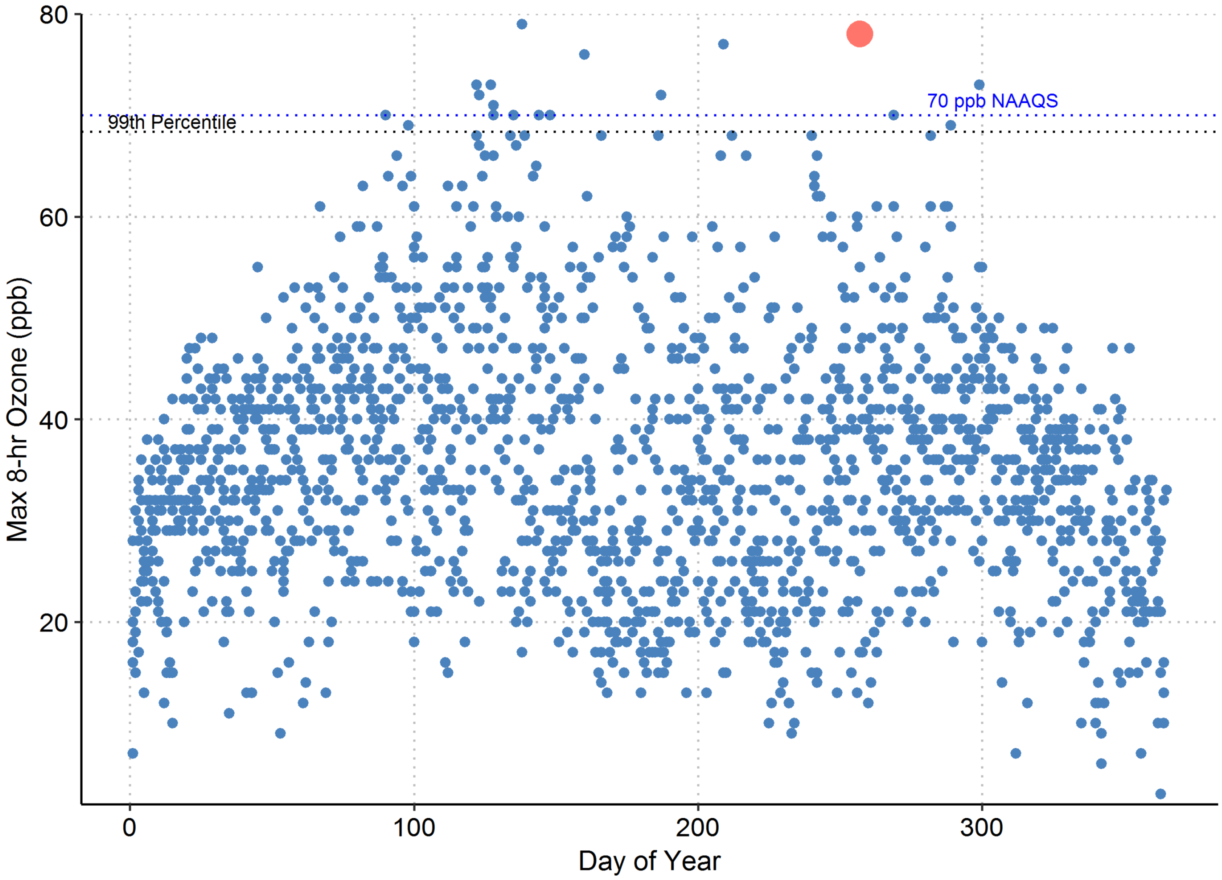

Figure A-6. Daily maximum 8-hr ozone concentrations at the Capitol monitoring site (AQS ID 22-033-0009) from 2013 through 2017 by day of year.

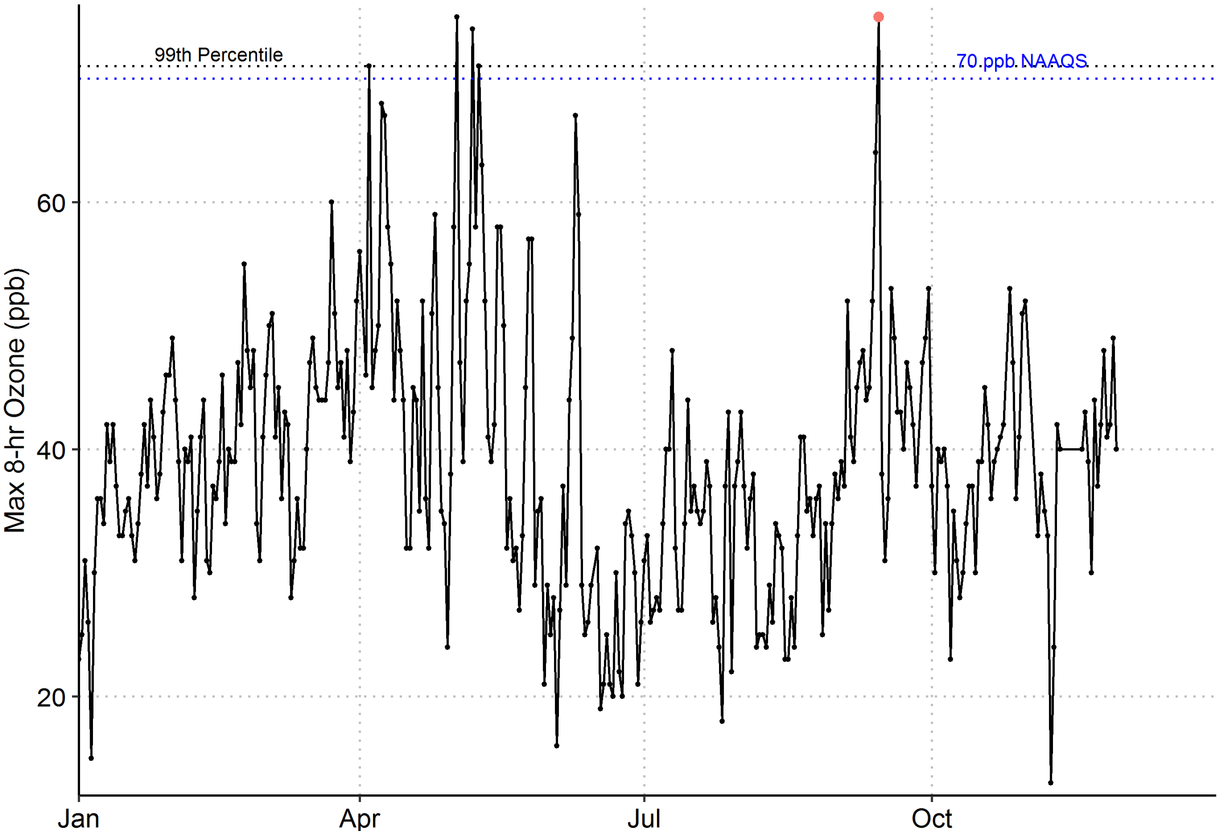

Figure A-7. Daily maximum 8-hr ozone concentrations at the Pride monitoring site (AQS ID 22-033-0013) in 2017.

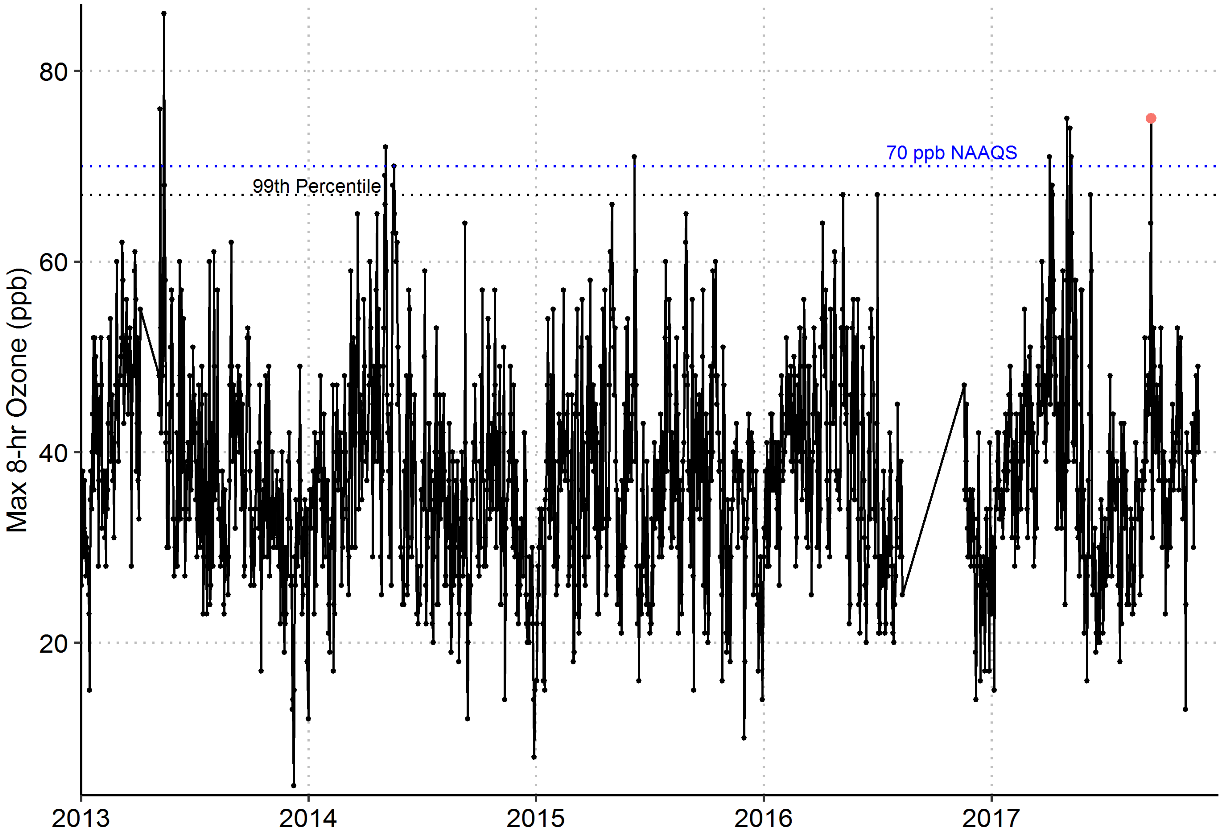

Figure A-8. Daily maximum 8-hr ozone concentrations at the Pride monitoring site (AQS ID 22-033-0013) from 2013 through 2017.

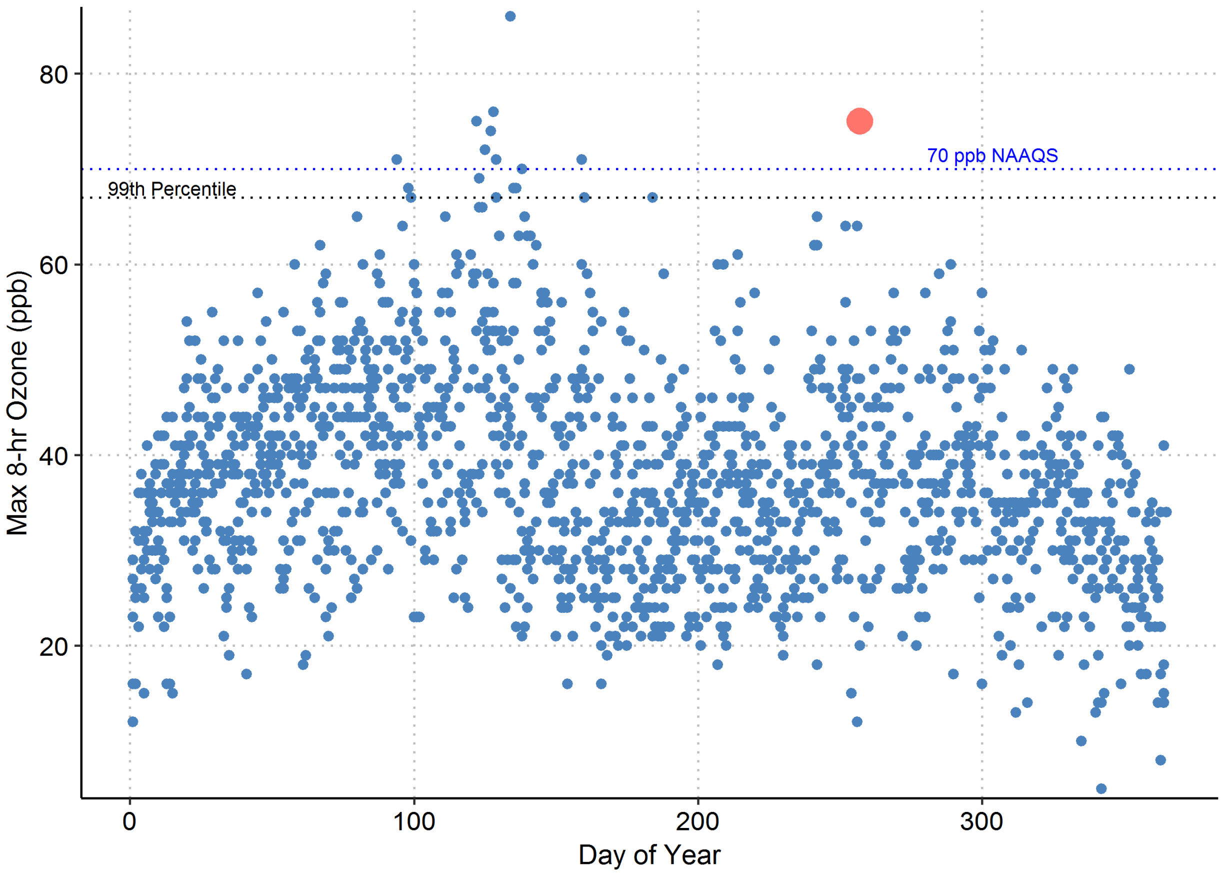

Figure A-9. Daily maximum 8-hr ozone concentrations at the Pride monitoring site (AQS ID 22-033-0013) from 2013 through 2017 by day of year.

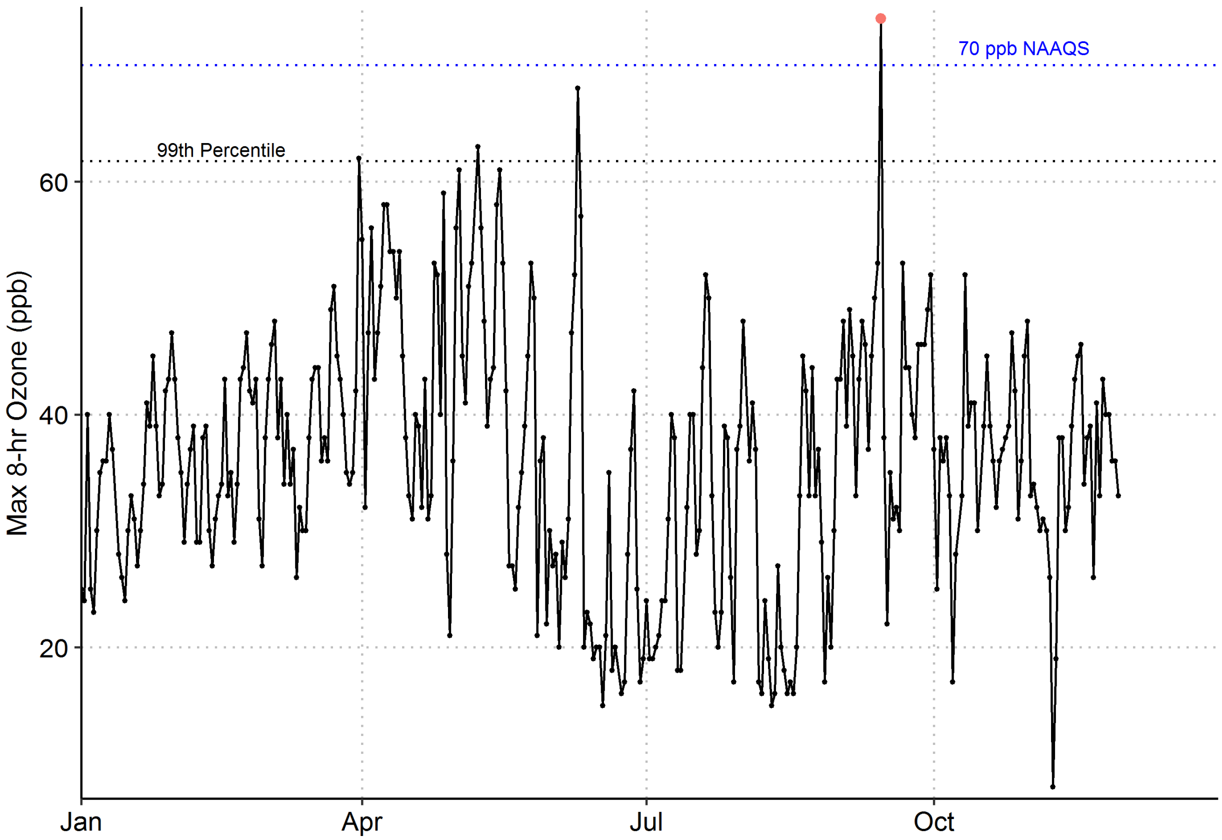

Figure A-10. Daily maximum 8-hr ozone concentrations at the Carville monitoring site (AQS ID 22-047-0012) in 2017.

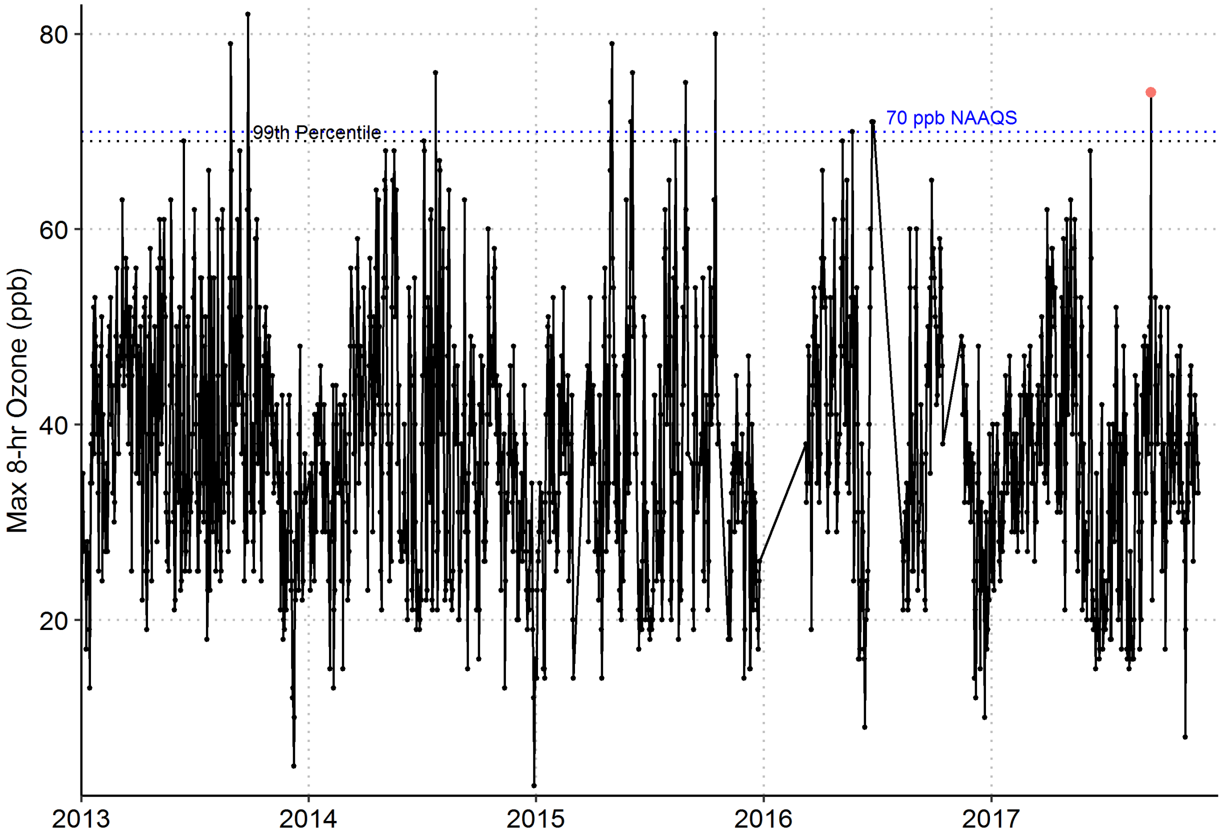

Figure A-11. Daily maximum 8-hr ozone concentrations at the Carville monitoring site (AQS ID 22-047-0012) from 2013 through 2017.

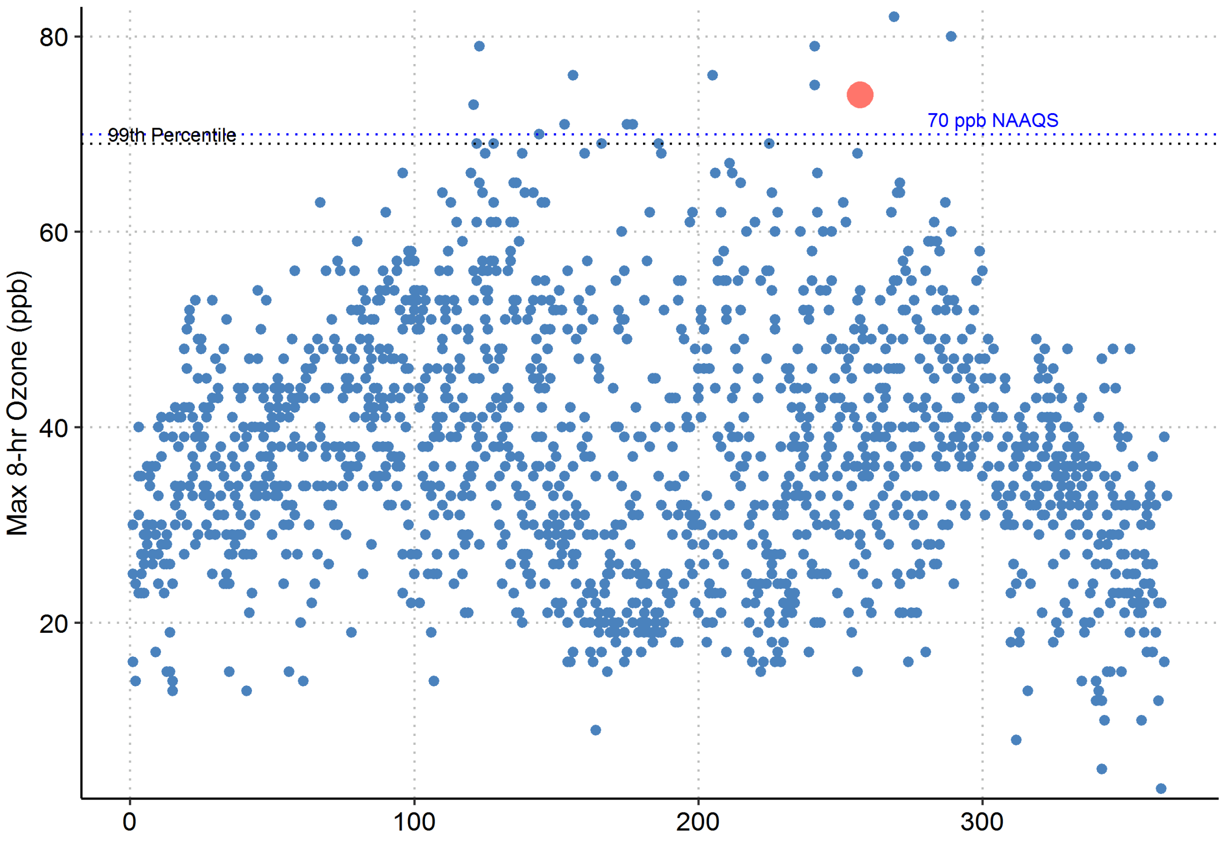

Figure A-12. Daily maximum 8-hr ozone concentrations at the Carville monitoring site (AQS ID 22-047-0012) from 2013 through 2017 by day of year.

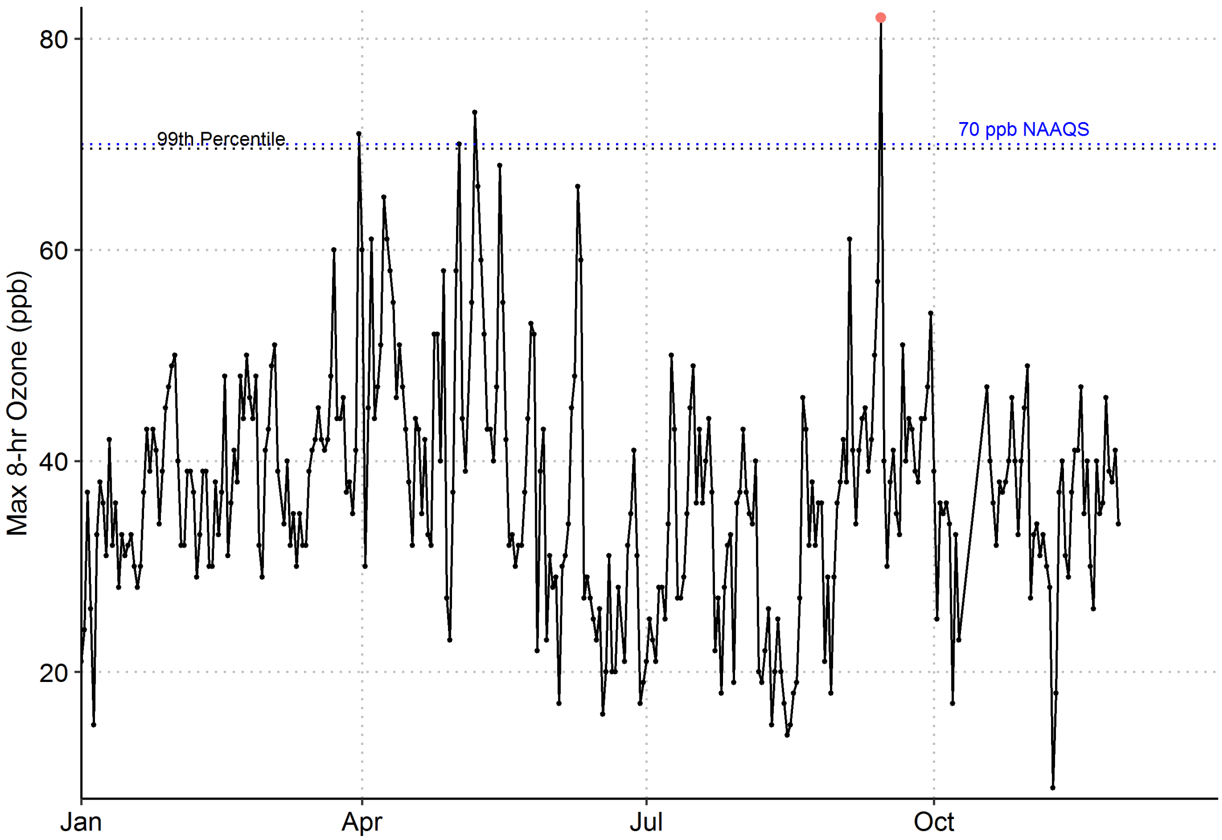

Figure A-13. Daily maximum 8-hr ozone concentrations at the Port Allen monitoring site (AQS ID 22-121-0001) in 2017.

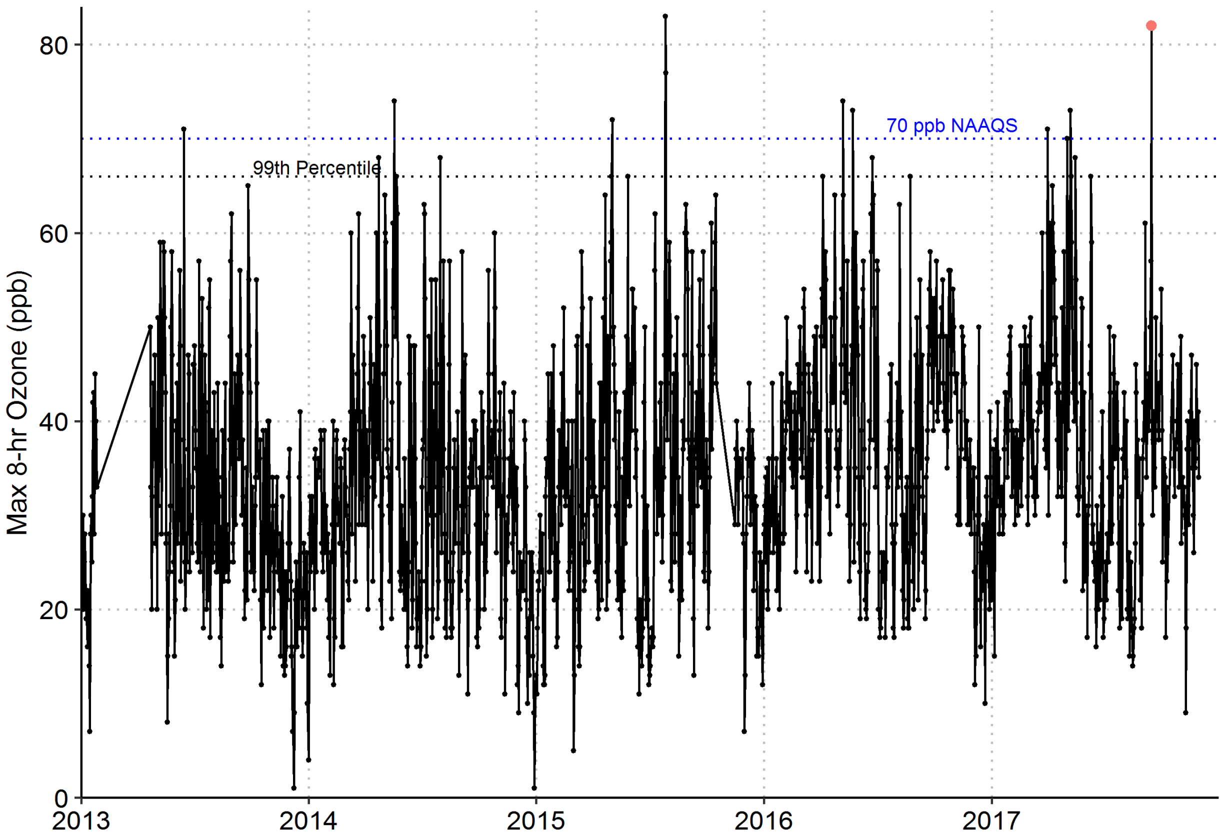

Figure A-14. Daily maximum 8-hr ozone concentrations at the Port Allen monitoring site (AQS ID 22-121-0001) from 2013 through 2017.

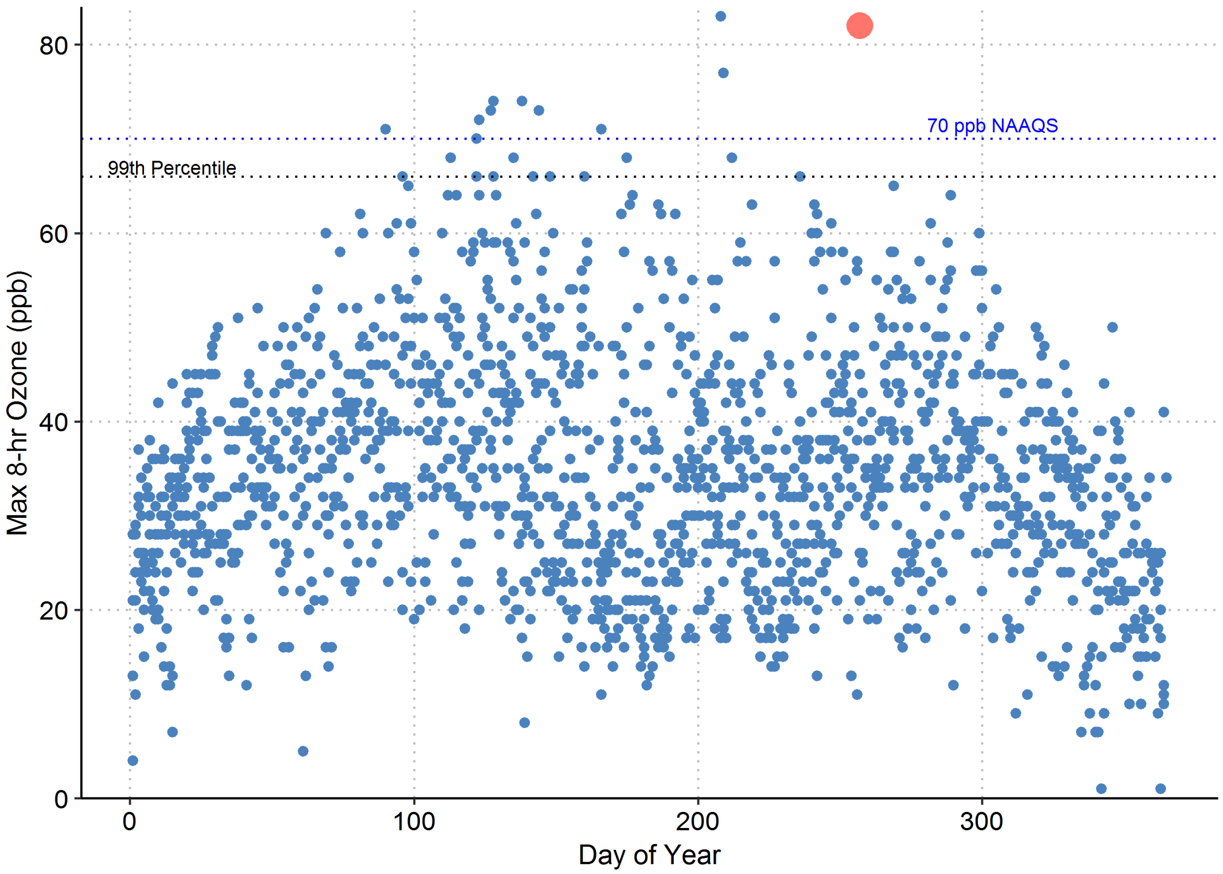

Figure A-15. Daily maximum 8-hr ozone concentrations at the Port Allen monitoring site (AQS ID 22-121-0001) from 2013 through 2017 by day of year.

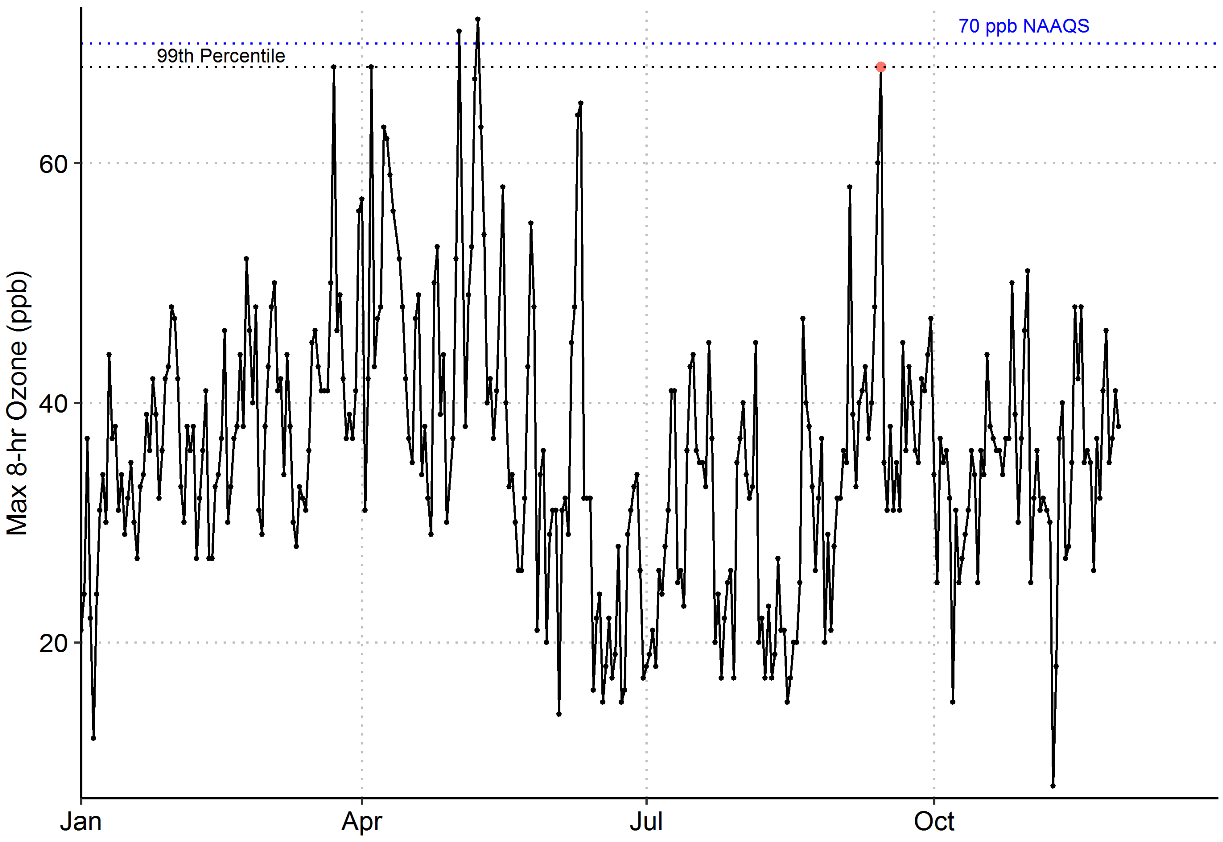

Figure A-16. Daily maximum 8-hr ozone concentrations at the New Roads monitoring site (AQS ID 22-077-0001) in 2017.

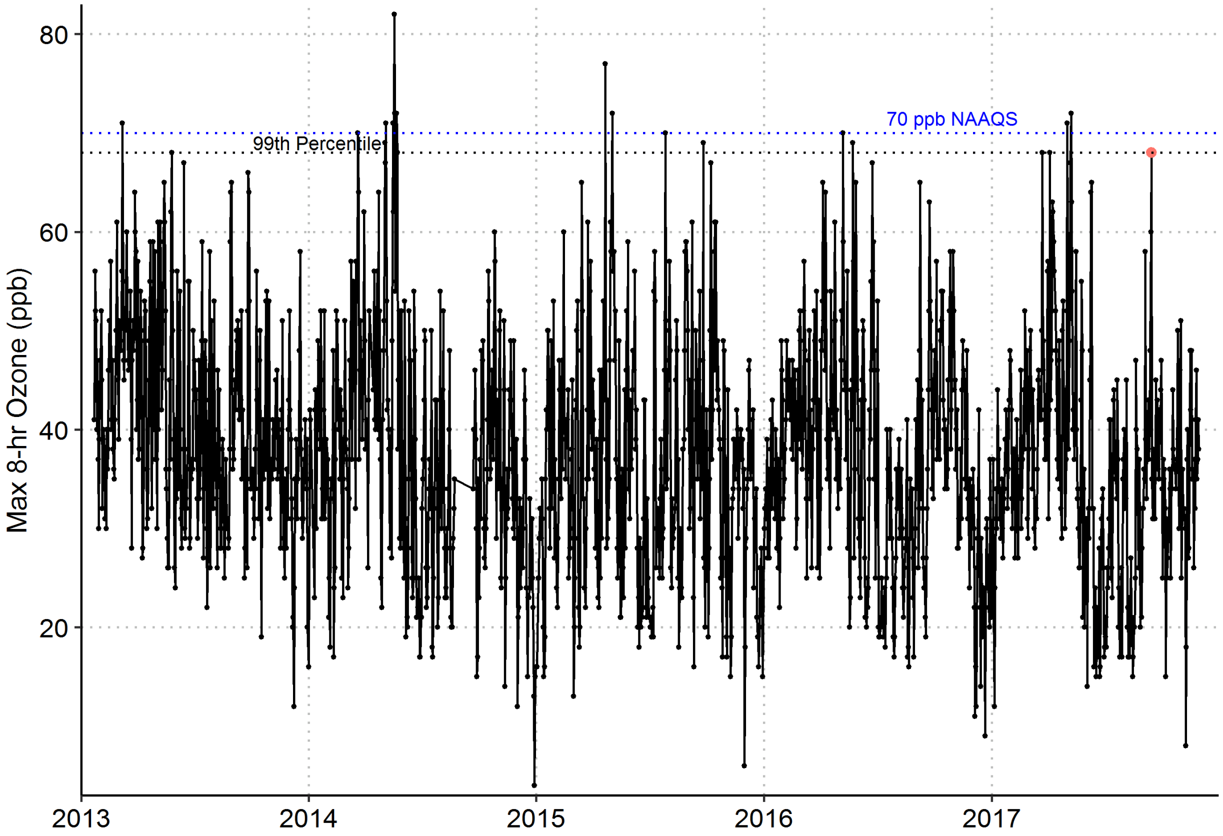

Figure A-17. Daily maximum 8-hr ozone concentrations at the New Roads monitoring site (AQS ID 22-077-0001) from 2013 through 2017.

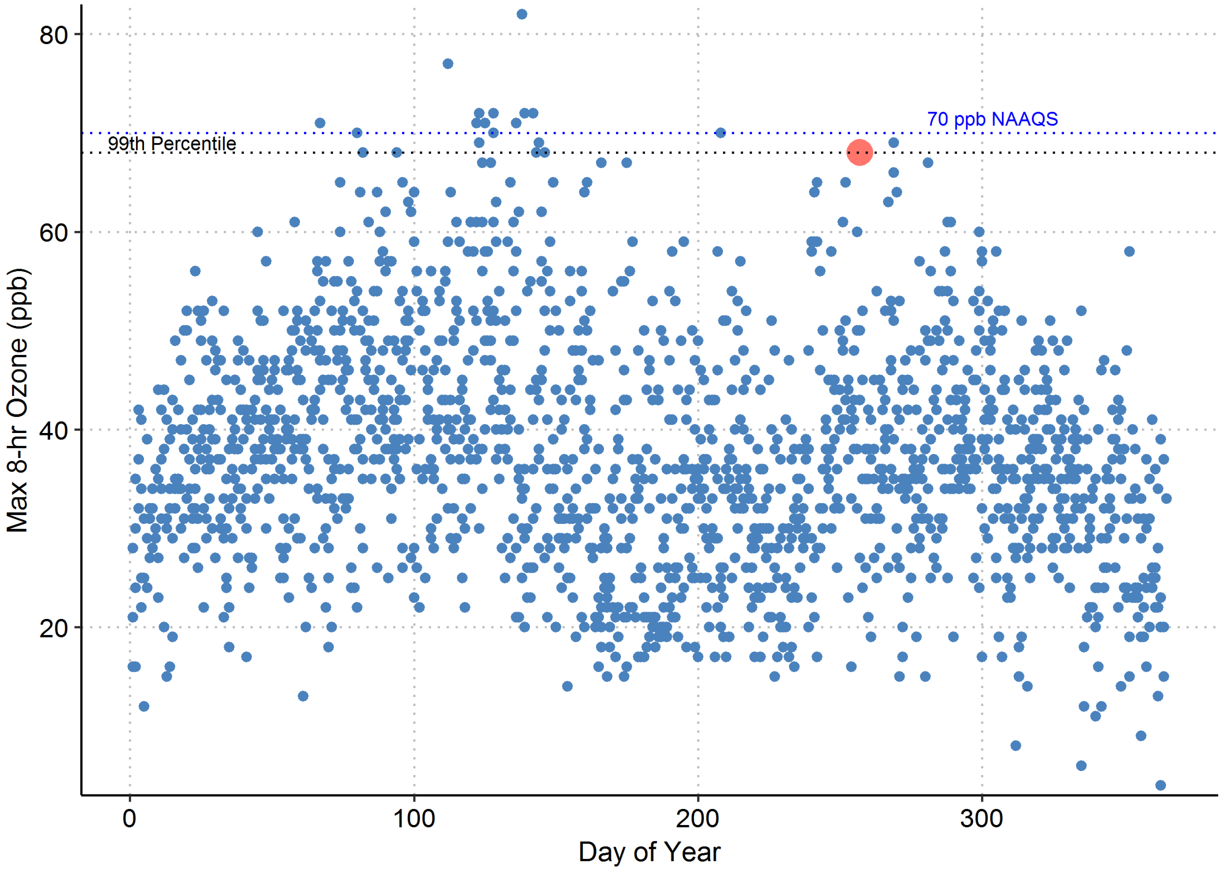

Figure A-18. Daily maximum 8-hr ozone concentrations at the New Roads monitoring site (AQS ID 22-077-0001) from 2013 through 2017 by day of year.

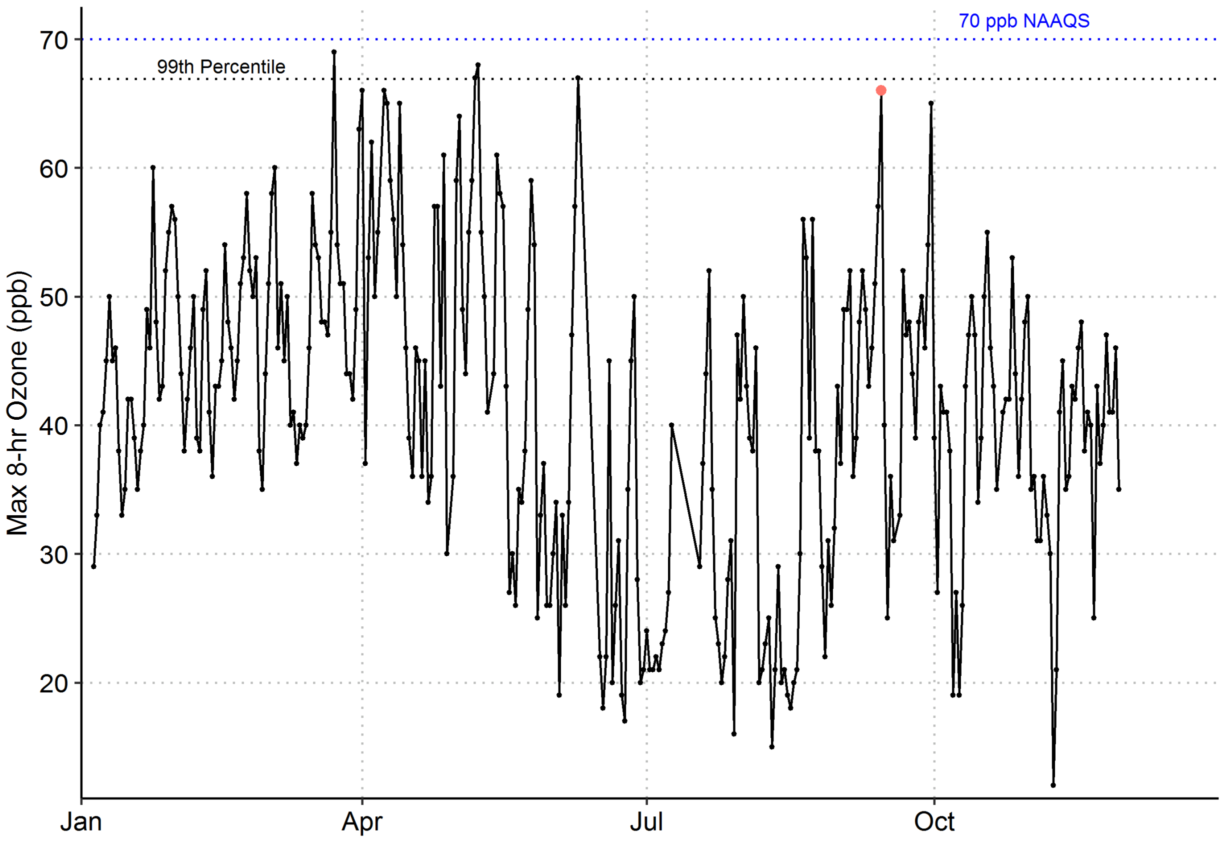

Figure A-19. Daily maximum 8-hr ozone concentrations at the Bayou Plaquemine monitoring site (AQS ID 22-047-0009) in 2017.

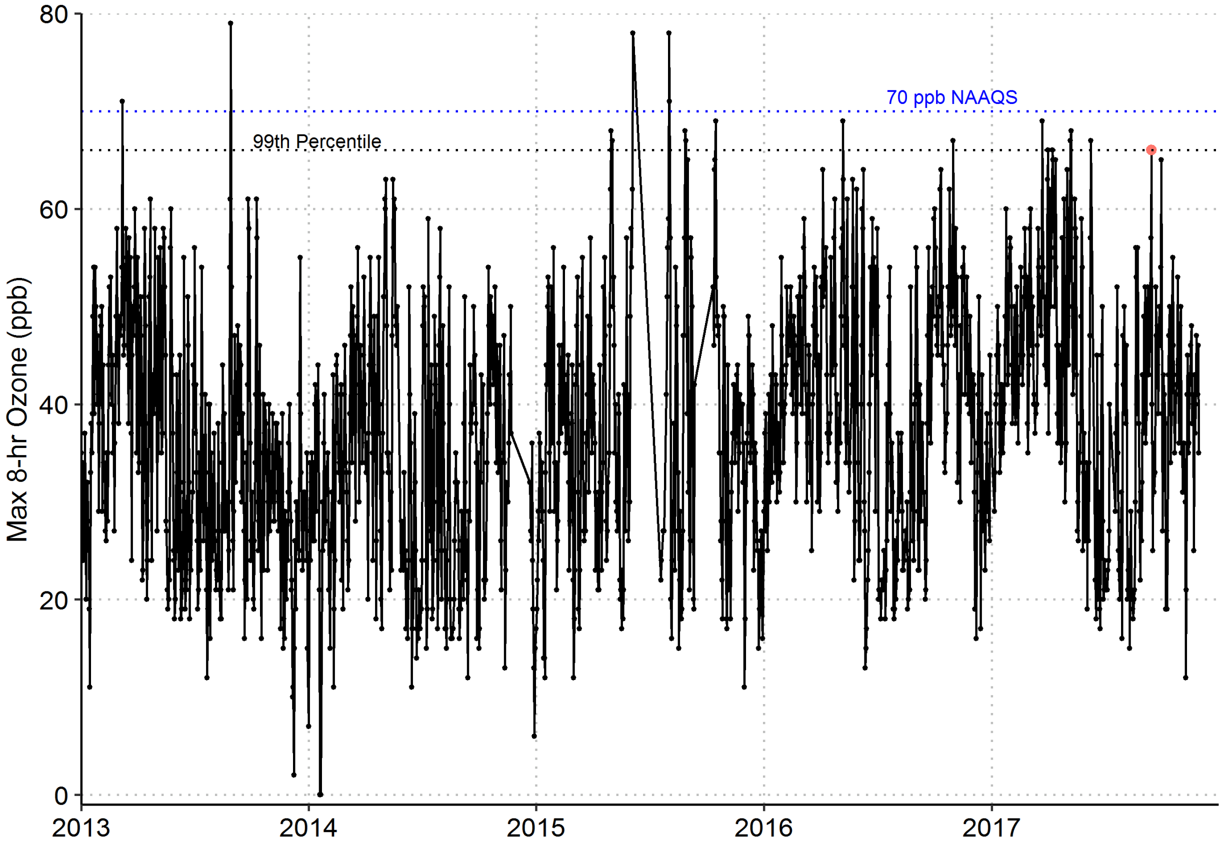

Figure A-20. Daily maximum 8-hr ozone concentrations at the Bayou Plaquemine monitoring site (AQS ID 22-047-0009) from 2013 through 2017.

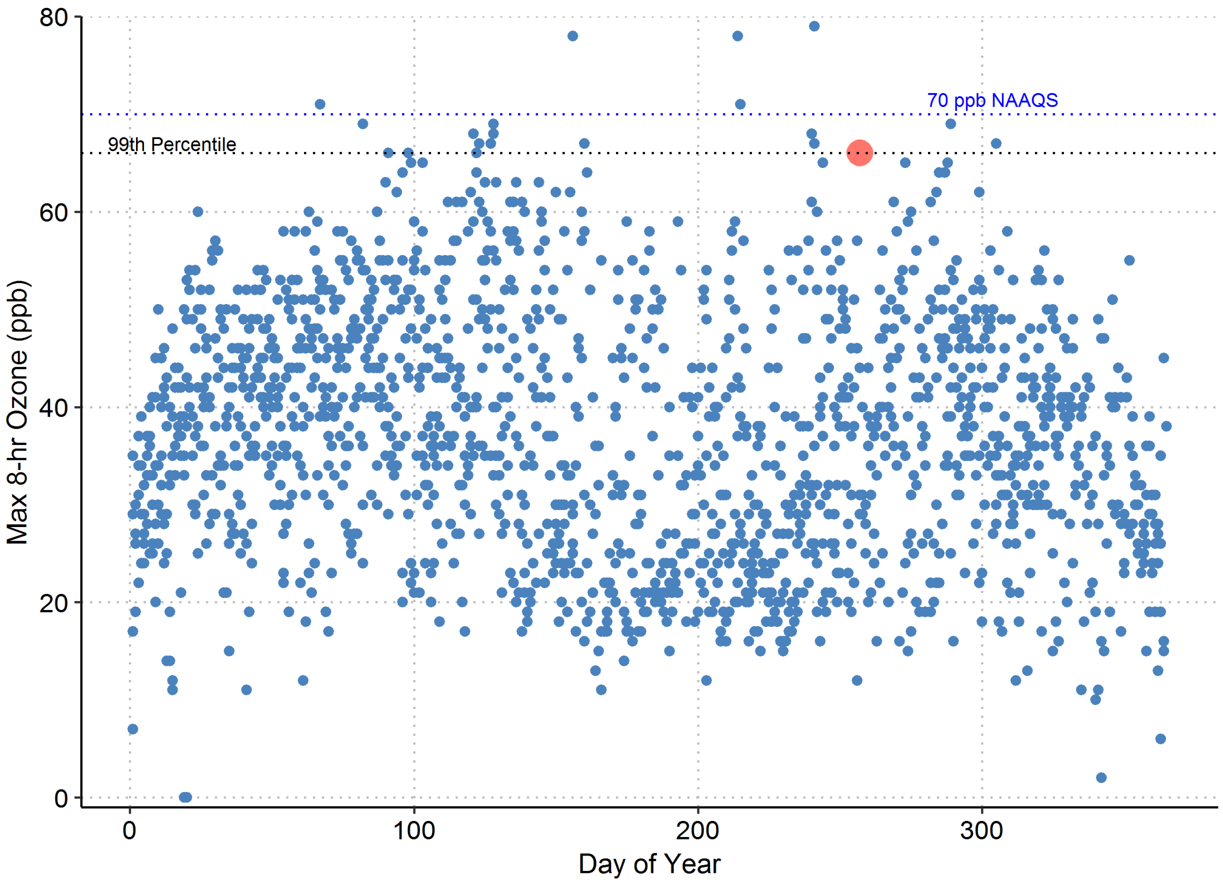

Figure A-21. Daily maximum 8-hr ozone concentrations at the Bayou Plaquemine monitoring site (AQS ID 22-047-0009) from 2013 through 2017 by day of year.

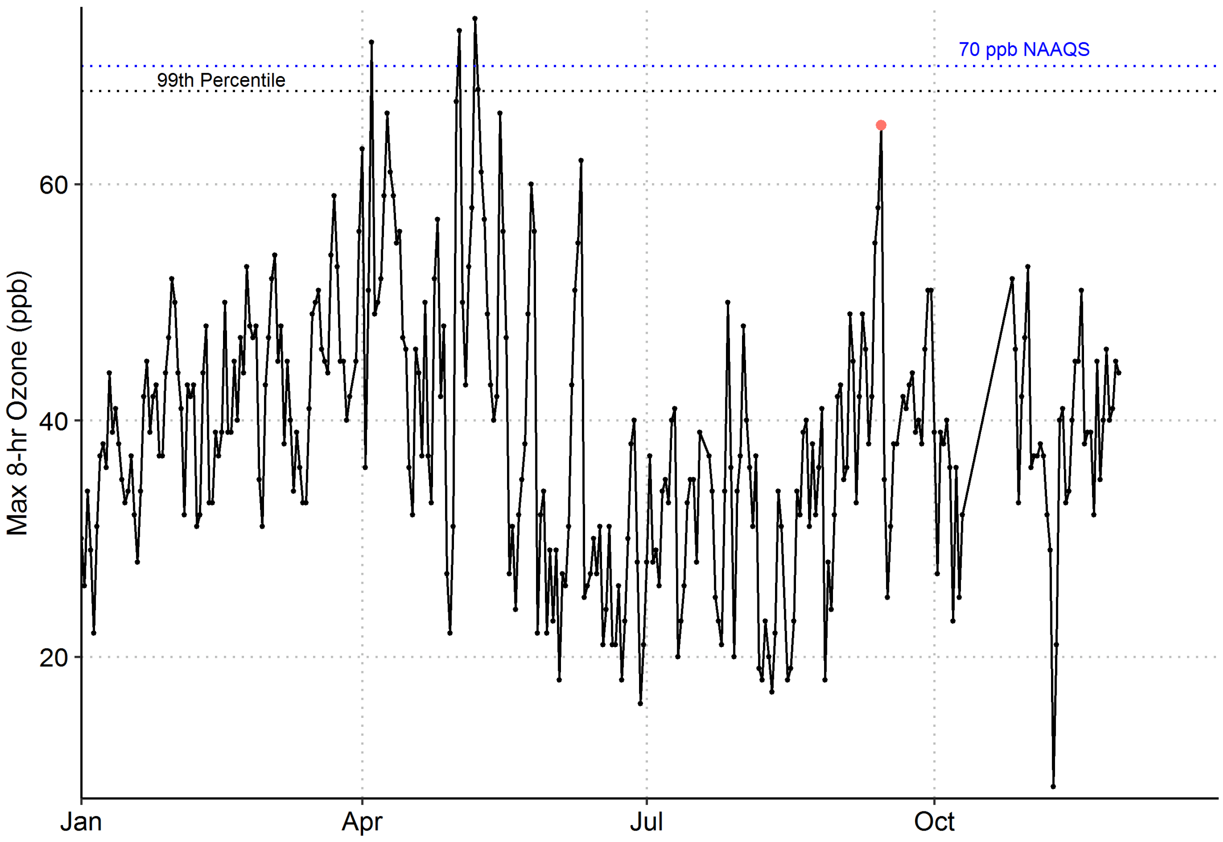

Figure A-22. Daily maximum 8-hr ozone concentrations at the French Settlement monitoring site (AQS ID 22-063-0002) in 2017.

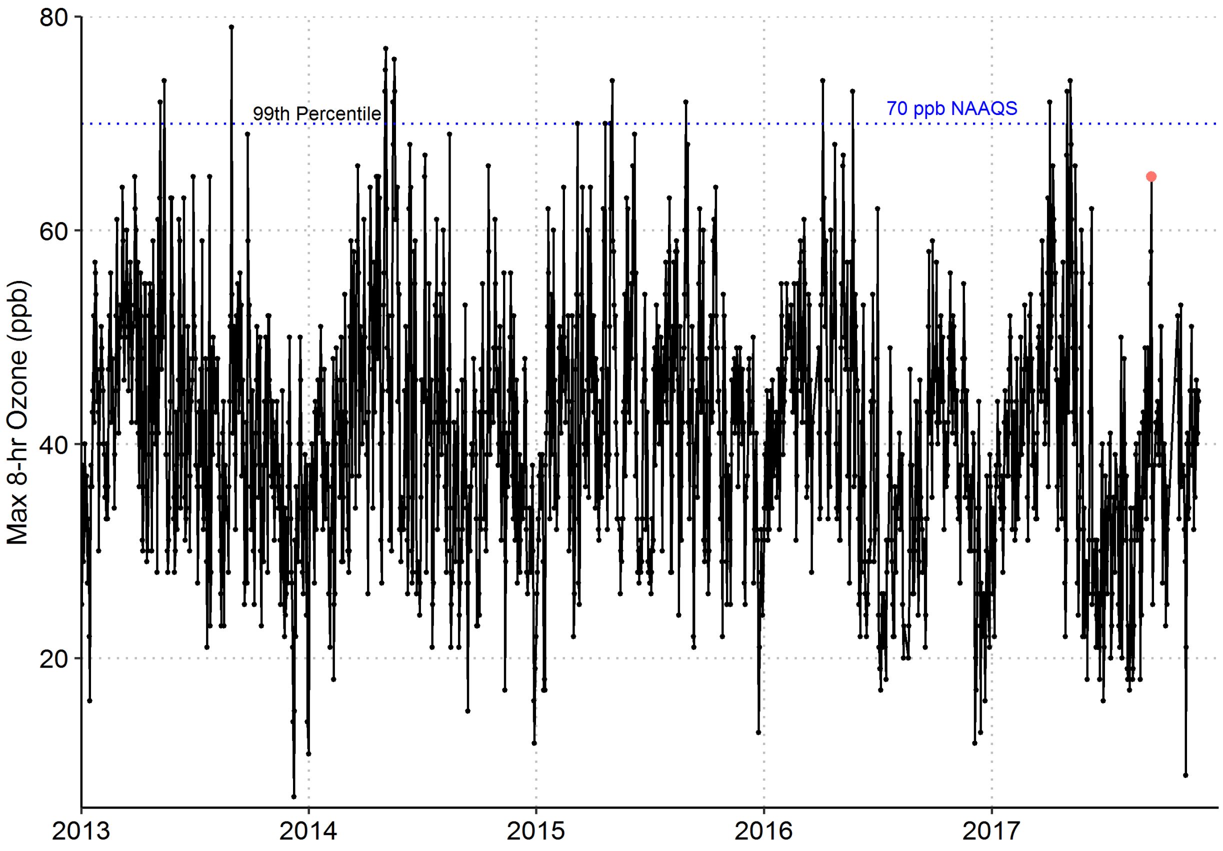

Figure A-23. Daily maximum 8-hr ozone concentrations at the French Settlement monitoring site (AQS ID 22-063-0002) from 2013 through 2017.

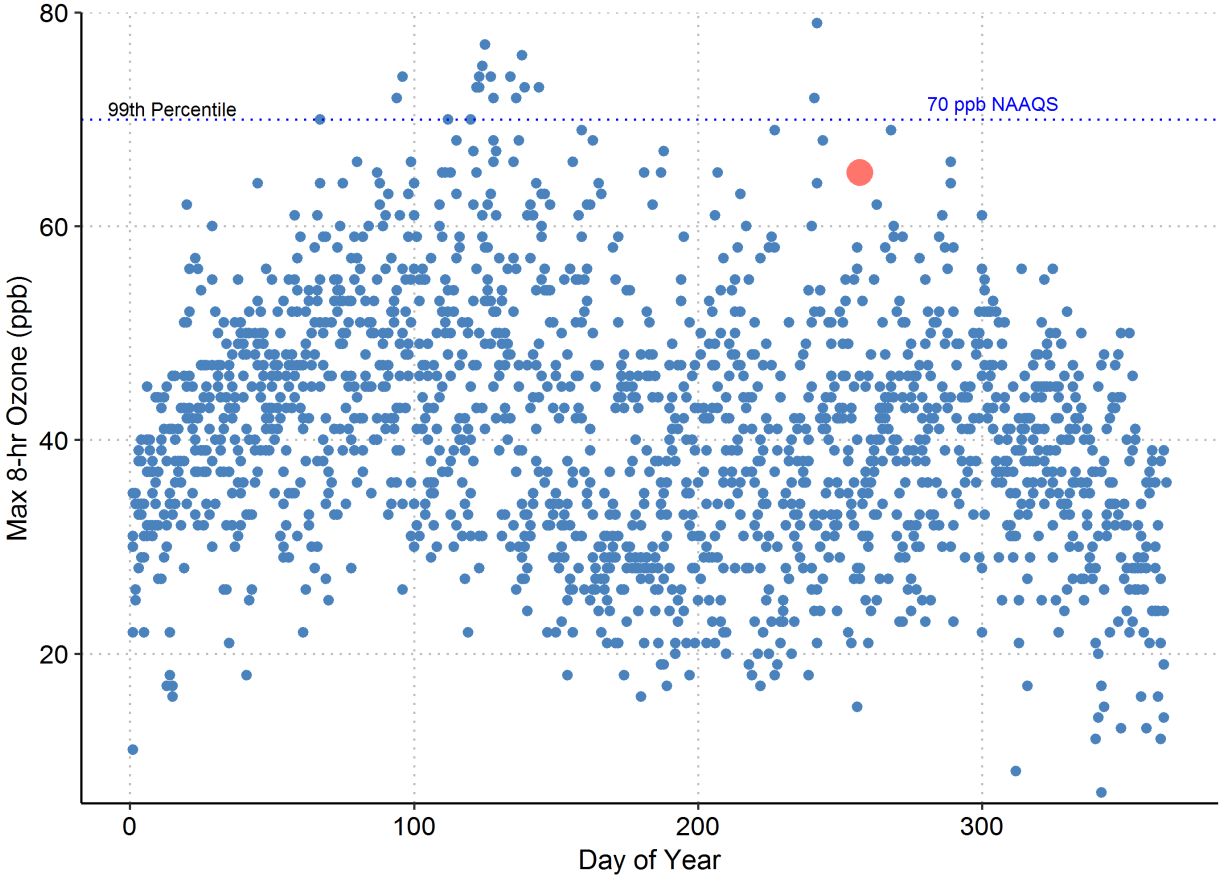

Figure A-24. Daily maximum 8-hr ozone concentrations at the French Settlement monitoring site (AQS ID 22-063-0002) from 2013 through 2017 by day of year.

Appendix B. Additional Supporting Measurements

Additional measurements collected at the Capitol monitoring site (AQS ID 22-033-0009) are shown in the following figures for September 1 through September 18, 2017. Measurements include speciated volatile organic compounds (VOCs) from the Photochemical Assessment Monitoring Stations (PAMS), NO, NO_x, NO_y, and CO. PAMS measurements track ozone and ozone precursors. Not all measurements are indicators of smoke impacts.

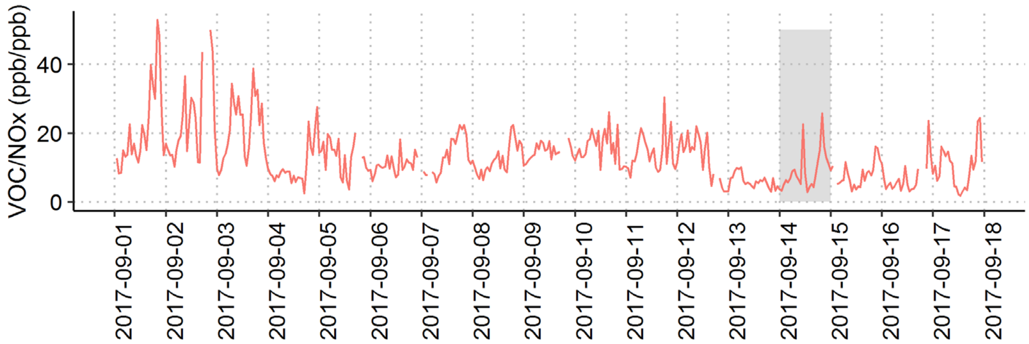

Figure B-1. VOC/NO_x ratio measured at the Capitol site between September 1 and 18, 2017.

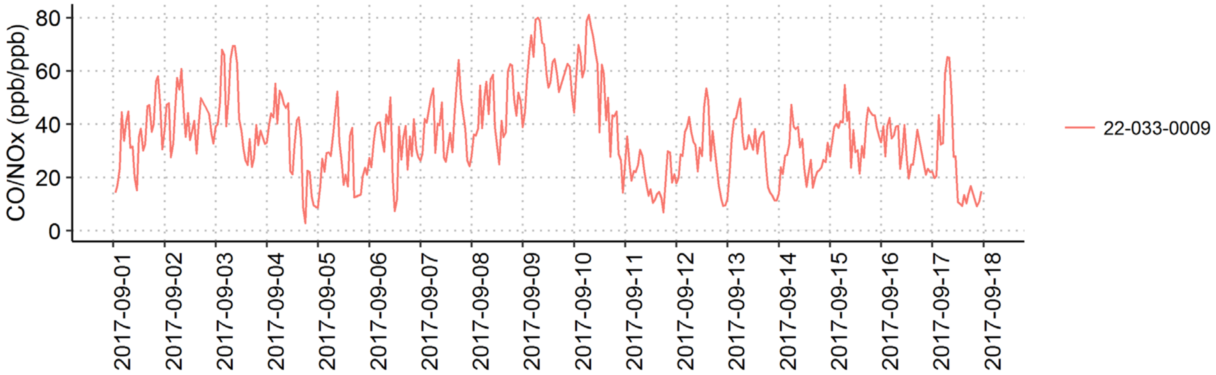

Figure B-2. CO/NO_x ratio measured at the Capitol site between September 1 and 18, 2017.

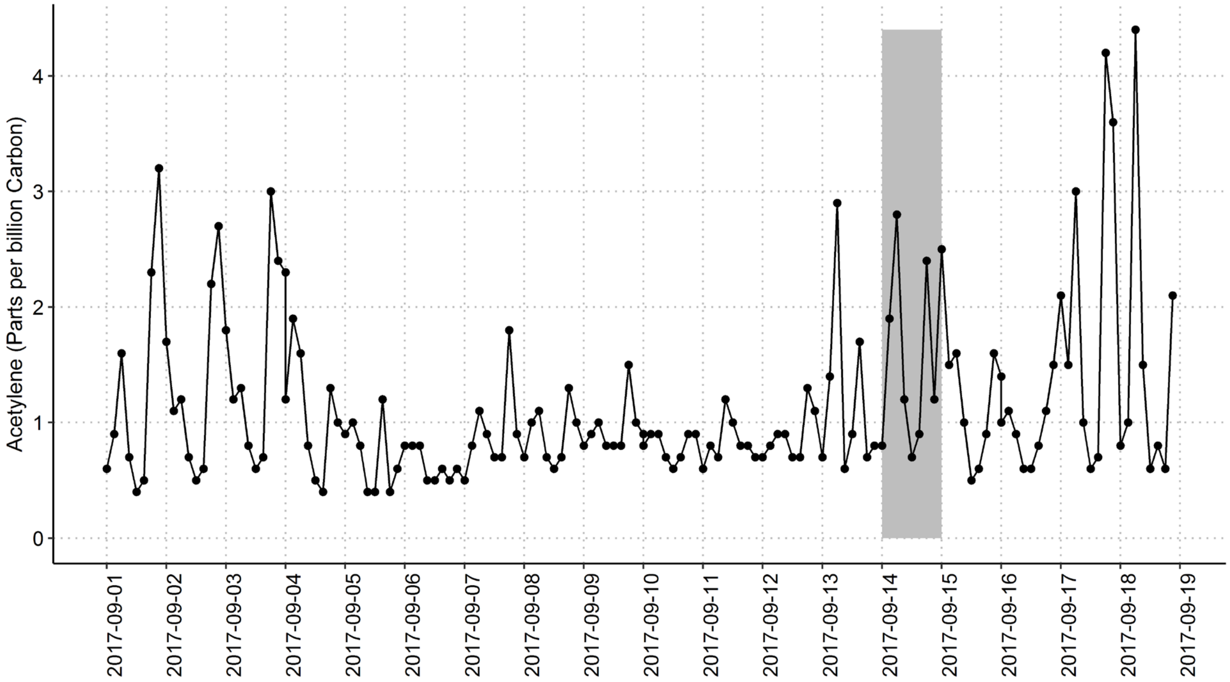

Figure B-3. Acetylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

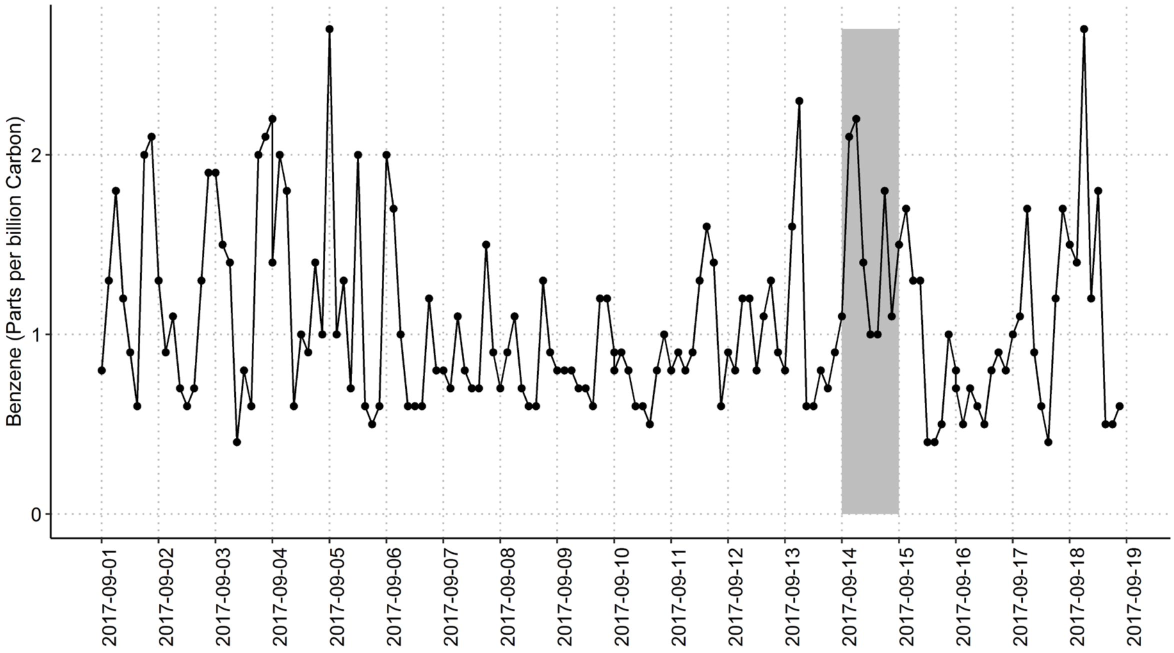

Figure B-4. Benzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

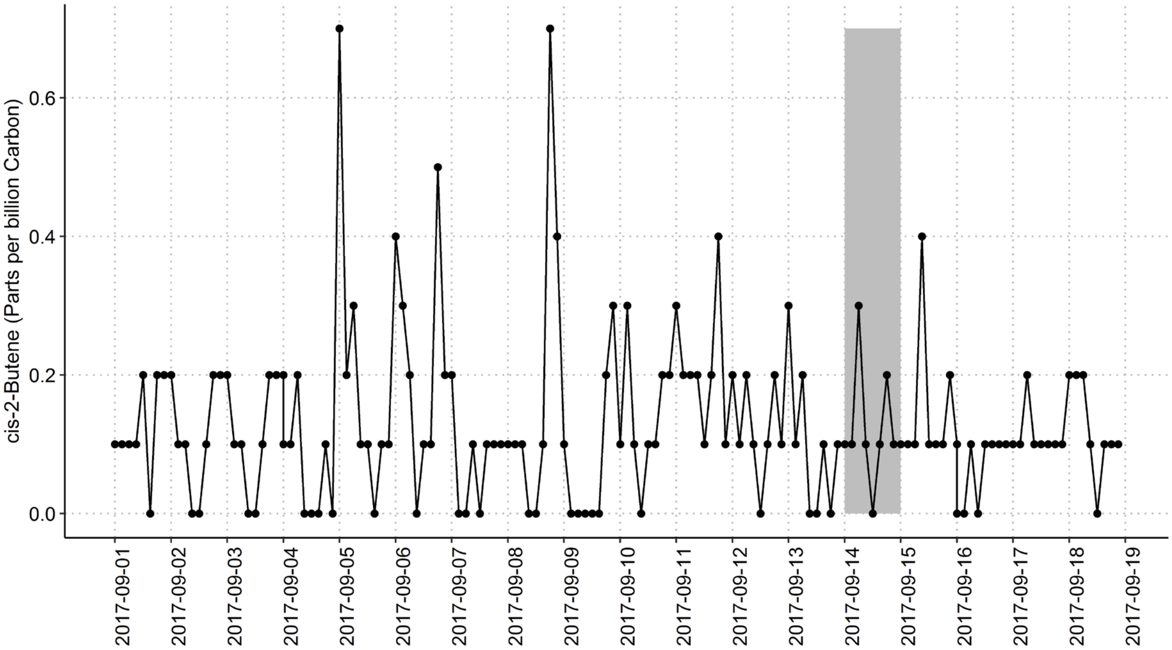

Figure B-5. cis-2-Butene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

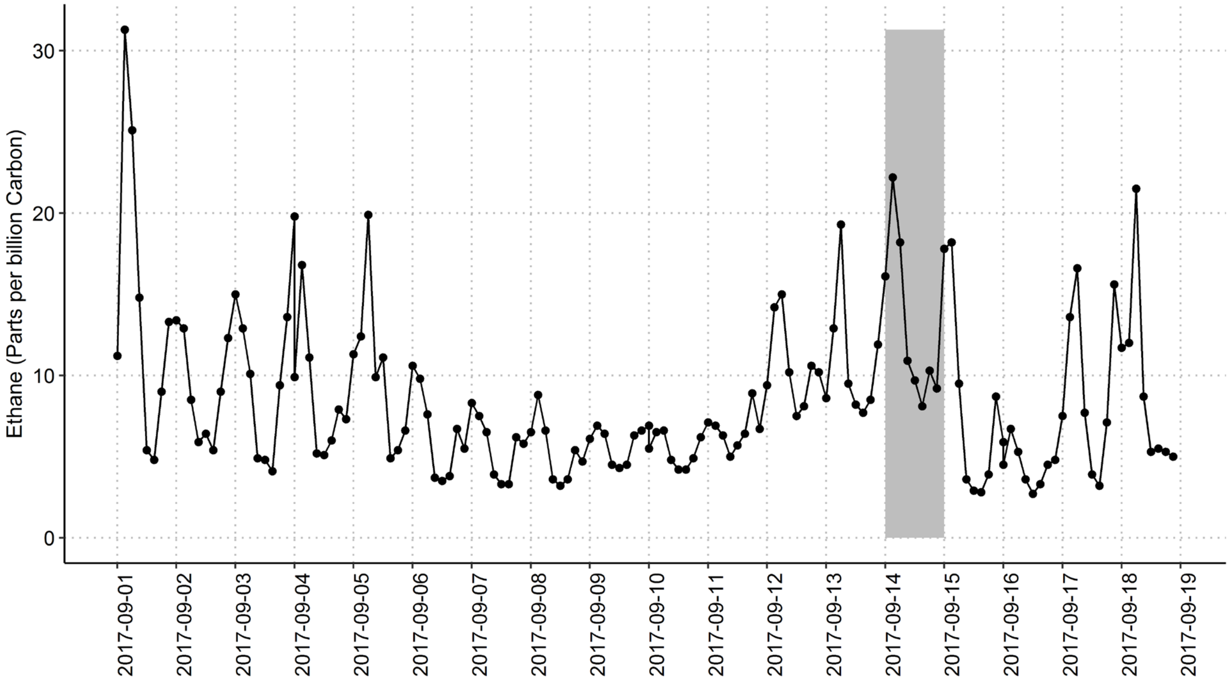

Figure B-6. Ethane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

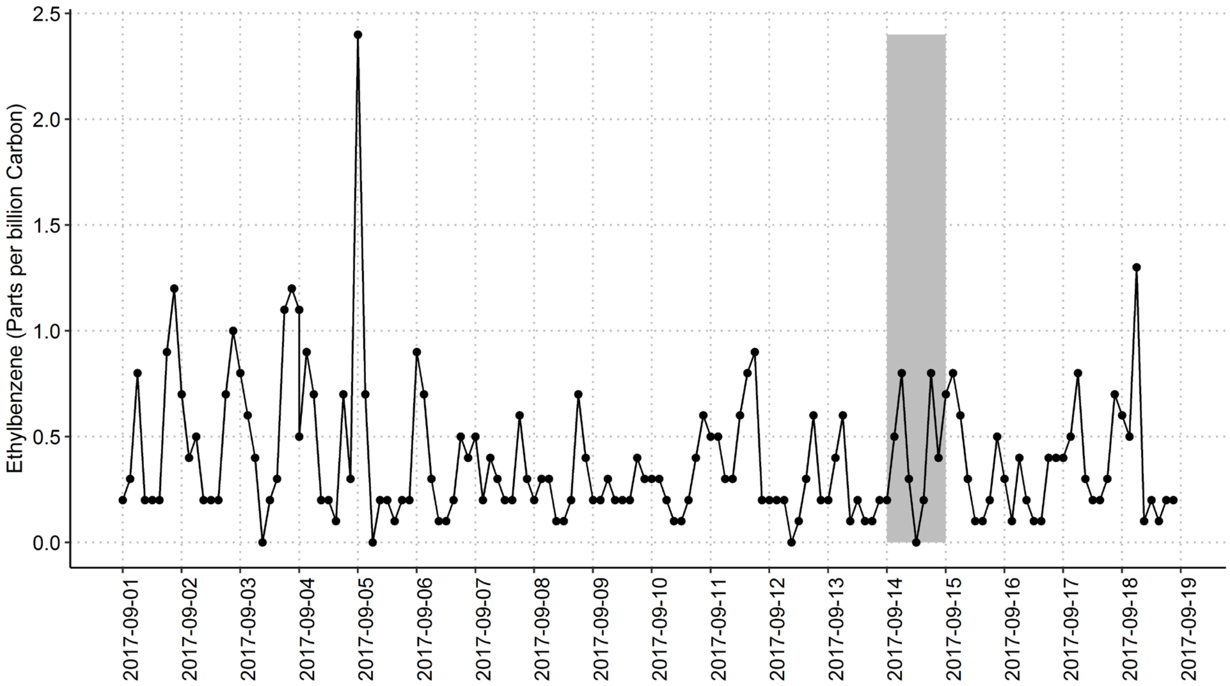

Figure B-7. Ethylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

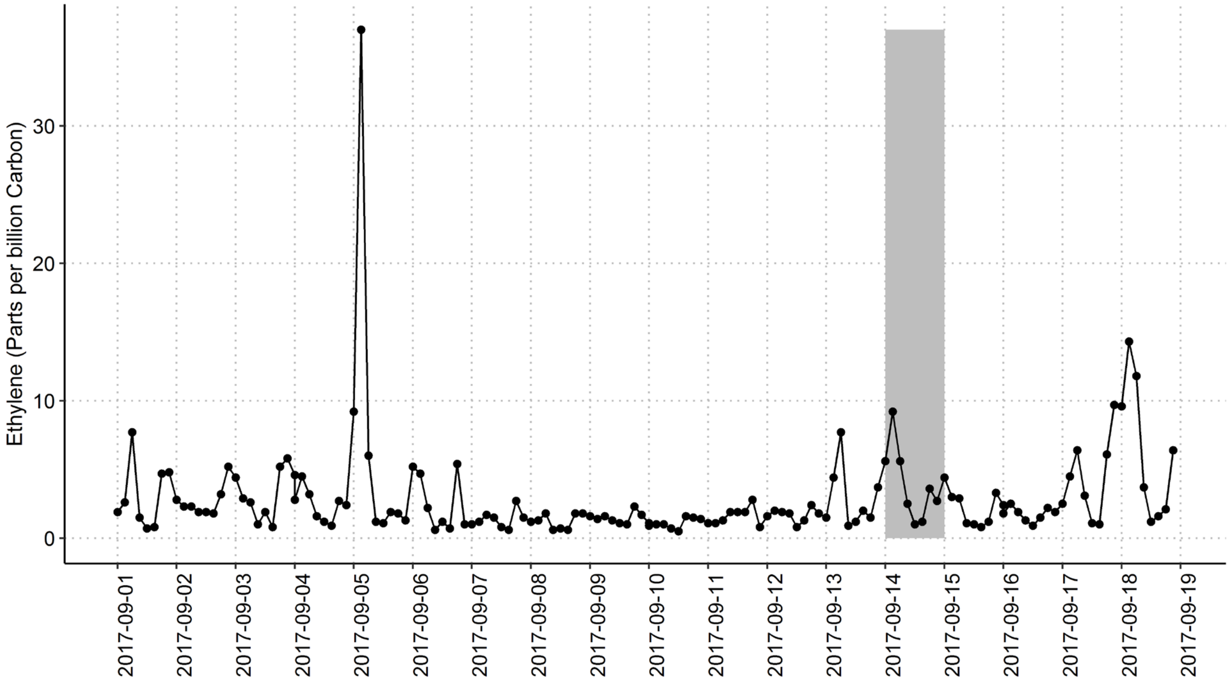

Figure B-8. Ethylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

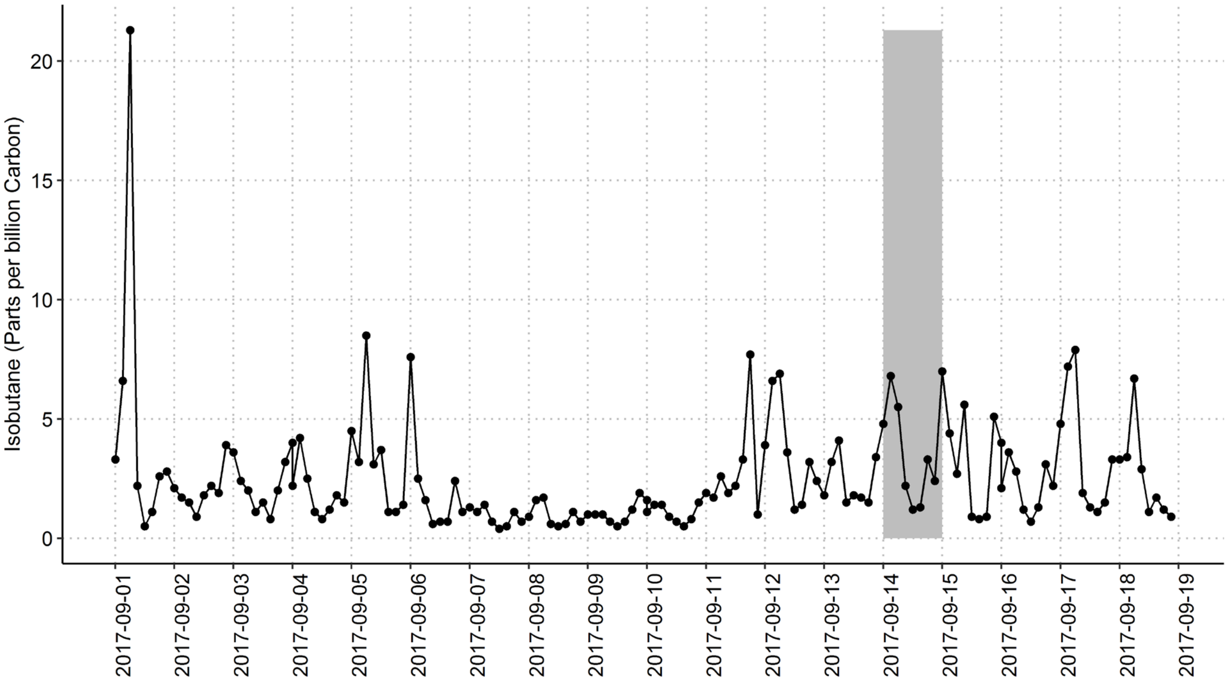

Figure B-9. Isobutane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

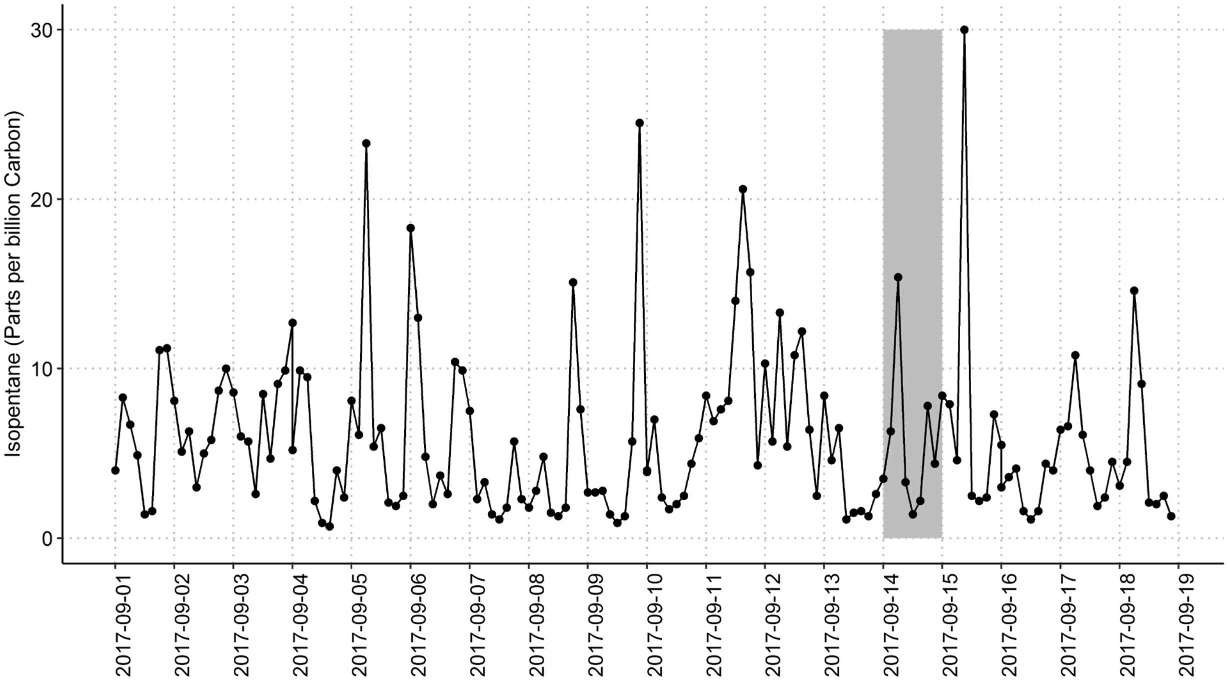

Figure B-10. Isopentane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

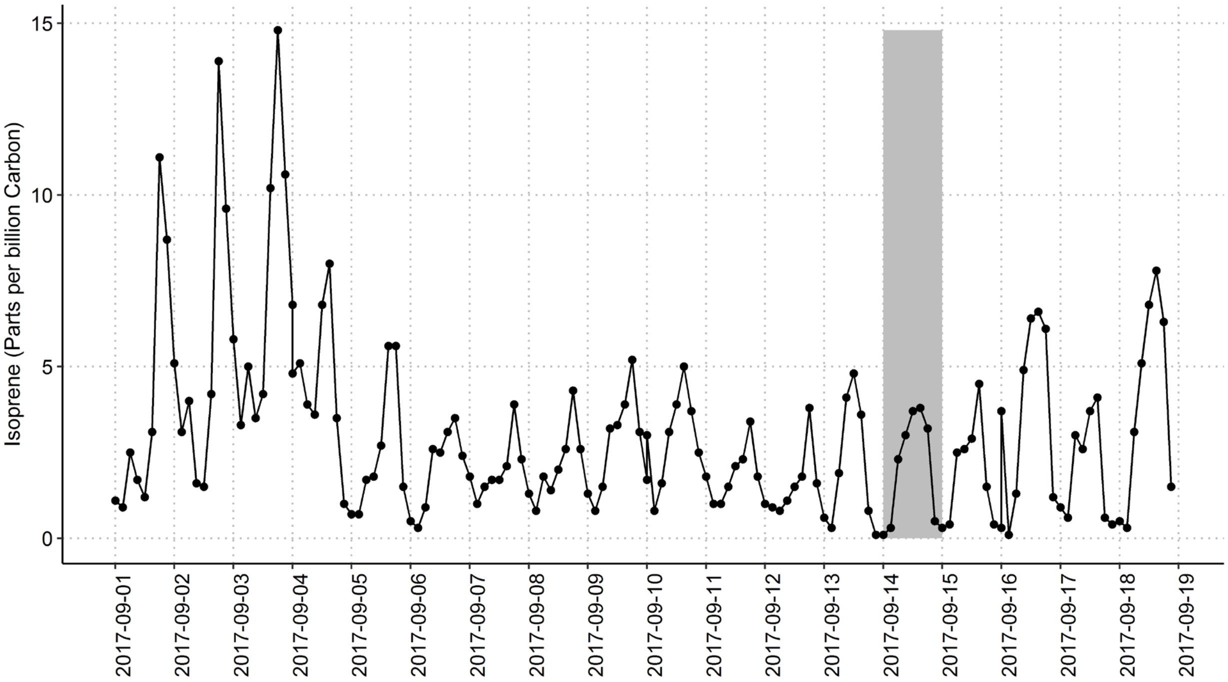

Figure B-11. Isoprene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

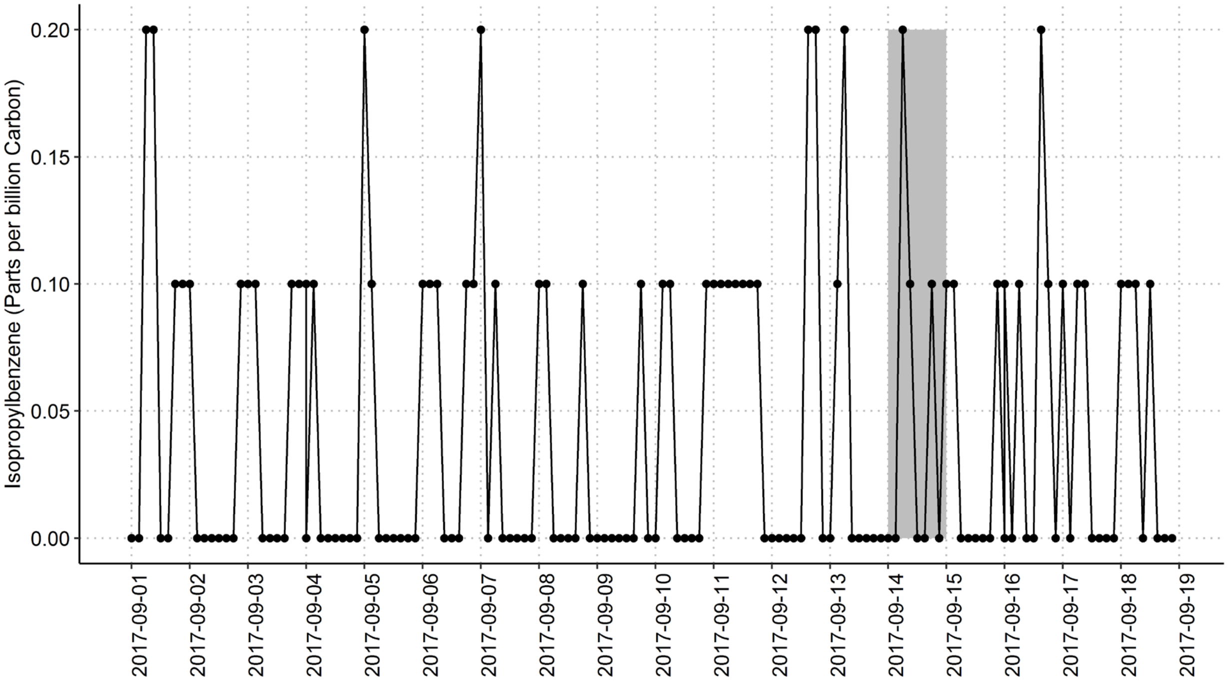

Figure B-12. Isopropylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

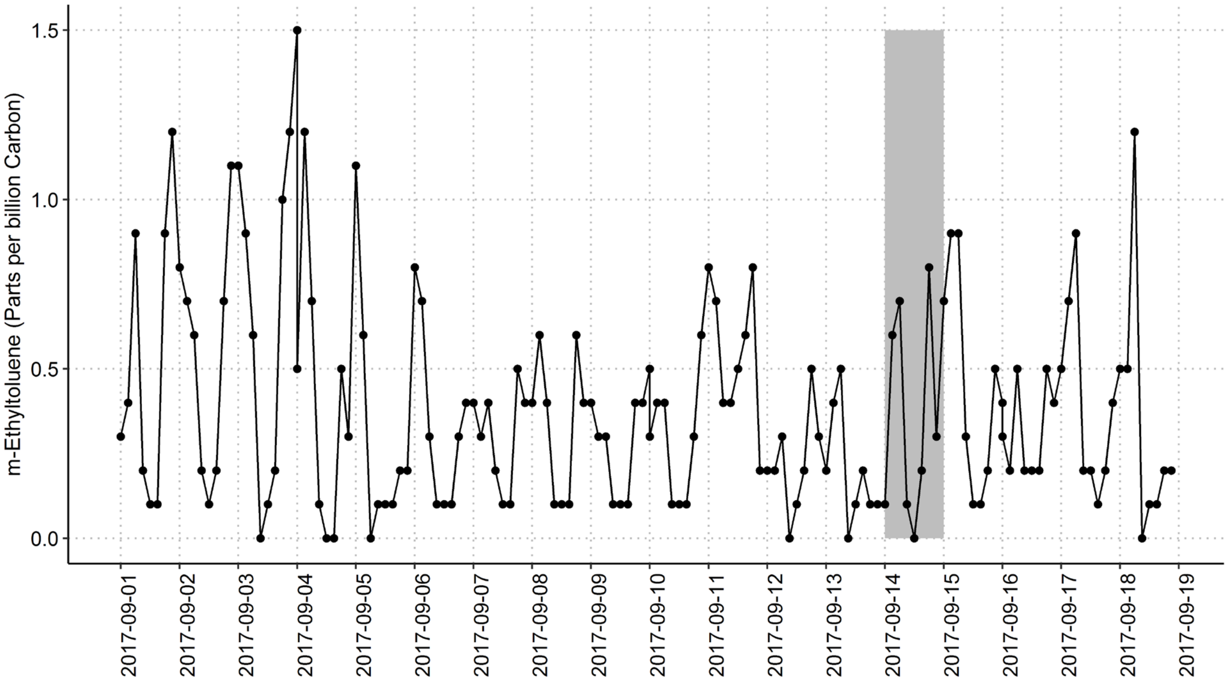

Figure B-13. m-Ethyltoluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

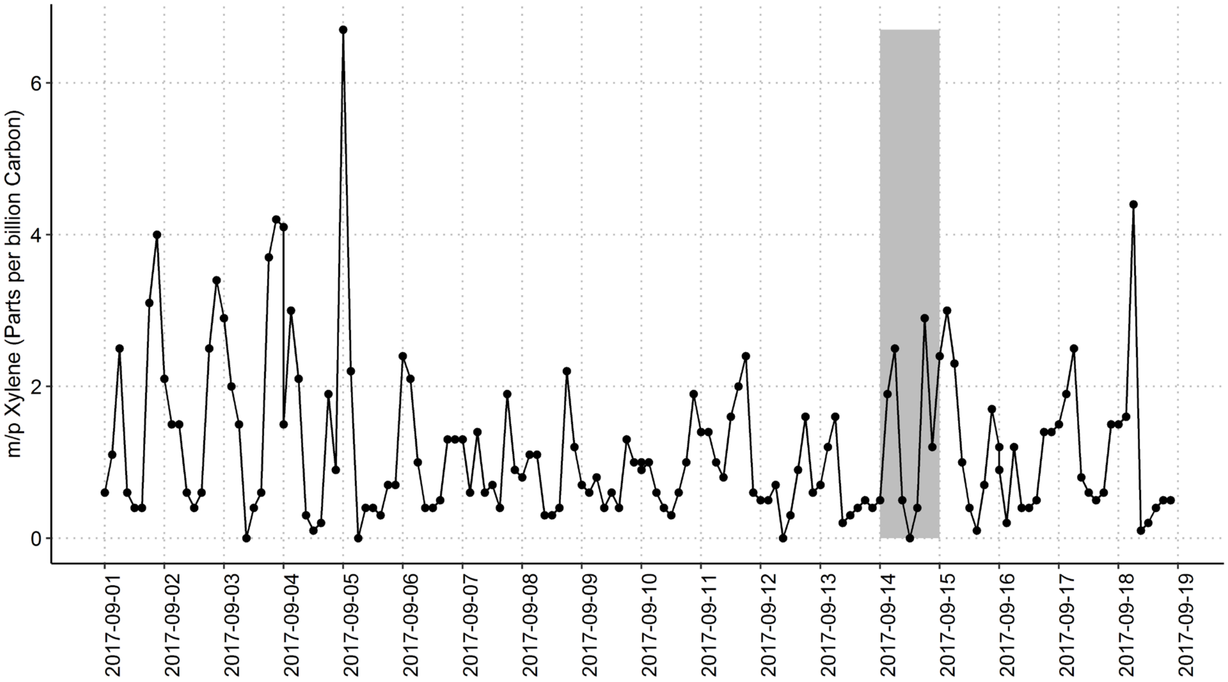

Figure B-14. m/p Xylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

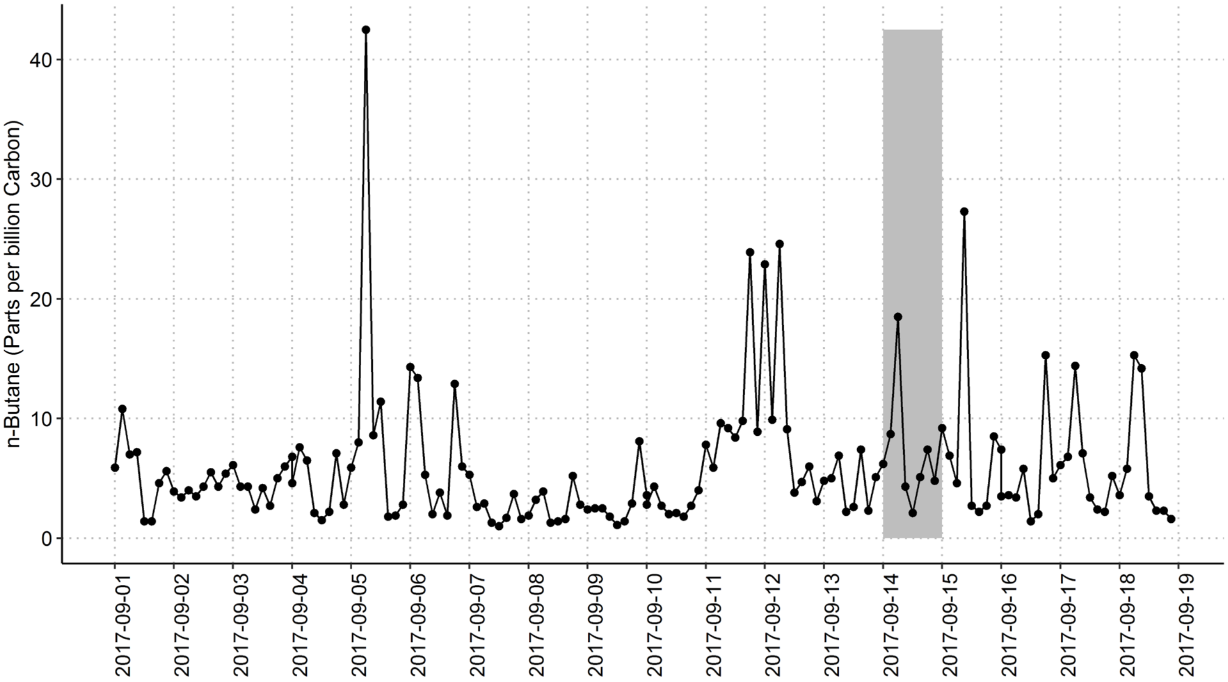

Figure B-15. n-Butane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

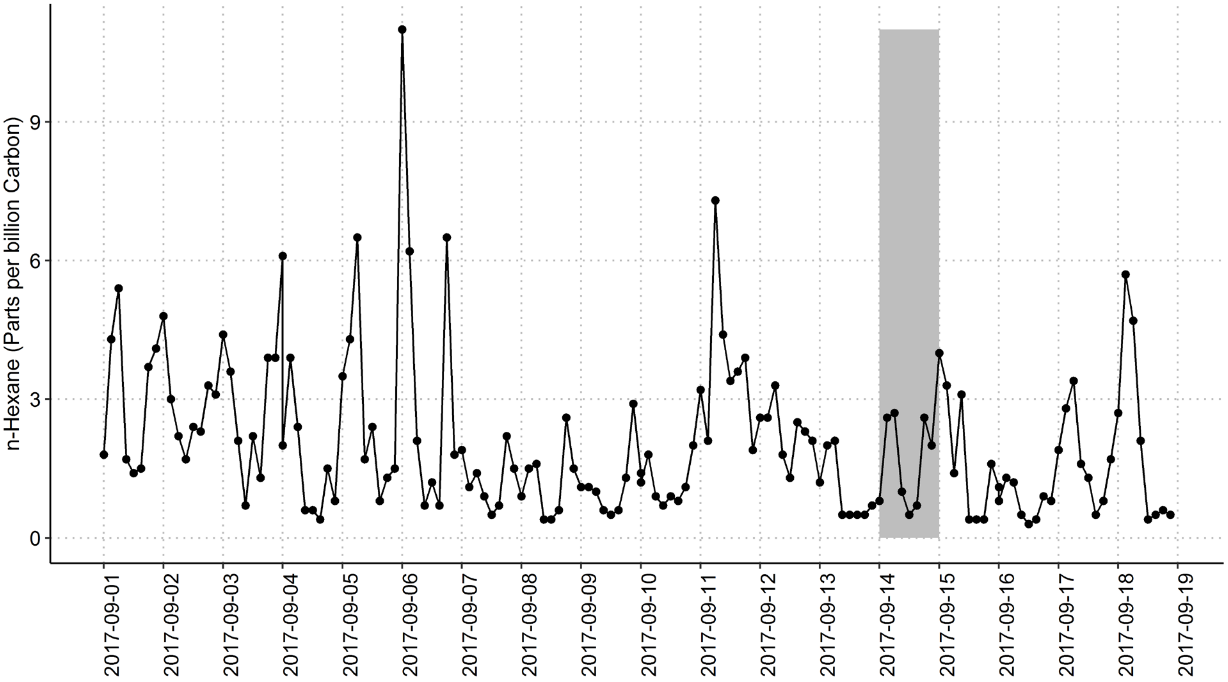

Figure B-16. n-Hexane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

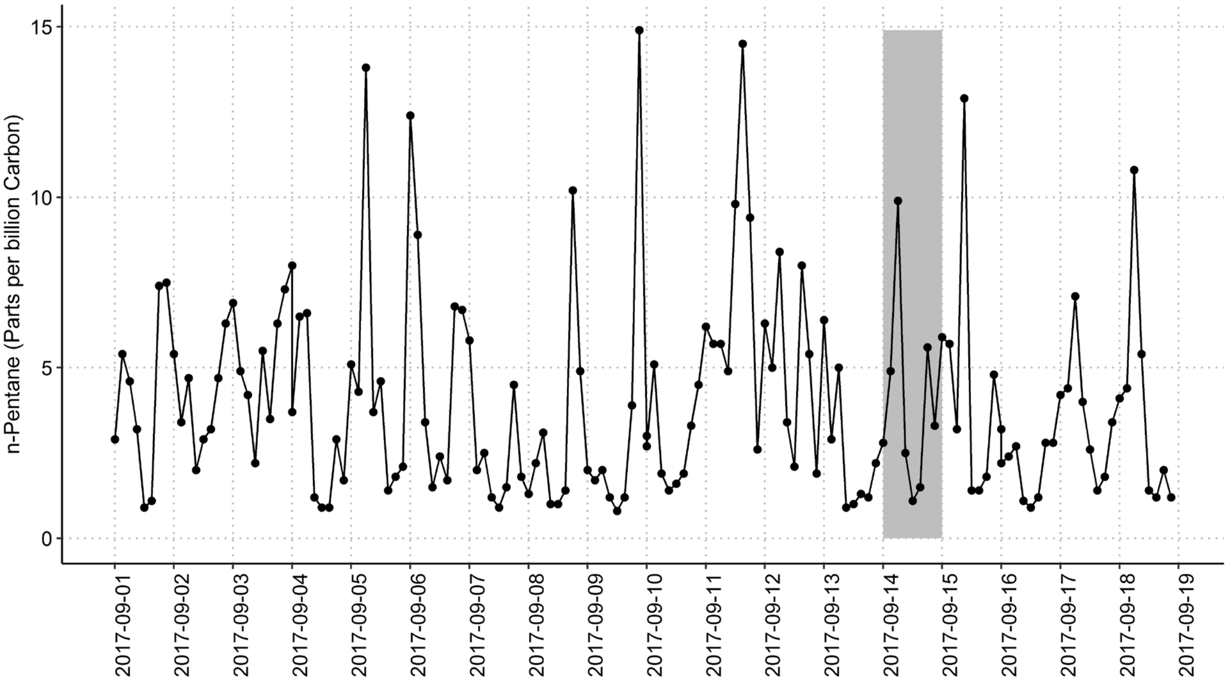

Figure B-17. n-Pentane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

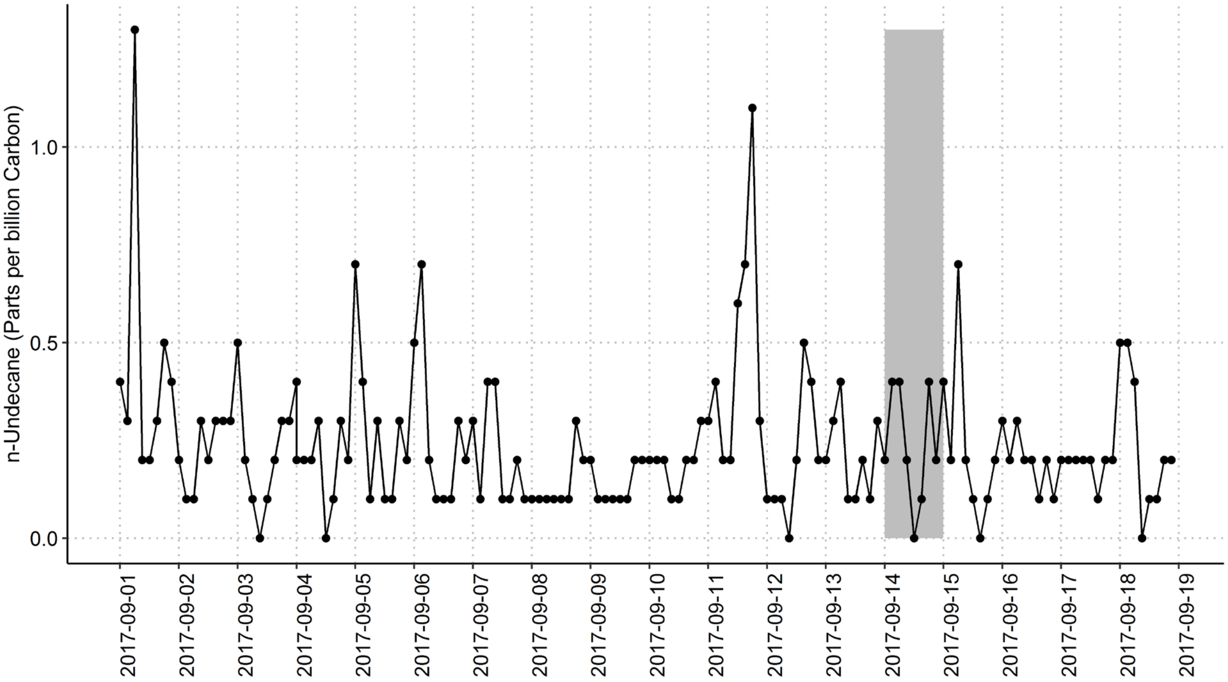

Figure B-18. n-Undecane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

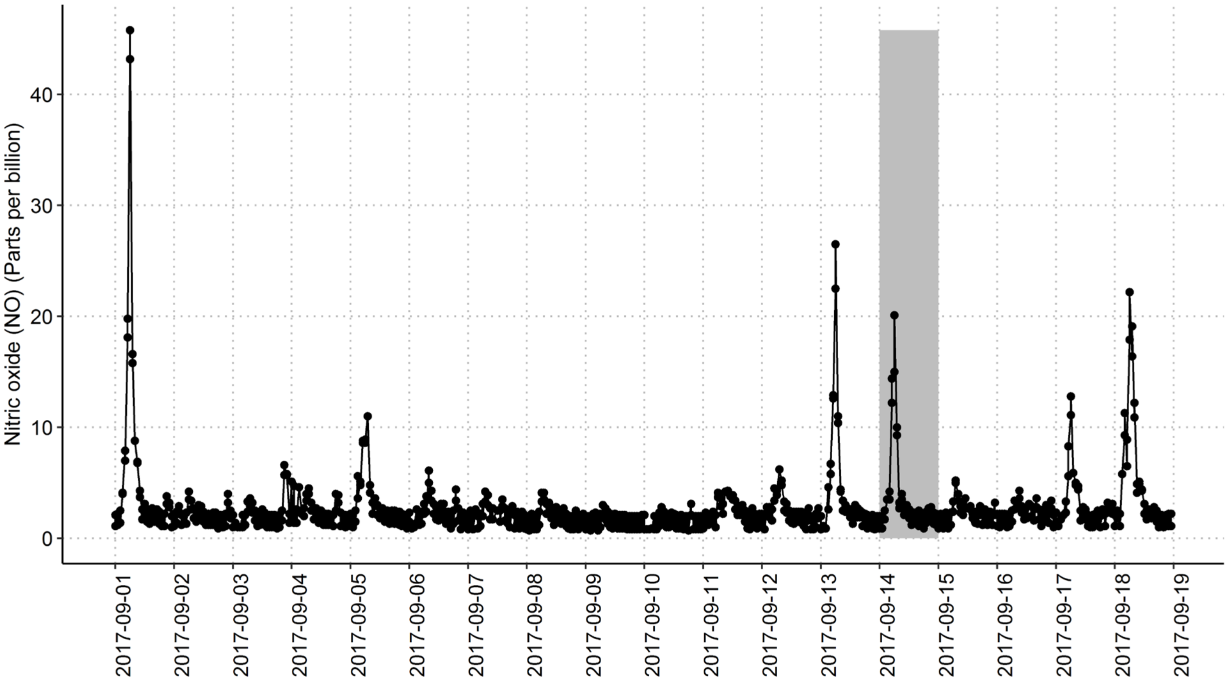

Figure B-19. Nitric oxide measurements at the Capitol monitoring site from September 1 through September 18, 2017.

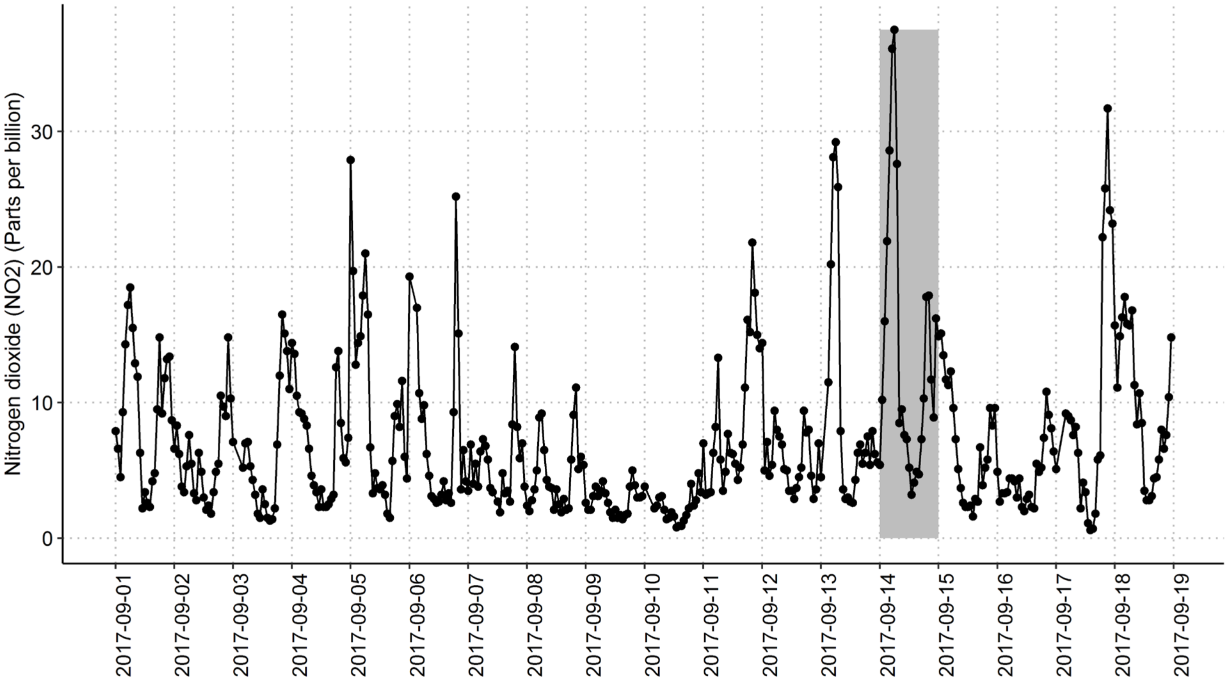

Figure B-20. Nitrogen dioxide measurements at the Capitol monitoring site from September 1 through September 18, 2017.

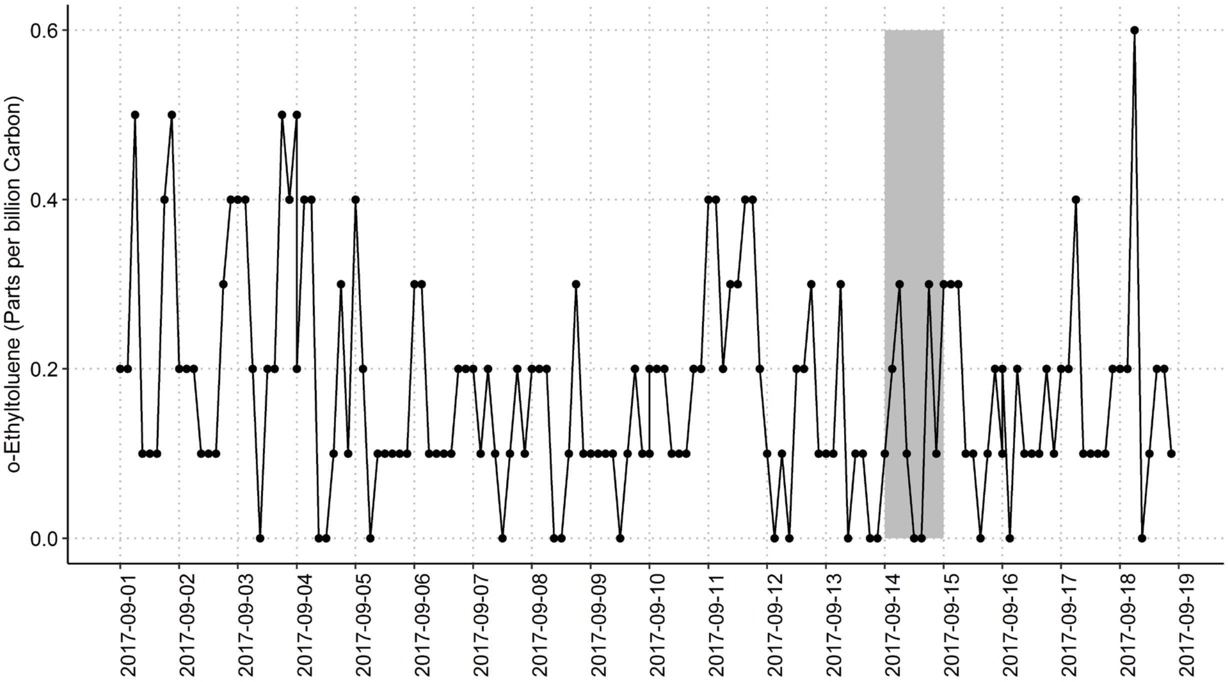

Figure B-21. o-Ethyltoluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

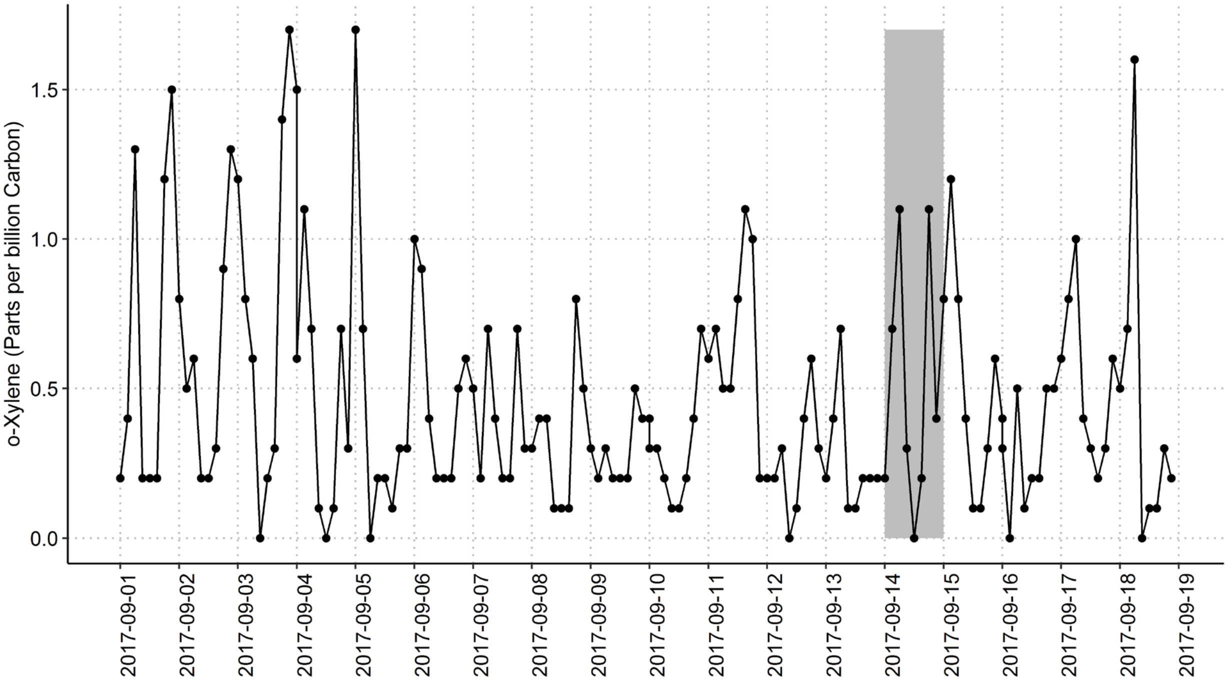

Figure B-22. o-Xylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

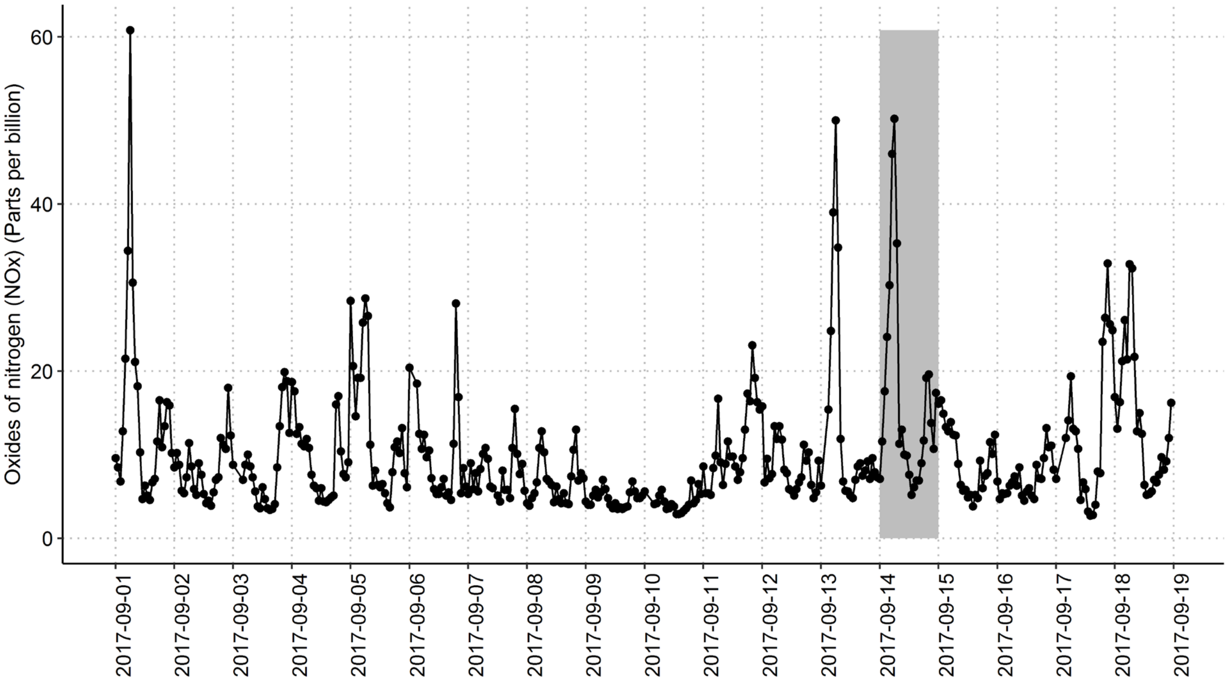

Figure B-23. Oxides of nitrogen (NO_x) measurements at the Capitol monitoring site from September 1 through September 18, 2017.

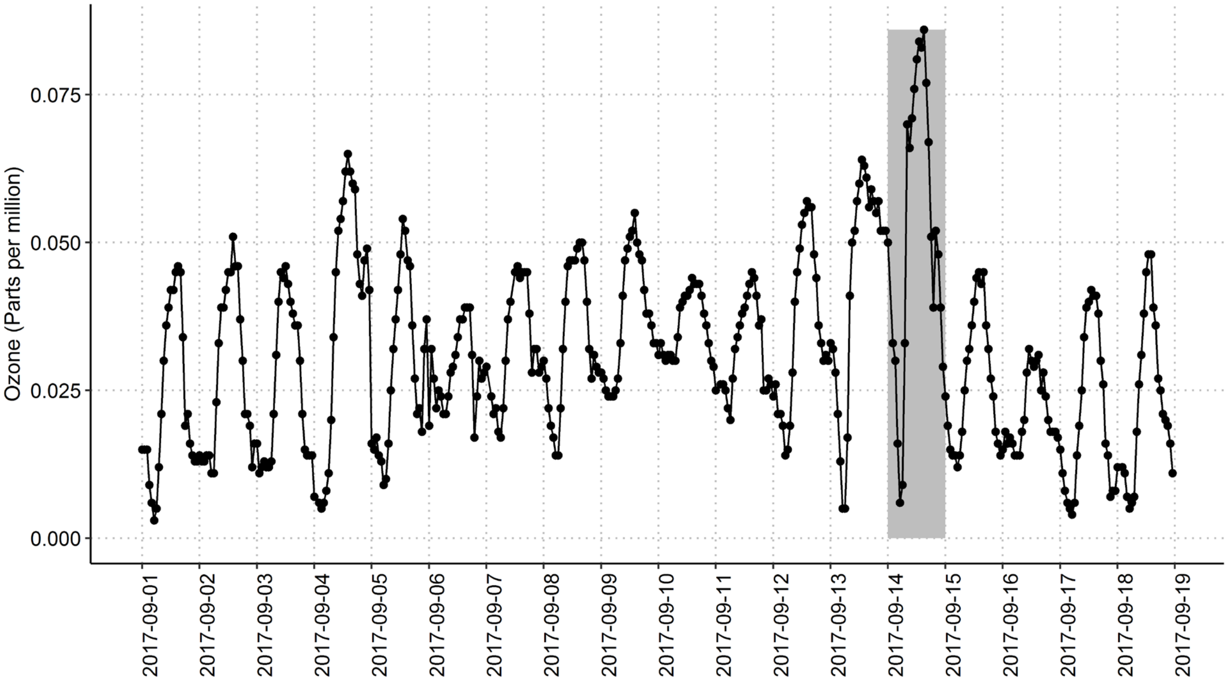

Figure B-24. Ozone measurements at the Capitol monitoring site from September 1 through September 18, 2017.

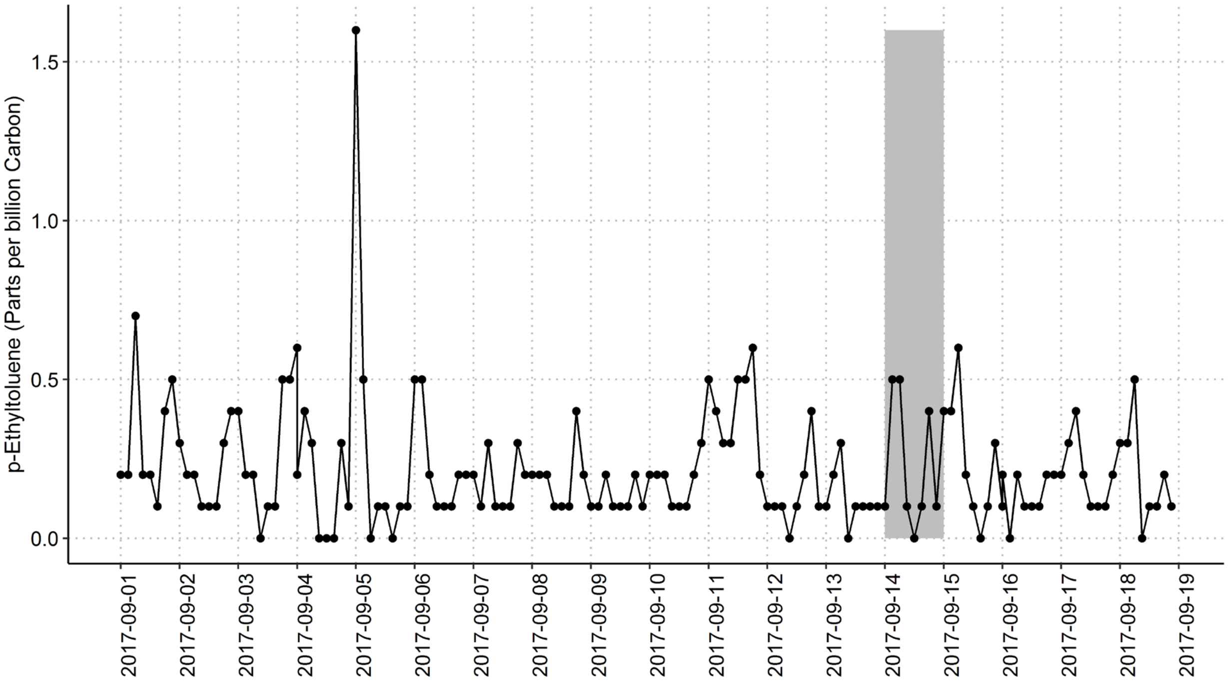

Figure B-25. p-Ethyltoluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

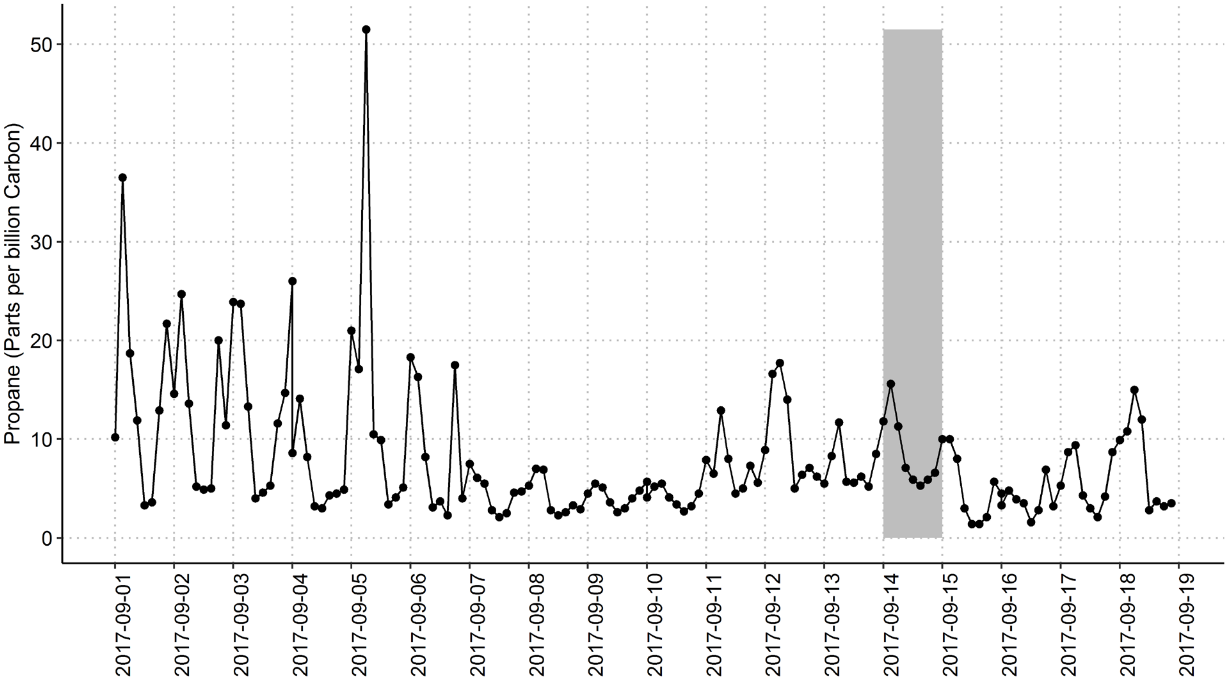

Figure B-26. Propane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

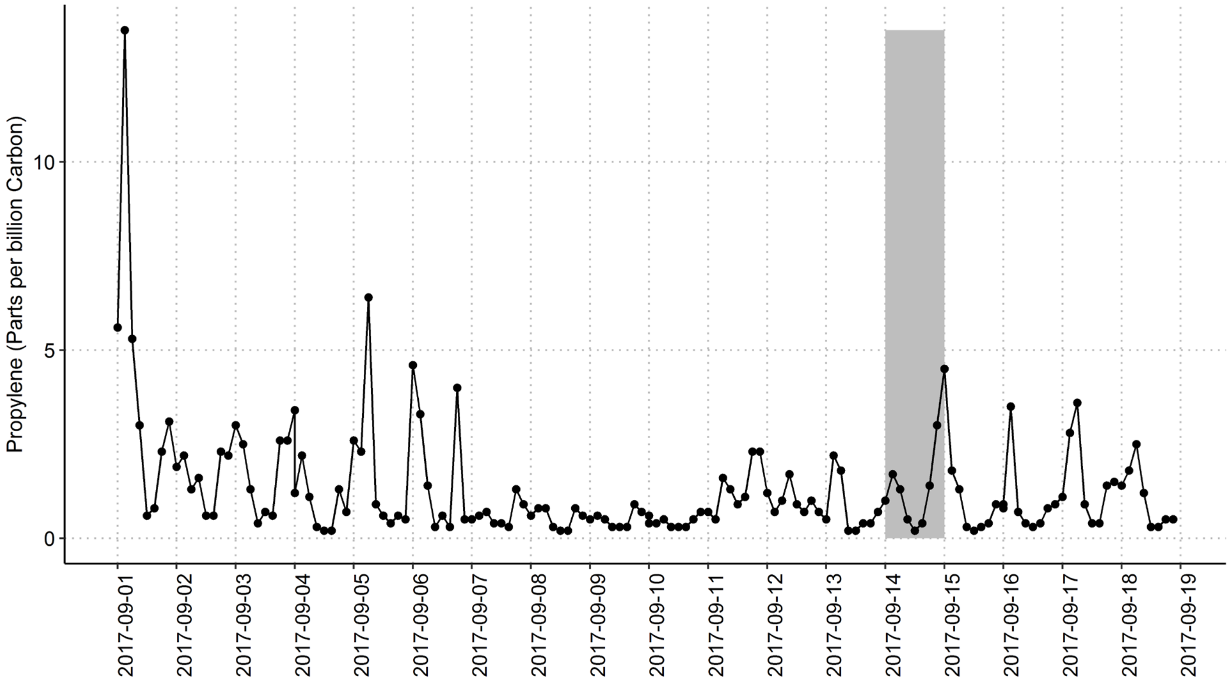

Figure B-27. Propylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

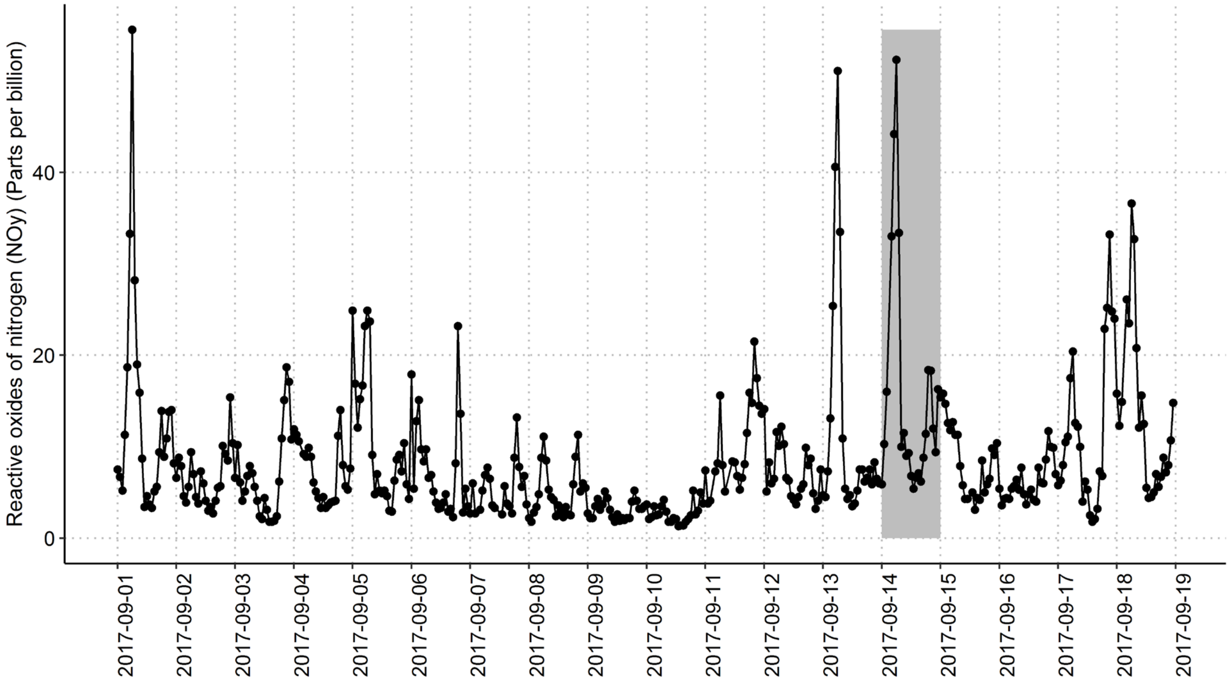

Figure B-28. Reactive oxides of nitrogen (NO_y) measurements at the Capitol monitoring site from September 1 through September 18, 2017.

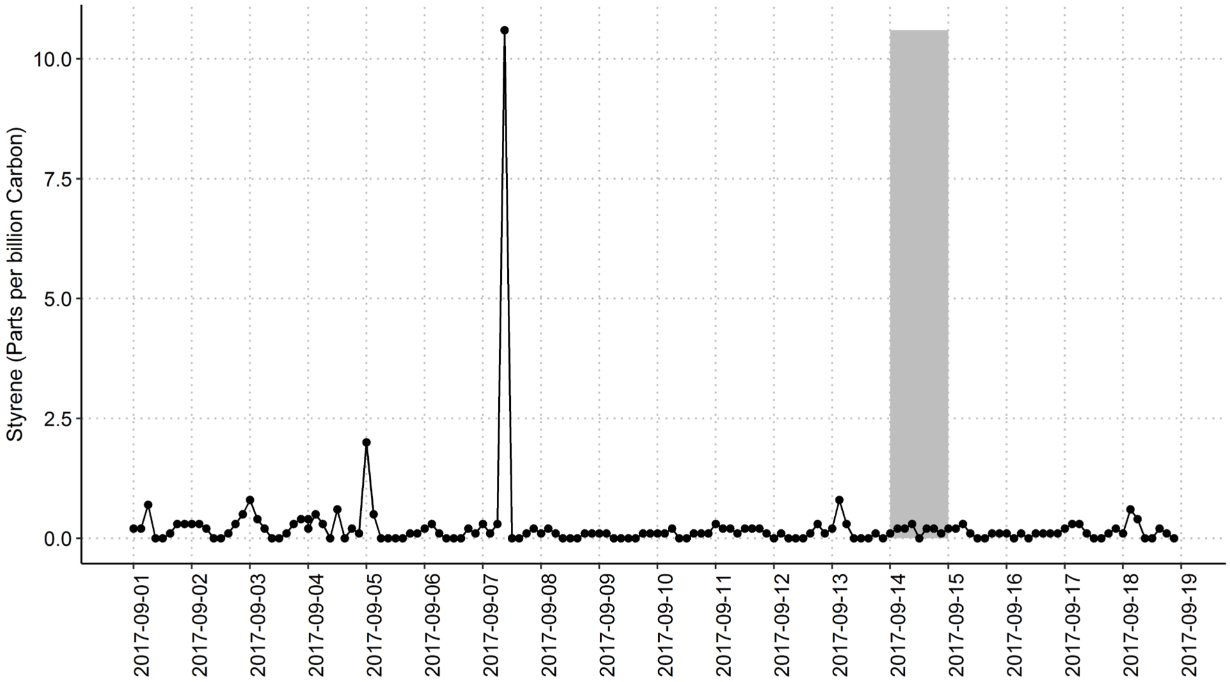

Figure B-29. Styrene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

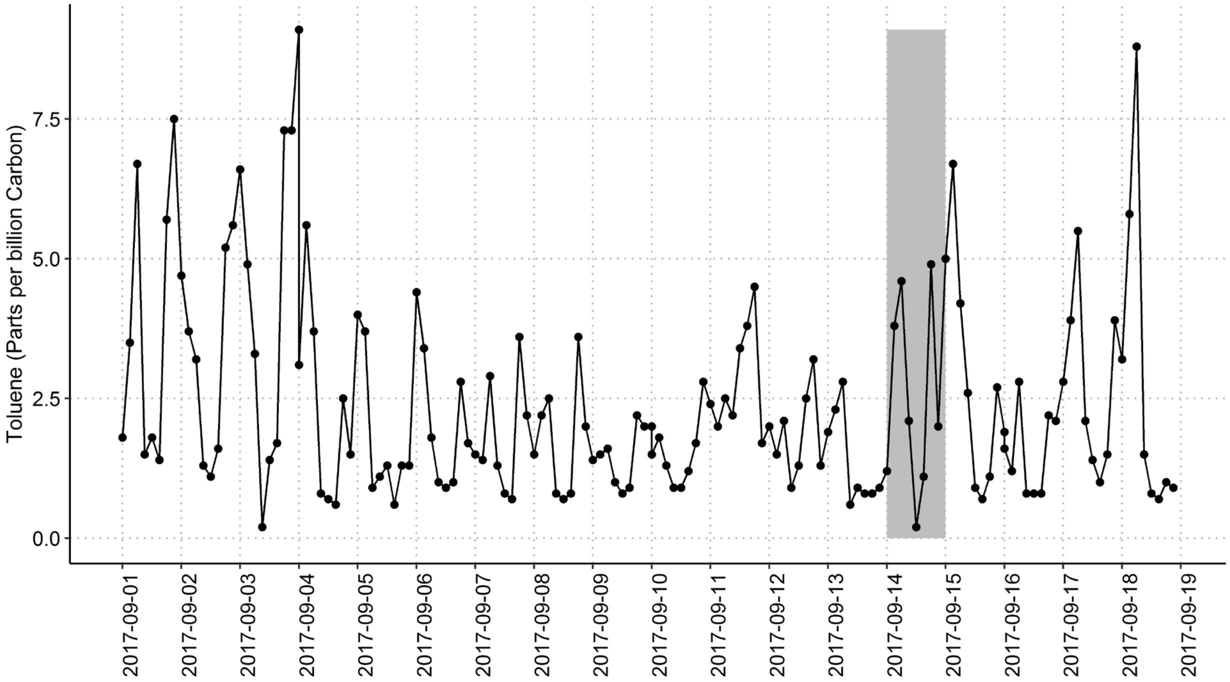

Figure B-30. Toluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

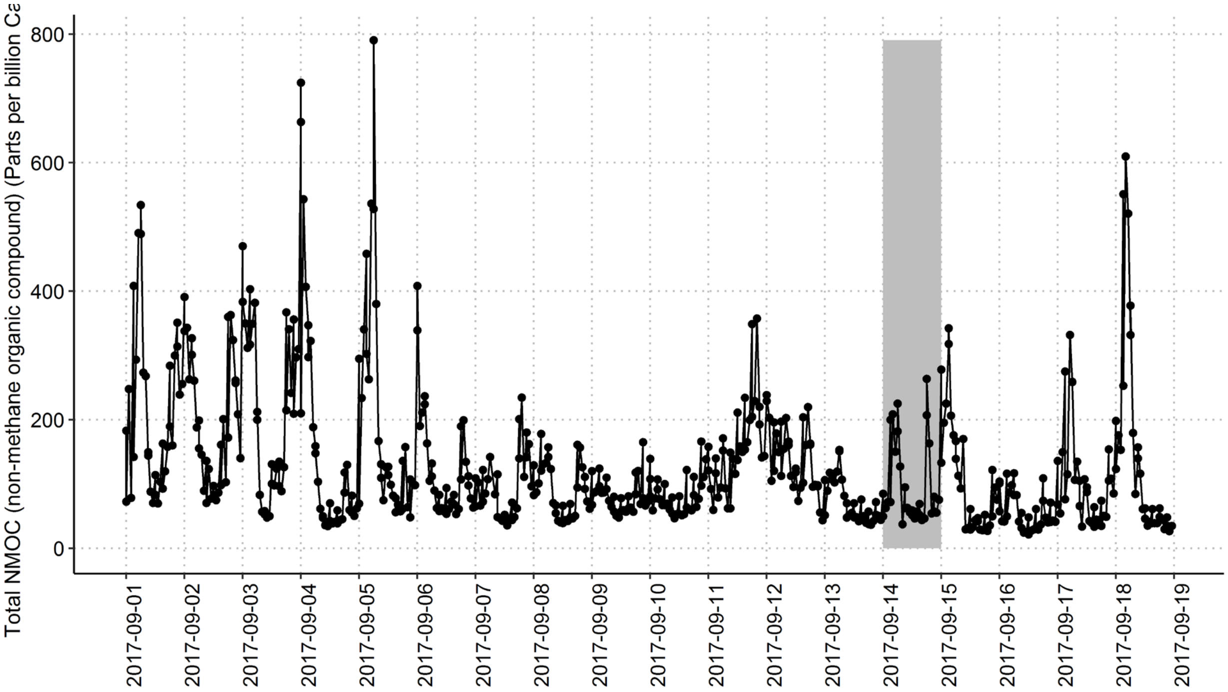

Figure B-31. Total non-methane organic compound measurements at the Capitol monitoring site from September 1 through September 18, 2017.

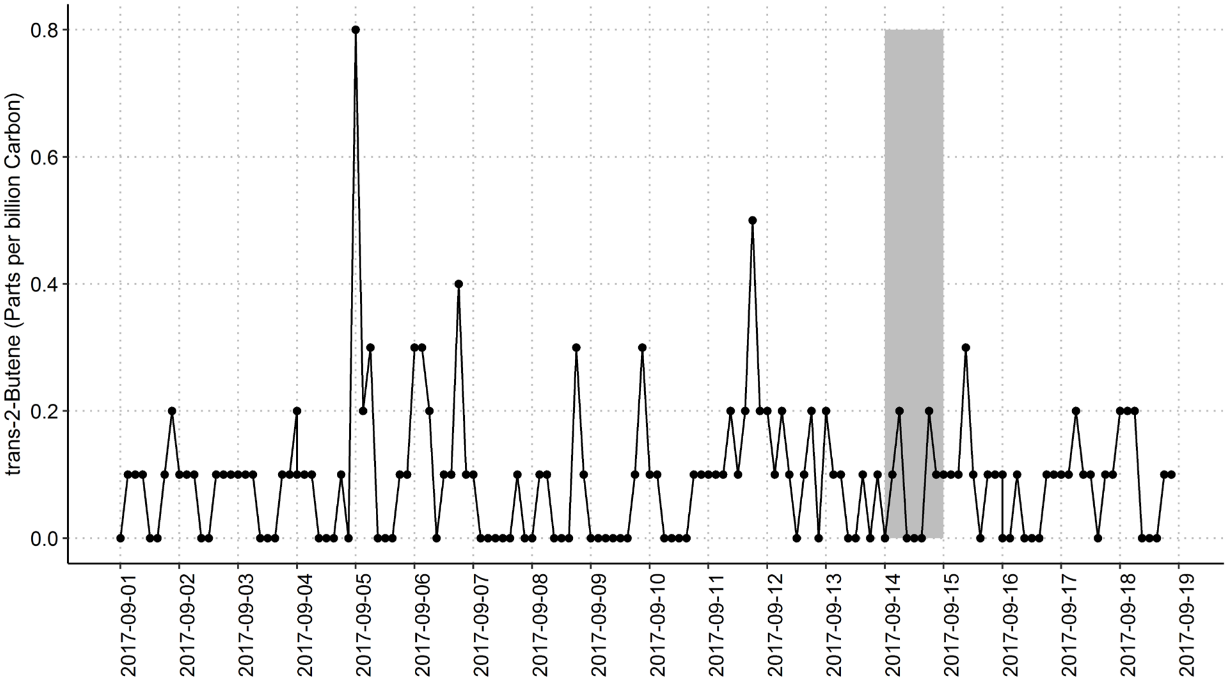

Figure B-32. Trans-2-butene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

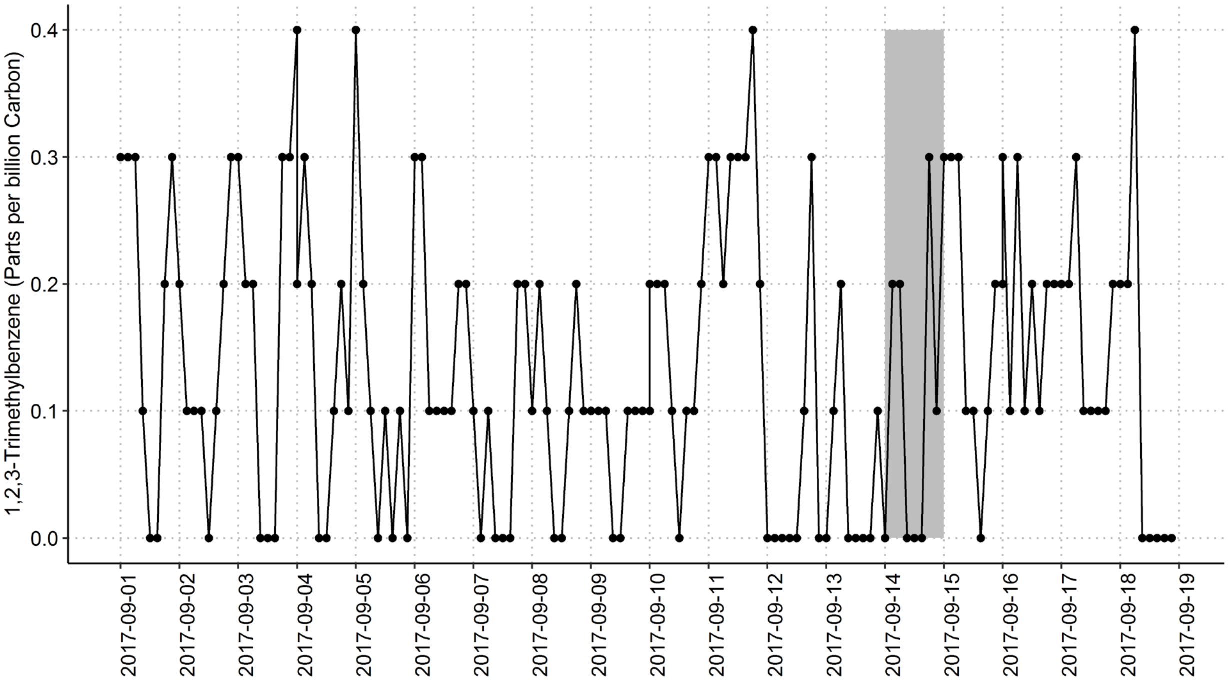

Figure B-33. 1,2,3-Trimethylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

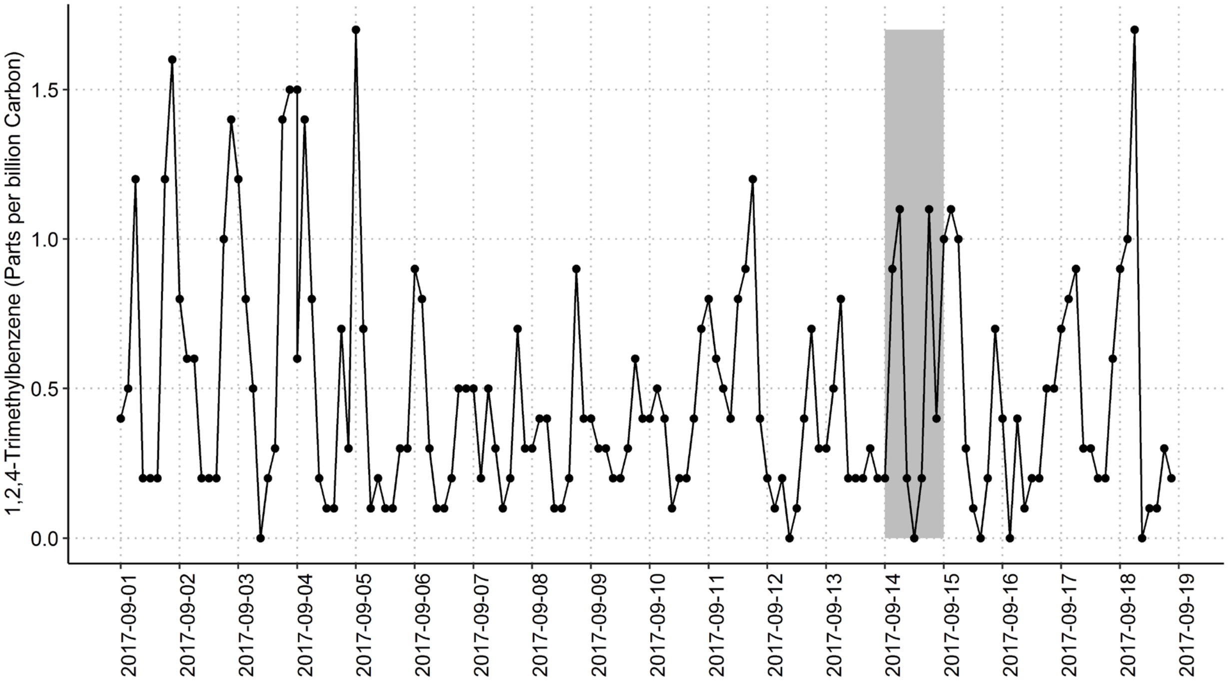

Figure B-34. 1,2,4-Trimethylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

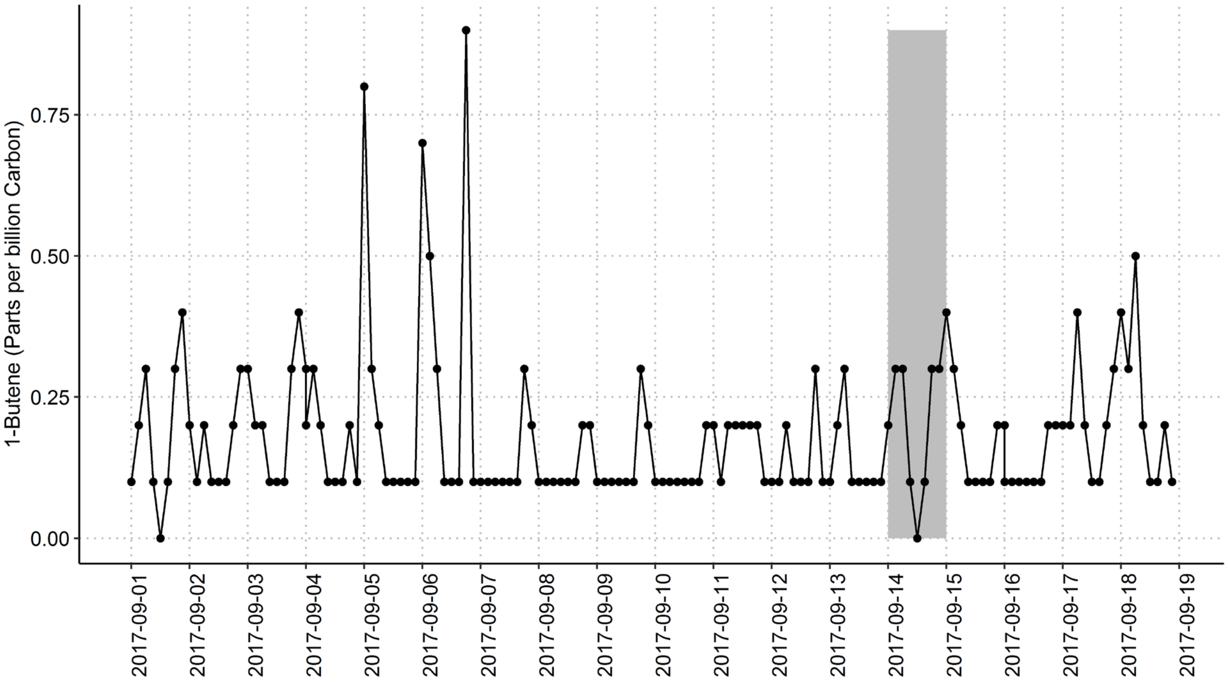

Figure B-35. 1-Butene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

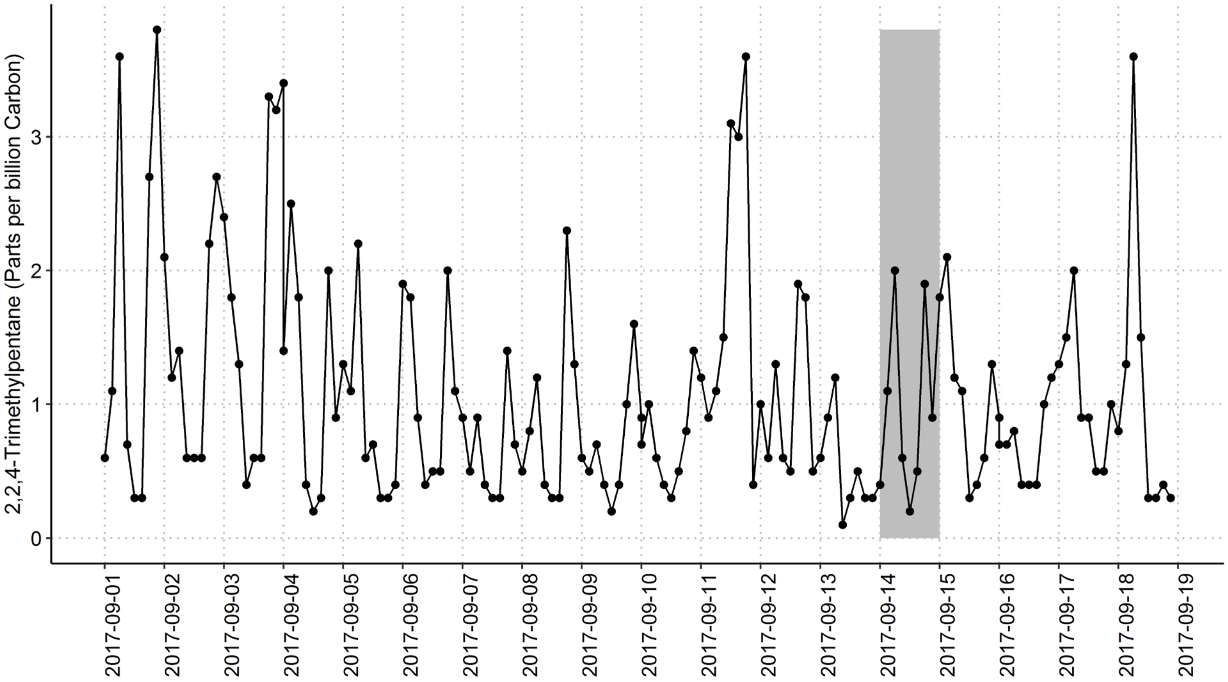

Figure B-36. 2,2,4-Trimethylpentane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

Appendix C. Coarse Resolution Photochemical Modeling With and Without Fire Emissions

Figure C-1 shows the BlueSky Gateway model's estimated impacts of fires in the United States on peak 8-hr average ozone concentrations at the surface on September 14, 2017. This result indicates qualitatively that ozone concentrations in Louisiana were impacted by smoke on September 14.

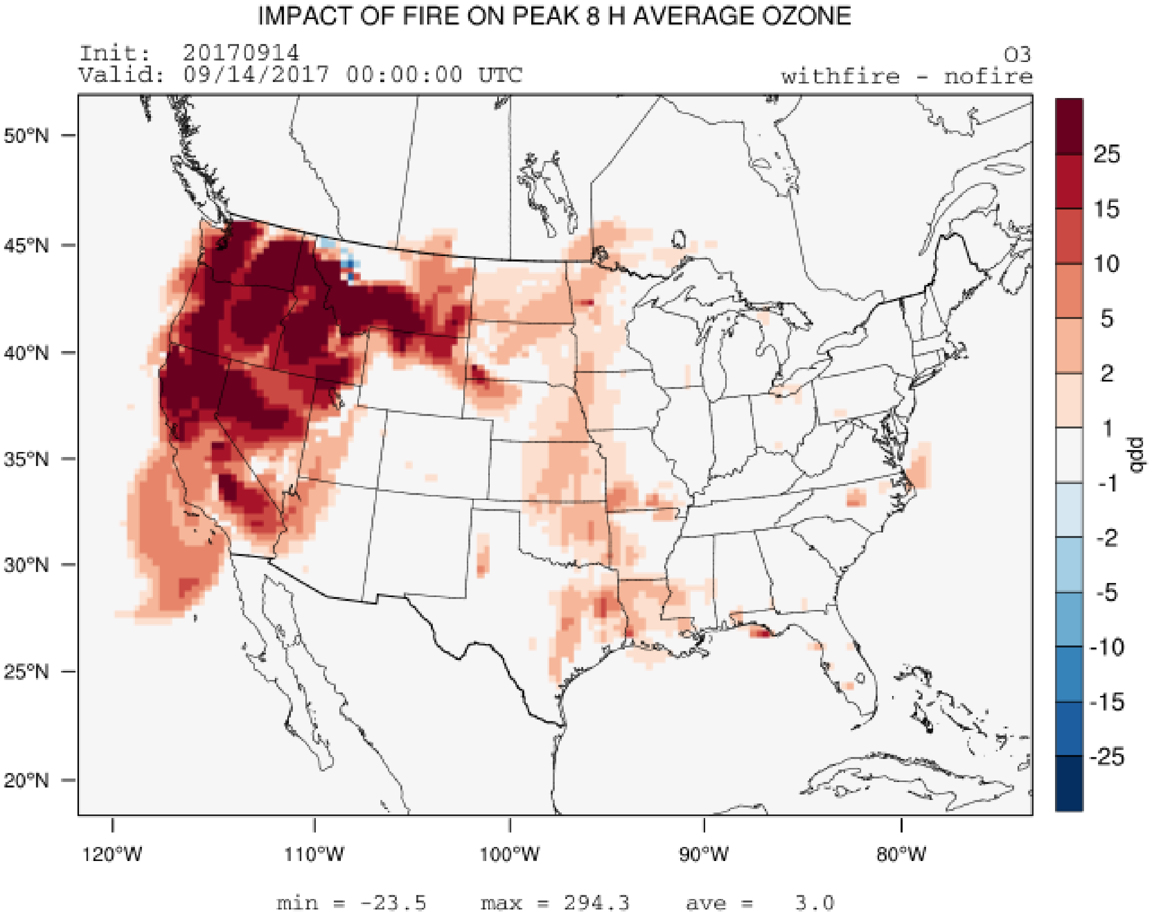

Figure C-1. Impact of fires within the United States on peak 8-h average ozone concentrations on September 14, 2017. Given the operational forecast nature of BlueSky Gateway, these results are best interpreted as a qualitative indicator of potential smoke impacts rather than as a quantitative measure of ozone present due to smoke.

BlueSky Gateway (Craig et al., 2007; Strand et al., 2012) is an operational air quality forecasting system developed by STI in collaboration with the USDA Forest Service to predict nationwide air quality impacts due to wildfires and other emission sources at 36-km resolution. BlueSky Gateway components include the BlueSky Framework for estimating fire emissions; the Pennsylvania State University/National Center for Atmospheric Research's Mesoscale Model (MM5) for predicting meteorological conditions; the Community Multiscale Air Quality (CMAQ) model for predicting gaseous and particulate pollutant concentrations; and the Sparse Matrix Operator Kernel Emissions (SMOKE) processing system for incorporating emissions. Simulations are initialized daily at 0000 GMT (00Z).

Daily fire locations and sizes are provided by the Satellite Mapping Automatic Reanalysis Tool for Fire Incident Reconciliation (SmartFire) (Raffuse et al., 2013), which integrates and reconciles satellite-detected fire data from the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) analyses into BlueSky Gateway. The BlueSky Framework was used to develop emissions estimates from the SmartFire burn area predictions. This methodology is similar to that currently used by the EPA for developing national fire emission inventories (Sullivan et al., 2009). Non-fire anthropogenic emissions from the National Emission Inventory are prepared for air quality modeling and merged with the fire emissions inputs using SMOKE.

Two CMAQ air quality simulations are run within the BlueSky Gateway each day. Simulations are run with and without smoke emissions. The purpose of this second simulation is to estimate the impact of fire emissions on ozone concentrations. The difference between the ozone concentrations modeled with and without fire emissions is calculated by subtracting the fire emissions model results from the model results without fire emissions. For retrospective purposes such as exceptional event demonstrations, additional information and computational approaches could be used to improve results. Therefore, for purposes of this report, the BlueSky Gateway results are best interpreted as a qualitative indicator of potential smoke impacts rather than as a quantitative measure of ozone present due to smoke.

References

Craig K.J., Wheeler N.J.M., Reid S.B., Gilliland E.K., and Sullivan D.C. (2007) Development and operation of national CMAQ-based $PM_{2.5}$ forecast system for fire management. Presented at the *6th Annual CMAS Conference, Chapel Hill, NC, October 1-3,* by Sonoma Technology, Inc., Petaluma, CA. STI-3228.

Raffuse S.M., Larkin N.K., and Dedecko T.M. (2013) SmartFire 2: a flexible framework for merging fire information. Presented at the *4th Fire Behavior and Fuels Conference, Raleigh, NC, February 21,* by Sonoma Technology, Inc., Petaluma, CA. STI-5467.

Strand T.M., Larkin N., Craig K.J., Raffuse S., Sullivan D., Solomon R., Rorig M., Wheeler N., and Pryden D. (2012) Analysis of BlueSky Gateway $PM_{2.5}$ predictions during the 2007 southern and 2008 northern California fires. *J. Geophys. Res*, 117(D17301), doi: 10.1029/2012JD017627. Available at http://onlinelibrary.wiley.com/doi/10.1029/2012JD017627/pdf.

Sullivan D.C., Du Y., and Raffuse S.M. (2009) SMARTFIRE- and BlueSky-enabled methodology for developing wildland fire emission inventories for 2006-2008. Technical memorandum prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC, by Sonoma Technology, Inc., Petaluma, CA, STI-905517-3714, October.

Appendix D. Meteorological Conditions

The upper-level weather pattern, surface weather pattern, and local meteorological conditions observed on September 13 and 14, 2017, suggest smoke transport, vertical mixing, and smoke accumulation in the Baton Rouge area.

Upper-Level Weather Pattern

Pressure patterns aloft can be used to determine regional atmospheric stability. In particular, 500-mb maps—which display height contours with winds at roughly 18,000 feet above sea level—are used to identify

- Ridges of high pressure, which are associated with a stable atmosphere with reduced vertical mixing.
- Troughs of low pressure, which are associated with an unstable atmosphere and enhanced vertical mixing.
- Aloft wind patterns that may indicate long-range pollutant transport.

On September 13, 2017, an upper-level trough of low pressure associated with the remnants of Hurricane Irma enhanced atmospheric mixing over the southeastern U.S. (**Figure D-1**). This mixing allowed aloft smoke to reach the lower levels of the atmosphere. Discussion of aloft winds and transport is provided in the Aloft Smoke Transport section in this appendix.

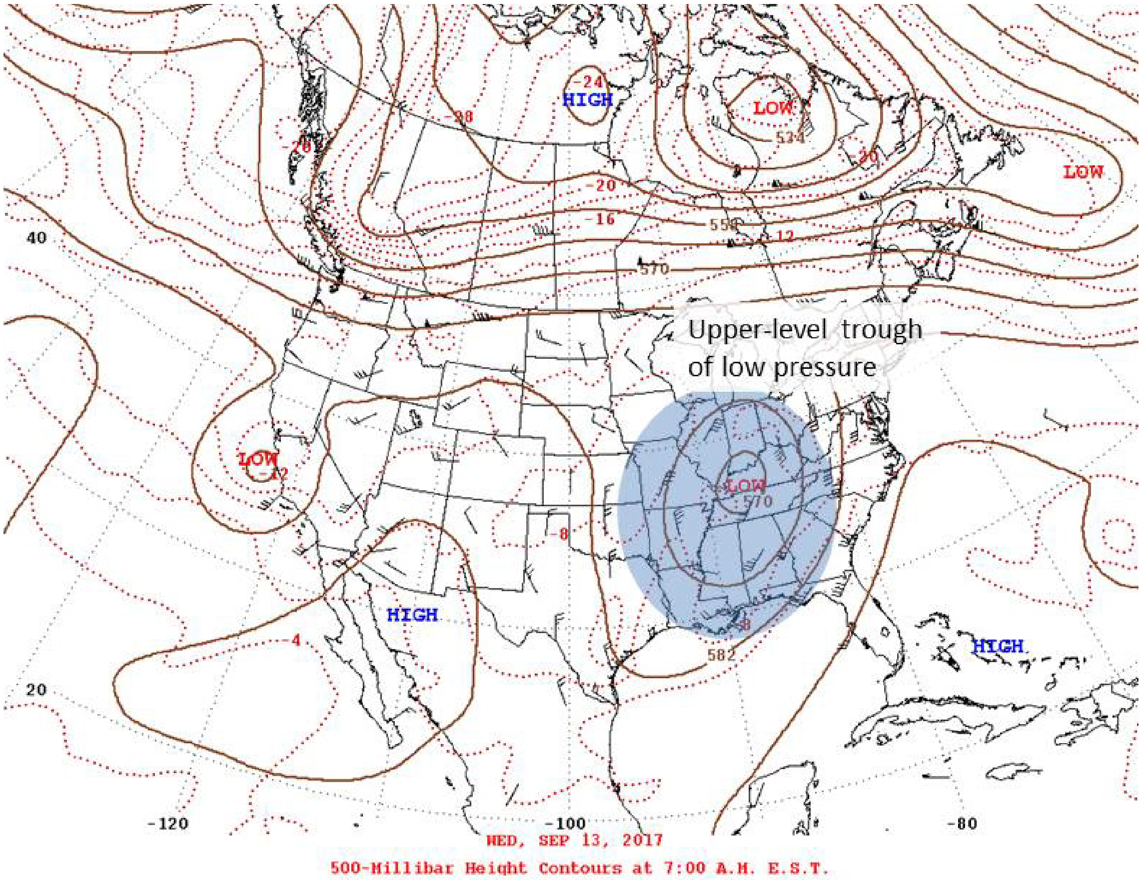

Figure D-1. Upper-level weather pattern on September 13, 2017. Contours indicate 500-mb heights and regions of aloft high pressure and low pressure. Source: http://www.wpc.ncep.noaa.gov/dailywxmap/.

On September 14, 2017, an upper-level ridge of high pressure reduced atmospheric mixing over Louisiana, trapping pollutants near the ground (**Figure D-2**). Under these stable conditions, smoke that had mixed down from aloft on September 13 or earlier would have been confined in the lower atmosphere. This ridge also produced partly to mostly sunny skies and temperatures in the mid- to upper-80s in Baton Rouge. These weather conditions supported the formation of ground-level ozone.

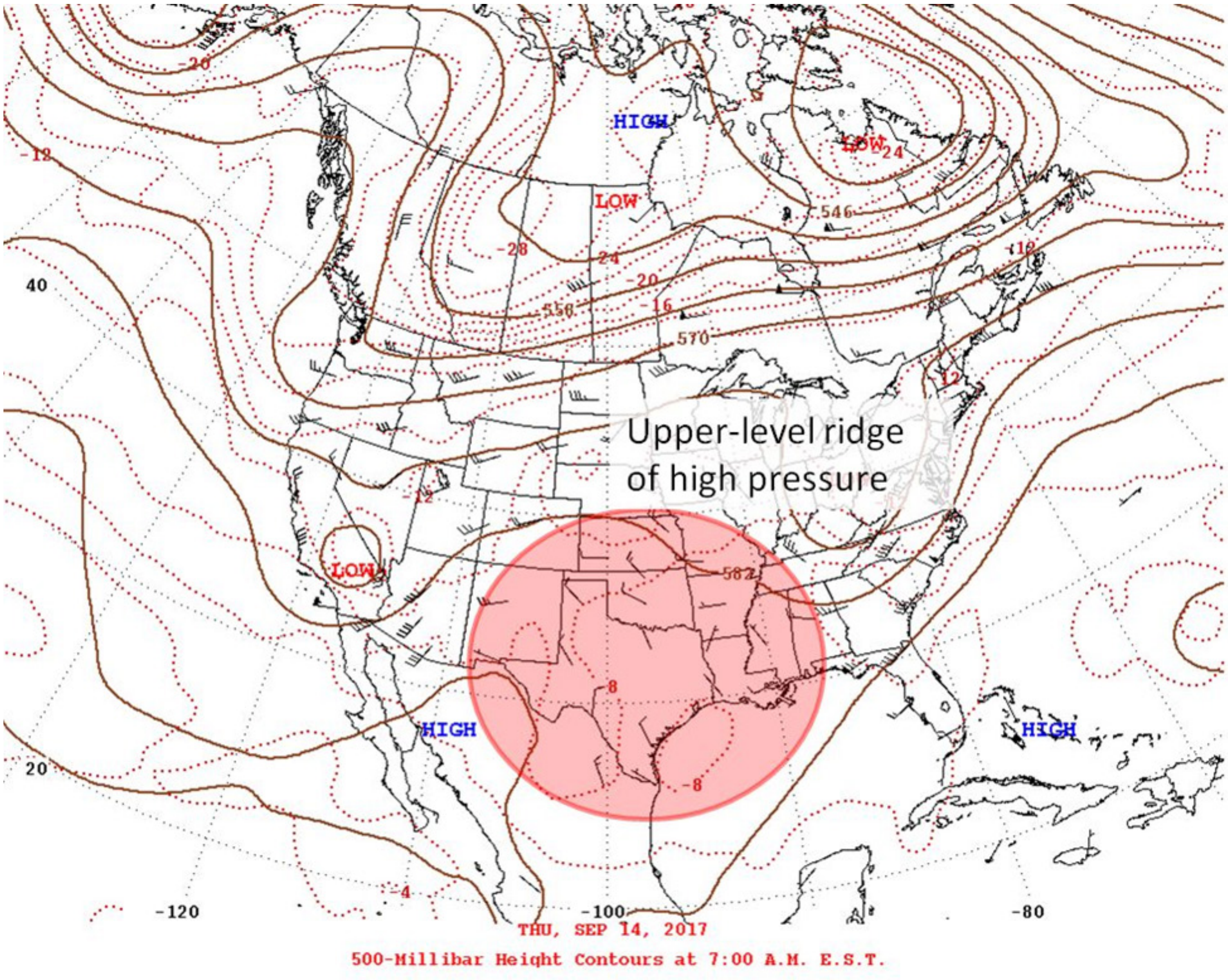

Figure D-2. Upper-level weather pattern on September 14, 2017. Contours indicate 500-mb heights and regions of aloft high pressure and low pressure. Source: http://www.wpc.ncep.noaa.gov/dailywxmap/.

Surface Weather Pattern and Winds

On September 14, 2017, surface high pressure over the southeastern U.S. produced light winds in Baton Rouge, reducing horizontal pollutant dispersion and allowing pollutants to accumulate (**Figure D-3**).

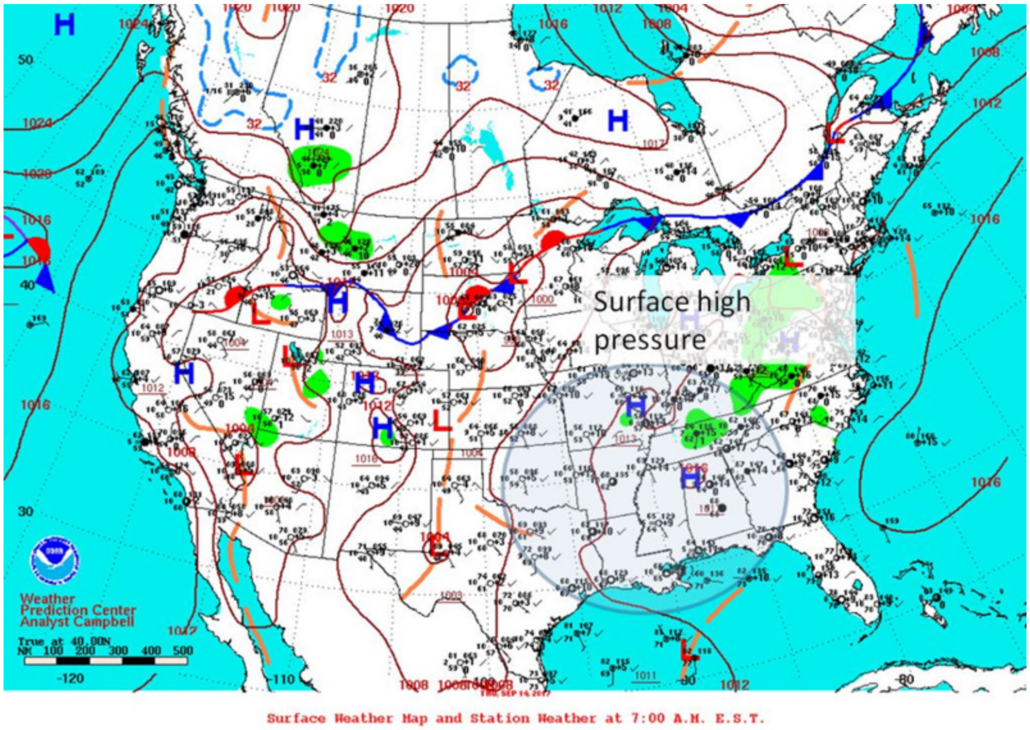

Figure D-3. Surface weather map for September 14, 2017. Contours indicate sea level pressure. Source: http://www.wpc.ncep.noaa.gov/dailywxmap/.

Aloft Smoke Transport

Although surface winds were light on September 13 and 14, aloft winds (at 500 mb, or approximately 18,000 feet above sea level) over the previous days indicated potential smoke transport from wildfires in the Pacific Northwest toward the Northern Plains and south toward the Gulf Coast. The upper-level wind pattern shown in **Figure D-4** for the afternoon of September 13 is consistent with this long-range transport path.

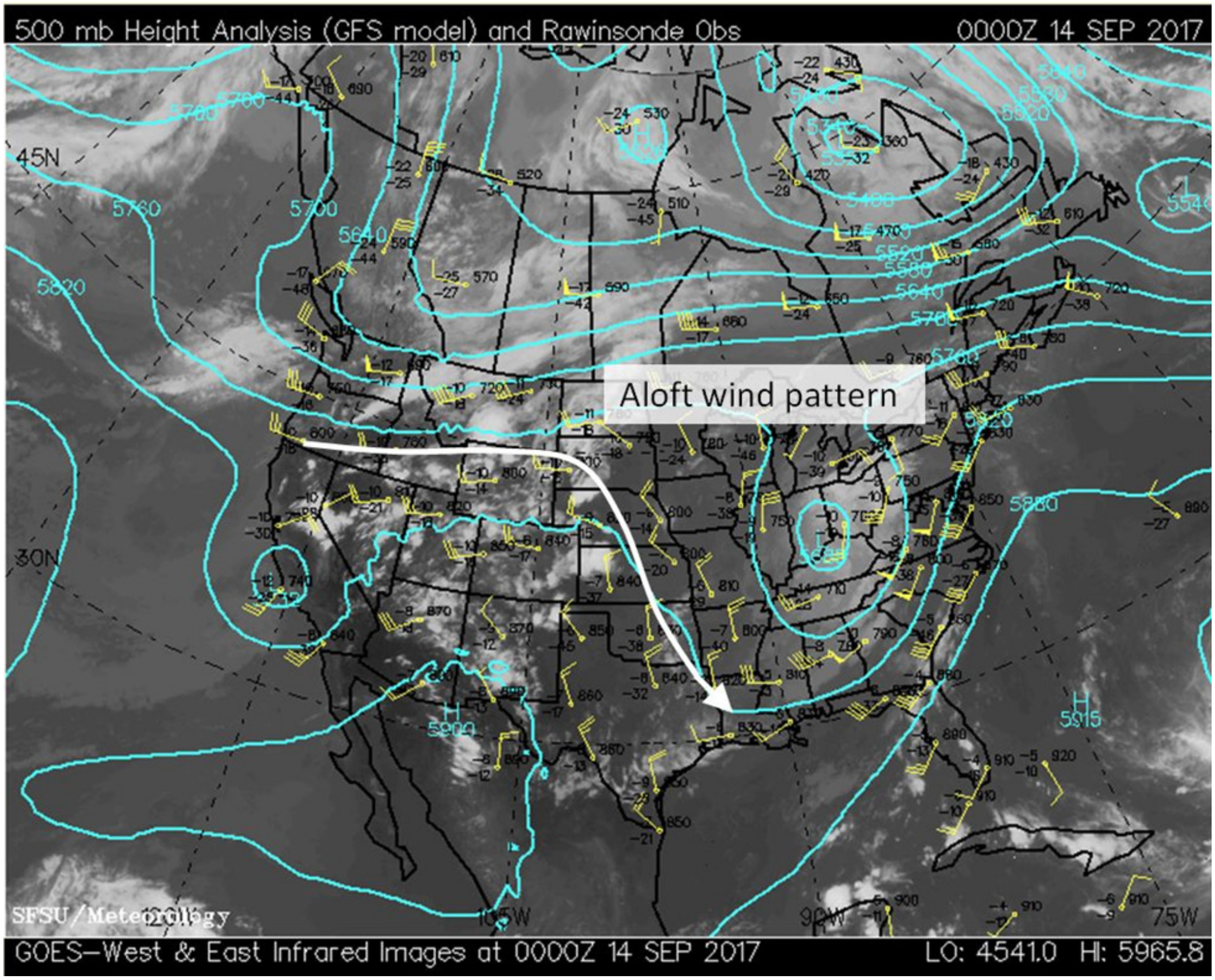

Figure D-4. Aloft (500-mb) wind pattern on the afternoon of September 13, 2017. Wind barbs (yellow) indicate upper-level transport from the Pacific Northwest to the east over the Northern Plains and south toward the Gulf Coast. Source: http://squall.sfsu.edu/scripts/sathts_500_archloop.html.

Local Weather Conditions in Baton Rouge

In addition to the stable upper-level weather pattern on September 14 which limited atmospheric mixing over Louisiana, local weather conditions in Baton Rouge were favorable for pollutant accumulation and ozone formation. Specifically, surface winds were light and variable throughout the day, reducing pollutant dispersion. Figure D-5 shows time series for wind speed and direction at the Baton Rouge Metropolitan Airport, Ryan Field (KBTR). The hours shown without wind speed data (top chart) are indicative of calm conditions. The variable wind directions during the other hours (bottom chart) allowed for pollutant recirculation and accumulation.

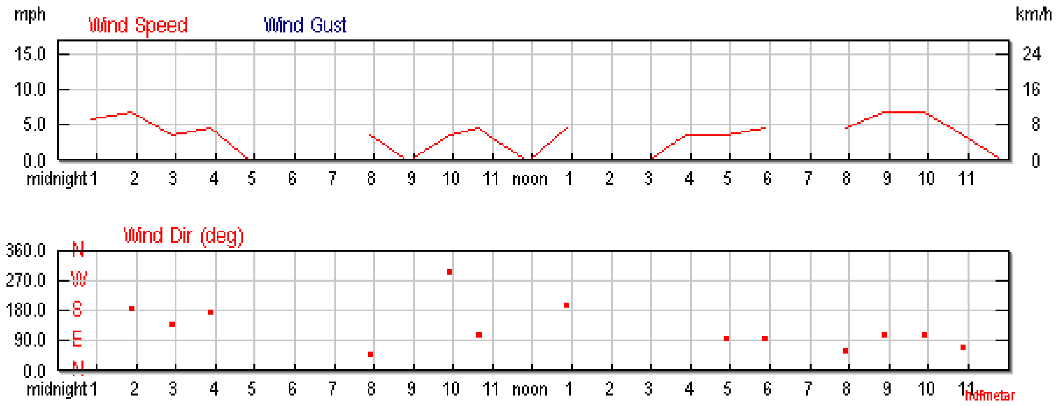

Figure D-5. Observed winds at KBTR on September 14, 2017, showing wind speeds (top chart) in mph and wind direction (bottom chart) in degrees from north. Source: http://www.wunderground.com.

Warm temperatures and sunny skies enhance the formation of ground-level ozone. The maximum temperature recorded at KBTR on September 14 was 88°F, which is about normal for mid-September in Baton Rouge. Skies were partly to mostly sunny throughout the day. However, cloud development may have reduced ozone production slightly (**Figure D-6**) during the midday and afternoon hours, which are typically peak production hours for ozone.

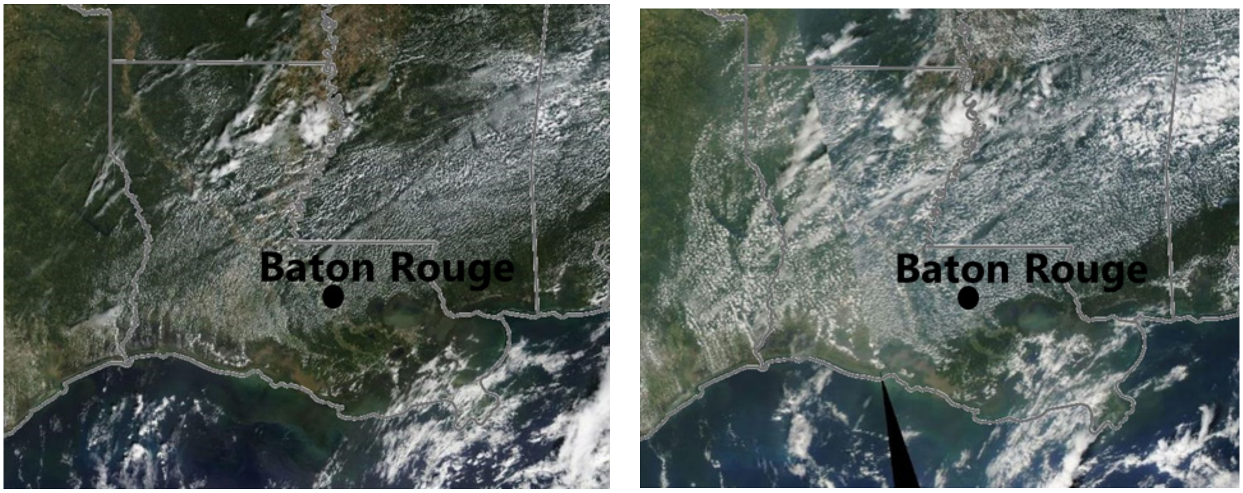

Figure D-6. Moderate Resolution Imaging Spectroradiometer (MODIS) Terra (left) and Aqua (right) visible satellite imagery on September 14, 2017, at approximately 11:00 a.m. and 12:30 p.m., respectively. Midday cloud development may have limited ozone production. Source: https://modis.gsfc.nasa.gov/.

Appendix 4

Sonoma Technology, Inc.
Innovative Environmental Solutions

Technical Memorandum

February 26, 2018 STI-918003-6877-TM

To: Vennetta Hayes, Louisiana Department of Environmental Quality, Air Permits Division

From: Nathan Pavlovic, Steve Brown, Theresa O'Brien, ShihMing Huang

Re: Addendum to "Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017" dated February 20, 2018

Introduction

On September 14, 2017, the Baton Rouge area of Louisiana experienced elevated ozone concentrations area-wide. Ozone concentrations on that day could result in an ozone nonattainment designation for the Baton Rouge area under the 2015 8-hr ozone National Ambient Air Quality Standards (NAAQS). Evidence suggests that wildfire smoke from the northwestern United States may have contributed to elevated ozone. If a clear causal relationship can be demonstrated between the smoke and ozone exceedances on September 14, then that day's data can be omitted from calculations for the purpose of ozone nonattainment designations.

To investigate a clear causal relationship between wildfire smoke and the September 14 exceedance, Sonoma Technology, Inc. (STI) previously conducted analyses consistent with Tier 1 and Tier 2 smoke exceptional event demonstrations (Pavlovic et al., 2018). Based on review of the initial analysis results, EPA determined that additional analyses of the event in question were needed. EPA recommended additional analysis of wind trajectories, additional analysis of Cloud Aerosol Transport System (CATS) satellite data, and a detailed analysis of hourly ground-level ambient monitoring data at regional/upwind sites in Louisiana and Texas. These additional analyses, performed by STI, demonstrate that smoke traveled from fires in the northwestern United States to Louisiana and other southern states, and that smoke from long-range transport influenced air quality at sites in Louisiana and surrounding states. These findings, together with previously reported findings, are supportive of a Tier 3 exceptional event demonstration.

Additional Wind Trajectories

Satellite data provided in the initial report show that smoke was transported from fires in the northwestern United States to Louisiana. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) runs from the fires in the northwestern United States also show that air was transported from these fires to the central United States by September 11 and to Texas and Oklahoma by September 13. In addition, HYSPLIT back trajectories from Louisiana on September 14 show that air was transported to Louisiana from Texas over September 11, 12, and 13. This transport pattern is apparent in forward HYSPLIT trajectories run from Idaho initiated on September 8 and back trajectories run from the Dutchtown monitoring site in the Baton Rouge area on September 14 (**Figure 1**).

To further investigate the transport of smoke from northwestern fires to Baton Rouge, we used satellite images and SmartFire/Bluesky (U.S. Environmental Protection Agency, 2016) emissions results to identify a high-emitting fire that contributed to the smoke plume that impacted Louisiana air quality. On September 4 and 5, 2017, the Highline Fire in the Payette National Forest, approximately 23 miles east/northeast of Warren, Idaho, was "extremely active".[1] The fire, which was caused by a lightning strike, is associated with large quantities of smoke emissions visible in satellite images on September 5 (**Figure 2**). We ran forward HYSPLIT trajectory ensembles from the location of this fire starting on September 5 using the NAM12 (hybrid sigma-pressure) model. A HYSPLIT trajectory ensemble represents uncertainty in HYSPLIT trajectories by initiating multiple runs from the same location, with meteorological data offset by a fixed grid factor. A starting height of 4000 km was chosen because smoke was observed by the Cloud-Aerosol Transport System (CATS) at this altitude on September 5 **(Figure 3**). The resulting trajectories for the Highline Fire show that smoke was transported eastward from the fires, with resulting air parcel locations at 2300 UTC on September 10 forming a north-south line from Texas to Iowa (**Figure 4**). This north-south line of air parcels aligns with actual satellite observations of the smoke plume on September 11.

Additional HYSPLIT trajectories initiated on September 11, 2017, at 0000 UTC show that the air parcels containing smoke were transported from the central United States southward over Texas. Over September 13 and 14, these air parcels were then transported northwestward over the Gulf of Mexico to Louisiana and directly northward into Oklahoma (**Figure 5**). This transport pattern is again confirmed by satellite smoke observations. Over those same days, the vertical motion of the trajectories indicates downward transport, which is observed in several other data sources discussed in Section 3.5 of the initial report (Pavlovic et al., 2018). These trajectories further confirm the observations that (1) smoke from northwestern wildfires traveled to Louisiana and surrounding states on September 13 and 14, and (2) transported smoke traveled to the surface on those days.

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[1] https://inciweb.nwcg.gov/incident/article/5500/40073/.

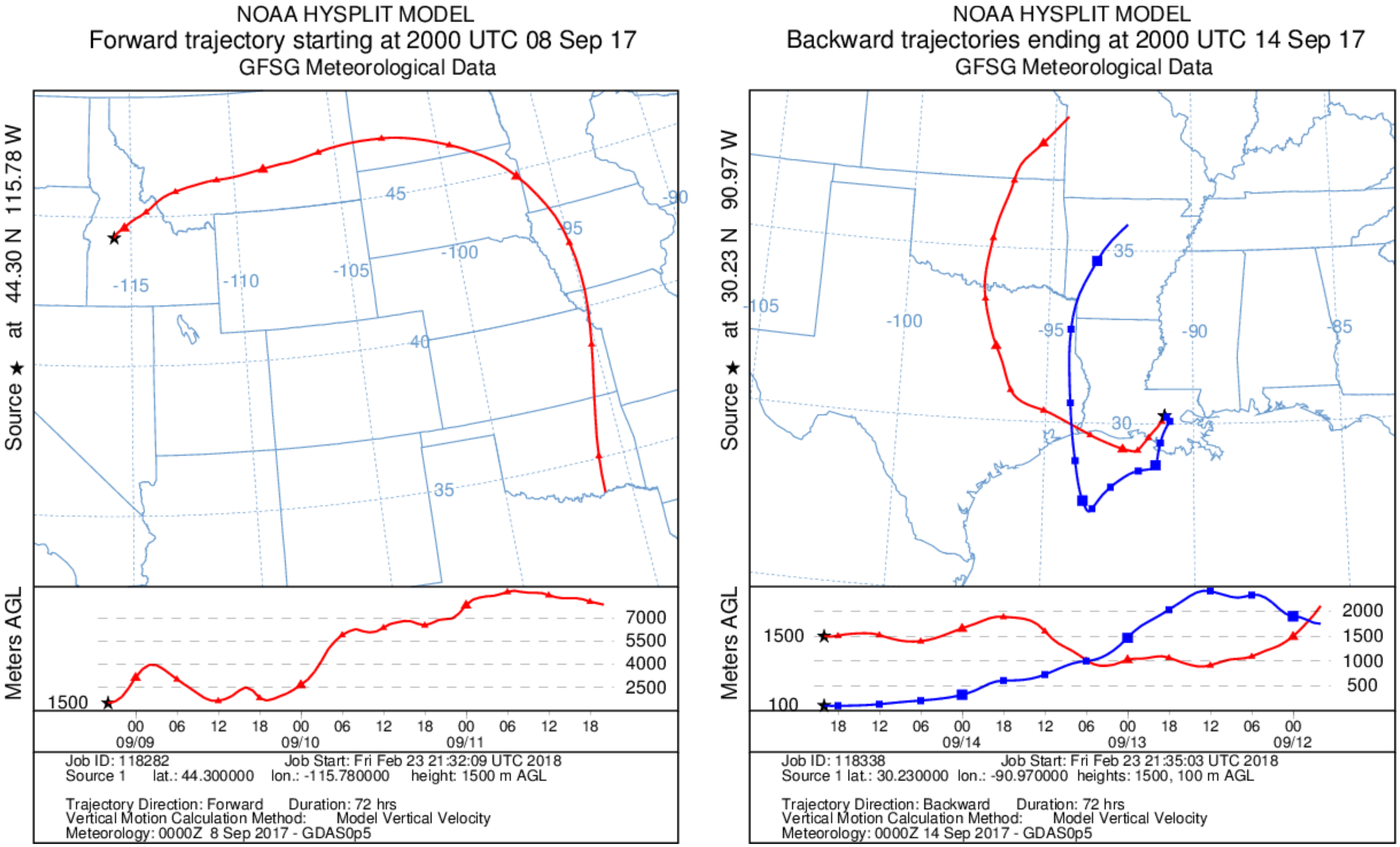


Figure 1. Forward HYSPLIT trajectories from the location of active fires in Idaho beginning on September 8, 2017 (left) and backward 72-hour trajectories from the Dutchtown monitor site in Baton Rouge beginning on the day of the exceedance, September 14, 2017 (right). The trajectories show the transport of smoke from fires in the northwest to Oklahoma by September 11, 2017, and further show that air parcels at Baton Rouge on September 14, 2017, were transported from Oklahoma beginning on September 11, 2017. The overlap of these trajectories indicates that smoke from northwestern fires was transported eastward, arriving in Louisiana on September 14, 2017.

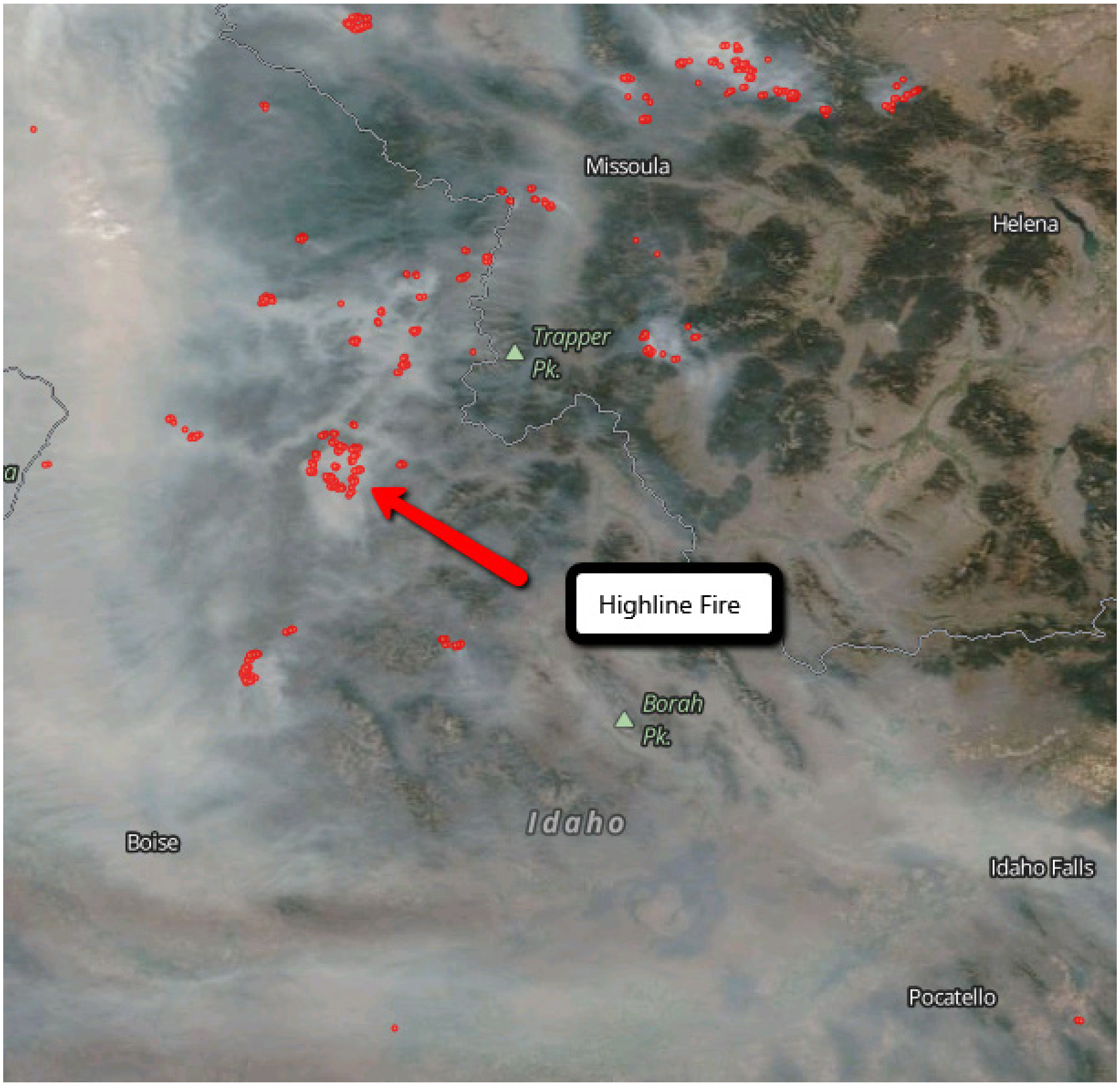


Figure 2. Visible Infrared Imaging Radiometer Suite (VIIRS) satellite image for September 5, 2017, showing widespread smoke, as well as Moderate Resolution Imaging Spectroradiometer (MODIS) active fire detections in red.

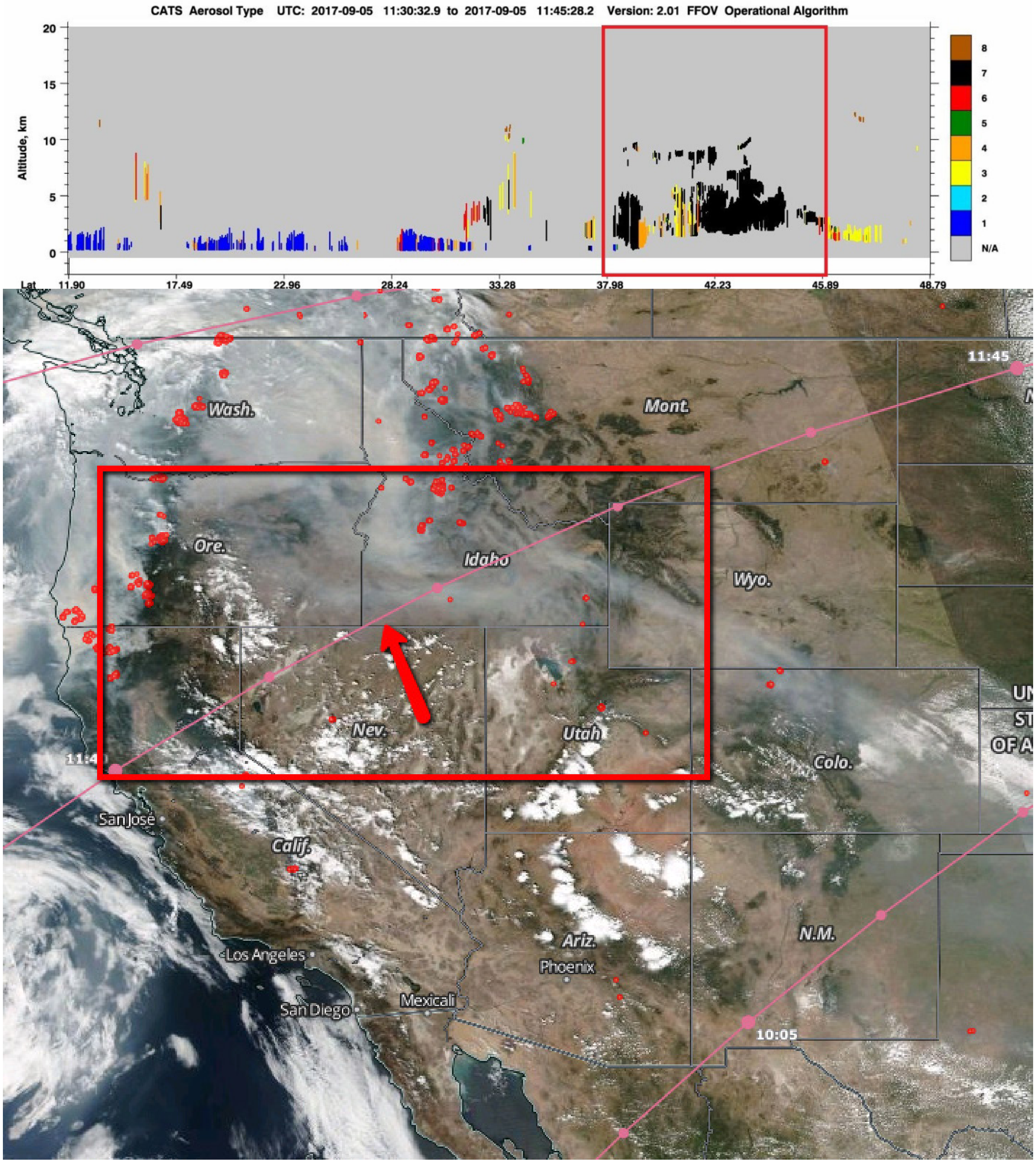


Figure 3. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-05 11:30. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box.

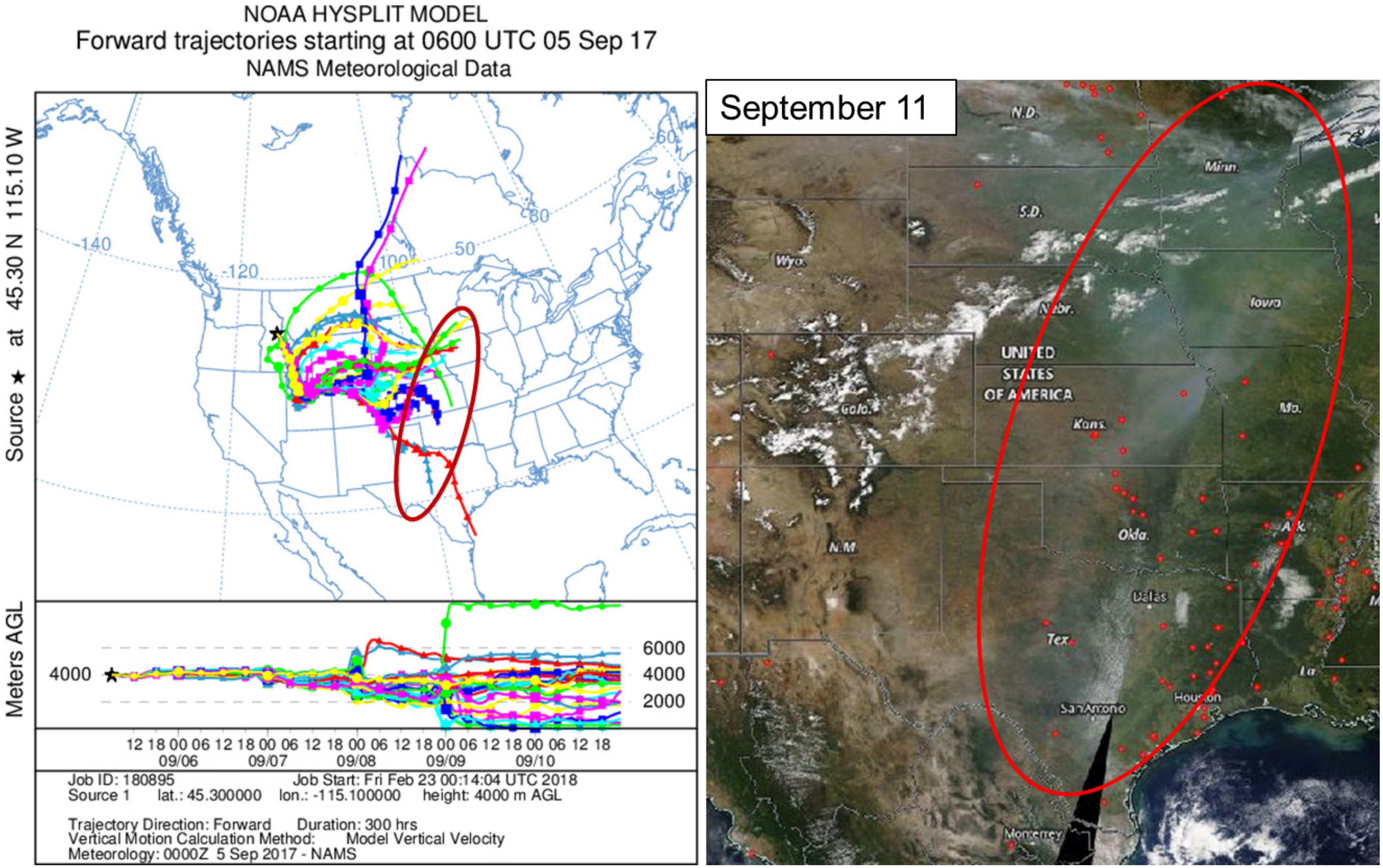


Figure 4. Forward HYSPLIT trajectory ensemble initiated at the location of the Highline Fire on September 5, 2017(left) and MODIS Terra true color satellite imagery from September 11, 2017 (right). The majority of trajectories end on September 10 at 2300 UTC between Texas and Iowa, as indicated with a red circle. The MODIS imagery also shows evidence of a smoke plume extending from Iowa to Texas.

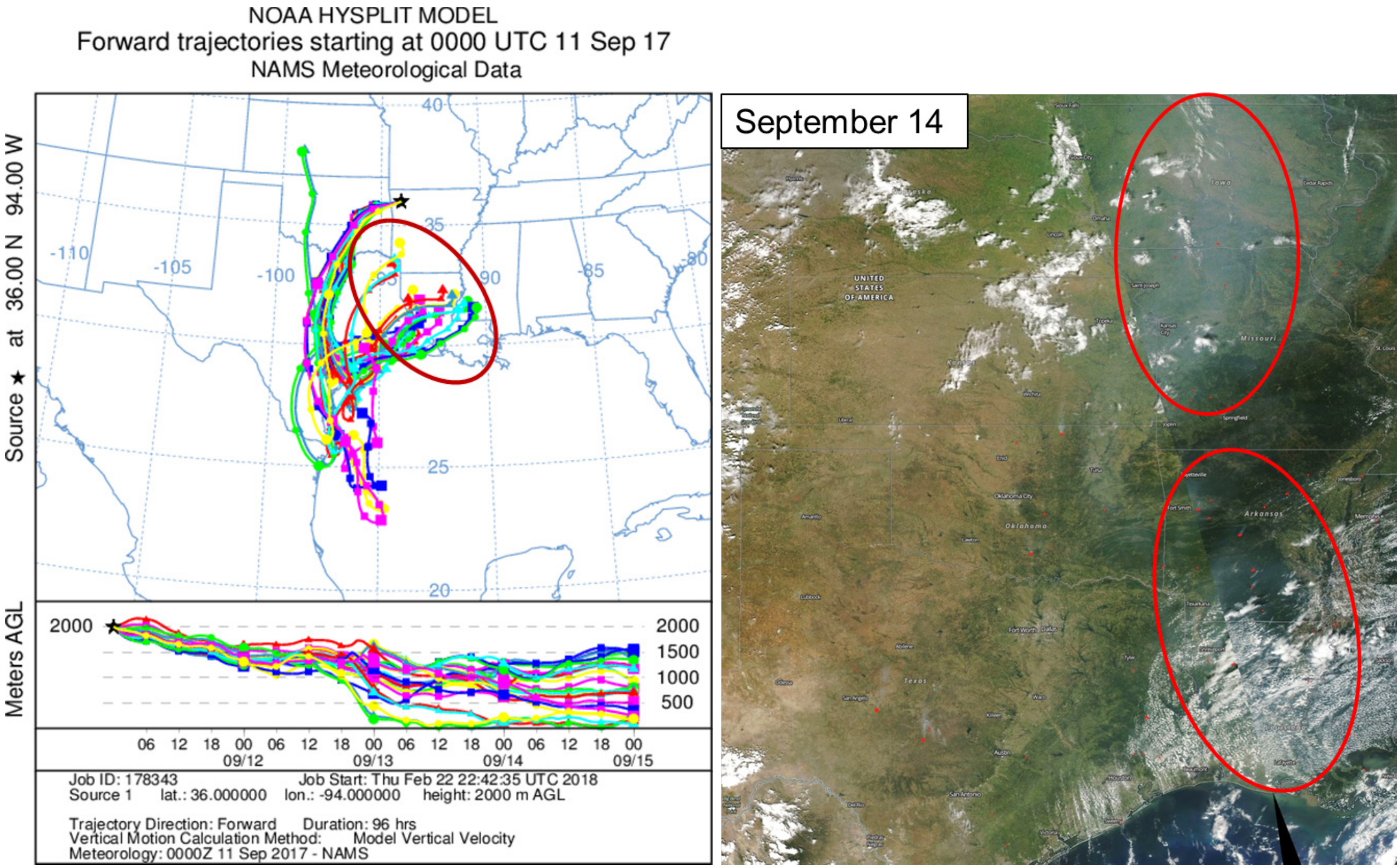


Figure 5. Forward HYSPLIT trajectory ensemble initiated on September 11, 2017, at 0000 UTC (left) and MODIS Aqua true color satellite imagery from September 14, 2017 (right). These trajectories begin in the region where trajectories run from the Highline Fire end and show continued transport of smoke from that fire. The majority of trajectories initiated on September 11 shown here end on September 14 in a line extending from Louisiana to Oklahoma. These locations correspond to observed smoke in MODIS imagery.

Additional CATS Satellite Data

The transport of smoke from northwestern states is also confirmed by multiple CATS aerosol profiles collected between September 9 and September 14, 2017. **Figures 6 through 15** show profiles that were collected by CATS on those days. These profiles indicate that the location and altitude of smoke plumes observed over multiple days align with the HYSPLIT trajectories shown above. They also indicate that smoke from northwestern fires arrived at Louisiana on September 14.

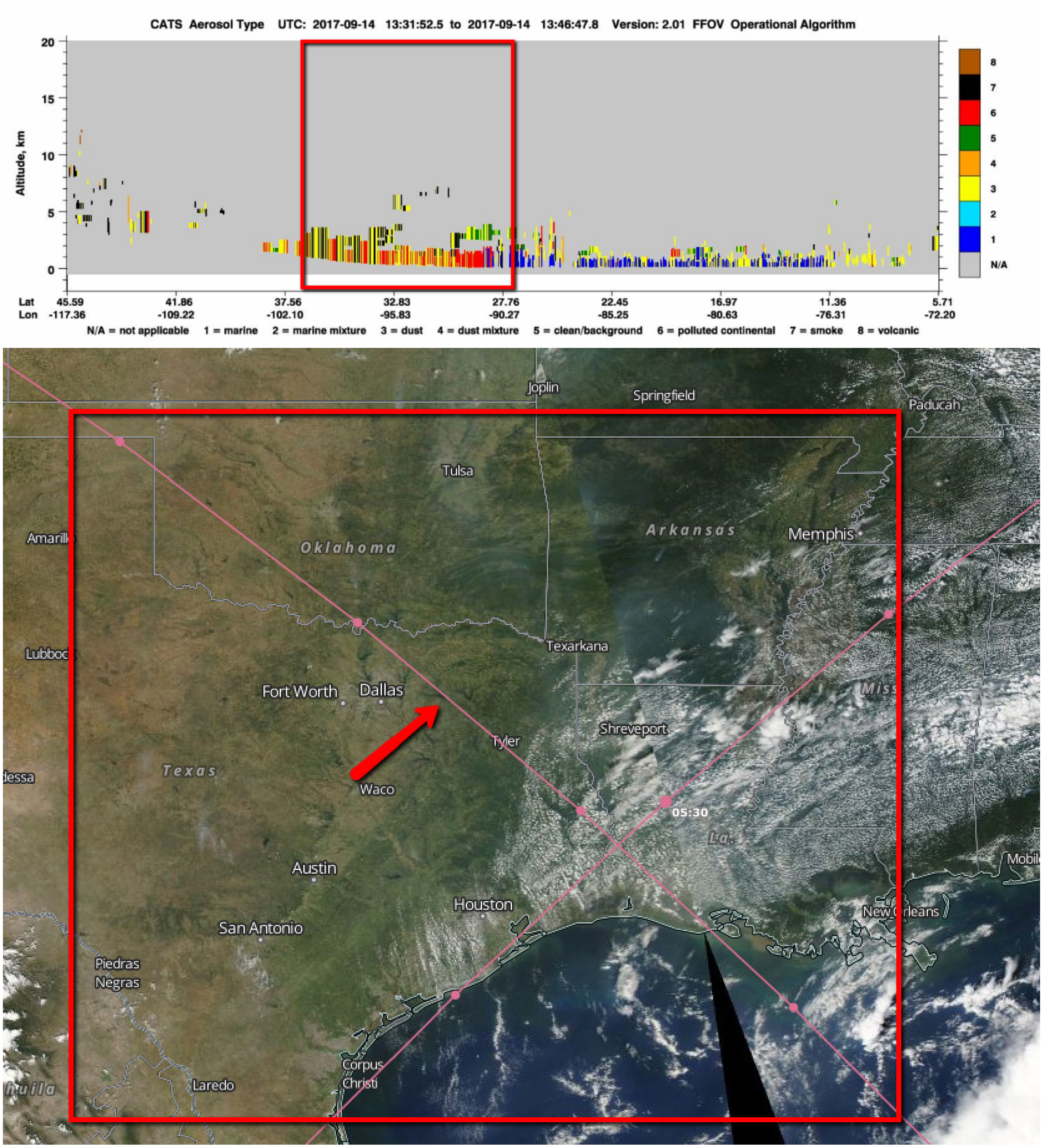


Figure 6. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-14 13:31. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box.

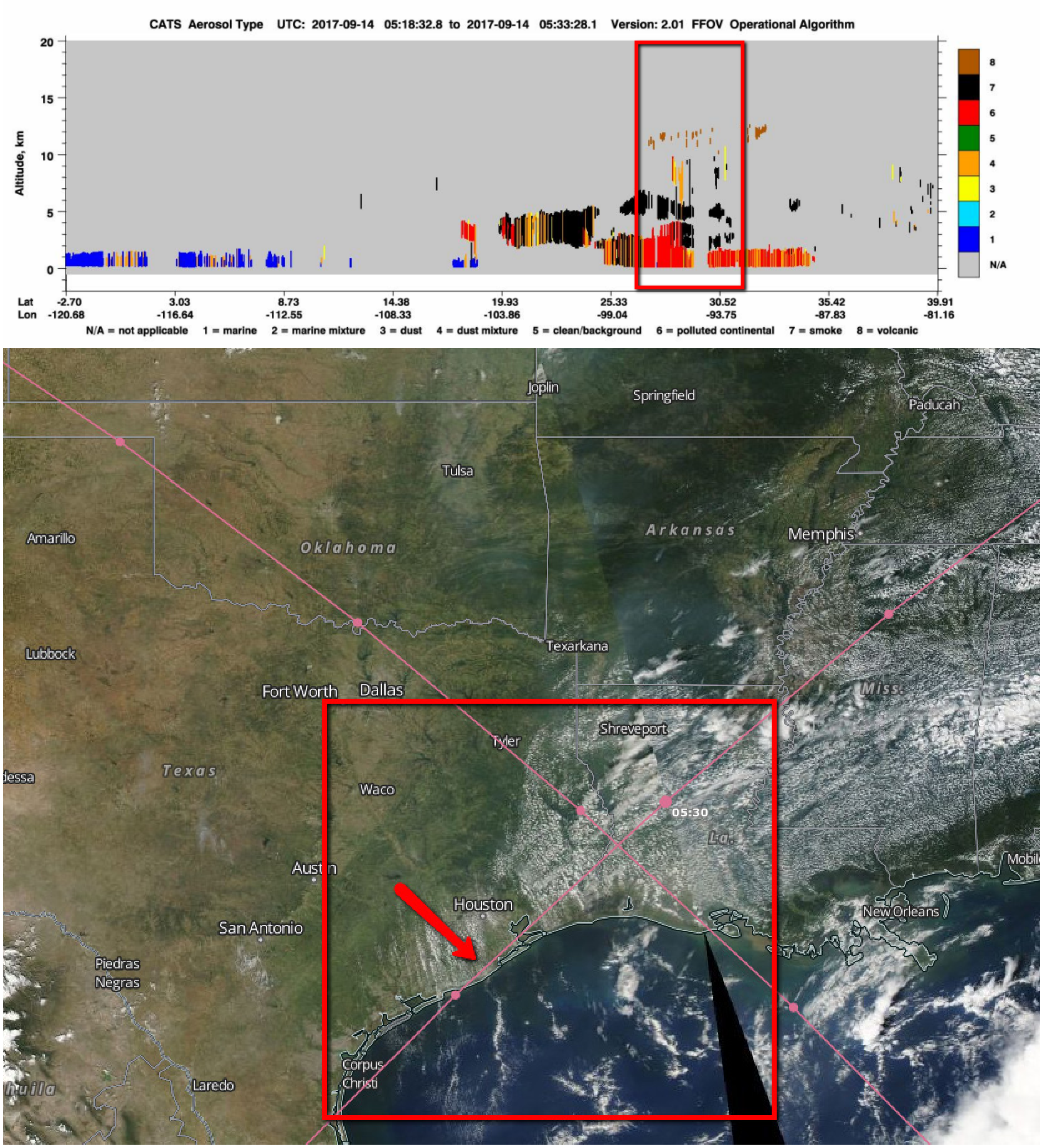


Figure 7. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-14 05:03. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box.

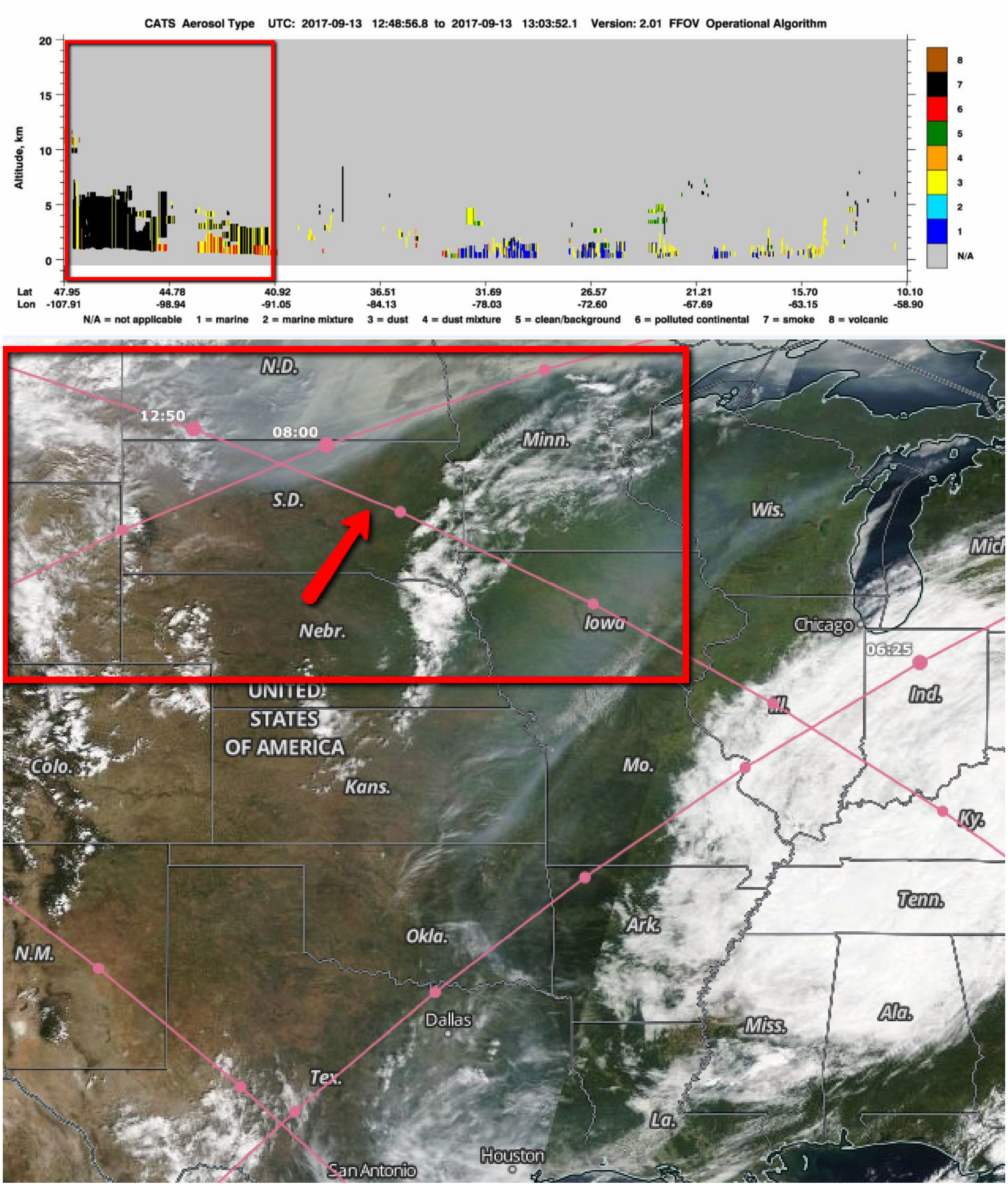


Figure 8. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-13 12:48. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box. Data from orbits that pass over New Mexico are not available.

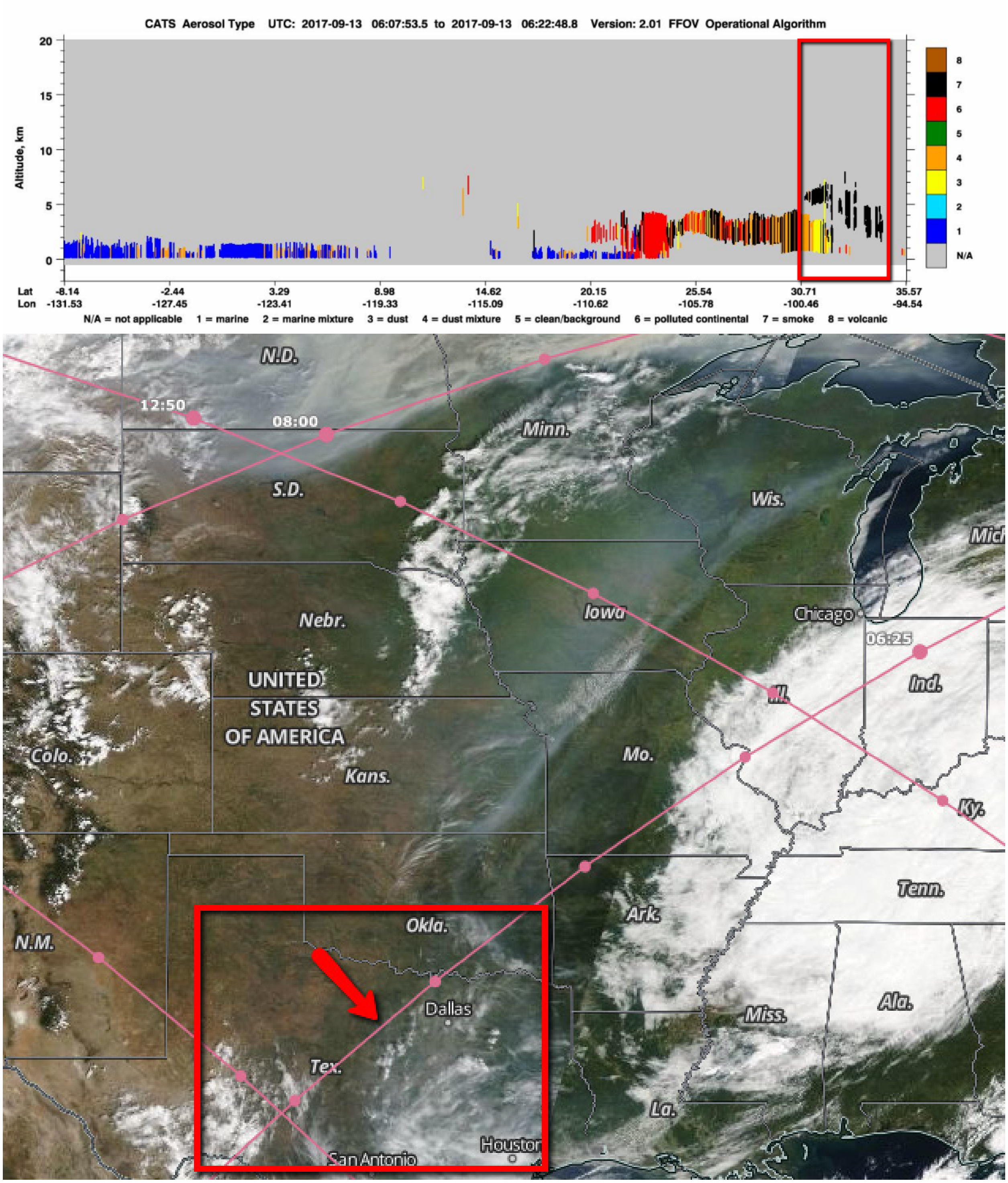


Figure 9. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-13 05:52. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box. Data from orbits that pass over New Mexico are not available.

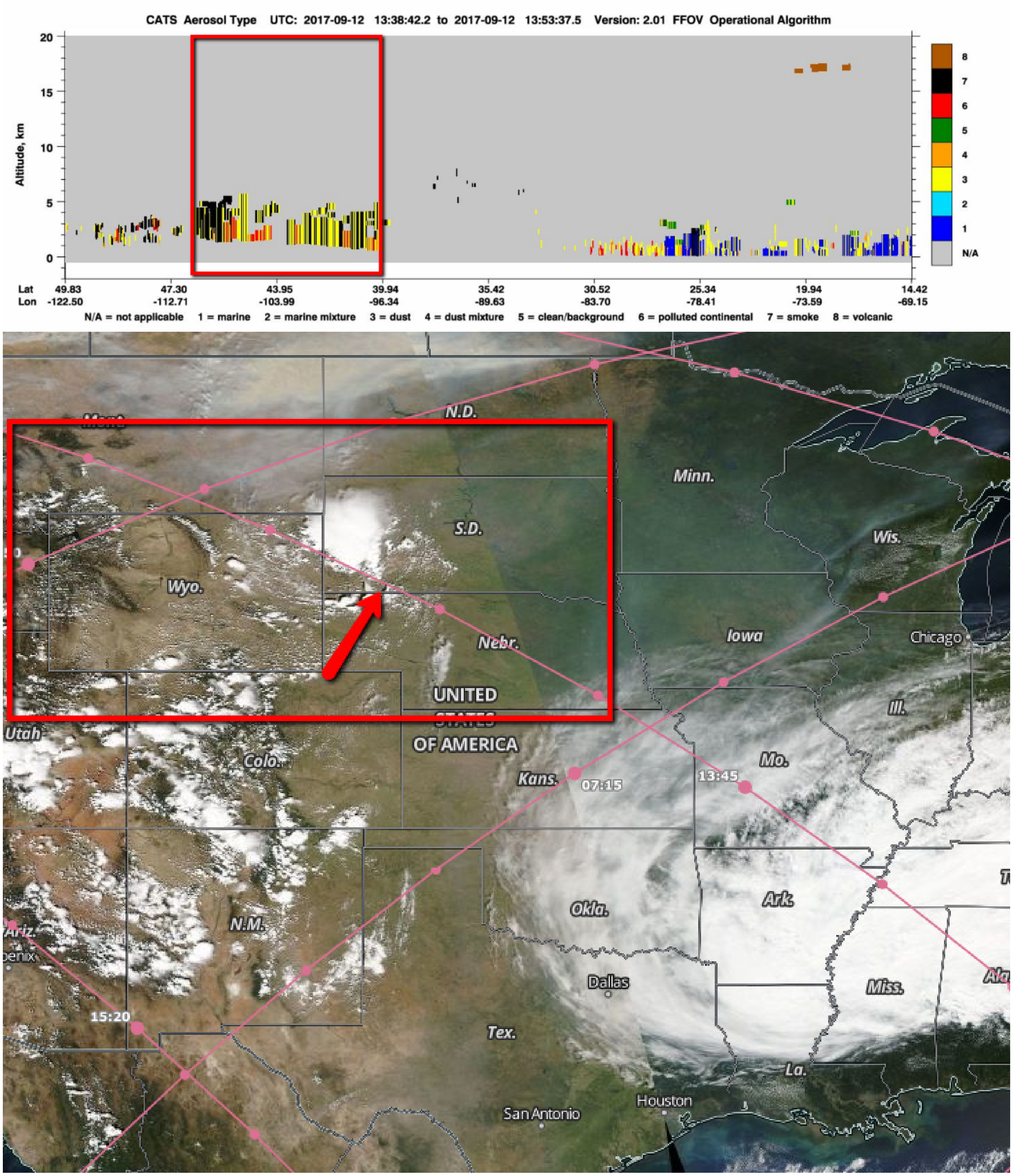


Figure 10. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-12 13:38. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box. Data from orbits that pass over Iowa and North Dakota are not available.

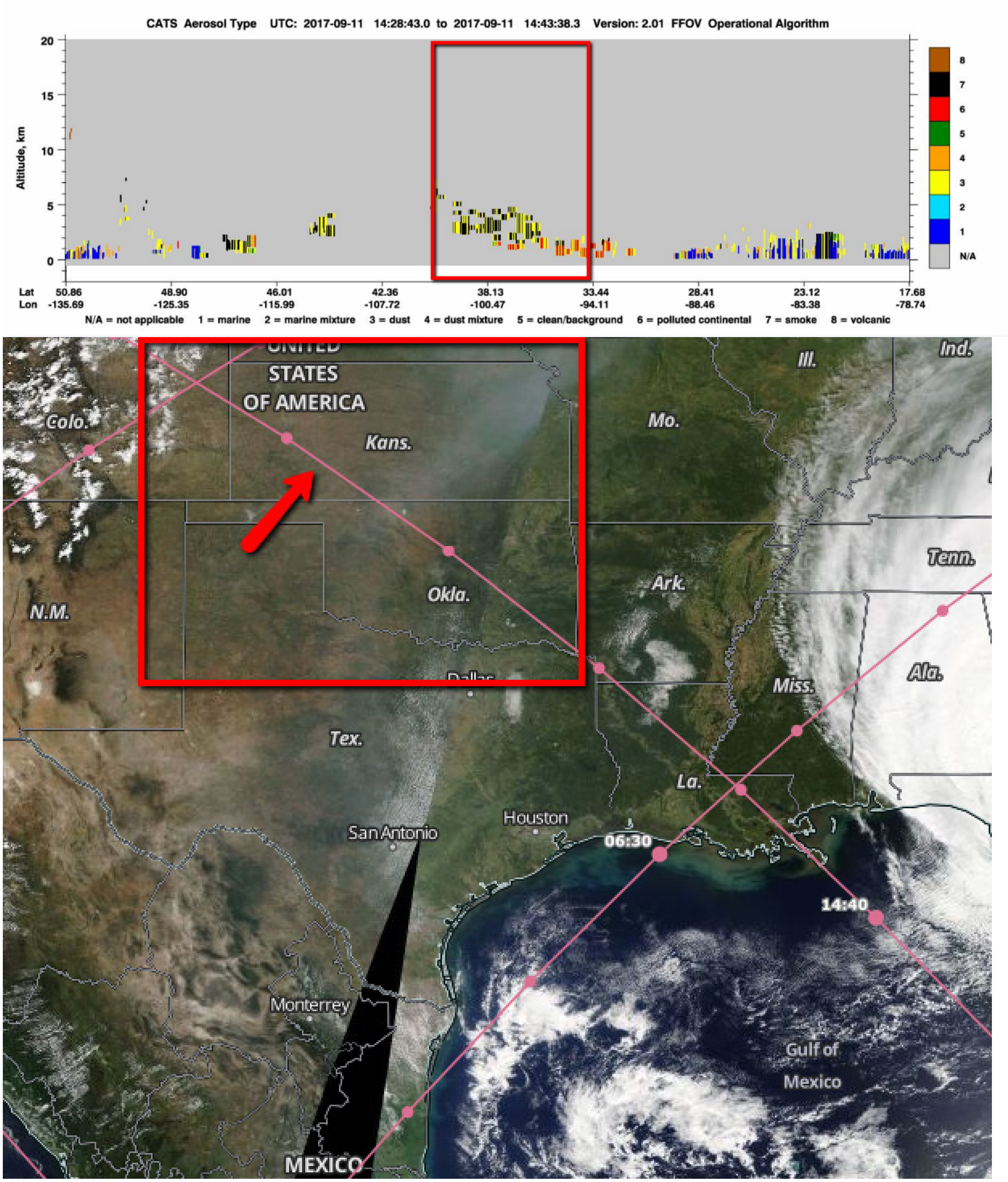


Figure 11. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-11 14:28. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box.

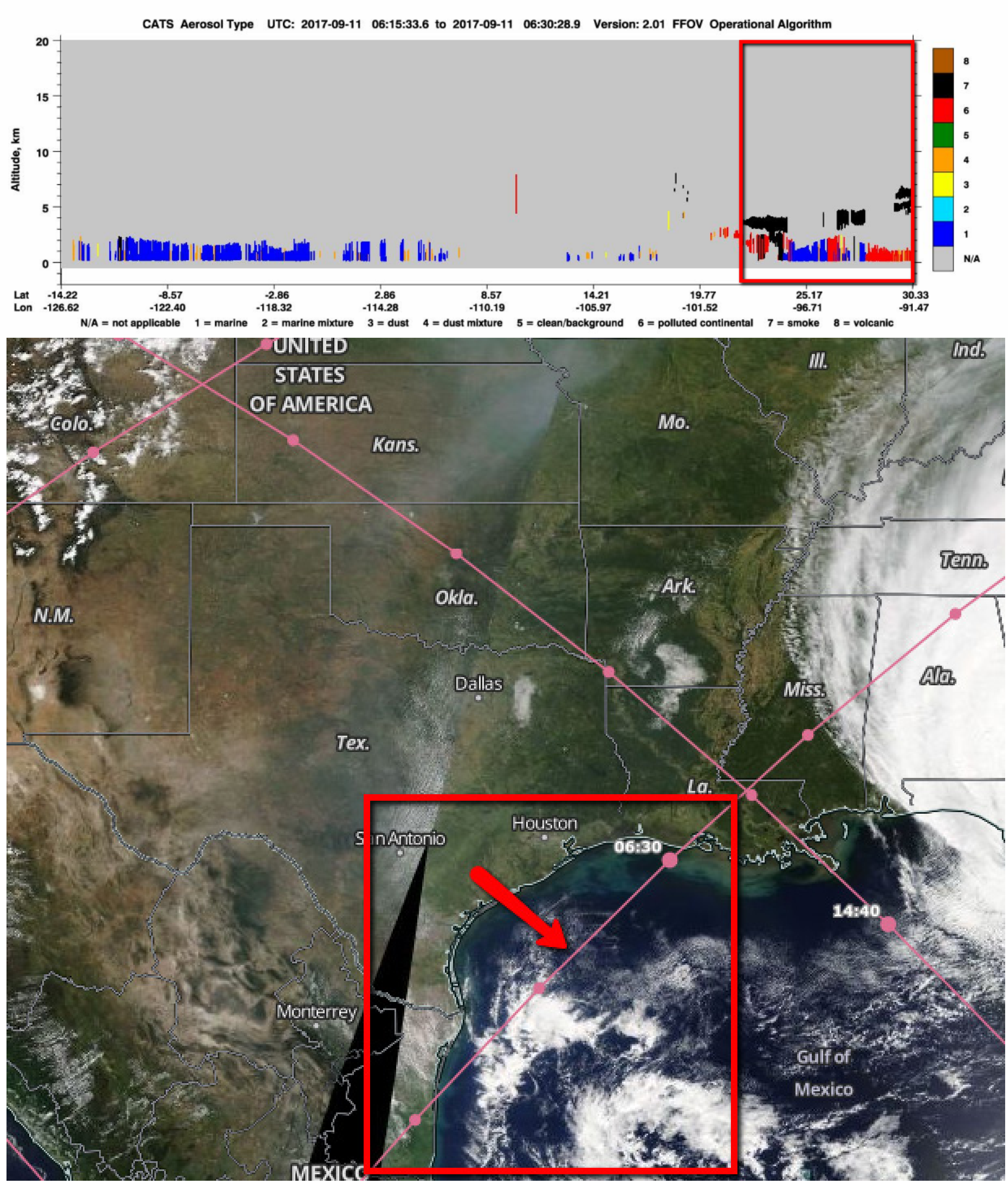


Figure 12. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-11 06:00. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box.

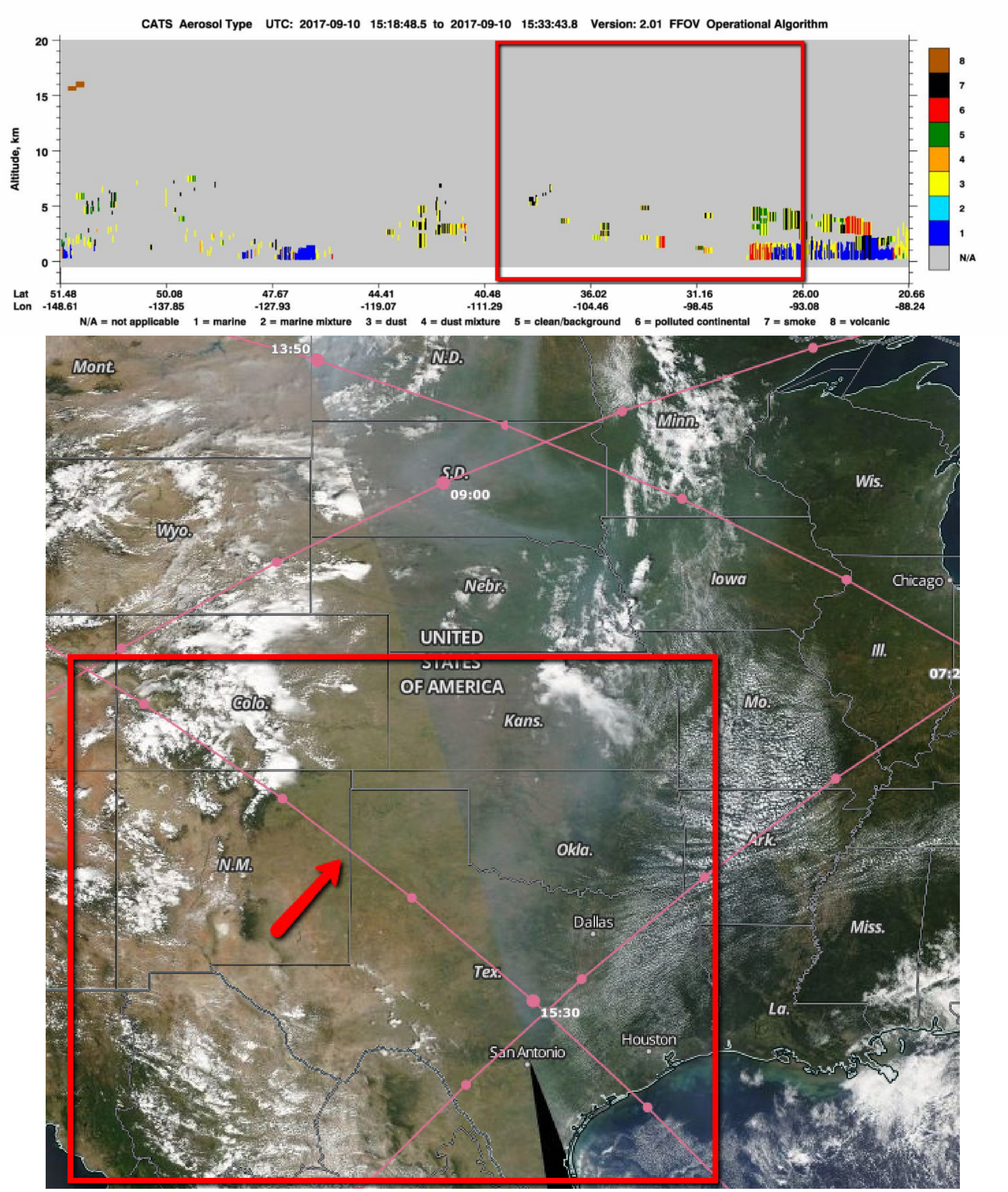


Figure 13. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-10 15:18. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box. Data from orbits that pass over Wyoming and Arkansas are not available.

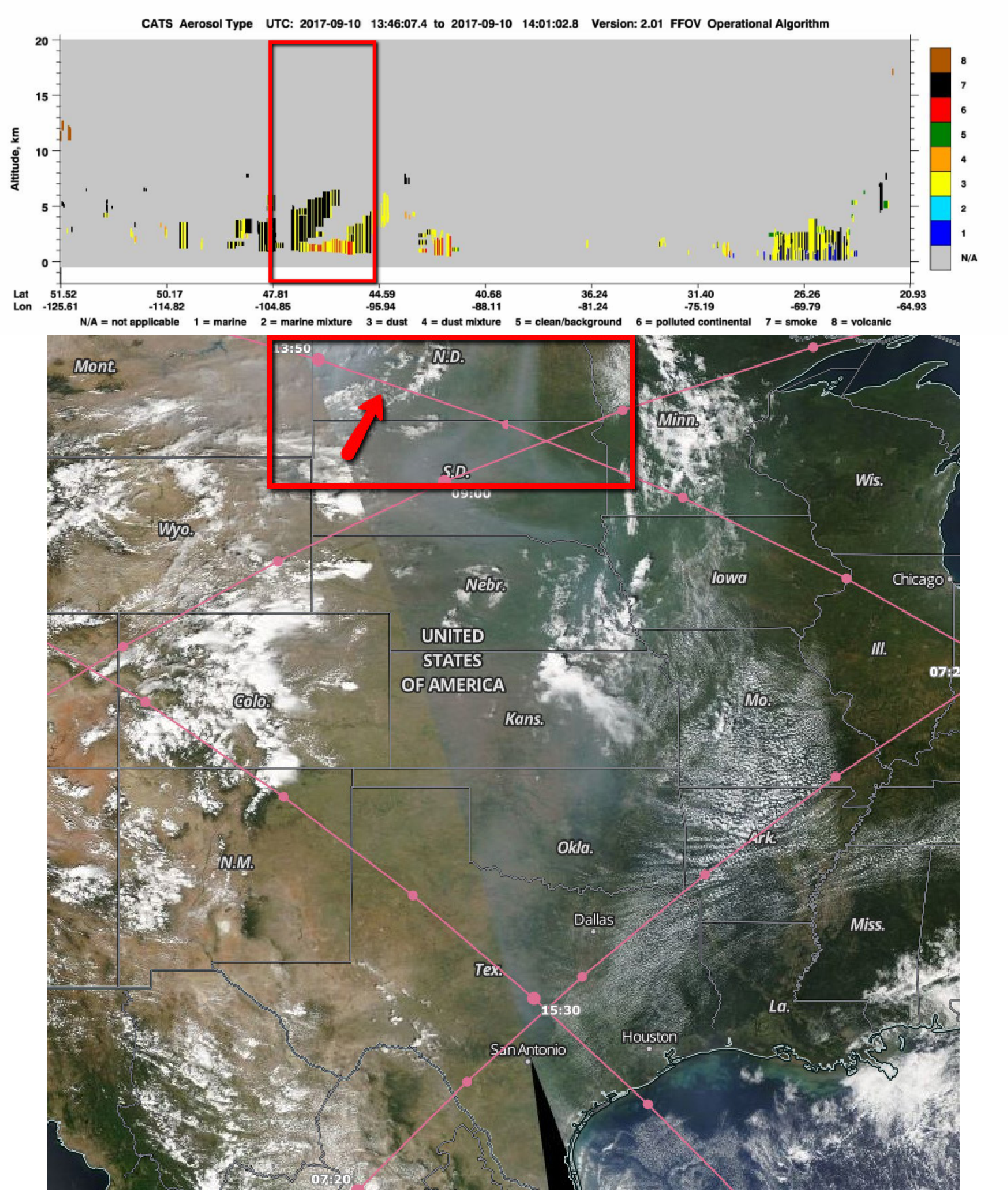


Figure 14. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-10 13:46. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box. Data from orbits that pass over Wyoming and Arkansas are not available.

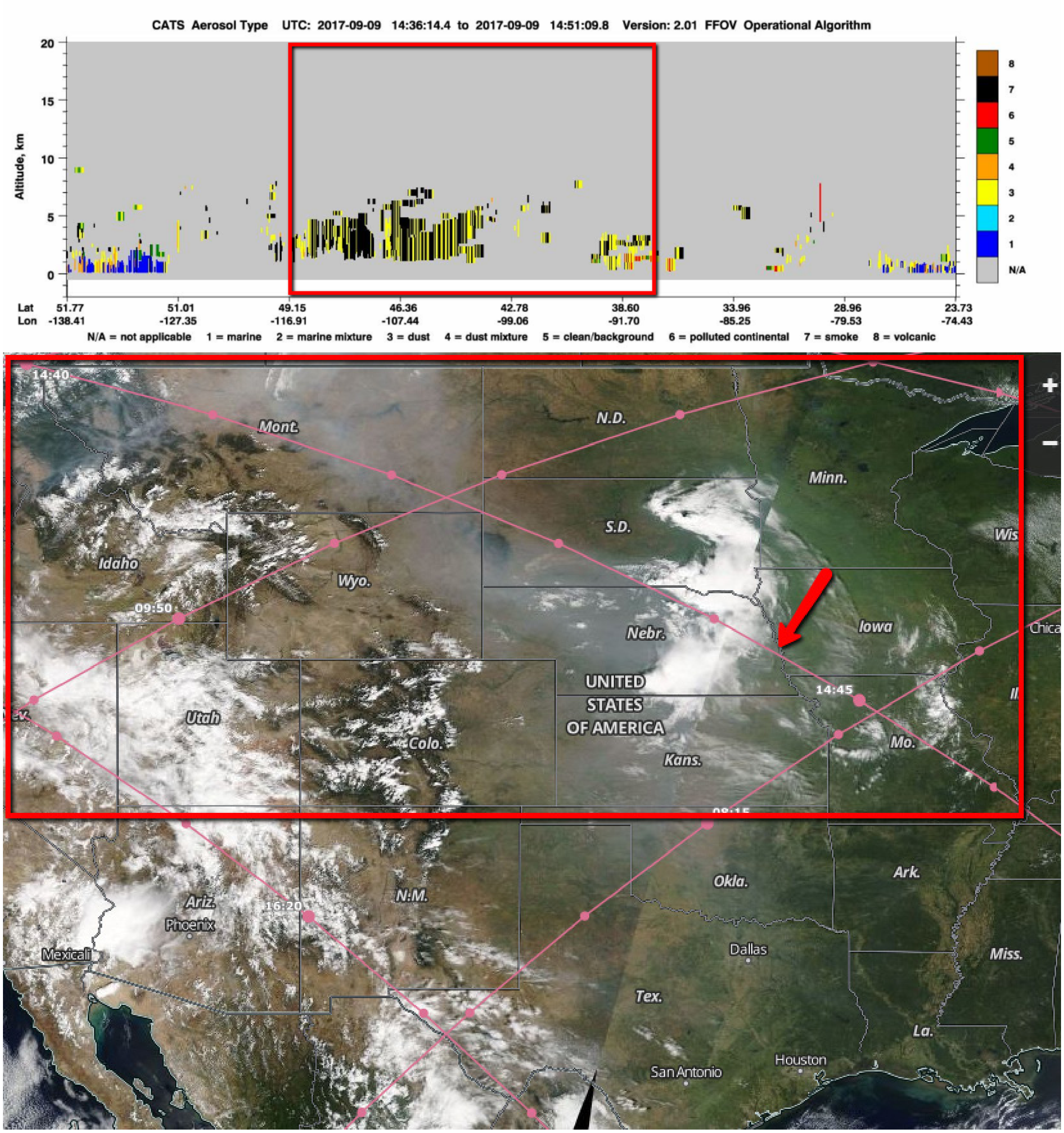
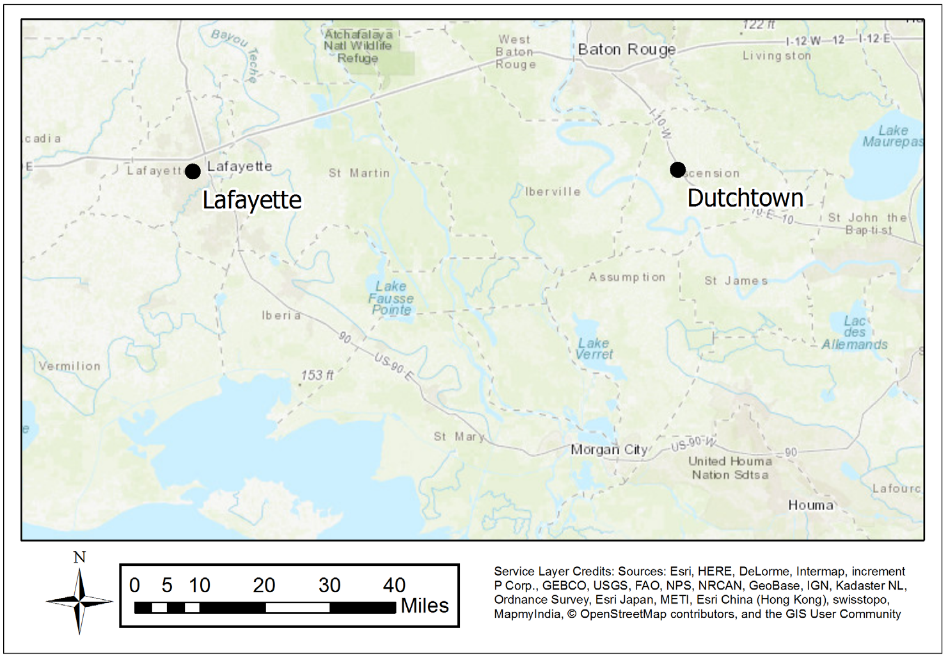


Figure 15. Top: The CATS aerosol type range-resolved vertical profile starting UTC 2017-09-09 14:36. Black color indicates smoke aerosols. Data spatially and temporally relevant to this exceptional event are highlighted by the red box, and their spatial coverage is displayed on the map (bottom). Bottom: The orbit (pink line) segment along which highlighted aerosol type data (top) were collected is indicated by the arrow and the bounding red box. Data from orbits that pass over Oklahoma and North Dakota are not available.

Regional/Upwind Site Supporting Measurements

An upwind site in Lafayette, Louisiana, was selected to examine whether it also experienced elevated ozone at the time of the September 14, 2017, ozone exceedance. Lafayette is approximately 65 miles due west of the Dutchtown monitor, well outside of the Baton Rouge urban area (**Figure 16**). On September 14, HYSPLIT trajectories show air transport to Baton Rouge from the southwest. Therefore, for the September 14 event, the Lafayette site may be considered upwind of Baton Rouge.



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 16. The Dutchtown monitor site and the upwind monitor site at Lafayette.

Ozone concentrations at the Lafayette site were unusually high on September 14, 2017, with a daily maximum 8-hr average ozone concentration of 73. The ozone measured there was the only exceedance at that site in 2017 (**Figure 17**) and was the first exceedance of the 70 ppb NAAQS measured at that site since September 26, 2013 (**Figure 18**). This finding demonstrates that ozone concentrations upwind of Baton Rouge were elevated at a historically high level.

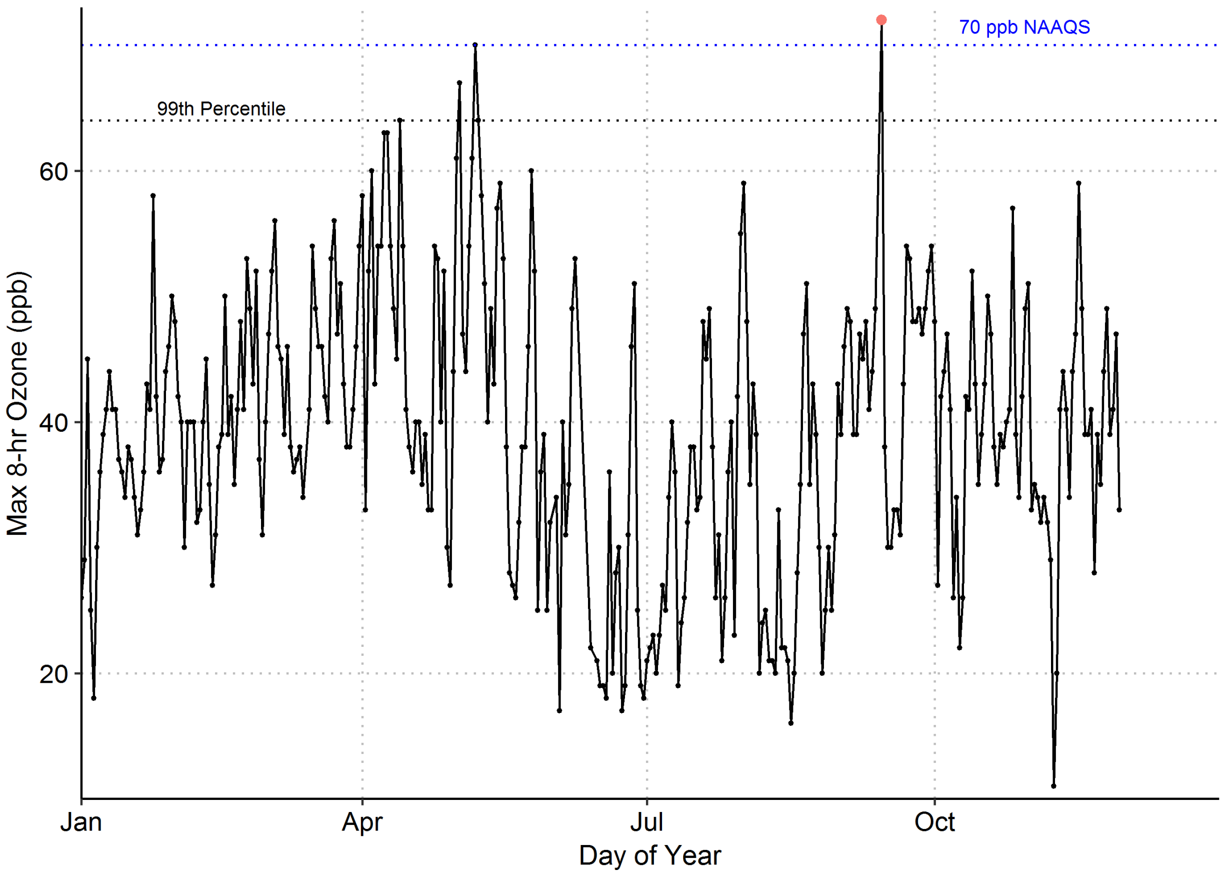


Figure 17. Daily maximum 8-hr ozone concentrations at the Lafayette monitoring site (AQS ID 22-055-0007) in 2017.

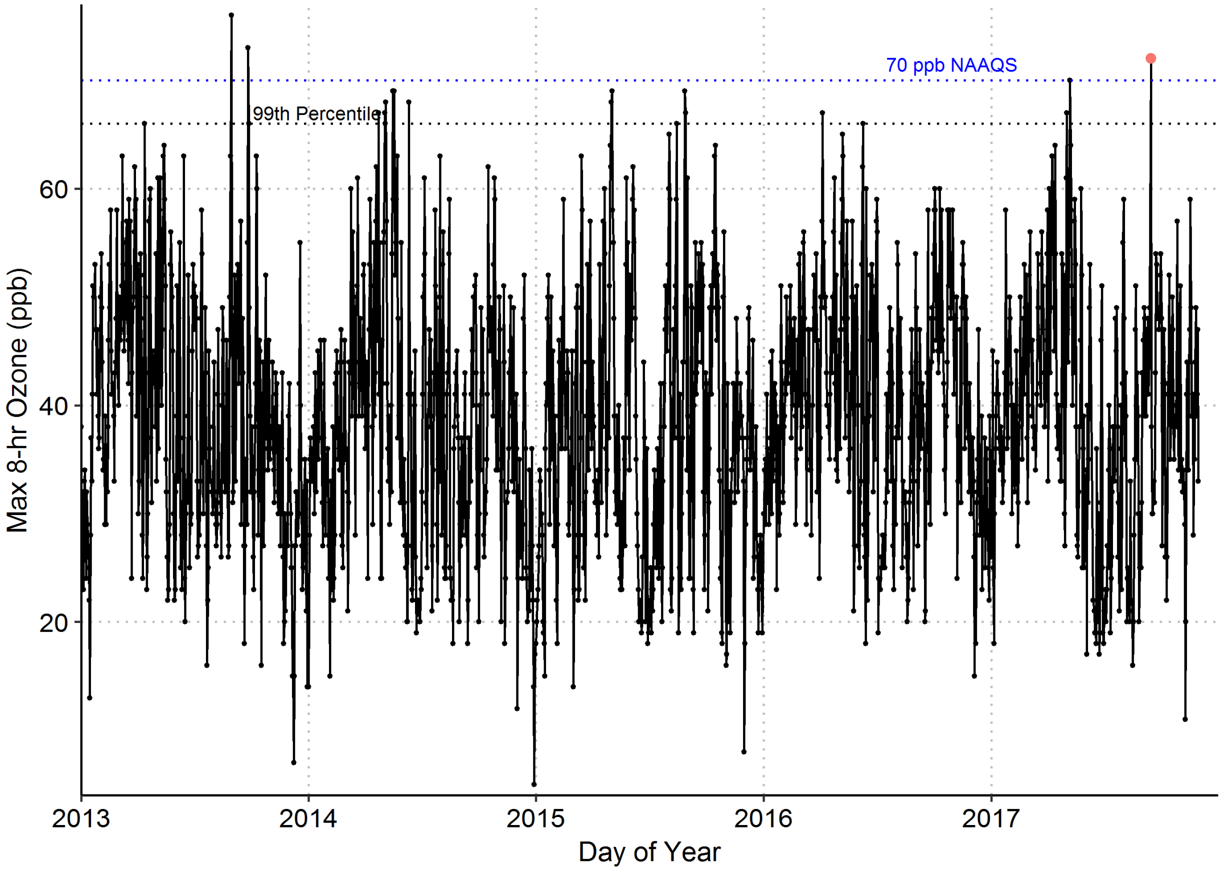


Figure 18. Daily maximum 8-hr ozone concentrations at the Lafayette monitoring site (AQS ID 22-055-0007) from 2013 through 2017.

Additional sites in Louisiana, Texas, Oklahoma, and Arkansas were selected for upwind data analysis (**Table 1** and **Figure 19**) to provide further supportive evidence of smoke impacts in the area. A broad geographic range of monitoring sites was selected because elevated ozone was evident at those sites leading up to or during the September 14, 2017, exceedance in Baton Rouge, showing that the exceedance was related to area-wide ozone impacts on that day. Site selection was also based on the ending location of HYSPLIT trajectories shown in Figure 5, which indicates that smoke was likely present at these sites. The sites at Love, Oklahoma; Caddo, Louisiana; and Comanche, Oklahoma, were selected because they fall outside major urban areas, providing information on background ozone in the area. Finally, the Oklahoma City and Houston sites were selected because of the availability of non-ozone supporting measurements. These sites provide a broad view of locations likely to have been impacted by smoke that was transported to the surface.

Table 1. Table of sites and measurements used for the upwind location analysis.

County	Sites	Measurements
Oklahoma, Oklahoma	Near Road OKC (40-109-0097)	NO_x, Black carbon
	North OKC (20-109-1037)	Ozone, CO, $PM_{2.5}$
Harris, Texas	Deer Park (48-201-1039)	Ozone, NO_x, CO
	Baytown (48-201-0058)	$PM_{2.5}$
Calcasieu, Louisiana	Carlyss (22-019-0002)	Ozone
Montgomery, Texas	Conroe Relocated (48-339-0078)	Ozone
Love, Oklahoma	Burneyville (40-086-0300)	Ozone
Caddo, Louisiana	Dixie (22-017-0001)	Ozone
Comanche, Oklahoma	Lawton North (40-031-0651)	Ozone
Polk, Missouri	Eagle Mountain (05-113-0003)	Ozone

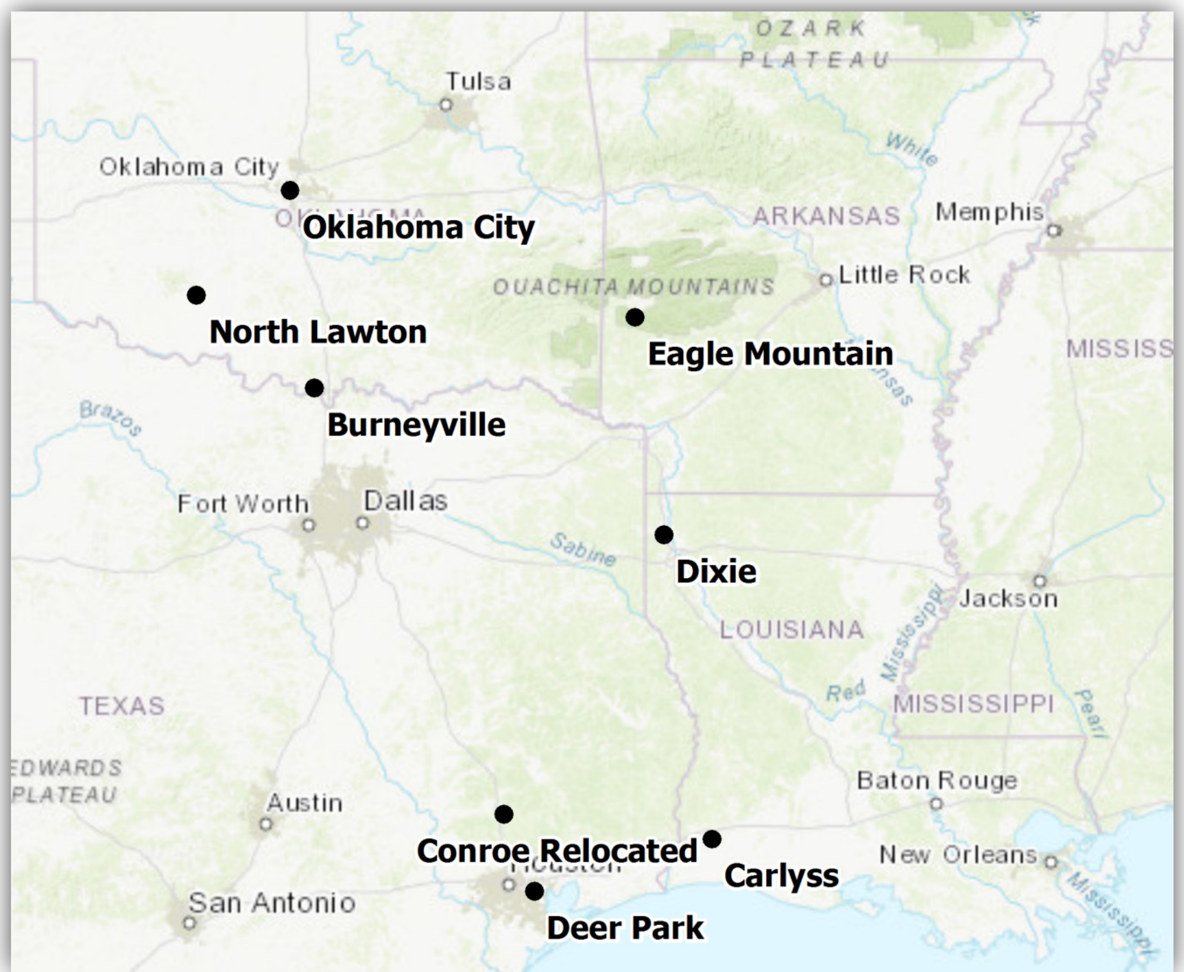


Figure 19. Map of upwind sites. Upwind sites are shown with black circles. Deer Park and Oklahoma City represent urban locations, while North Lawton, Waurika, Burneyville, Conroe Relocated, Dixie, Eagle Mountain, and Carlyss represent suburban or background sites.

Examination of ozone concentrations over the past five years shows that ozone was unusually elevated at sites throughout the Louisiana, Texas, and Oklahoma areas on September 14, 2017, where meteorology and satellite observations indicate smoke transport was likely to occur (Figures 20-27). Ozone concentrations were elevated at all sites on September 12, 13, or 14 relative to surrounding dates, and all but one monitor measured ozone concentrations on September 14 above the 99th percentile for five years of ozone observations. At Deer Park, daily maximum 8-hr ozone concentrations were below the 99th percentile on September 14, but measurements on September 12 did exceed the 99th percentile. These findings provide supporting evidence of broad-scale ozone impacts. In addition, measurements of black carbon, NO_x, CO, and $PM_{2.5}$ indicate that smoke likely elevated ozone in Houston and Oklahoma City on the dates of interest (Figures 28 through 30).

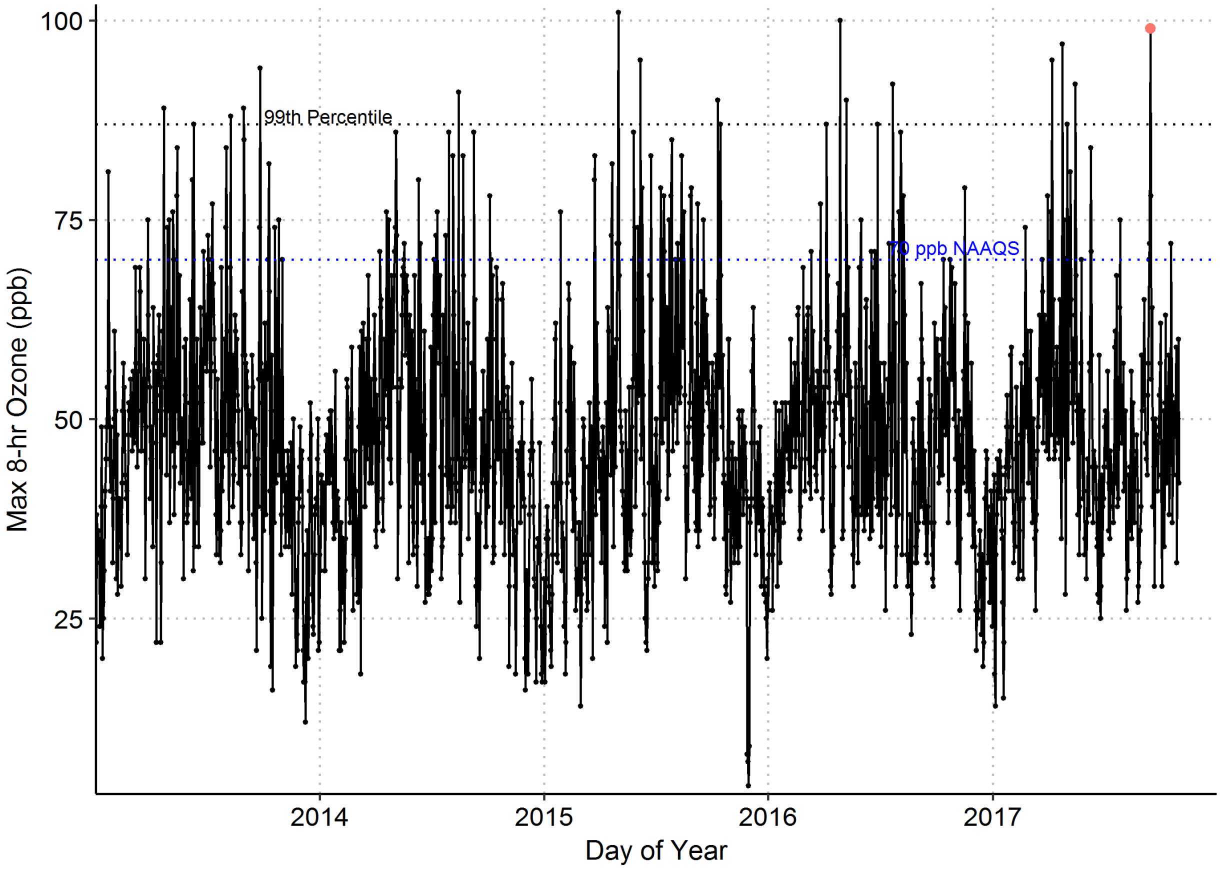


Figure 20. Daily maximum 8-hr ozone concentrations at the Conroe Relocated monitoring site in Texas (AQS ID 48-339-0078) from 2013 through 2017.

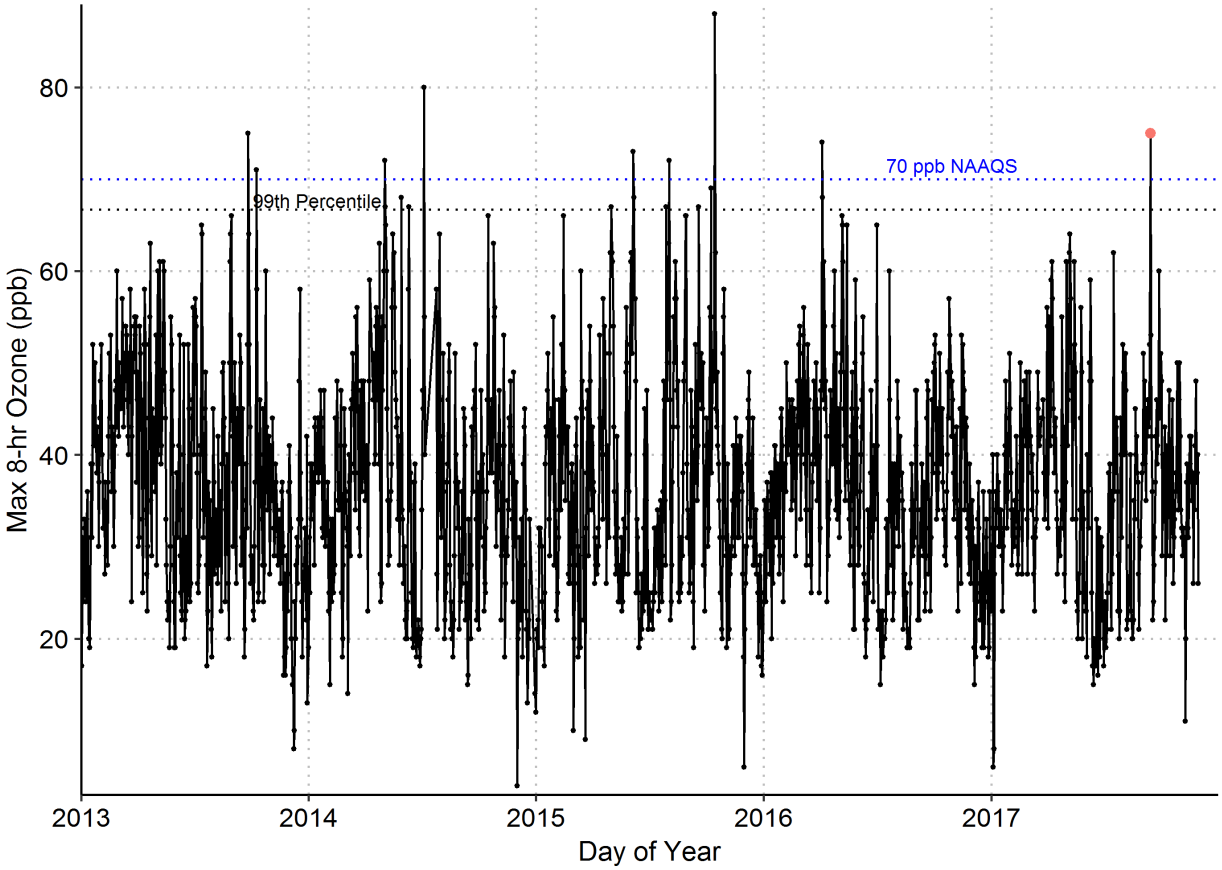


Figure 21. Daily maximum 8-hr ozone concentrations at the Carlyss monitoring site in western Louisiana (AQS ID 22-019-0002) from 2013 through 2017.

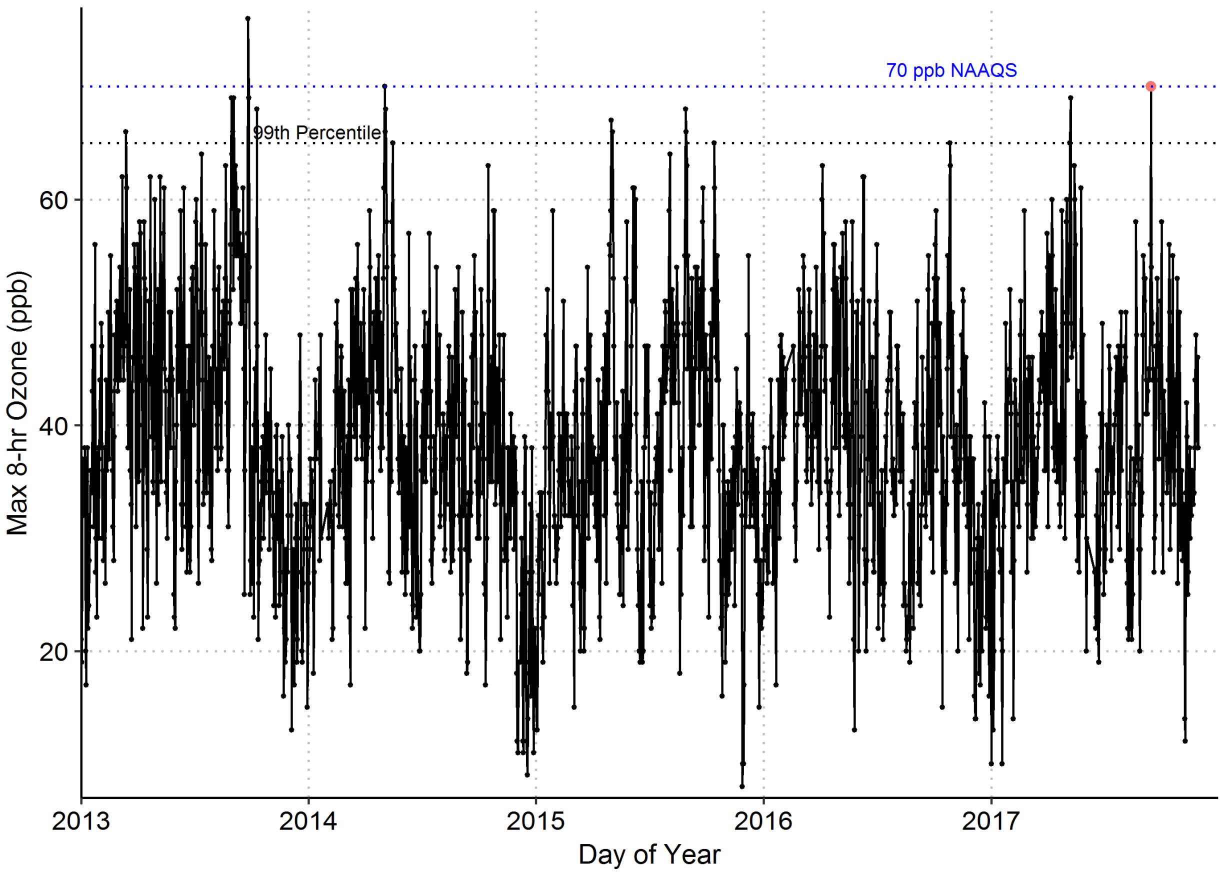


Figure 22. Daily maximum 8-hr ozone concentrations at the Dixie monitoring site in northern Louisiana (AQS ID 22-017-0001) from 2013 through 2017.

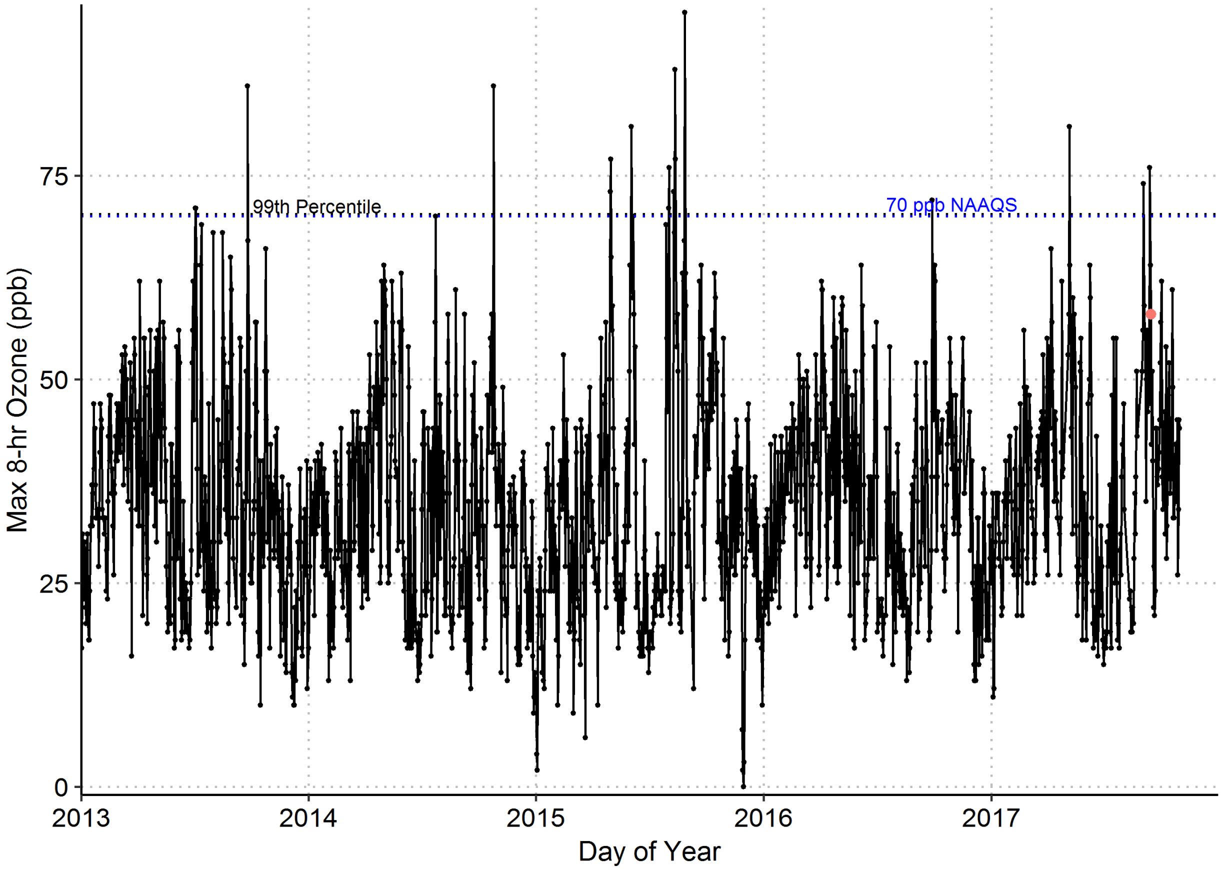


Figure 23. Daily maximum 8-hr ozone concentrations at the Deer Park monitoring site in Texas (AQS ID 48-201-1039) from 2013 through 2017.

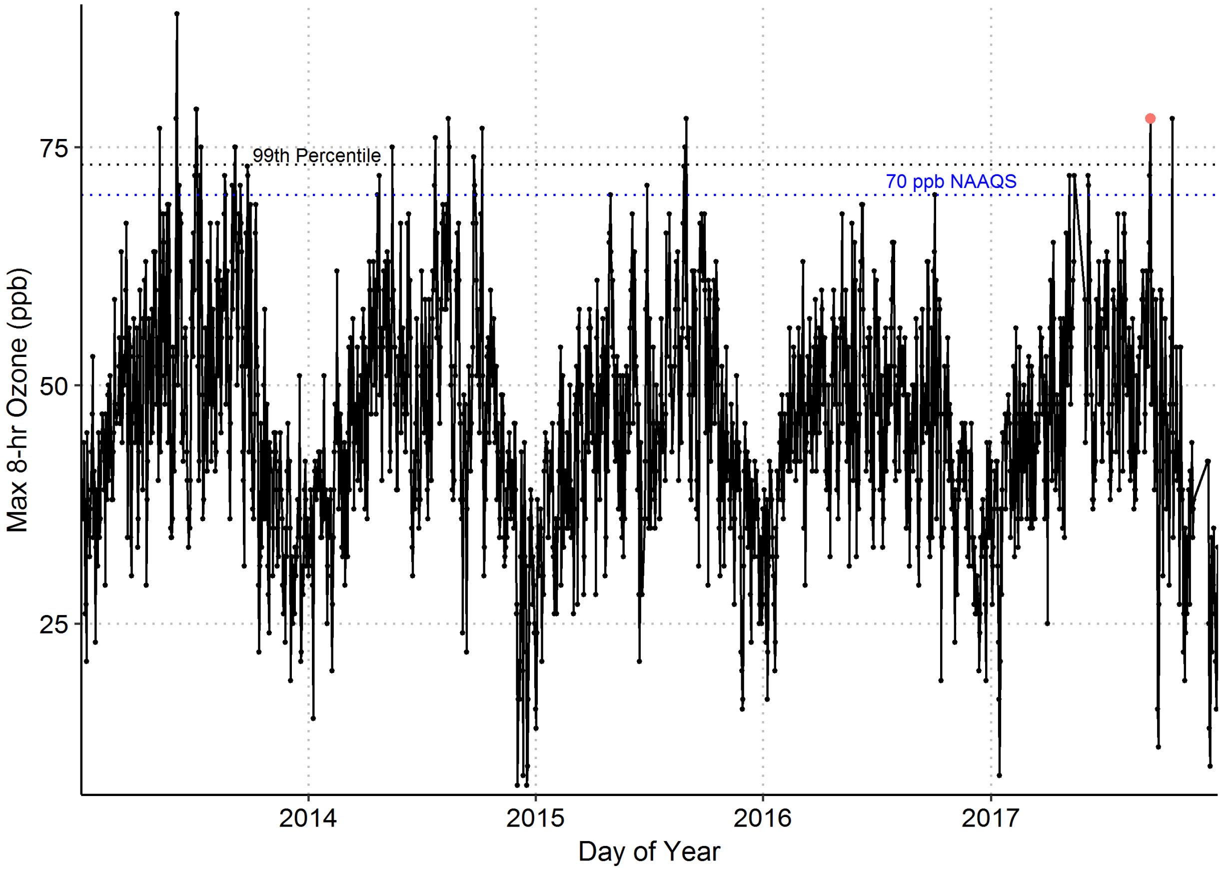


Figure 24. Daily maximum 8-hr ozone concentrations at the Lawton North monitoring site in Oklahoma (AQS ID 40-031-0651) from 2013 through 2017.

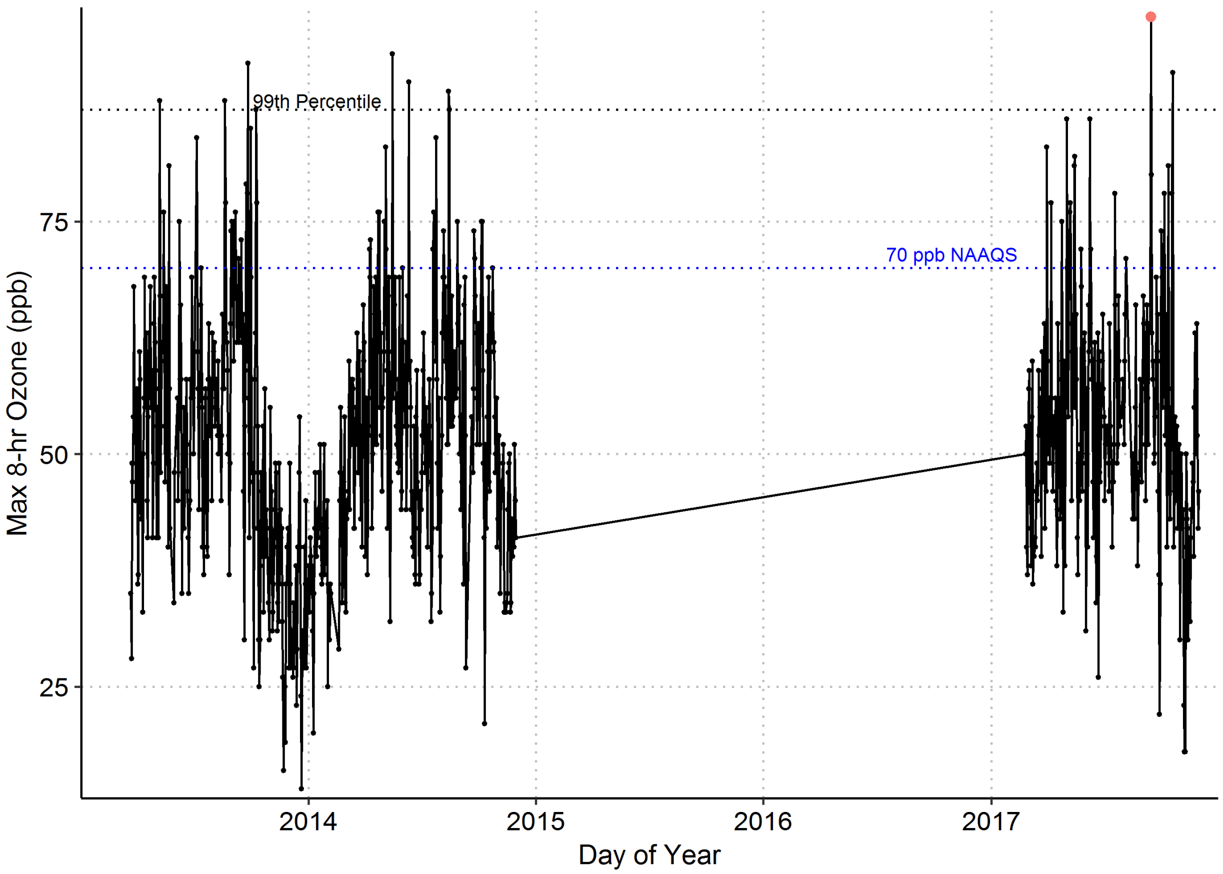


Figure 25. Daily maximum 8-hr ozone concentrations at the Burneyville monitoring site in Oklahoma (AQS ID 40-086-0300) from 2013 through 2017.

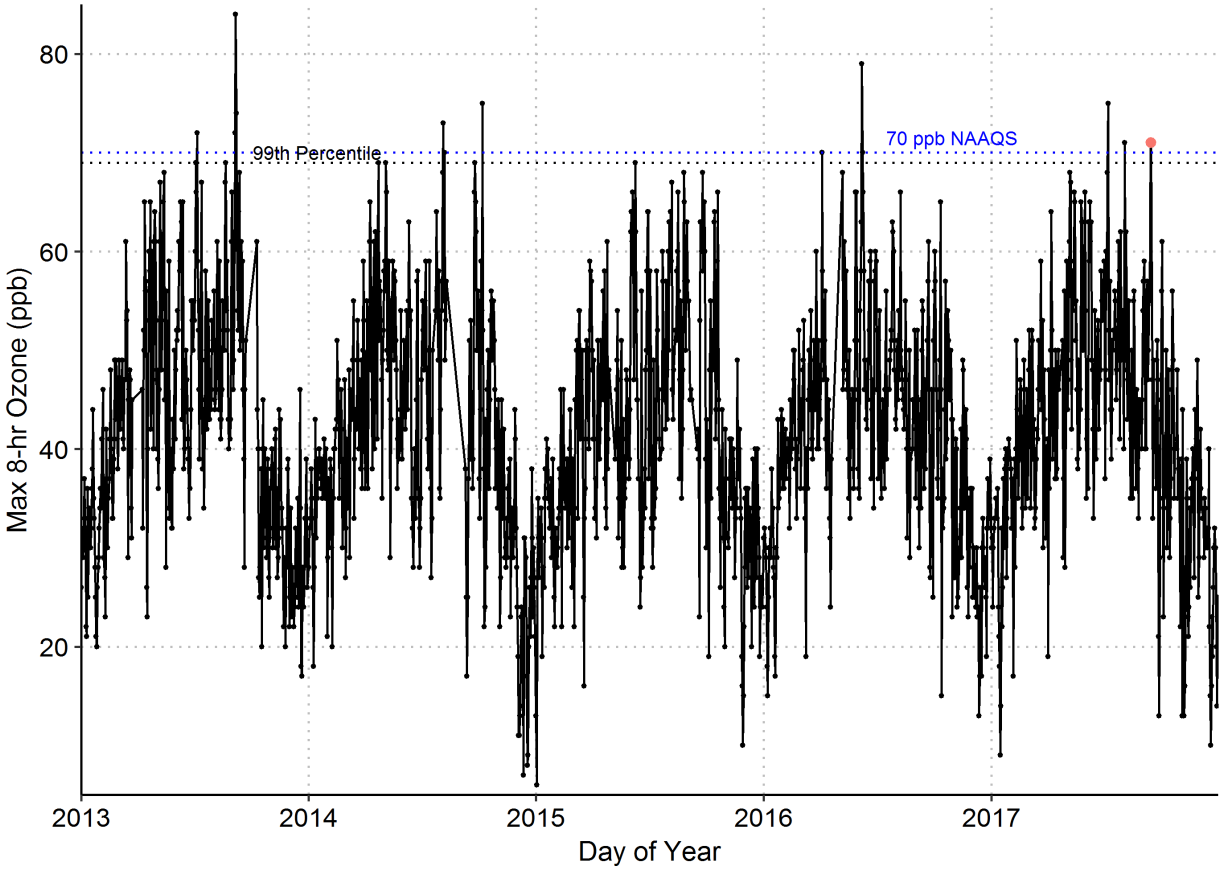


Figure 26. Daily maximum 8-hr ozone concentrations at the North OKC monitoring site in Oklahoma (AQS ID 20-109-1037) from 2013 through 2017.

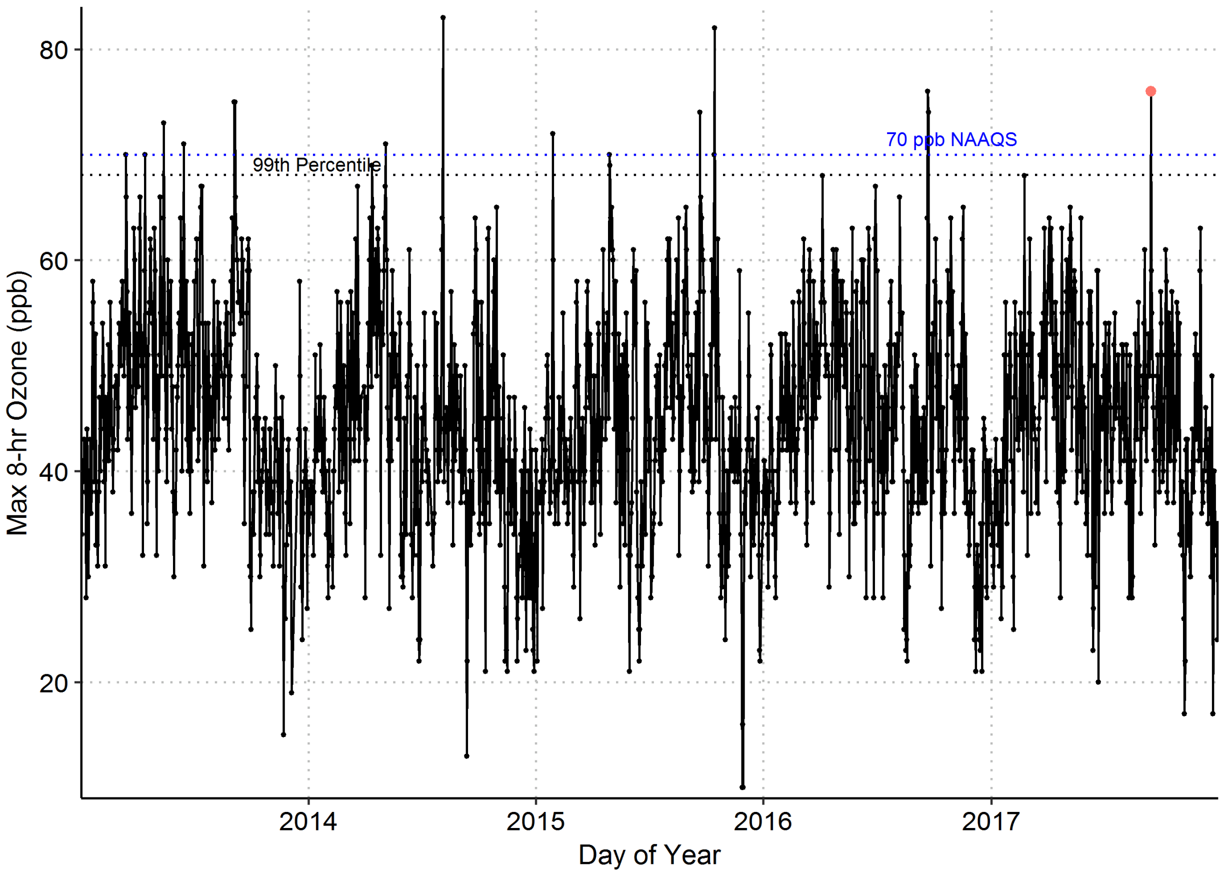


Figure 27. Daily maximum 8-hr ozone concentrations at the Eagle Mountain monitoring site in Arkansas (AQS ID 05-113-0003) from 2013 through 2017.

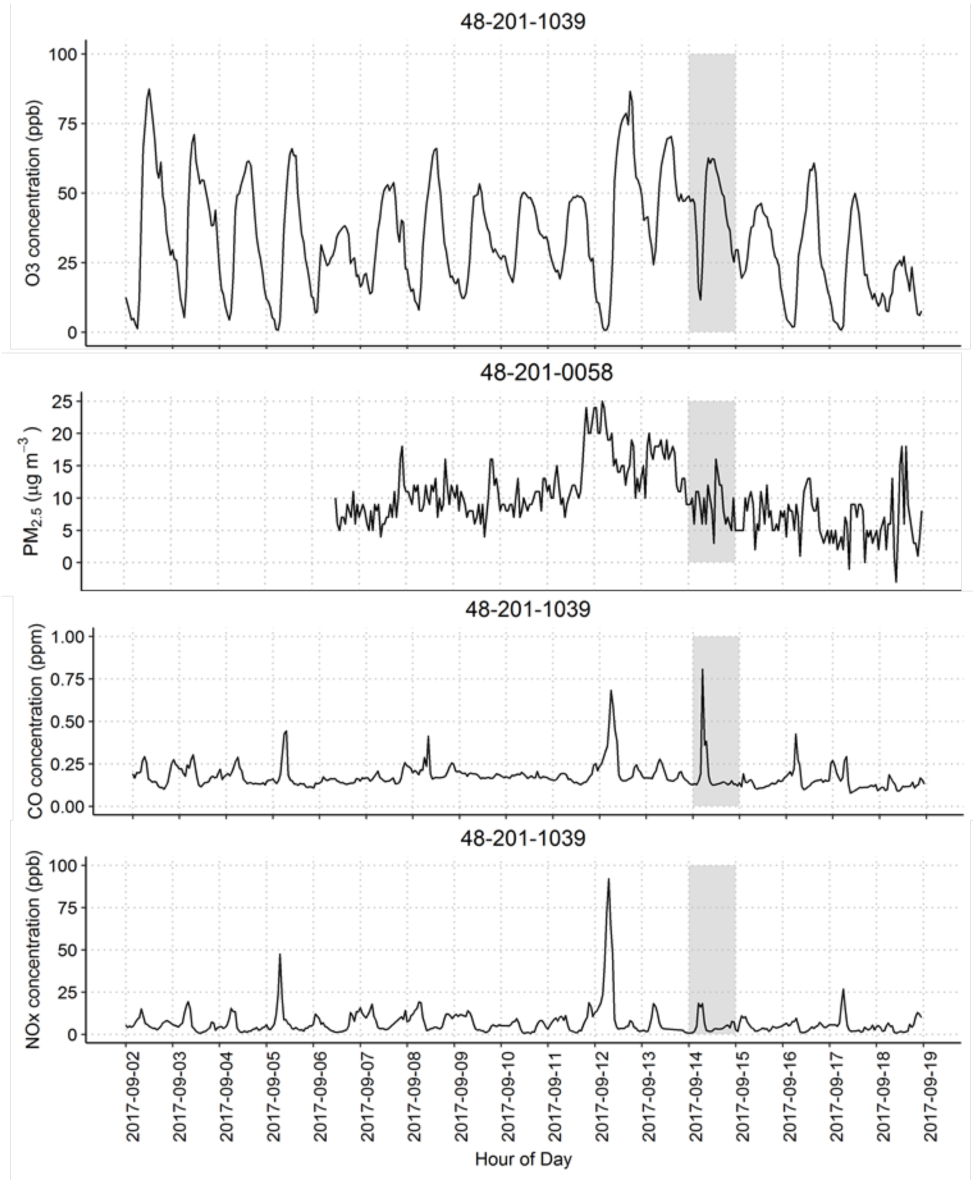


Figure 28. Hourly concentrations of ozone, $PM_{2.5}$, NO_x, and CO in Houston. $PM_{2.5}$ concentrations are shown for the Baytown site (48-201-0058), while all other measurements were collected at the Deer Park site (48-201-1039). The gray bar indicates September 14, 2017. Elevated concentrations of $PM_{2.5}$ and NO_x are observed on September 11 and 12, while elevated CO concentrations are observed on both September 12 and 14. This data set demonstrates the arrival of smoke at Houston one or two days before air parcels arrived in Louisiana and at other sites.

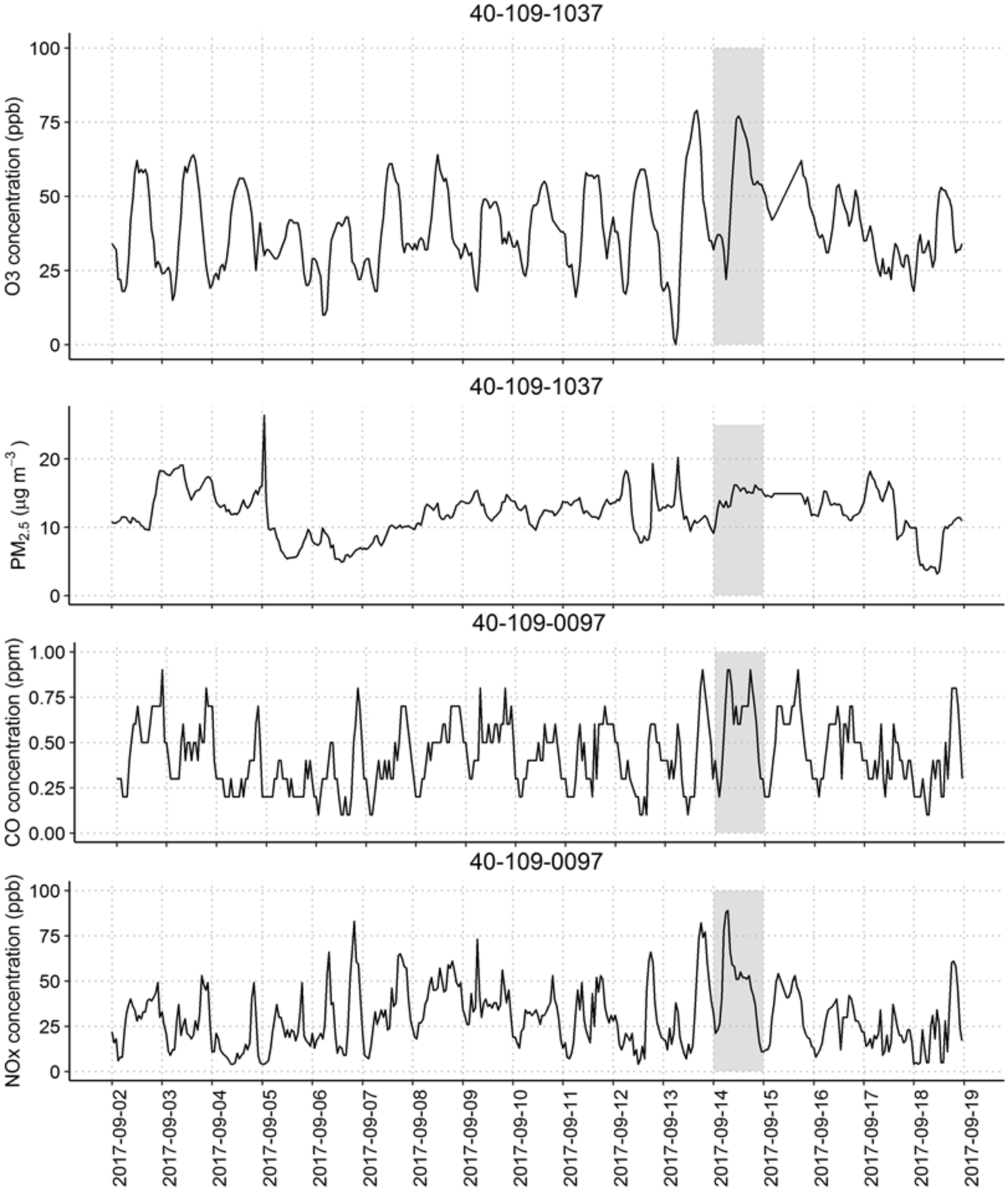


Figure 29. Hourly concentrations of ozone, $PM_{2.5}$, NO_x, and CO in Oklahoma City, Oklahoma. Ozone and $PM_{2.5}$ are shown for the North OKC site (40-109-1037), while NO_x and CO measurements were collected at the Near Road OKC site (40-109-0097). The gray bar indicates September 14, 2017. Ozone concentrations are elevated on September 13 and 14. CO and NO_x concentrations are also somewhat higher on these days.

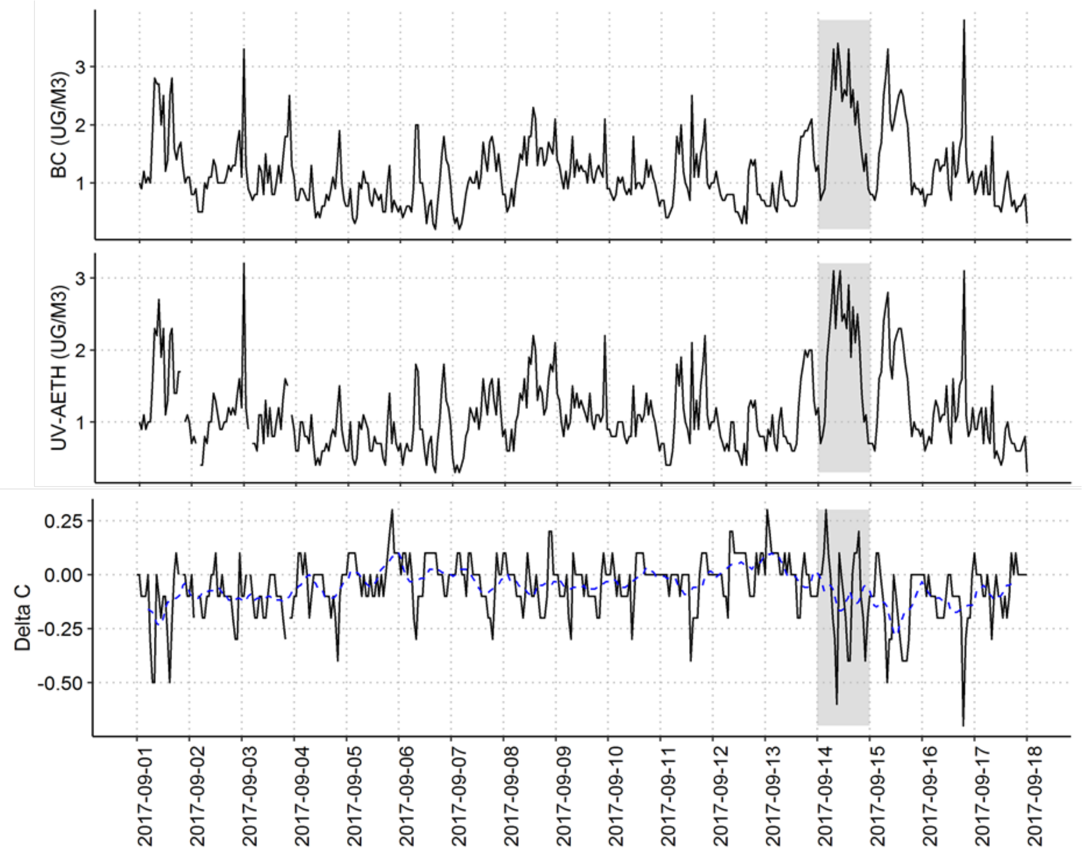


Figure 30. Hourly concentrations of black carbon (BC), UV-channel BC (UV-AETH), and deltaC (the difference between BC and UV-AETH) at the Near Road OKC site in Oklahoma City, Oklahoma (40-109-0097). The dotted blue line indicates the 12-hour moving average Delta-C. The gray bar indicates September 14, 2017. BC and UV-AETH concentrations were elevated in the evening of September 13, and on September 14 and 15. Delta-C was also higher on September 13. Delta-C is used to measure the presence of smoke from fires (Allen et al., 2004; Dreessen et al., 2016). These measurements suggest that wildfire smoke was present in Oklahoma City on September 13 and 14.

References

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Dreessen J., Sullivan J., and Delgado R. (2016) Observations and impacts of transported Canadian wildfire smoke on ozone and aerosol air quality in the Maryland region on June 9–12, 2015. *J. Air Waste Manage.*, 66(9), 842-862, doi: 10.1080/10962247.2016.1161674.

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