Wildfire Exceptional Events Demonstration for Ground-Level Ozone in Western Michigan 2015 Ozone Nonattainment Areas of Allegan and Muskegon Counties
August 26, 2020 Episode

Draft Demonstration Document

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Prepared by:

Alpine Geophysics, LLC
387 Pollard Mine Road
Burnsville, NC 28714

For

Michigan Department of Environment, Great Lakes, and Energy

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Introduction

The following is Michigan's Exceptional Event Demonstration, which clearly establishes that plumes from California wildfires adversely affected ozone data in a regulatorily significant way at ozone monitors in Allegan and Muskegon Counties in Michigan during an August 26, 2020 episode. Wildfires occurred across northern California throughout August 2020 with meteorological conditions (at the surface and aloft) favorable for transport of smoke from the wildfires into the region, including Michigan, during August 26, 2020. Maximum daily 8-hour average ozone (MDA8) concentrations in parts of western Michigan on August 26 exceeded the 2015 ozone National Ambient Air Quality Standards (NAAQS) after the precursor-rich smoke plume subsided to the surface (Figure 1). Western Michigan MDA8 concentrations reached 83 ppb on the day of the event at the Muskegon and 78 ppb at the Holland (Allegan) monitor. These measurements are considered "Unhealthy for Sensitive Groups" using the U.S. Air Quality Index (AQI) and were among the highest MDA8s during the 2020 ozone season for those sites.

Figure 1. Ozone Air Quality Index (AQI) maps on August 26, 2020.

Table 1 presents the MDA8 ozone concentrations for the episode day of August 26, 2020 with an indicator (in parentheses) of the rank of that day's value compared to 2020 at each monitor.

Table 1. MDA8 ozone concentrations and ranks on August 26, 2020 for western Michigan monitors.

		MDA8 [ppb] (rank)	Preliminary 2020 (ppb)	
Site Name	**Monitor ID**	**8/26**	**4th High**	**DV**
Holland	26-005-0003	78 (3)	76	73
Muskegon	26-121-0039	83 (3)	80	76

Table 2 identifies the Michigan monitors that were affected by smoke transported from California wildfires on August 26, 2020 such that the data should be excluded from regulatory determinations.

Table 2. Ozone Data Requested for Exclusion

Nonattainment Area	Monitor ID	Site Name	Dates
Allegan	26-005-0003	Holland	August 26, 2020
Muskegon	26-121-0039	Muskegon	August 26, 2020

40 CFR 50.14 establishes the procedures for submitting an Exceptional Event Demonstration. Specifically, 40 CFR 50.14(c)(3)(iv) states: "The demonstration to justify data exclusion must include:

A. 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);
B. A demonstration that the event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation;
C. Analyses comparing the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times to support the requirement at paragraph (c)(3)(iv)(B) of this section. The Administrator shall not require a State to prove a specific percentile point in the distribution of data;
D. A demonstration that the event was both not reasonably controllable and not reasonably preventable; and
E. A demonstration that the event was a human activity that is unlikely to recur at a particular location or was a natural event."

The following demonstration was prepared in accordance with 40 CFR 50.14, U.S. Environmental Protection Agency's (EPA) September 16, 2016, "Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations"[1] (herein referred to as Exceptional Events Guidance), and U.S. EPA's "EPA Review Technical Support Document Template for Wildfire/Ozone Events."[2]

[1] https://www.epa.gov/sites/production/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf
[2] https://www.epa.gov/sites/production/files/2017-06/documents/tsd_template_ozone_wildfire_ee_2017_0606.pdf

Summary of Findings

This report:

1. Contains the required narrative conceptual model describing the California wildfire event that caused violations at the Holland and Muskegon ozone monitors and how emissions from those events reached the affected monitors, leading to elevated measured ozone concentrations on the specific days in question.
2. Demonstrates that there was a clear causal relationship between smoke and the maximum daily average 8-hour (MDA8) ozone exceedances.
3. Contains analyses comparing the ozone concentrations during the event-influenced days to concentrations at the same monitor at other times on days with similar meteorological conditions.
4. Demonstrates that the wildfires causing smoke were not reasonably controllable or preventable and are unlikely to recur, and that they were considered natural events.

Key findings and evidence supporting these assertions include the following:

1. Considerable ozone was created upstream of Michigan due to the presence of wildfire smoke generated during California's largest recorded wildfire year, which was then transported into Michigan over several days in August 2020.
2. Meteorological conditions (at the surface and aloft) were favorable for transport of smoke from the wildfires in California into the region, including Michigan, during August 2020.
3. Ozone concentrations during the August 26, 2020 episode at the Muskegon and Holland monitors were measured above the 99^{th} percentile of the 5-year distribution of ozone monitoring data at the sites.
4. Satellite images captured visual smoke plumes that were transported into the Lake Michigan region on days when the ozone concentrations were highest.
5. Analysis of the National Oceanic and Atmospheric Administration's (NOAA) Hazard Mapping System (HMS) smoke product and Ozone AQI shows an enhanced ozone concentration impact at monitors along the wildfire smoke transport path that eventually culminates with excess ozone observations in western Michigan.
6. Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) retrievals identified smoke among the classified aerosols at the surface in the region during the August 26, 2020, episode.
7. Regional upwind measurements identify multiple monitors with unusually high ozone concentrations during the dates when the transported smoke plume passes through the region prior to the August 26, 2020 episode event.
8. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model forward and backward trajectory analyses demonstrate that wildfire smoke was transported into the region and was then transported into the western Michigan area during the August 2020 event.
9. Additional satellite retrievals demonstrate the transport of wildfire smoke into the region and provide additional evidence that the smoke plume and associated ozone precursor emissions were present during the August 26, 2020 episode.
10. Fine particulate matter (PM2.5), was elevated during the event, consistent with a wildfire smoke plume.
11. PM2.5 speciated data (organic carbon and potassium ion) showed elevated wildfire attributable concentrations during the August 26, 2020 event.

12. Comparable meteorological and typical non-event ozone exceedance day analyses suggests that the August 26, 2020 exceedance events were influenced by factors not explained by meteorology alone, lending support to the conclusion that the influence of wildfire smoke created the ozone exceedances on August 26, 2020.
13. A multi-day buildup of both wildfire smoke and ozone precursor concentrations in the Michigan area enhanced ozone concentrations in the days building up to the August 26, 2020 episode days.
14. A screening analysis of average standardized log-transformed timeseries concentrations of key pollutants provides supporting evidence for smoke influence in the western Michigan region during the August 26, 2020 episode.
15. Q/d analyses, while not meeting specific U.S. EPA thresholds for clear causal influence, are consistent with other previous long-range smoke and ozone transport events approved by U.S. EPA.

Several analytical methods were used to develop a weight of evidence demonstration that the 8-hour ozone concentrations above 70 parts per billion (ppb) during the August 26, 2020 event meet the rules for data exclusion as an Exceptional Event. In summary, satellite images and data, meteorological data, trajectory analysis, screening tools, and speciated PM2.5 data were used to assess whether conditions were favorable for transport of smoke from the California wildfires to monitors that showed 8-hour ozone concentrations above 70 ppb. The data also showed that during the August 2020 episode, the transported smoke degraded air quality upstream of Michigan first, then this photochemically aging airmass was transported eastward, creating a period of enhanced ozone along the border with Canada and into the region, including Michigan.

Michigan's analysis strongly supports that the Muskegon and Holland monitors were impacted by smoke, that concentrations on August 26, 2020, meet the rules as Exceptional Events, and that the Muskegon and Holland monitors and associated ozone observations on this day should be excluded from design value calculations.

Exceptional Event Demonstration

A. Regulatory Significance

The Exceptional Events rule applies to data showing an exceedance of a standard which may affect regulatory determinations regarding attainment designation status or other actions by the Administrator.

Exclusion of the August 26, 2020 data, in combination with a separate June 17-20, 2020 exceptional event, may allow the Allegan 2015 ozone nonattainment area (NAA) to be eligible for redesignation to attainment for the 2015 ozone National Ambient Air Quality Standard (NAAQS). Table 3 compares preliminary 2018-2020 design values calculated with and without the inclusion of data from the events. The 2020 design value data are preliminary and based on data reported through December 8, 2020, which have not yet been certified.

Exclusion of the August 26 and June 17-20, 2020 ozone data would reduce the preliminary 2018-2020 design value for the Holland monitor (26-005-0003) from 73 ppb (nonattainment) to 70 ppb (attainment) thereby bringing the Allegan NAA into attainment with the 2015 ozone NAAQS.

Exclusion of the August 26 and June 18-20, 2020, data may allow the Muskegon 2015 ozone nonattainment area to be eligible for one-year extension of the attainment date for the 2015 ozone NAAQS. Table 3 presents the preliminary 2020 maximum daily 8-hour average (MDA8) observations calculated with and without the inclusion of data from the event. The 2020 data are preliminary and based on data reported through December 8, 2020, which have not yet been certified.

Exclusion of the August 26 and June 18-20, 2020 ozone data would reduce the preliminary 2020 4th high concentration for the Muskegon monitor (26-121-0039) from 80 ppb to 70 ppb thereby bringing the NAA below the threshold necessary to meet the criteria, as provided in CAA section 181(a)(5) and 40 Code of Federal Regulations (CFR) 51.1107, to qualify for a 1-year attainment date extension for the 2015 ozone NAAQS even though the monitor did not attain the NAAQS by the applicable deadline.

Depending on 2021 or 2022 data, exclusion of August 26 and June 17-20, 2020 data may have regulatory significance for other actions by the Administrator, including future clean data determinations, redesignations, 2015 ozone NAAQS, or violations of the 2015 ozone NAAQS.

As a result, Michigan has decided to focus this demonstration on only the dates necessary to demonstrate attainment or reach 4th high MDA8 levels for eligibility for a one-year extension of the 2015 ozone NAAQS attainment date and notes that if future assessments of attainment status based on inclusion of sites and dates provide lower controlling critical differences, then Michigan will revisit this analysis.

Table 3. Ozone monitors at which Michigan is seeking EPA concurrence to exclude data.

		Preliminary 2020 Ozone						
Site Name	Monitor ID	MDA8 [ppb] (rank)	4th High [ppb]			DV [ppb]		
		8/26	Including	Excluding	Excluding June & Aug	Including	Excluding	Excluding June & Aug
Holland	26-005-0003	78 (3)	76	72	67	73	72	70
Muskegon	26-121-0039	83 (3)	80	76	70	76	74	72

B. Narrative Conceptual Model

Area Descriptions

As shown in Figure 2, Michigan has four 2015 ozone NAAs, Muskegon County, Allegan County, Berrien County, and Detroit. This document has been prepared to address exceptional events that impacted two NAAs on the western side of the state, Muskegon and Allegan NAAs.

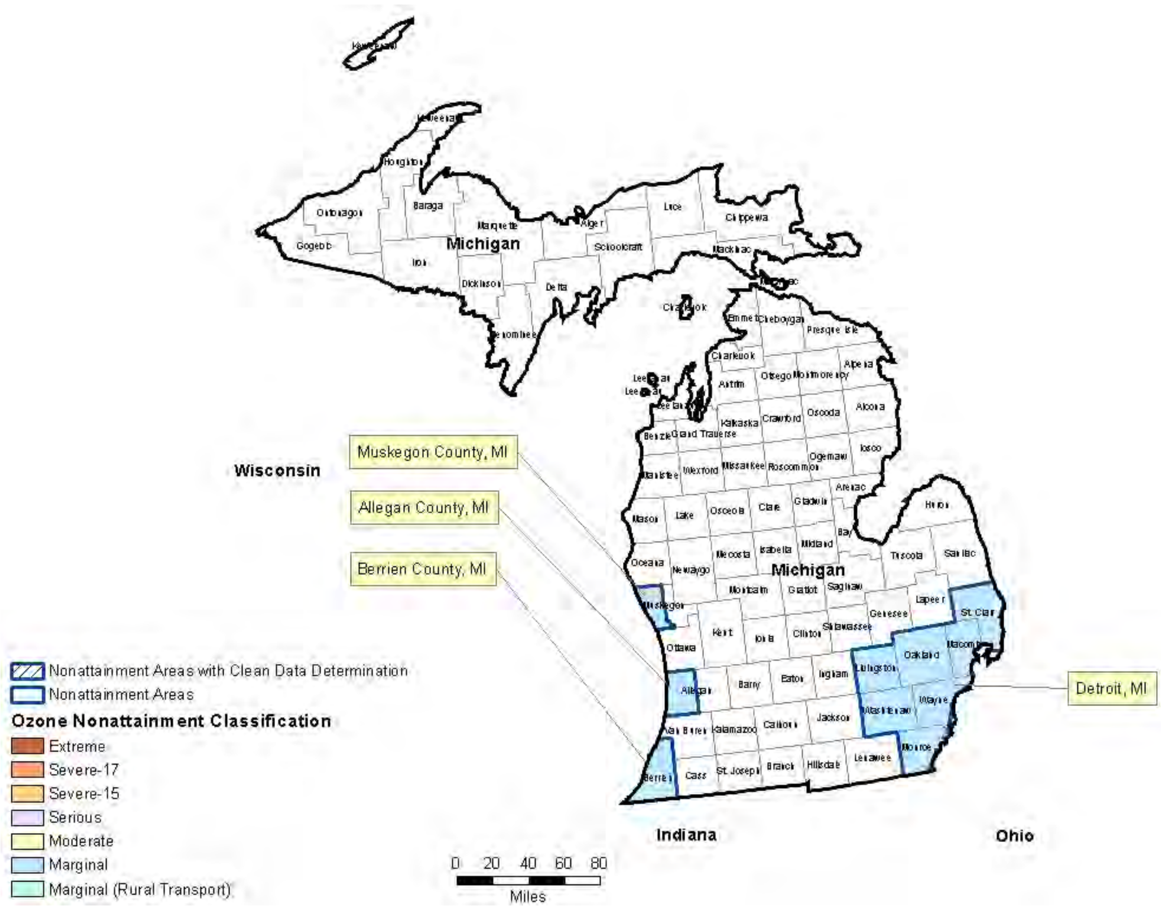

Figure 2. Michigan 8-hour Ozone Nonattainment Areas (2015 NAAQS).

On June 4, 2018, U.S. EPA designated Berrien County and portions of Allegan and Muskegon Counties in western Michigan as "marginal" ozone NAAs based on monitoring data from 2014-2016[3]. The attainment deadline for marginal NAAs to meet the 2015 ozone NAAQS is August 3, 2021.

These and the Detroit NAA are classified as marginal nonattainment, which is the lowest level of classification and means that ozone concentrations are less than 10 parts per billion (ppb) above the standard. A redesignation request was submitted for Berrien County in January of 2020 and is available on the Recent Air Quality Planning Actions and Documents webpage[4]. This request has not yet been acted on by U.S. EPA.

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[3] 83 FR 25776

[4] https://www.michigan.gov/documents/egle/aqd-aqe-sip-Berrien_County_Redesignation_Request_680643_7.pdf

As a result of the action for the NAAs described above, the State of Michigan must submit a State Implementation Plan (SIP) that meet the requirements applicable to marginal ozone NAAs.

Ozone has significantly decreased in the western Michigan NAAs due to sizeable and sustained reductions in ozone precursor emissions. This is evident in Figure 3 and Figure 4 below, showing the number of days in each year since 2000 exceeding the 70 ppb NAAQS for ozone for Allegan and Muskegon County, respectively.

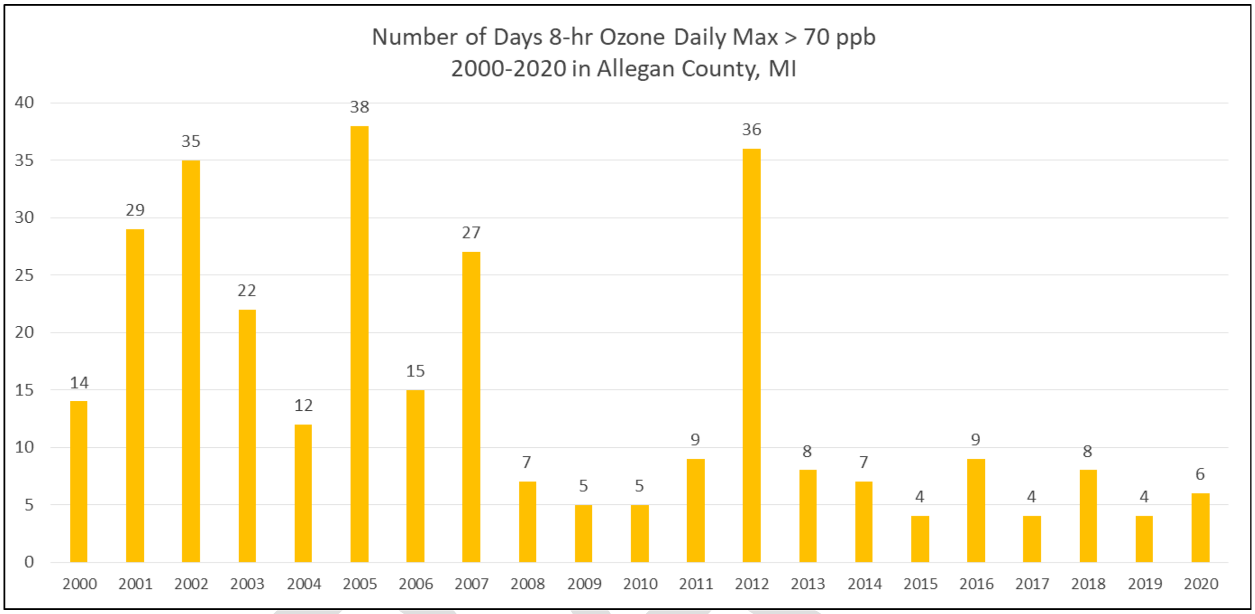

Figure 3. Number of Days Exceeding 2015 Ozone NAAQS Level of 70 ppb in Allegan NAA.

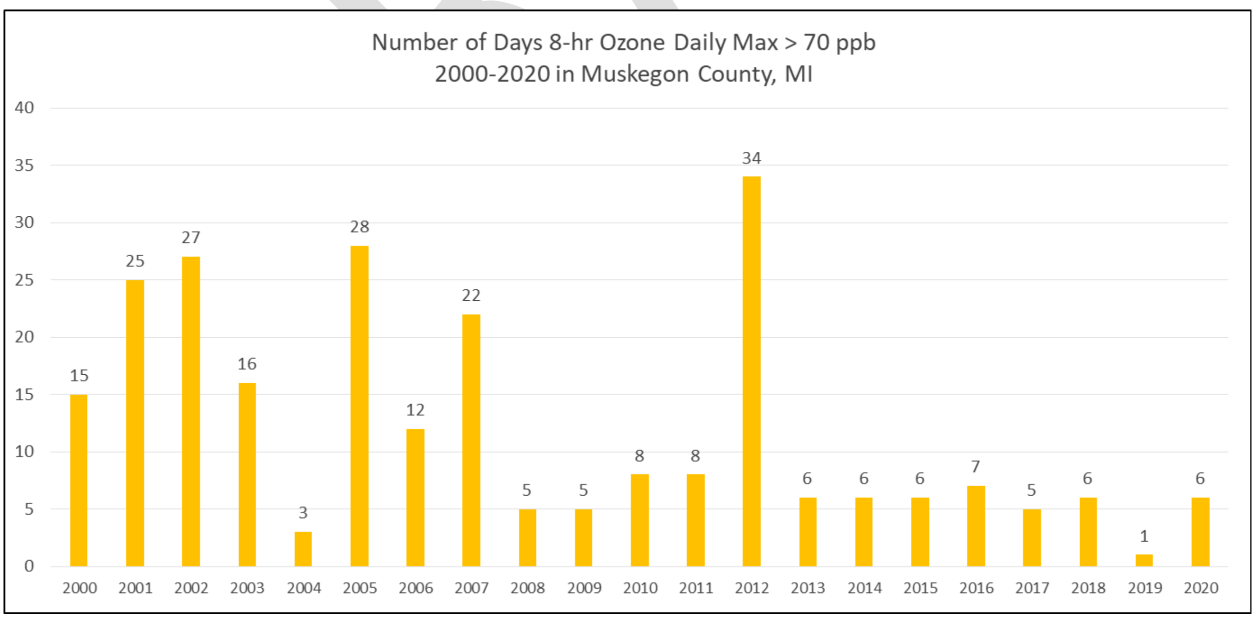

Figure 4. Number of Days Exceeding 2015 Ozone NAAQS Level of 70 ppb in Muskegon NAA.

The Muskegon site (Muskegon County; Monitor ID 26-121-0039; Lat 43.2781, Lon -86.31111) is a regional scale site located in a residential area in Laketon Township. It is a SLAMS station located at 1340 Green Creek Road, at the Laketon Township Hall approximately 3 miles east of Lake Michigan and monitors ozone.

The Holland site (Allegan County; Monitor ID 26-005-0003; Lat 42.7678, Lon -86.14861) is an urban scale site purposed to monitor maximum concentrations. It is a State and Local Air Monitoring Station (SLAMS) station located approximately 3 miles east of Holland State Park on Lake Michigan monitoring ozone and continuous PM2.5.

Figure 5 presents the location of these monitors.

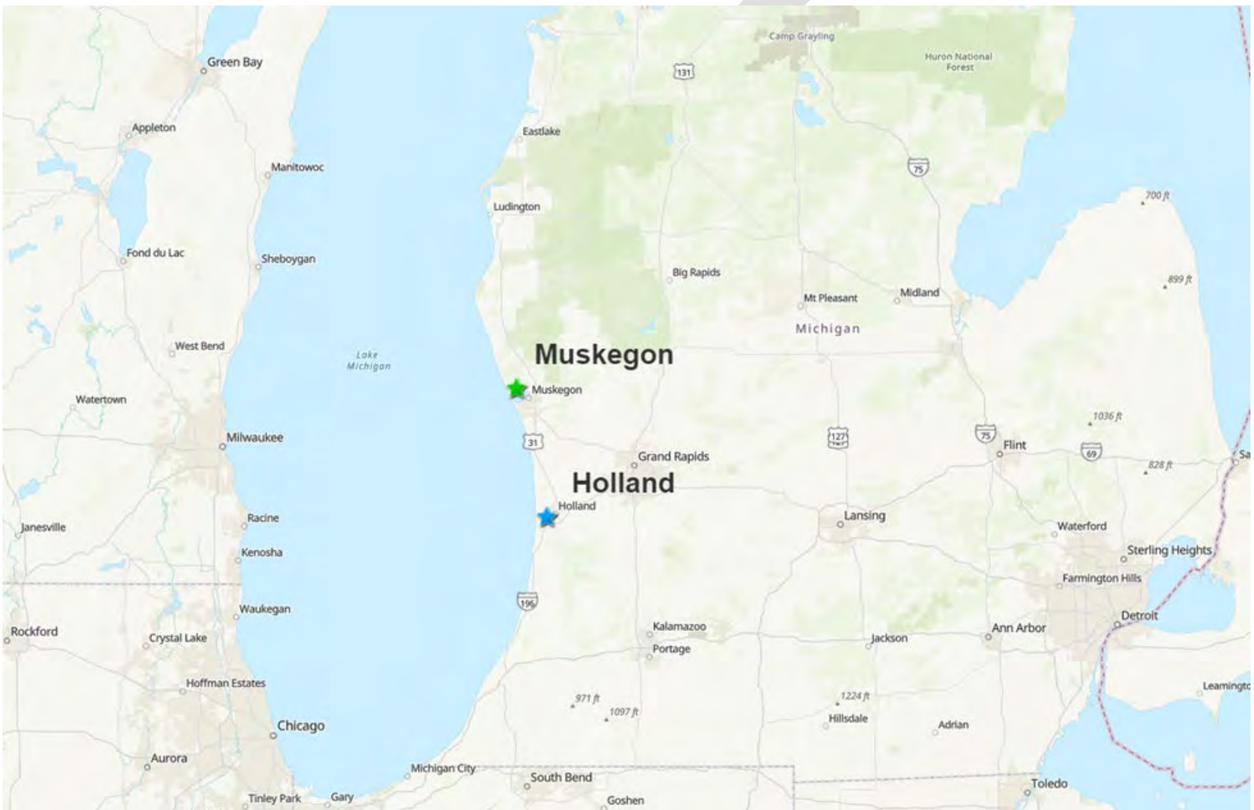

Figure 5. Western Michigan NAA monitors.

Characteristics of Non-Exceptional Event (Typical) Ozone Formation

The following conceptual model of typical ozone formation characteristics is adopted from Lake Michigan Air Directors Consortium's (LADCO) November 19, 2020, "Attainment Demonstration Modeling for the 2008 Ozone National Ambient Air Quality Standard Technical Support Document."[5] This regional description is applicable to the western Michigan area.

Based on the data and analyses presented in the LADCO report and previous conceptual models and technical support documents developed for the Lake Michigan region, a conceptual model of the behavior, meteorological influences, and causes of high ozone in the western Michigan NAAs is summarized below:

- Monitoring data show that, as of 2019, neither of these two NAAs was meeting the 2015 8-hour ozone NAAQS. As shown in Figure 3 and Figure 4 historical ozone data show year to year variation with an overall downward trend over the past 19 years, due likely to federal and state emission control programs.
- Ozone concentrations are strongly influenced by meteorological conditions, with high ozone days and higher ozone levels occurring more frequently during summers with above-normal temperatures. Nevertheless, meteorologically-adjusted trends at the controlling monitors show that concentrations have declined, even on hot days, which provides strong evidence that emission reductions of ozone precursors have been effective.
- The presence of Lake Michigan influences the formation, transport, and duration of elevated ozone concentrations along its shoreline. Depending on large-scale synoptic winds and local-scale lake breezes, different parts of the area experience high ozone concentrations. For example, under southerly flow, high surface ozone concentrations can occur in eastern Wisconsin, and under southwesterly flow, high surface ozone can occur in western Michigan.
- A natural lake-land breeze circulation pattern is a major cause of the high ozone concentrations observed along the lakeshore. This pattern is driven by surface temperature gradients between the lake and the land. At night and during the early morning hours, when the lake surface is warmer than the land surface, a land breeze forms (surface winds travel from the land to the lake). The land breeze transports ozone precursors from industrial and mobile sources on land to the area over the lake. When the sun rises, the ozone precursors over the lake begin to rapidly react to form ozone. The lake breeze transports the ozone precursors and the concentrated ozone that has formed above the lake surface and precursors from the lake, inland to a narrow band along the lake shore. The ozone concentrations observed along the lakeshore that violate the NAAQS are often associated with lake-land breeze patterns.
- Areas in closer proximity to the lake shoreline display the most frequent and most elevated ozone concentrations.

Transport of ozone and its precursors is a significant factor and occurs on several spatial scales. Regionally, over a multi-day period, somewhat stagnant summertime conditions can lead to the build-up in ozone and ozone precursor concentrations over a large spatial area. This polluted air mass can be transported long distances, resulting in elevated ozone levels in locations far downwind.

[5] https://www.ladco.org/wp-content/uploads/Documents/Reports/TSDs/O3/LADCO_2008O3_SeriousNAASIP_TSD_19Nov2020.pdf

Locally, emissions from urban areas add to the regional background leading to ozone concentration hot spots downwind. Depending on the synoptic wind patterns (and local land-lake breezes), different downwind areas are affected.

Electric generating units (EGUs) are a major source of ozone precursors. EGUs can produce large amounts of emissions over a short duration and generally emit at stack elevations conducive to transport. During hot days many of the less frequently used high-emitting EGUs come online to supply the high electric demand of air conditioning and refrigeration along with base load units operating at full capacity. To examine if the high observed ozone concentrations on August 26, 2020 were a result of high EGU NOx emissions, an analysis was conducted to examine the correlation of EGU emissions and ozone concentrations during the 2020 ozone season.

U.S. EPA's preliminary transport modeling for the 2015 ozone standard[6] shows that ozone concentrations at these monitors are most influenced by emissions from Illinois, Indiana, Kentucky, and Ohio, in addition to Michigan's own emissions. Figure 6 and Figure 7 show EGU NOx emissions[7] from these states during the ozone season and during August has significantly decreased from 2016 to 2020.

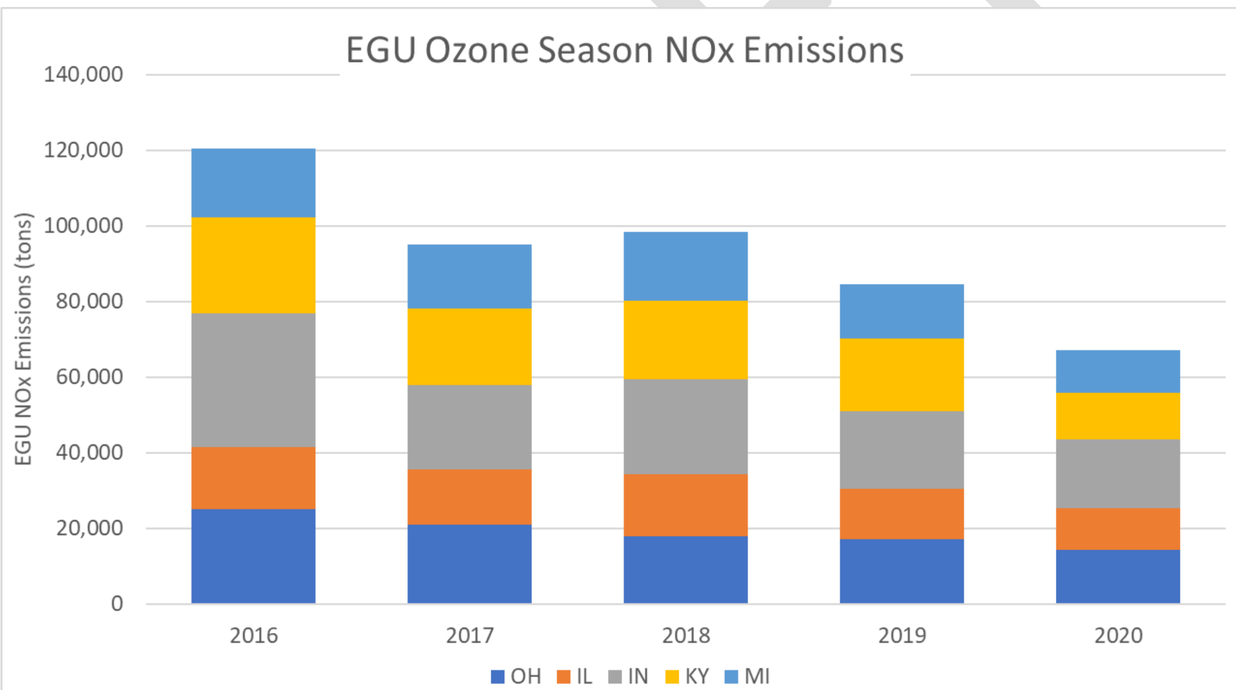

Figure 6. 2016-2020 EGU NOx Emissions (OH, IL, IN, KY, MI) – Ozone Season

[6] https://www.epa.gov/sites/production/files/2017-01/documents/aq_modeling_tsd_2015_o3_naaqs_preliminary_interstate_transport_assessmen.pdf
[7] Data obtained from U.S. EPA's Clean Air Markets Division (CAMD) at https://ampd.epa.gov/ampd/

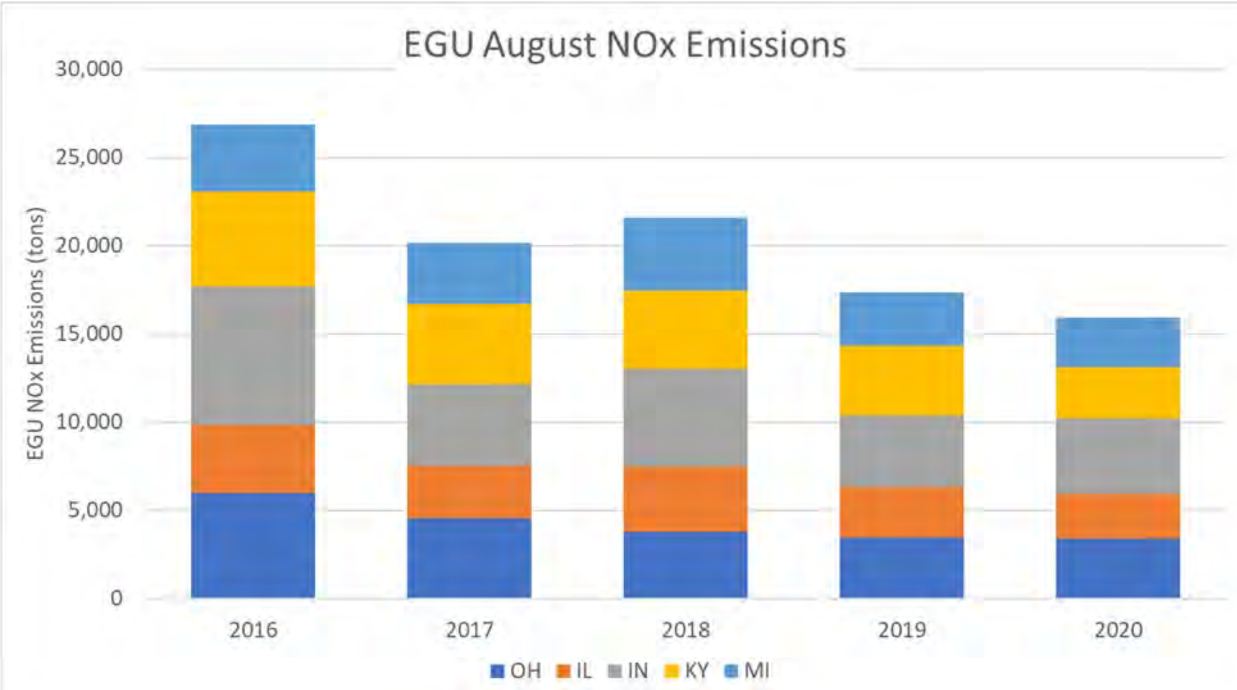

Figure 7. 2016-2020 EGU NOx Emissions (OH, IL, IN, KY, MI) – August

Wildfire Description

The year of 2020 was the largest wildfire season recorded in California history, according to the California Department of Forestry and Fire Protection (CalFire)[8]. The season was extremely active during August 2020.

According to CalFire[9]:

> *"The 2020 California wildfire season was characterized by a record-setting year of wildfires that burned across the state of California as measured during the modern era of wildfire management and record keeping. As of the end of the year, nearly 10,000 fires had burned over 4.2 million acres, more than 4% of the state's roughly 100 million acres of land, making 2020 the largest wildfire season recorded in California's modern history. California's August Complex fire has been described as the first "gigafire" as the area burned exceeded 1 million acres. The fire crossed seven counties and has been described as being larger than the state of Rhode Island. On August 19, 2020, California Governor Gavin Newsom reported that the state was battling 367 known fires, many sparked by intense thunderstorms on August 16–17."*

The record 2020 wildfire season was set up by a combination of events. The western US was in extreme drought conditions. An early end to rain across northern California started in February. [10] Combined with a record setting heat wave over the West during the middle of August, vegetation was extremely flammable.

In the early morning hours of Sunday, August 16 through Monday, August 17, a series of highly unusual thunderstorms rolled through most of northern California, which came from the moisture of the diminishing Tropical Storm Fausto. About 2,500 cloud-to-ground lightning strikes were recorded during a 12-hour period. These lightning strikes were responsible for the ignition of dozens of wildfires.[11]

As of August 24, many large fires were reported burning in California, including 5 major Lightning Complex fires (over 50,000 acres) in the Northern/Central California regions: The August Complex, LNU, SCU, CZU and North (BTU/TGU) Complex. By August 24, these five fire designations alone had burned 1,006,023 in Northern and Central California.[12] The terrain burned in these fires encompassed a wide range of timber, brush, chaparral, tall and short grasses. Approximately 6,600 structures were also destroyed.

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[8] https://www.fire.ca.gov/incidents/2020/

[9] Id.

[10] https://www.climate.gov/news-features/event-tracker/over-million-acres-burned-california-second-half-august-2020 (August 26,2020)

[11] https://www.latimes.com/california/story/2020-08-16/moisture-from-tropical-storm-fausto-fuels-northern-california-storms

[12] https://www.sfgate.com/california-wildfires/article/map-wildfires-Bay-Area-Northern-California-where-15495664.php

The magnitude of these fire events was further described by CalFire[13]:

> *"How rare is it for such a massive acreage to burn so quickly? Cal Fire, the Department of Forestry and Fire Protection for California, says it's unprecedented in a "single fire siege." In just nine days, more than three times the average acreage was burned in California than in the "normal" wildfire* ***season*** *in the state. An area the size of Rhode Island burned in less than a fortnight. Over the second half of August, 1.42 million acres of land has burned, larger than the state of Delaware.*
>
> *The two largest current fires, which constitute the second and third-largest wildfires on record for California, are the LNU Lightning complex fire to the north of San Francisco and the SCU Lightning Complex fire to the south. They have burned 750,000 acres combined. The LNU Lightning Complex fire has torn through California wine country, killing five people and destroying 1,198 structures. In any given year, one of these fires would present a monumental challenge. But in 2020, firefighters must fight both* ***simultaneously*** *as the fires burn—only 50-60% contained as of August 30—within 100 miles of the Bay Area.*
>
> *And these were just the biggest two! There are* ***hundreds*** *of wildfires of various degrees of severity occurring across the state. As of August 24, three other fires have* ***at least*** *burned through an area the size of Washington, DC. The largest of those, the CZU Lightning fire, has burned over 84,000 acres of coastal forests, including California's famed redwoods. Redwoods are naturally fire-resistant, but even they have limits."*

[13] https://www.climate.gov/news-features/event-tracker/over-million-acres-burned-california-second-half-august-2020 (August 26,2020)

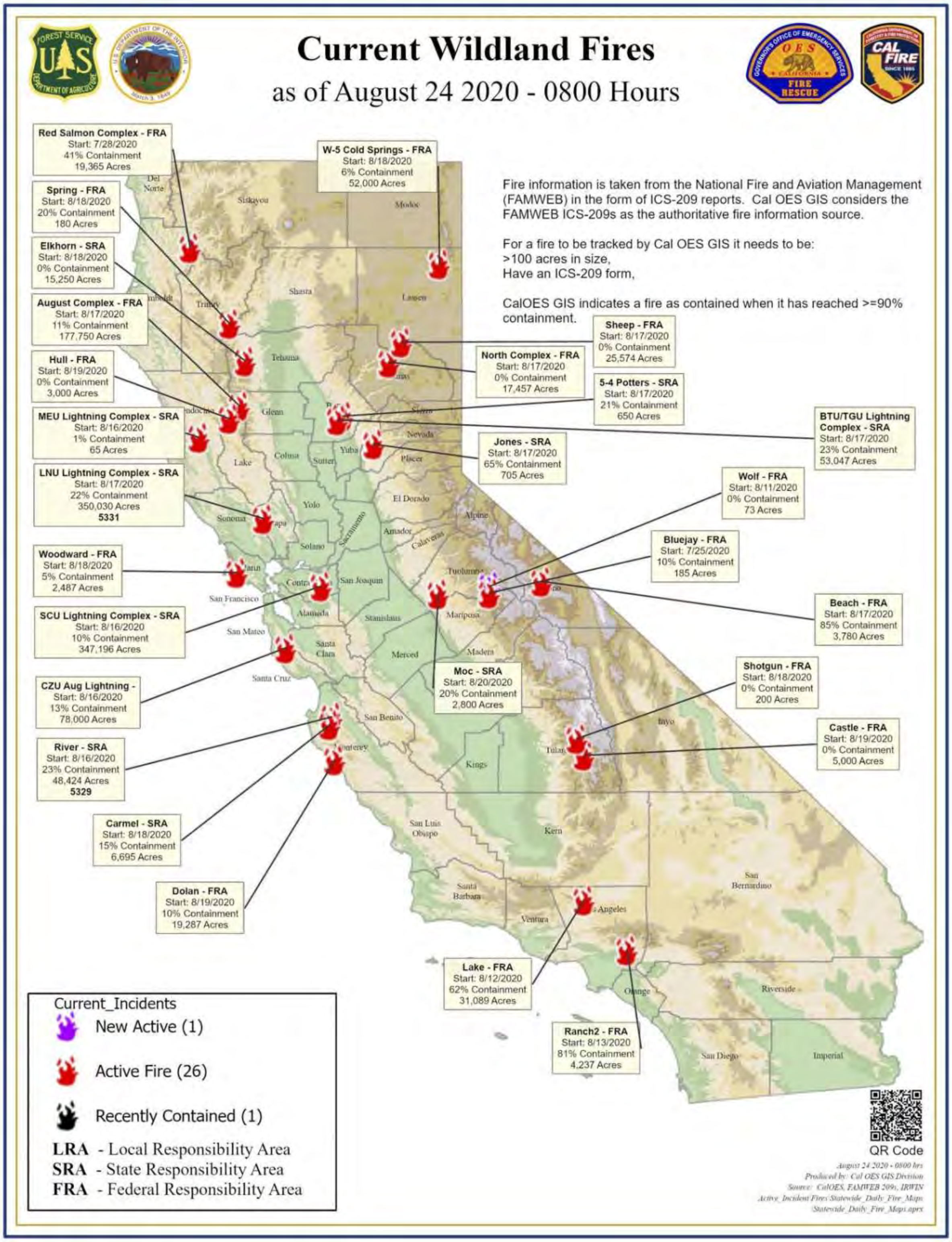

Figure 8. Location of active wildland fires in the state of California as of August 24, 2020[14].

[14] https://images.app.goo.gl/VqFwe7K7akd7CP846.

August Complex

The August Complex Fire [15] started on August 16, 2020 and was ignited by multiple lightning strikes across the Mendocino National Forest. At 177,750 acres burned by August 24, it eventually reached a total of 1,032,648 acres before it was declared contained on November 11, 2020, burning into Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, and Colusa counties.

Figure 9. August Complex Fire- Rockwell looking SE from 21N07. Taken on August 18, 2020. USDA Forest Service photo by Roy Jones[16].

[15] https://fire.ca.gov/incidents/2020/8/16/august-complex-includes-doe-fire/
[16] https://www.actionnewsnow.com/content/news/4-fires-have-combined-into-the-August-Complex-572376531.html

Sonoma-Lake-Napa Unit Lightning Complex

The Sonoma-Lake-Napa Unit (LNU) Lightning Complex[17] fire was 37 fires ignited by multiple lightning strikes on August 17, 2020. The combined fires burned into Napa, Sonoma, Lake, Yolo, and Solano counties, with a total of 350,030 acres burned by August 24, 2020. It was contained on October 2, 2020, with a total of 363,220 acres burned.

Figure 10. SAINT HELENA, CA - AUGUST 18: The Hennessey Fire rages in the mountains behind the Beckstoffer Vineyards in Napa, Calif., Tuesday, Aug., 18, 2020. (Karl Mondon/Bay Area News Group[18])

[17] https://www.fire.ca.gov/incidents/2020/8/17/lnu-lightning-complex-includes-hennessey-gamble-15-10-spanish-markley-13-4-11-16-walbridge/
[18] https://www.mercurynews.com/2020/08/20/lnu-complex-fire-sonoma-winery-flees-mid-harvest-napa-evacuations-expand/

Santa Clara Unit Lightning Complex

The Santa Clara Unit (SCU) Lightning Complex[19] Fire consisted of approximately 20 separate fires ignited by lightning strikes in multiple locations throughout Santa Clara County, Alameda County, Contra Costa County, San Joaquin County, Merced and Stanislaus Counties. The fires started on August 16, 2020 and were contained on October 2, 2020 after burning approximately 396,624 acres.

Figure 11. **A photo from CalFire[20], posted Aug. 31 by Henry W. Coe State Park, shows a dramatic view of control burns set on the west side of a dozer line.**

[19] https://www.sfchronicle.com/projects/california-fire-map/2020-scu-lightning-complex

[20] https://morganhilltimes.com/scu-complex-fully-controlled-after-record-setting-wildfire-season/

San Mateo-Santa Cruz Unit Complex

The San Mateo-Santa Cruz Unit (CZU) Complex[21] fire consisted of lightning ignited fires in multiple locations across San Mateo and Santa Cruz Counties. Contained by September 22, 2020, it burned a total of 86,509 acres.

Figure 12. Photo credit: Cal Fire CZU San Mateo-Santa Cruz Unit August 20, 2020[22]

[21] https://inciweb.nwcg.gov/incident/7028/

[22] https://climaterwc.com/2020/08/20/czu-lightning-complex-fires-grow-to-48000-acres-20952-structures-threatened/

North Complex (includes BTU/TGU)

The North Complex[23] fire was lightning ignited on August 17, 2020 and contained on December 2, 2020 after burning 318,935 acres in the Plumas National Forest.

Figure 13. North Complex column 1300 hours 9-8-2020[24].

[23] https://inciweb.nwcg.gov/incident/6997/

[24] https://inciweb.nwcg.gov/incident/photograph/6997/27/105324

Conceptual Model of Ozone Formation and Transport from Wildfires

Wildfire smoke plumes contain gases including non-methane hydrocarbons (NMHCs), CO, NOx, and aerosols, which are all important precursors to photochemical production of tropospheric ozone and can travel thousands of kilometers. Smoke plume transport may cause areas far downwind of the fires to see greater enrichment of ozone compared to areas closer to the wildfires. Upper-level winds at the western Michigan monitors during the August 26, 2020 event originated from a western direction, bringing with it smoke plumes attributed to multiple California wildfire complexes.

Many variables, such as type of fuel or forest burned, plume path, and acreage burned, affect the intensity of the fire and ability of a plume to enhance downwind ozone production. High elevation temperate coniferous forests, like those associated with California wildfires sustain the highest levels of biomass in any terrestrial ecosystem and are notable for trees of massive proportions in temperate rainforest regions.[25]

Structurally, these forests are rather simple, consisting of 2 layers generally: an overstory and understory. However, some forests may support a layer of shrubs. Pine forests support an herbaceous ground layer that may be dominated by grasses and forbs that lend themselves to ecologically important wildfires. Emissions from these forests can be much higher than from typical forests in the U.S. due to the high available biomass that may be stored in the understory of the forest floor.

The impact of wildfires on regional-scale atmospheric chemistry depends on the physical and chemical transformations that take place as fire emissions are transported, diluted, and exposed to chemical oxidants. Ozone and other oxidants can be formed along the way, and particle mass-loadings can grow or shrink[26]. Not all the factors that regulate these processes are well understood and individual fire plumes can have different behaviors.

The reasons for these complexities may have to do with how fast the plume was lofted and cooled or how efficiently NOx was converted to products such as peroxyacetyl nitrate (PAN). When mixed with urban emissions[27], it is clear is that fire emissions often have broad-scale impacts on ozone formation[28] and can be decisive factors in triggering air quality exceedances.

Photo oxidation of the NOx and volatile organic compounds (VOCs) emitted by fire plumes shows complex behavior, sometimes leading to production of ozone[29]. Other cases have confirmed that the maximum ozone production is often observed substantially downwind of the fire, after the smoke plumes have aged for several days. Dreessen *et al*[30] noted in their analysis of a June 2015 wildfire that at peak smoke concentrations in Maryland, wildfire-attributable VOCs more than doubled, while non-NOx oxides of nitrogen (NOz) tripled. These findings suggest the long-range transport of NOx within the smoke plume. They also noted that ozone peaks a few days after the maximum smoke plume due to

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[25] http://wwf.panda.org/about_our_earth/ecoregions/about/habitat_types/selecting_terrestrial_ecoregions/habitat05.cfm

[26] Akagi, S. K., et al. (2012), Evolution of trace gases and particles emitted by a chaparral fire in California, Atmos. Chem. Phys., 12(3), 1397-1421, doi:10.5194/acp-12-1397-2012.

[27] Singh, H. B., C. Cai, A. Kaduwela, A. Weinheimer, and A. Wisthaler (2012b), Interactions of fire emissions and urban pollution over California: Ozone formations and air quality simulations, Atmos Environ., 56, 45-51, doi:10/1016/j.atmosenv.2012.03.046.

[28] Pfister, G. G., et al. (2006), Ozone production form the 2004 North American boreal fires, J. Geophys. Res., 111, D24S07, doi:10.1029/2006JD007695.

[29] Jaffe, D.; Wigder, N. Ozone production from wildfires: A critical review. Atmos. Environ. 51, 1−10, 2012.

[30] Dreessen, J. et. Al., Observations and impacts of transported Canadian wildfire smoke on ozone and aerosol air quality in the Maryland region on June 9–12, 2015. Journal of the Air & Waste Management Association, 66(9), 842-862, 2016.

ultraviolet light attenuation, lower temperatures, and non-optimal surface layer composition. Putero *et al*[31] observed the largest increases in ozone from fires five days (120 hours) after the initial pollutants were emitted from the fire (Figure 14).

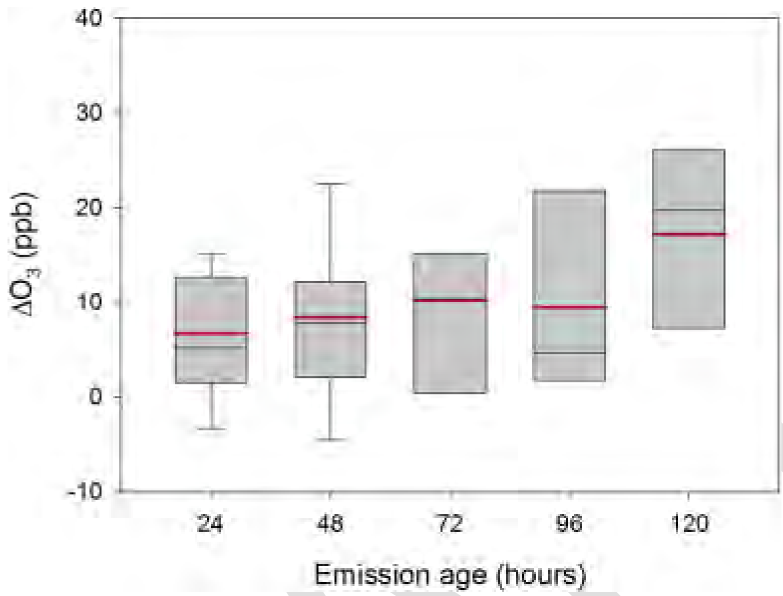

Figure 14. Ozone Enrichment by Age of Plume

[31] Putero, D. et. al., Influence of open vegetation fires on black carbon and ozone variability in the southern Himilayas, Environmental Pollution, vol 184, pp 597-604, 2014.

Meteorological Conditions Driving Smoke and Ozone Transport

Table 4 shows representative meteorological conditions[32], (between 9 AM and 9 PM ET) at the Muskegon County Airport (KMKG) in Muskegon County, from August 23-28, 2020 along with MDA8 ozone from the Muskegon monitor. Table 5 provides the same information for the West Michigan Regional Airport (KBIV) in Allegan County along with MDA8 values from the Holland monitor.

Fluctuating maximum temperatures and moderate winds are seen in the days prior to the episode with noted wind speed increase and direction change on the day of the event. The overall collective of the readings indicates an unstable system in the region. A substantial MDA8 increase is seen at both monitors on the day of the event (August 26, 2020) compared to the day before. At the Muskegon monitor, this was a 58 ppb increase and at the Holland monitor, an MDA8 increase of 45 ppb was observed.

Table 4. Meteorological Conditions August 23-28, 2020 at KMKG with MDA8 from Muskegon monitor.

Variable	8/23/30	8/24/20	8/25/20	8/26/20	8/27/20	8/28/20
Maximum Temperature (F)	84	85	82	86	87	82
Surface Wind Direction (degree direction)	189	220	211	155	229	190
Avg Wind Speed (mph)	5.8	5.2	2.3	7.8	4.9	5.6
MDA8 Ozone (ppb)	59	72	25	83	46	49

Table 5. Meteorological Conditions August 23-28, 2020 at KBIV with MDA8 from Holland monitor.

Variable	8/23/30	8/24/20	8/25/20	8/26/20	8/27/20	8/28/20
Maximum Temperature (F)	85	87	82	88	87	87
Surface Wind Direction (degree direction)	236	247	184	209	260	232
Avg Wind Speed (mph)	5.3	5.4	2.4	7.2	6.3	6.3
MDA8 Ozone (ppb)	55	66	33	78	62	54

Surface pressure[33], upper air 700 millibar (mb), and 850 mb height maps[34], where long range transportation can occur, for August 22-26, 2020, are shown in Figure 15 through Figure 19.

Figure 22 though Figure 25 provide daily ozone AQI and 48-hour HYSPLIT back-trajectory plots for August 24-26, 2020 of KMKG and KBIV, respectively. These figures demonstrate the movement of the enhanced ozone concentrations associated with the transported wildfire smoke plume and indicate the movement of air concentrations observed at the monitors on these days.

These figures also provide surface wind roses[35] and representative 12km resolution North American Mesoscale Forecast System (NAM12)-modeled surface and upper air wind roses that show the prevailing wind directions divided into sectors around the compass with due north at the top. The longer "petals" of the rose represent sectors where the wind direction is more prominent. Overlaid on these petals are

[32] https://mesonet.agron.iastate.edu/
[33] Id.
[34] http://www.spc.noaa.gov/obswx/maps/
[35] https://mesonet.agron.iastate.edu/

color bars representing specific ranges of wind speed for each wind direction sector. The upper air wind direction and speed were informed using upper air soundings at 700 mb through 850 mb pressures from KDTX, representative of western Michigan, for 8 am EDT (12Z) on August 24, 25, and 26, 2020.

Soundings from the upper air station at the Detroit/Pontiac (KDTX) station,[36] and corroborating NAM12-modeled conditions representative of KMKG and KBIV[37], representing western Michigan's upper air conditions on August 24-26, 2020, are provided in Figure 26 through Figure 28.

The synoptic patterns from August 22 through August 26, 2020 show weak forcing over much of the Continental United States with some influence of the outflow of Hurricane Laura on August 26. The outflow caused a weak surface cold front to drop south and at upper levels, a trough sank in producing a northwesterly flow, lighter at the surface but more prevalent at upper levels. This was short lived, but strong enough to bring in clouds and scattered precipitation for one day keeping ozone levels lower on August 25, 2020. Again, this was short lived because by the morning of August 26, 2020, the boundary lifted back north with all levels back to a weaker, but southerly flow.

Throughout the period a weakening blocking structure over Northern Utah and surrounding areas is diverting flows from southern California to the east where they are captured in the more northerly winds toward the Upper Midwest. Conversely, the winds from Northern California are directed to the north, where they meet more westerly winds toward the Upper Midwest near the Canadian border.

[36] https://rucsoundings.noaa.gov/
[37] https://www.ready.noaa.gov/READYamet.php

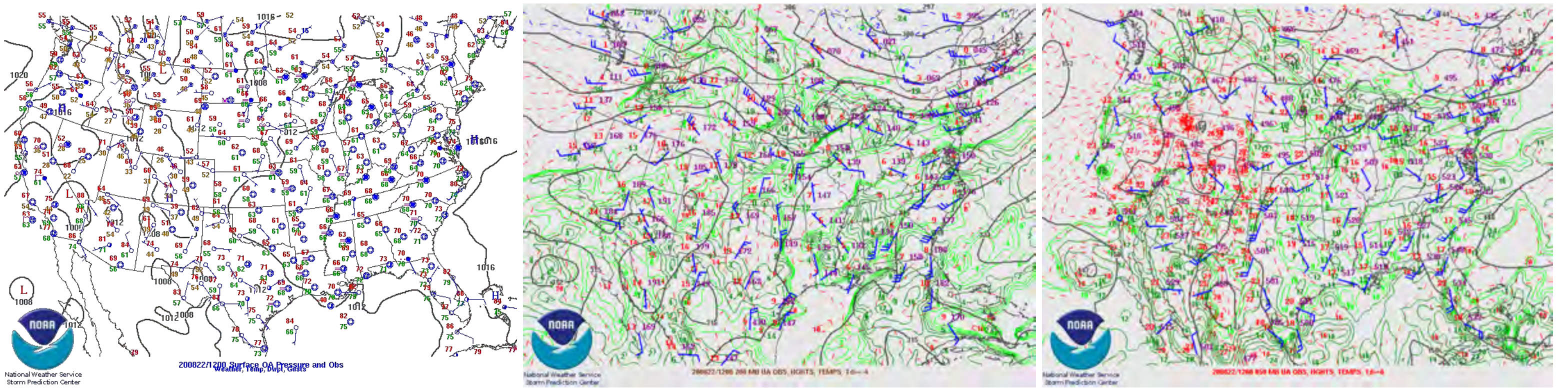

Figure 15. Surface (left), 700 mb (middle), and 850 mb (right) Pressure Patterns at 8 am EDT with Winds for August 22, 2020

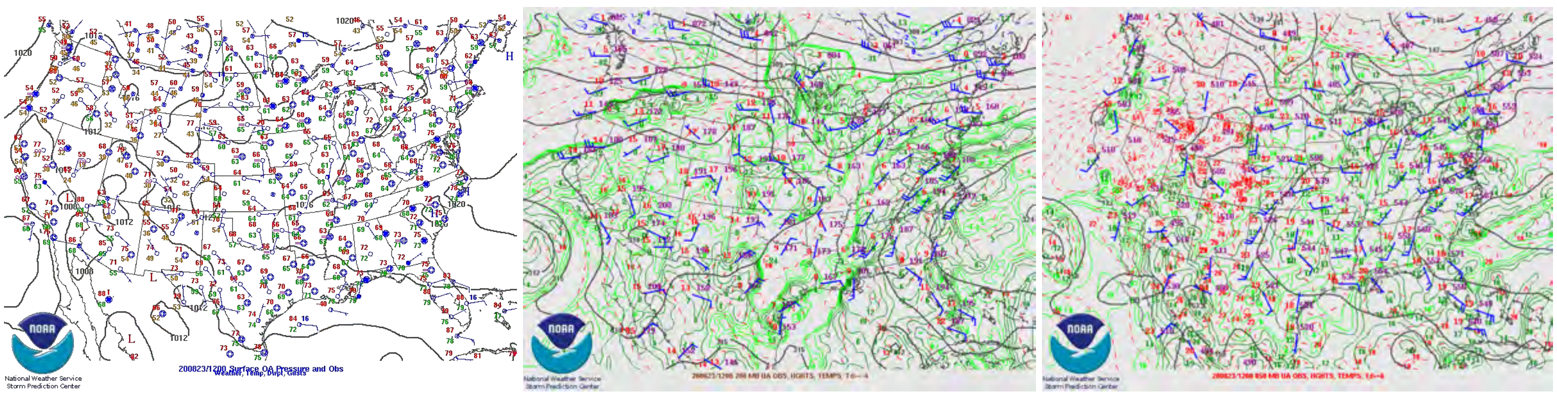

Figure 16. Surface (left), 700 mb (middle), and 850 mb (right) Pressure Patterns at 8 am EDT with Winds for August 23, 2020

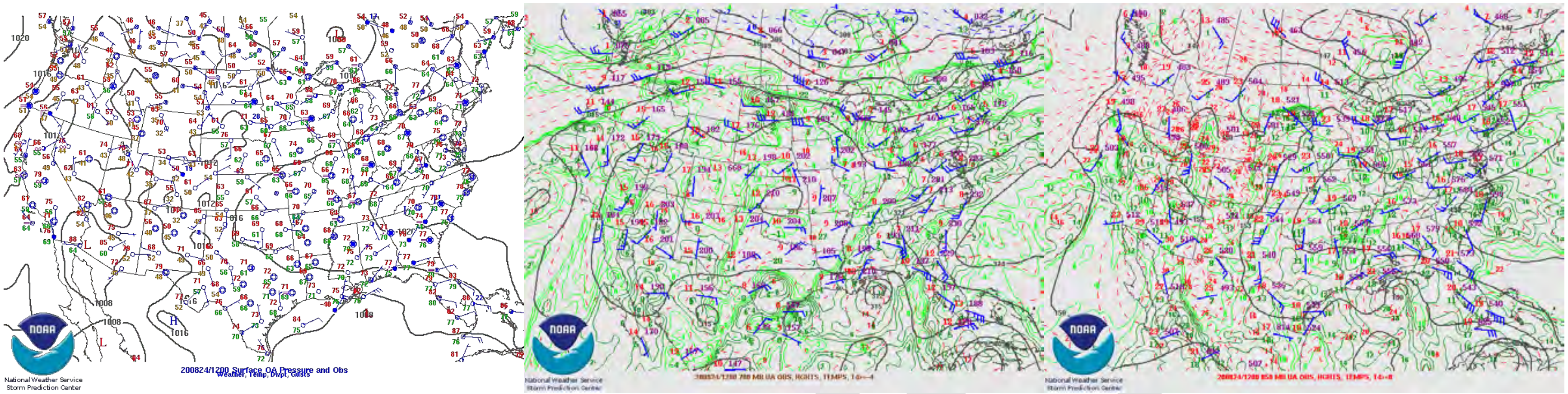

Figure 17. Surface (left), 700 mb (middle), and 850 mb (right) Pressure Patterns at 8 am EDT with Winds for August 24, 2020

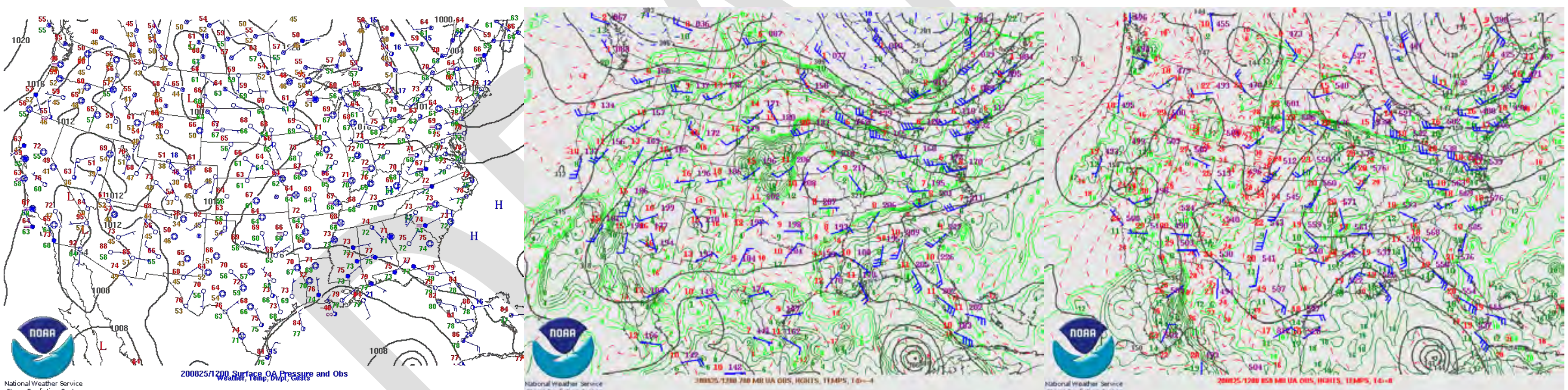

Figure 18. Surface (left), 700 mb (middle), and 850 mb (right) Pressure Patterns at 8 am EDT with Winds for August 25, 2020

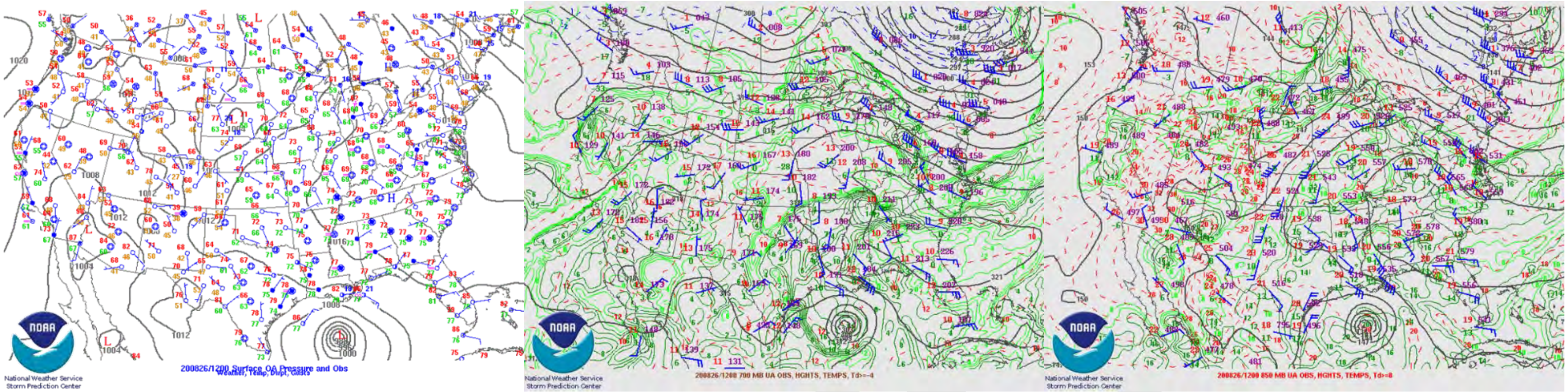

Figure 19. Surface (left), 700 mb (middle), and 850 mb (right) Pressure Patterns at 8 am EDT with Winds for August 26, 2020

Using GEOS-17 true color satellite images from these days with an overlay of wind data, utilizing lines that are used to illustrate the movement of particles in liquids[38] (Figure 20 and Figure 21), it is clearly seen that the wildfire smoke sinks south with the pressure boundary on August 25, 2020 compared to August 24 and August 26, 2020.

As is seen at both monitors starting on August 25, 2020 (Figure 22 and Figure 24), the AQI maps demonstrate the southernly movement of polluted air associated with the boundary. This differs from August 26, 2020 (Figure 23 and Figure 25) in the fact that wind direction reverses from an onshore to an offshore flow creating an event that returns the transported wildfire smoke from the south over the western Michigan area.

On the day of the episode, poor air quality and high ozone concentrations returns from the south over Lake Michigan and continues moving with the wildfire smoke plume and is seen transported from the southwest of the NAA. These wind roses indicate the unsteady movement of winds on August 25, 2020 allowing the regionally polluted air already present from the smoke plume to mix over the NAAs.

Figure 20. GEOS-17 true color image and wind vector data for August 24, 2020.

[38] https://www.ventusky.com/

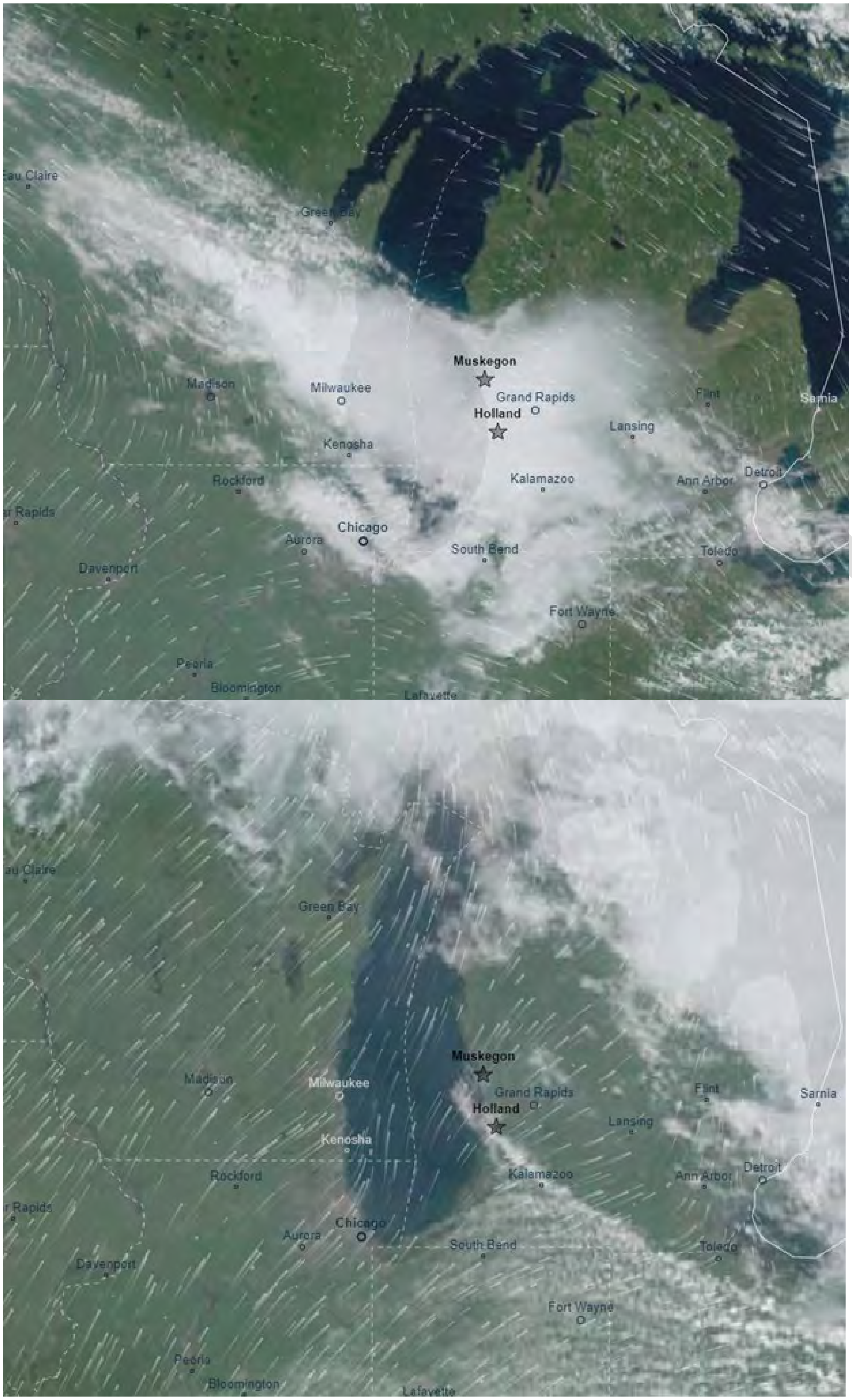

Figure 21. GEOS-17 true color image and wind vector data for August 25 (top) and August 26, 2020 (bottom).

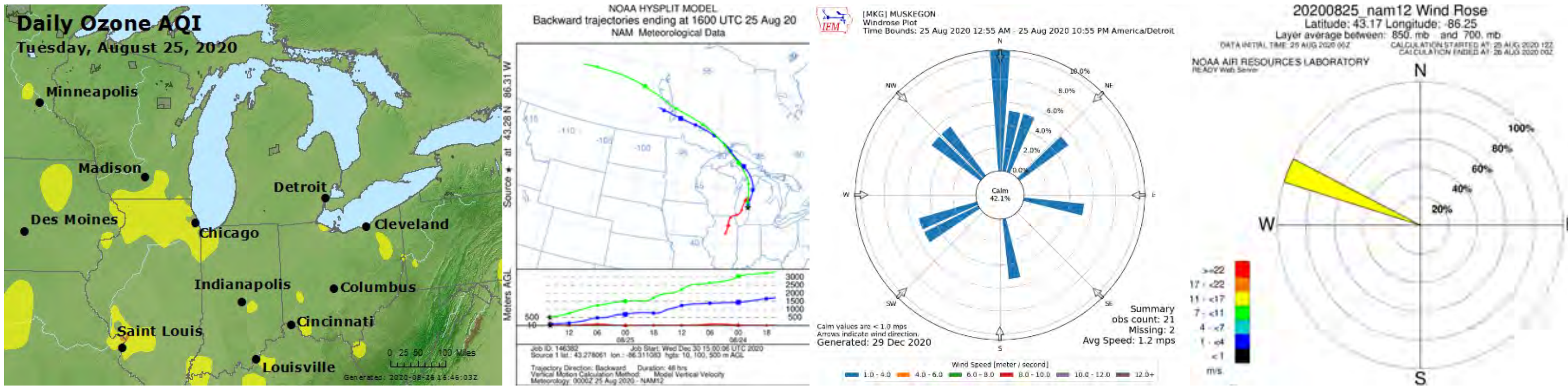

Figure 22. Ozone AQI, 48-hour HYSPLIT back trajectories, surface, and upper air wind roses for Muskegon NAA on August 25, 2020.

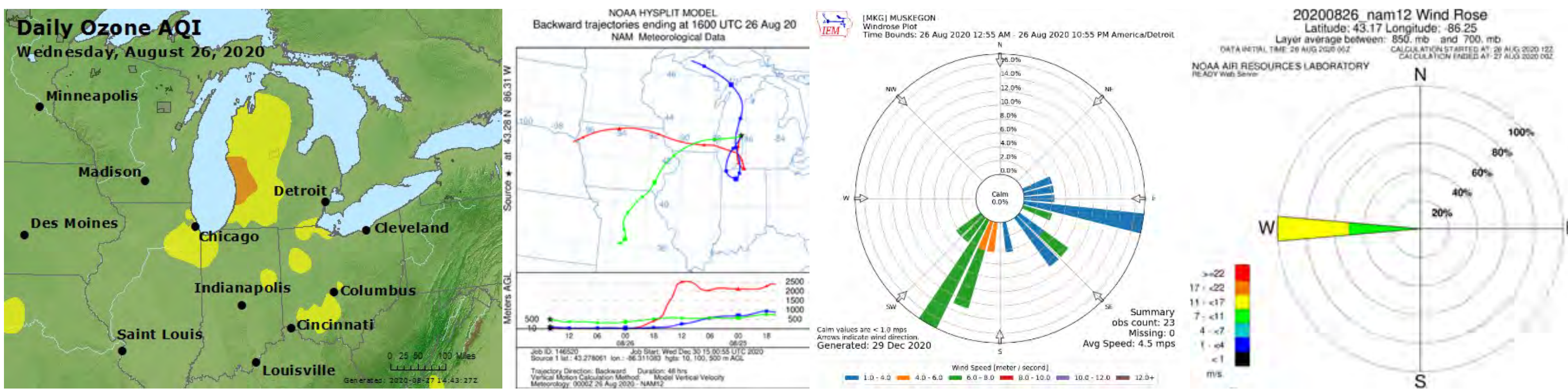

Figure 23. Ozone AQI, 48-hour HYSPLIT back trajectories, surface, and upper air wind roses for Muskegon NAA on August 26, 2020.

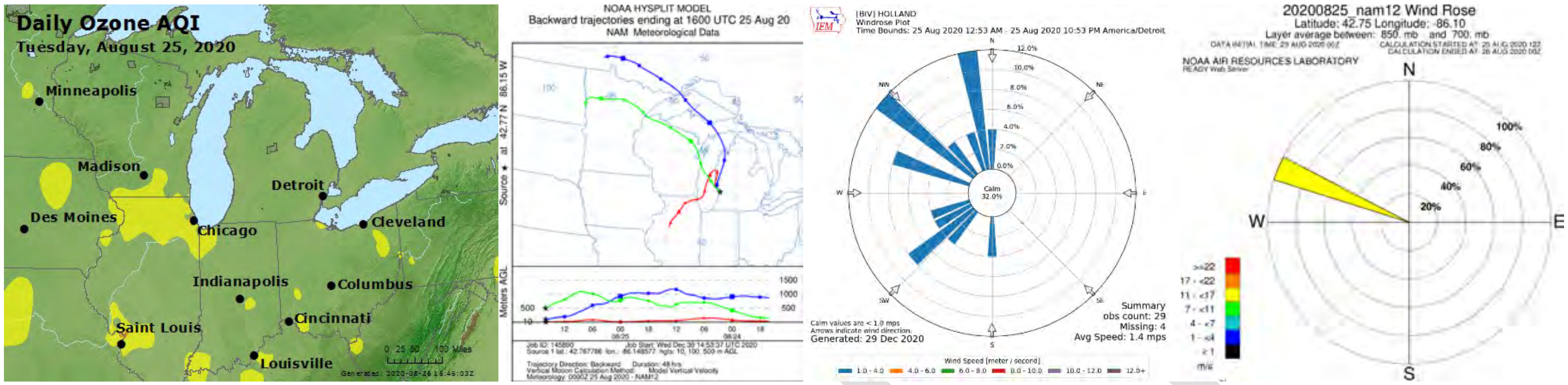

Figure 24. Ozone AQI, 48-hour HYSPLIT back trajectories, surface, and upper air wind roses for Allegan NAA on August 25, 2020.

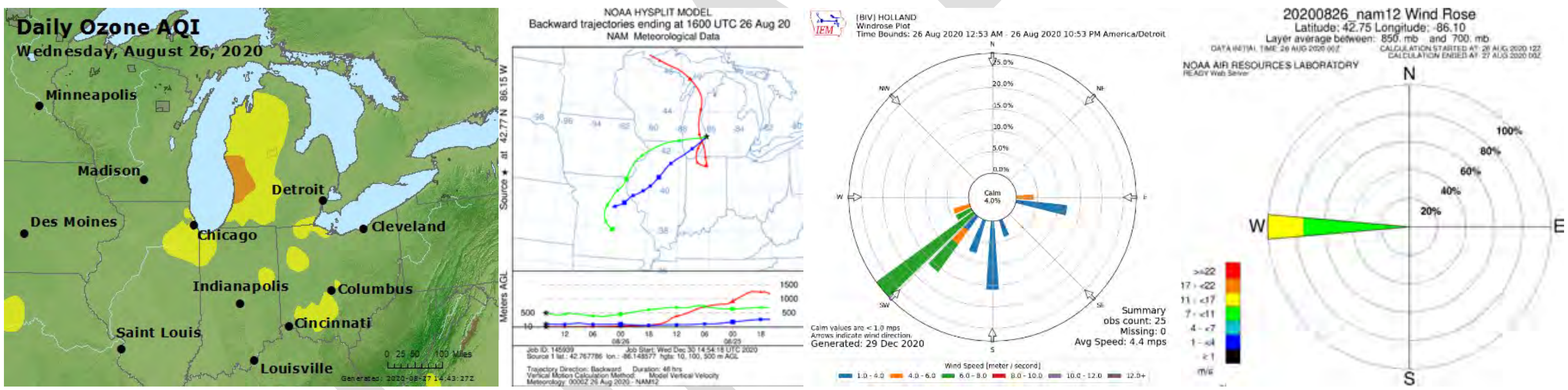

Figure 25. Ozone AQI, 48-hour HYSPLIT back trajectories, surface, and upper air wind roses for Allegan NAA on August 26, 2020.

The sounding plots for August 25 and 26, 2020 provided below show each day's modeled morning (left side) and evening (right side) temperature profiles. The vertical temperature profiles for the morning of August 26, 2020 showed temperature inversions at about 1000 meters (m) above ground level (circled in the figures), the same general altitude as the smoke plume. Evening temperature profiles for this day indicate that more vigorous vertical mixing occurred up to the height of the cap. This further supports mixing of the smoke plume to the surface. Smoke that was transported in the upper layer winds and arrived from the west would have been mixed with surface layer air and would have impacted ozone observations on August 26, 2020.

The mixing presented in these soundings is further corroborated with National Weather Service (NWS) Fire Weather Planning Forecasts which provide twice daily predictions of mixing heights and smoke dispersion factors for the period of August 20-30, 2020. In the reporting from NWS, predictions of mixing heights of up to 1200 m AGL mixed to ground level are presented in Figure 29 and Figure 30. This is consistent with observed smoke aerosols in the 1000-5000 m AGL altitude presented later in this document.

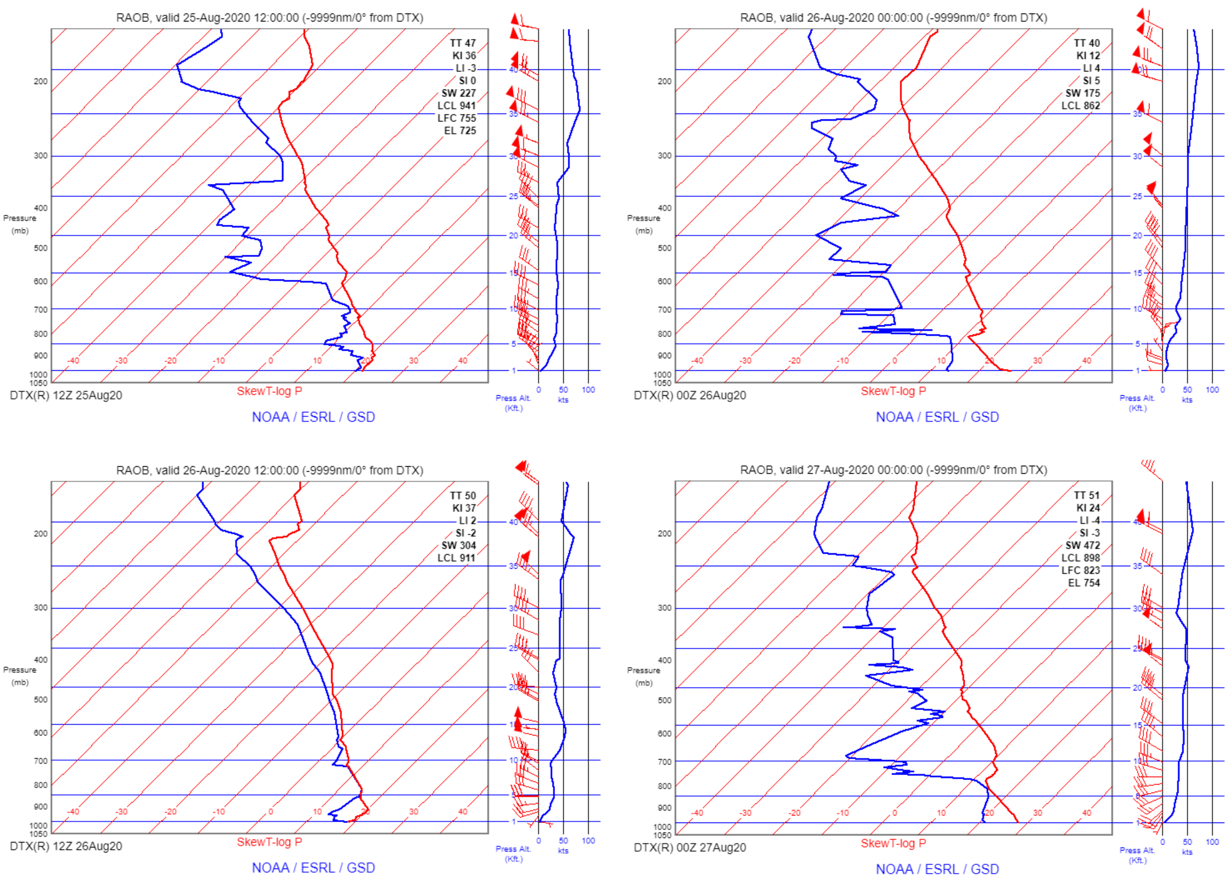

Figure 26. 8 am (left) and 8 pm (right) EDT sounding at DTX (left) on August 25 (top) and August 26 (bottom), 2020.

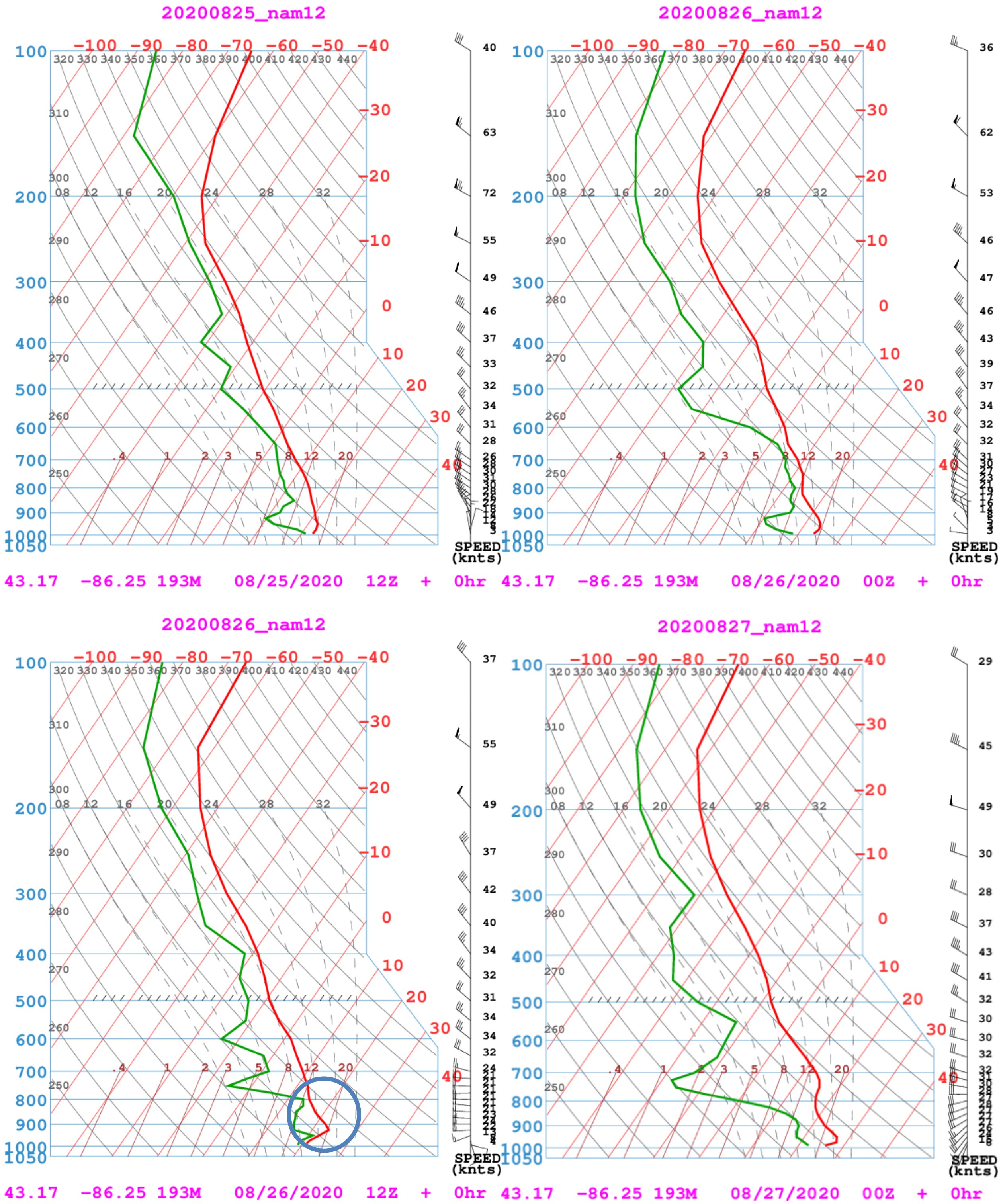

Figure 27. 8 am (left) and 8 pm (right) NAM12 modeled sounding at MKG on August 25 (top) and August 26 (bottom), 2020.

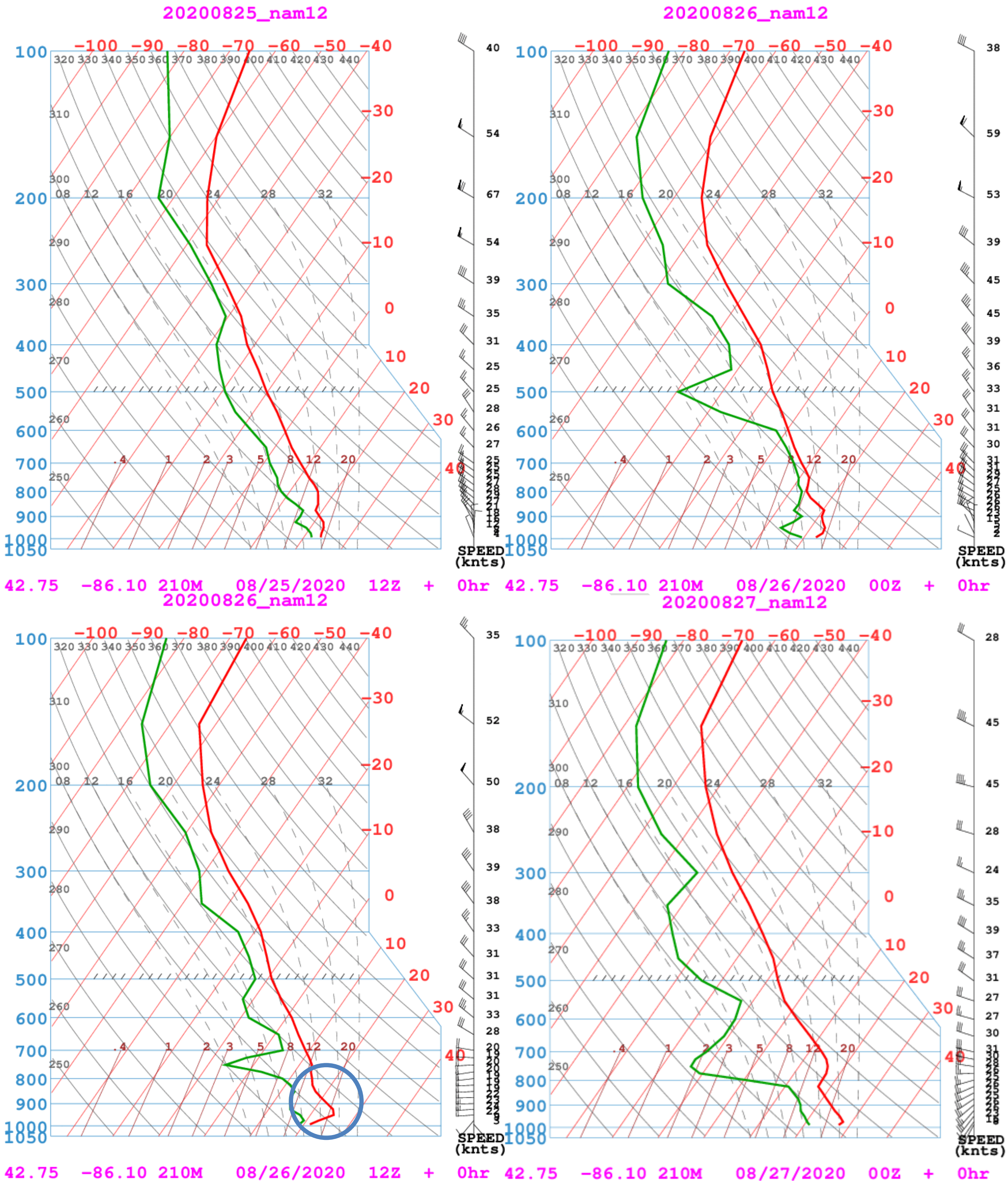

Figure 28. 8 am (left) and 8 pm (right) NAM12 modeled sounding at BIV on August 25 (top) and August 26 (bottom), 2020.

In the absence of any measured planetary boundary layer (PBL) height measurements at individual monitors, daily predicted values provided in Fire Weather Planning Forecasts[39] developed by the National Weather Service (NWS) can provide additional evidence related to the transport of smoke. These reports use meteorological parameters such as relative humidity, wind speed and direction, mixing heights, and soil moisture to determine whether conditions are favorable for fire growth and smoke dispersion. The National Weather Service issues several fire weather products on both a daily basis and when conditions warrant. Despite the limitations of frequency in the NWS day-night forecasts, these data provide crucial insight into the daily boundary layer dynamics at the nonattainment areas in Western Michigan.

Figure 29 provides an extract from a fire weather planning forecast for Southwest Lower Michigan as prepared by the NWS Grand Rapids, MI (KGRR) on the afternoon of August 24, 2020. In this specific report, NWS notes the smoke from western wildfires impacting the regional airshed. From the aggregate of reports like these, NWS forecasts throughout the period predicted that mixing heights would fall to 0 – 200 ft during the evening and overnight hours and then rise to altitudes of 4000 ft AGL or higher during the midday periods indicating a vigorous mixing from elevated layers. In combination with evidence presented later showing that smoke was observed in the free troposphere at these elevations (2000 - 5000 m AGL), these plots indicate a connection between the surface and the observed smoke aerosols in aloft layers. These were also accompanied with “poor to fair” smoke dispersal values (0 – 300), a numerical indicator of how well and how rapidly smoke will be dispersed (good to excellent) or if stagnant conditions exist (poor to fair), when the smoke enhanced ozone exceedance was recorded (Figure 30).

We contrast these findings with a typical non-event ozone exceedance (June 2, 2020) in the region and immediately note the differences in the day-night mixing predicted and leading up to the event (Figure 31). Unlike the smoke enhanced event of August 26, 2020 which predicted a day-night variance in mixing heights, NWS predicted almost no change in mixing height leading up to the day of the June 2, 2020 ozone exceedance. This is an indicator of little vertical mixing and conditions where the ozone was likely maintained at low levels for extended periods as the buildup of ozone precursor emissions reacted favorably for ozone formation. This buildup analysis is also demonstrated in later sections of this document.

[39] https://www.weather.gov/fire/

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904
FNUS53 KGRR 242029
FWFGRR

Fire Weather Planning Forecast for Southwest Lower Michigan
National Weather Service Grand Rapids MI
429 PM EDT Mon Aug 24 2020

.DISCUSSION...Increasing clouds and gusty winds this afternoon will
give way to showers and storms overnight tonight into Tuesday morning.
The humid conditions will continue through the week with another
chance for storms Wednesday morning. The increased haziness will
continue and smoky skies are expected due to smoke moving over
Michigan from the western US fires. Temperatures will be
rather warm with typical summer humidity. Cooler temperatures are
expected behind a front on Saturday.

.TONIGHT...
Sky/weather.........Partly cloudy (25-35 percent) until 0500, then
                    mostly cloudy (70-80 percent). Chance of
                    showers and thunderstorms.
Chance of pcpn......50 percent.
Min temperature.....Around 69.
   24 hr trend......Unchanged.
Max humidity........99 percent.
   24 hr trend......Unchanged.
20-foot winds.......Light winds becoming west around 5 mph
                    overnight.
Haines Index........5 or moderate potential for large plume
                    dominated fire growth.
Mixing height.......0-400 ft AGL.
Transport winds.....Southwest around 5 mph.
Smoke dispersal.....0-100 (poor).
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Figure 29. Extract of NWS fire weather planning forecast from Grand Rapids at 4:29 PM EDT on August 24, 2020.

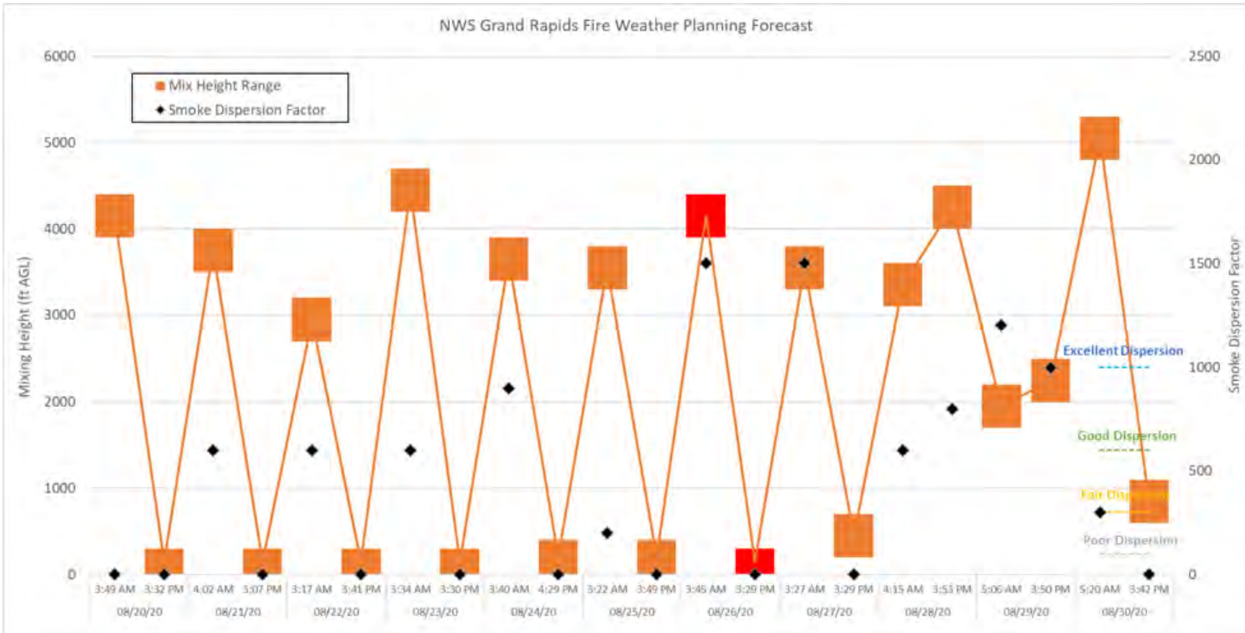

Figure 30. Fire weather planning forecast metrics at Grand Rapids (KGRR) between August 20 and 30, 2020. Red highlight represents exceptional event ozone exceedance day of August 26, 2020.

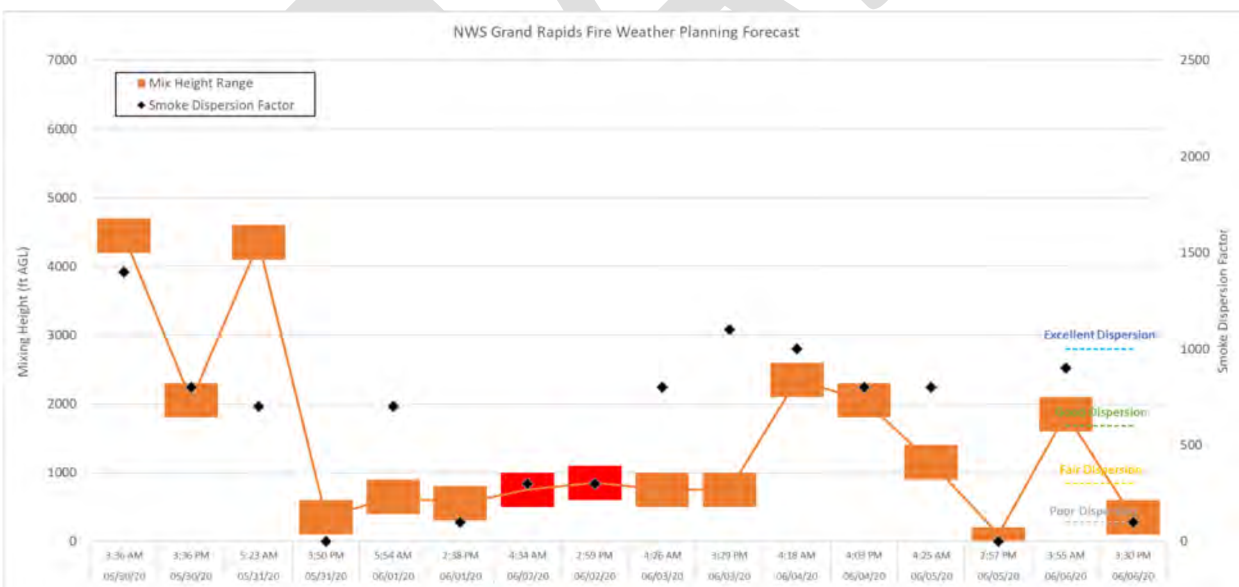

Figure 31. Fire weather planning forecast metrics at Grand Rapids (KGRR) between May 30 and June 5, 2020. Red highlight indicated typical, non-event ozone exceedance on June 2, 2020.

It is important to note that the episode of smoke transport between the California wildfires and the western Michigan monitors occurred during relatively dry conditions. Figure 32 shows the 24-hour precipitation levels[40] (ending at 7:00 AM EST) for August 23 through 26, 2020. The path from northern California eastward into the region shows a clear path of limited precipitation along the Rocky Mountain states and southern Canadian border. Like June 2020 conditions, this provides evidence that ozone precursors and PM species did not precipitate out during the transport from the wildfires to western Michigan during this period.

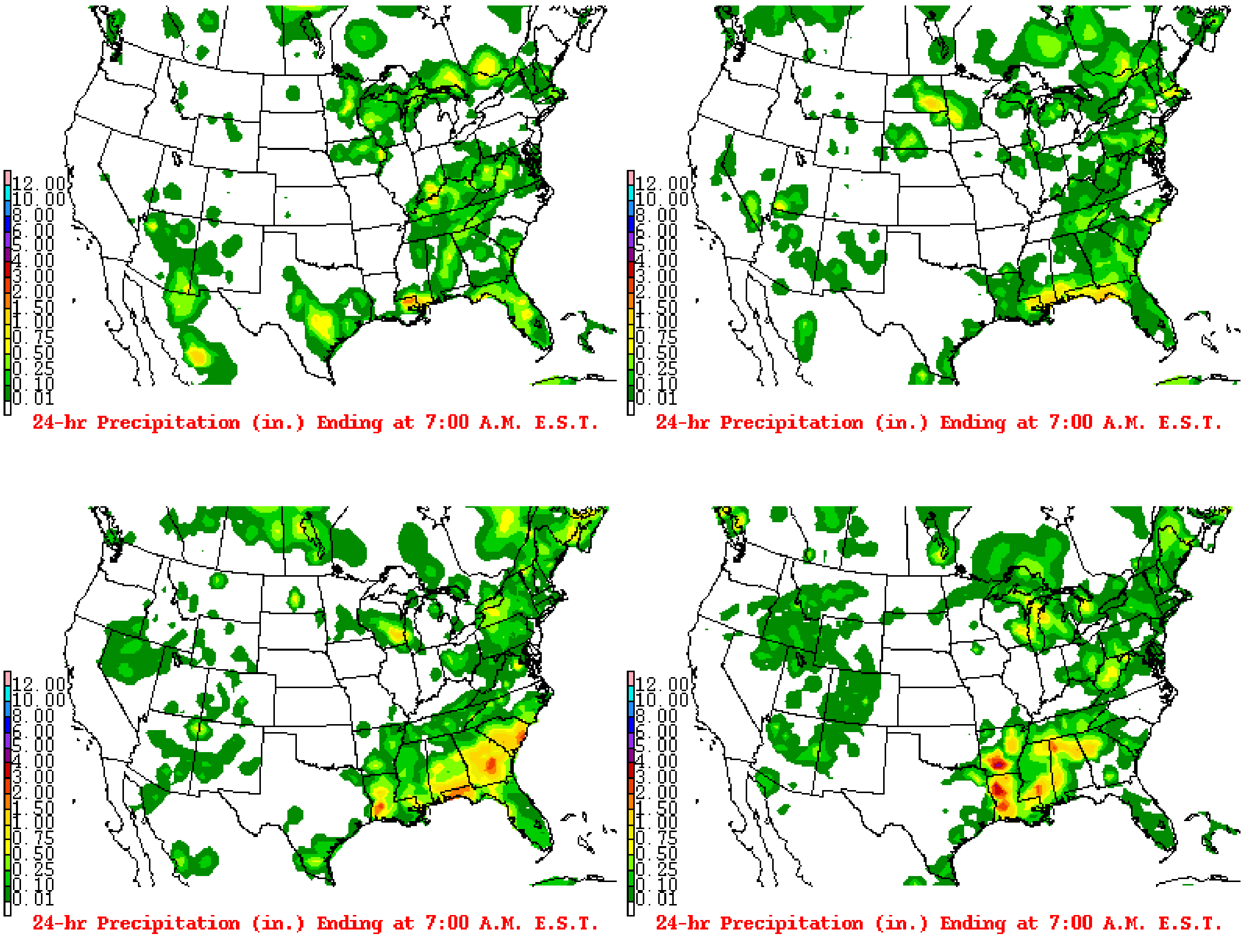

Figure 32. 24-hour Precipitation August 23 (top left), August 24 (top right), August 25 (bottom left), and August 26 (bottom right), 2020.

[40] https://www.wpc.ncep.noaa.gov/dailywxmap/

C. Clear Causal Relationship and Supporting Analyses

U.S. EPA's Exceptional Event Guidance outlines a three-tiered approach for the clear causal relationship analysis, along with examples of supporting documentation for each tier.

A Tier 1 demonstration requires the least amount of evidence and is appropriate for wildfires that clearly influenced monitored concentrations, either during a time of year that typically has no exceedances or is clearly distinguishable from non-event concentrations. The August 26, 2020 event occurred during the typical ozone season in Michigan and although concentrations were higher than normal for those times of year, a Tier 1 demonstration may not be appropriate in this case.

A Tier 2 analysis is necessary when the wildfire impacts are less clear and includes a comparison of the fire emissions to the fire's distance to the monitor (Q/d analysis). Using gridded wildfire emissions data from the Fire INventory of NCAR ("FINN")[41], a Q/d analysis was performed on the California fires. As the FINN data are represented as molar grid-based estimates and not associated with specific fires, grid cell NOx and reactive VOCs were aggregated from closely related FINN data to estimate the individual fires and converted emissions to tons per day. As each of the fires was located approximately 3,000 km away from the western Michigan NAA monitors, daily emissions from any one fire would need to exceed 300,000 tons in order to meet the criteria of a Q/d ≥ 100 tons/km. Michigan's initial Q/d from the August Fire Complex was estimated well below 1.0 tons/km.

This and the other calculated values for the remaining fires are well below the U.S. EPA recommended level of 100 tpd/km indicating a clear causal relationship. It should be noted that in *none* of the eastern U.S. exceptional events demonstrations approved by U.S. EPA in the past few years and reviewed for comparison to this analysis has the demonstration come close to meeting the Q/d threshold of 100 tons/km. As the Q/d analysis for this area does not satisfy the criteria for clear causality under a Tier 2 demonstration, additional evidence is provided below for a Tier 3 analysis to establish a clear causal relationship.

Comparison of Fire-Influenced Ozone Exceedances with Historical Concentrations

U.S. EPA's Exceptional Events Guidance indicates that a clear-causal demonstration should include a comparison of the event-related exceedance with historical concentrations measured at each monitor requested for data exclusion. Examples of supporting documentation include time-series plots overlaying five years of data and five-year percentiles. The Exceptional Events Guidance indicates that if the flagged data is above the 99th or higher percentile of the five-year distribution of ozone monitoring data or is one of the four highest ozone concentrations within one year, these data can be considered outliers and provide strong evidence for the event.

[41] https://www2.acom.ucar.edu/modeling/finn-fire-inventory-ncar

Figure 33 and Figure 34 show the MDA8 during 2020 at the Muskegon and Holland (Allegan) monitors where data exclusion is requested. Increased ozone is evident on August 26, 2020, as indicated within the grey columns. Both monitors recorded MDA8 ozone concentrations above their 99th percentile values on August 26, 2020, signifying rare ozone episodes. As previously shown in Table 3, the observations from this day at the NAA monitors were among the top days of 2020.

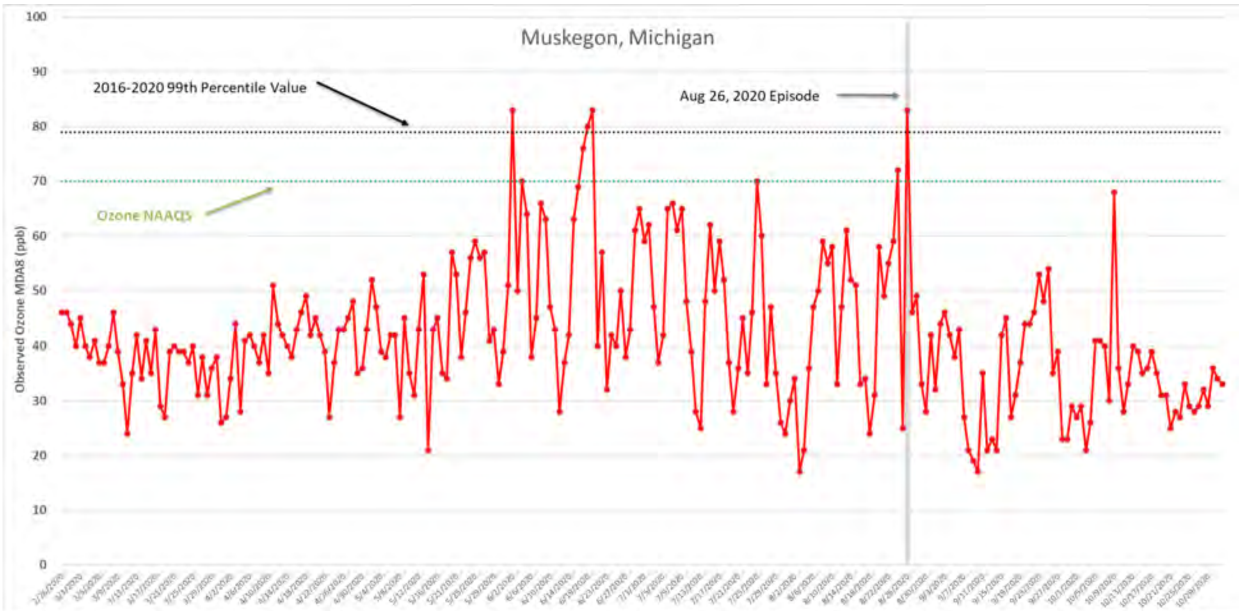

Figure 33. MDA8 ozone concentrations in 2020 at the Muskegon monitor.

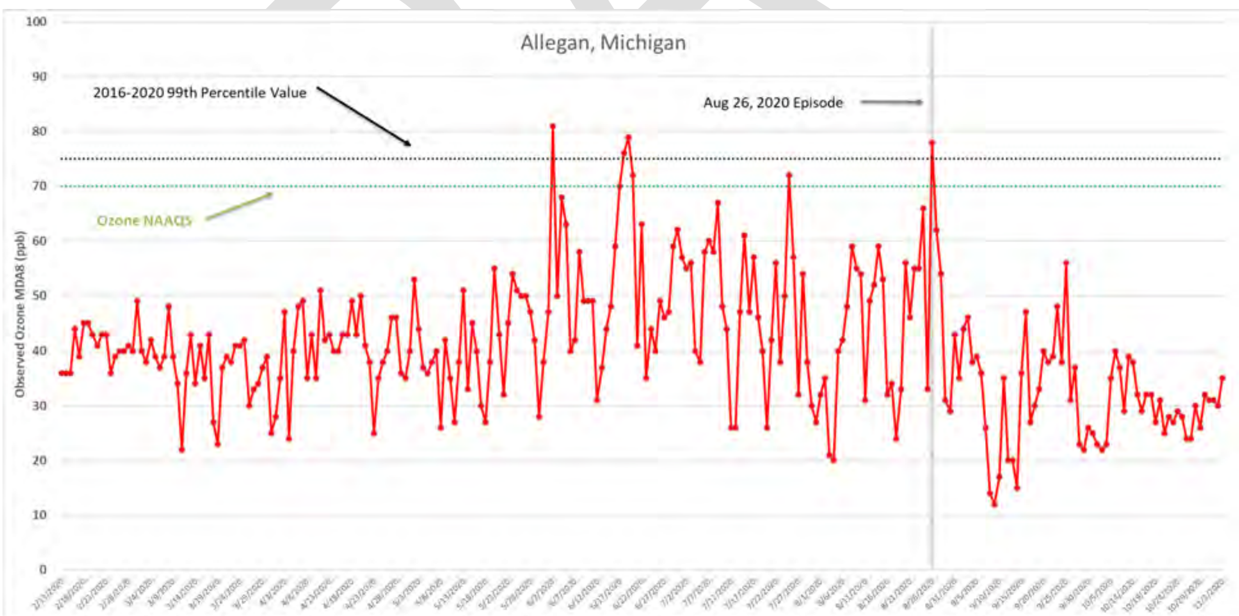

Figure 34. MDA8 ozone concentrations in 2020 at the Holland monitor.

Figure 35 and Figure 36 provide historical context of ozone concentrations at the monitors and present the MDA8 concentrations across the past five years with the August 26, 2020 episode highlighted with gray columns in the graphics. These dates are all among the observations that exceeded the 70 ppb threshold for the year and are among the highest observations during the past five years.

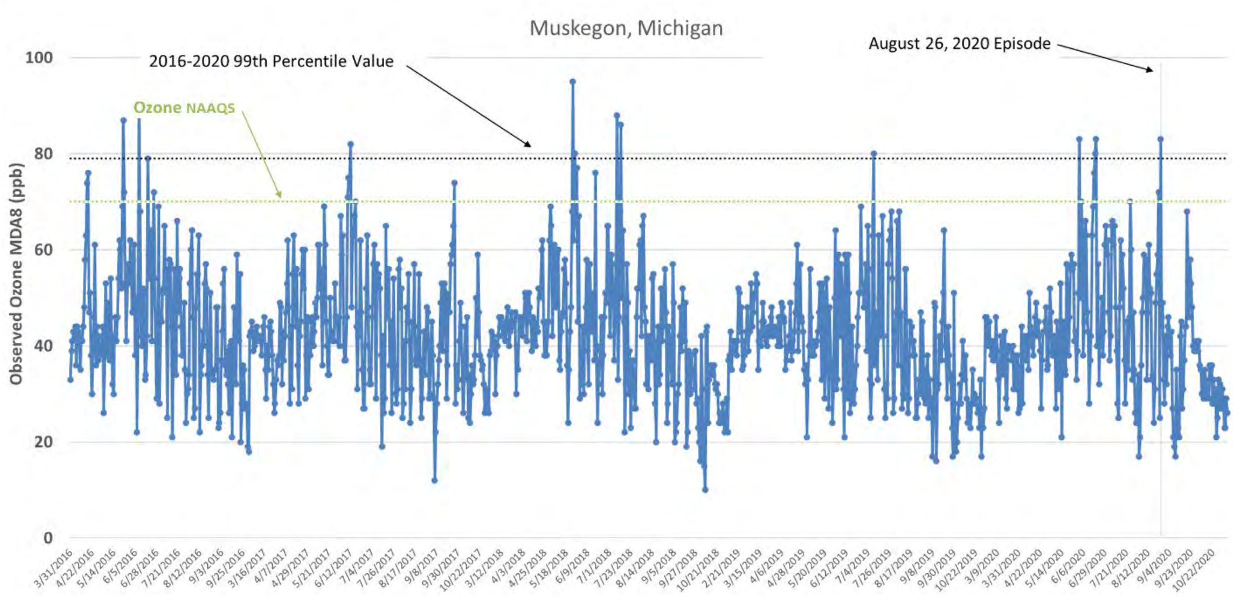

Figure 35. Muskegon MDA8 Ozone, 2016-2020

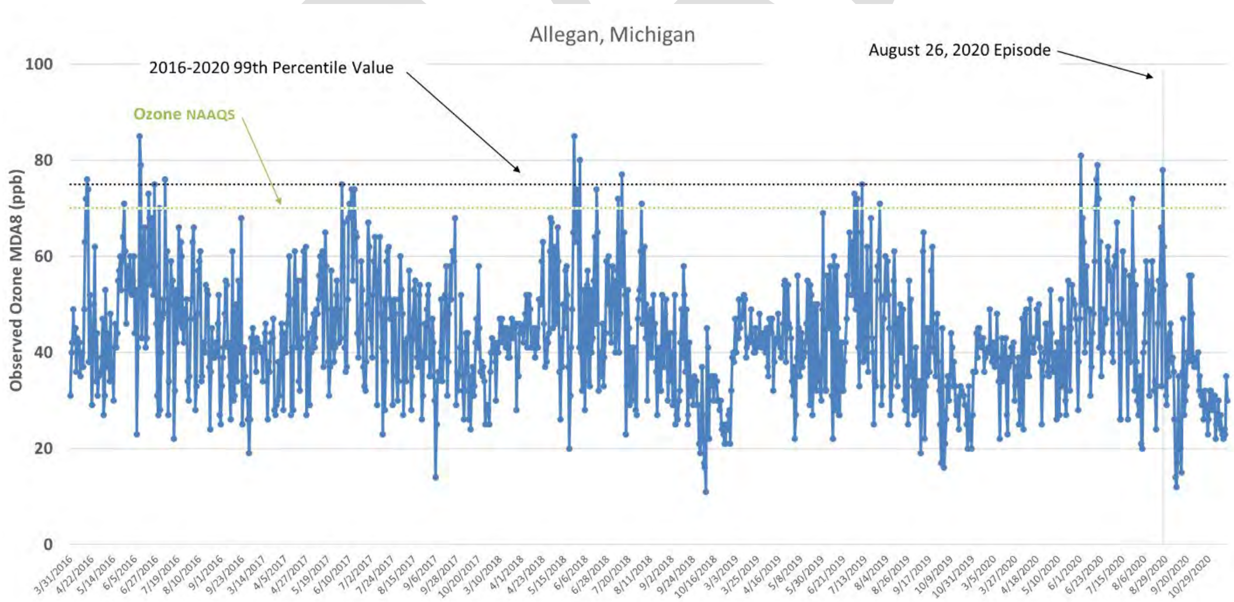

Figure 36. Holland MDA8 Ozone, 2016-2020

Figure 37 and Figure 38 demonstrate that the August 26, 2020 MDA8 observations were unusually high compared to five-year August 2016-2020 average MDA8 concentrations. Figure 37 presents observed August 2020 MDA8 concentrations at the Muskegon monitor compared to five-year monthly averages at the same location. Identified by the red bars, August 26 was 41.1 ppb higher than the average August MDA8 from 2016-2020. This value also significantly exceeded the standard deviation of observations over this period, as represented by the orange dotted line in the figure.

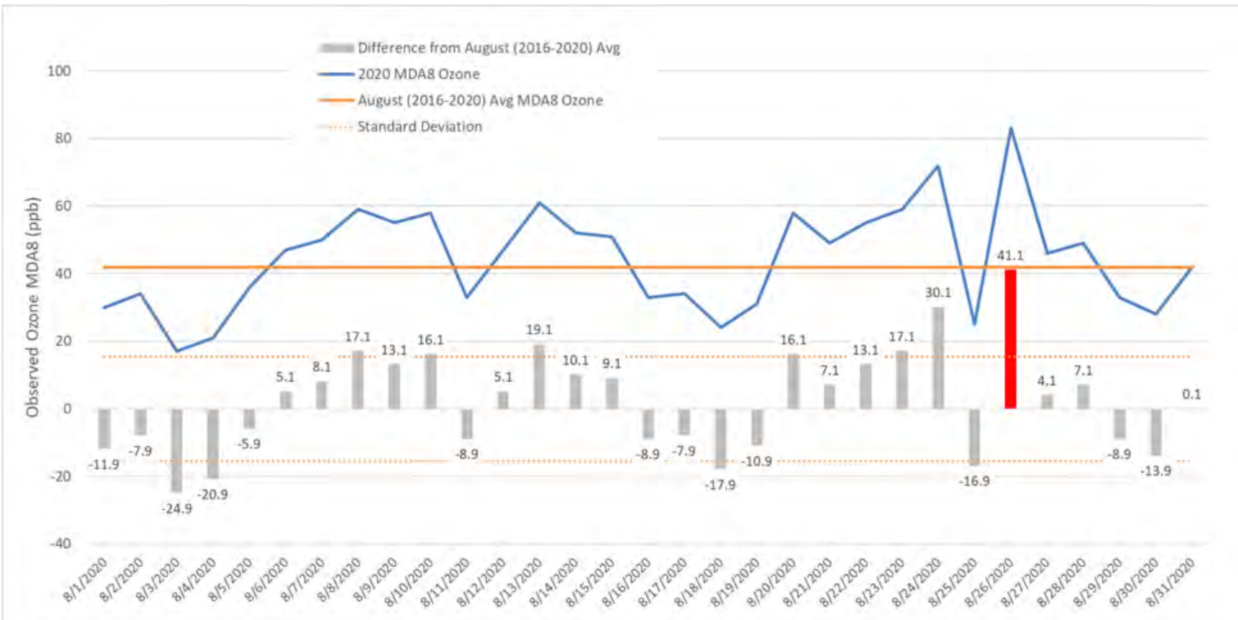

Figure 37. Muskegon August 2020 8-hr Ozone Comparison to August 2016-2020 Average 8-hr.

Similar results are seen in Figure 38 at the Holland monitor where observed August 26, 2020 MDA8 concentration was again significantly higher than the five-year monthly averages at the same location. As shown by the red bar in this figure, August 26 was 34.2 ppb higher than the average August MDA8 and standard deviation from 2016-2020.

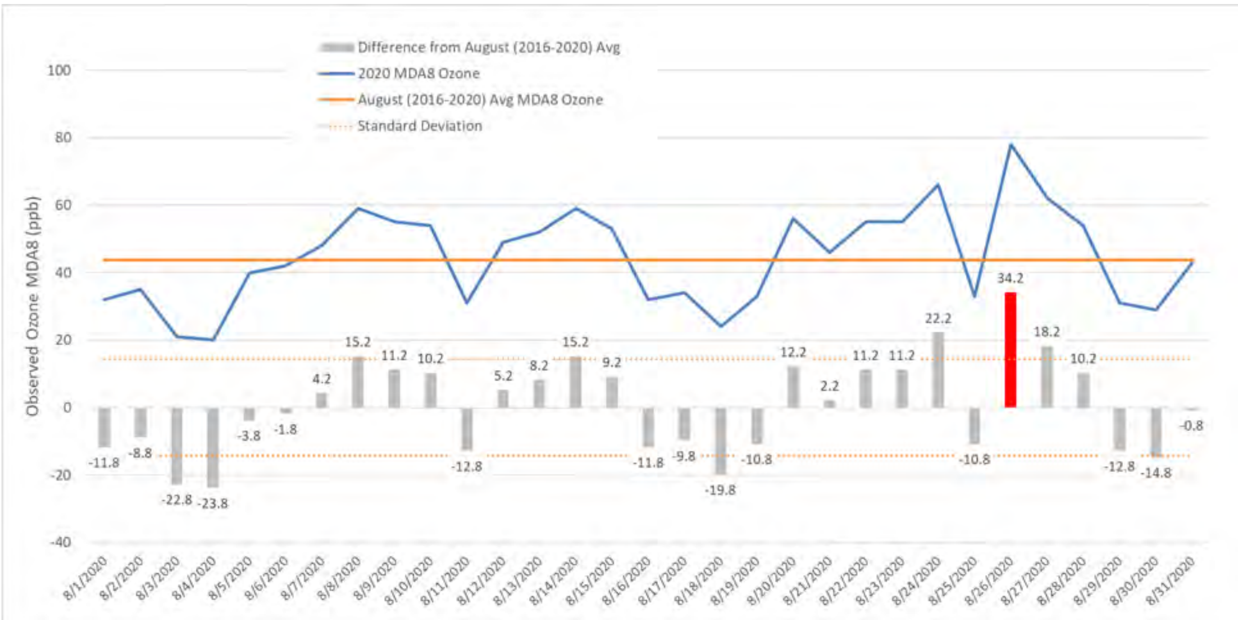

Figure 38. Holland August 2020 8-hr Ozone Comparison to August 2016-2020 Average 8-hr.

Table 6 shows the MDA8 ozone levels at the West Michigan NAA monitors on August 26, 2020 compared with the 99th percentile ranked MDA8 ozone concentrations observed during the last five years.

Table 6. MDA8 Ozone Five-year (2016-2020) 99th Percentile Comparison for Western Michigan Monitors.

Monitor ID	Site Name	NAA	MDA8 Ozone (ppb)	
			8/26/20	99th Percentile
26-005-0003	Holland	Allegan	78	75
26-121-0039	Muskegon	Muskegon	83	79

Figure 39 shows a time-series plot of ozone concentrations at the Holland monitor for the ozone season overlaying ozone monitoring data from 2016 through November 2020. The black dotted line in this figure represents the five-year 99th percentile value (75 ppb). The green dotted line represents the 2015 8-hour ozone NAAQS of 70 ppb. Each of the five years is represented by colored dots and the event-related day of August 26, 2020 is represented as a red diamond. Figure 40 presents this same information for the Muskegon monitors.

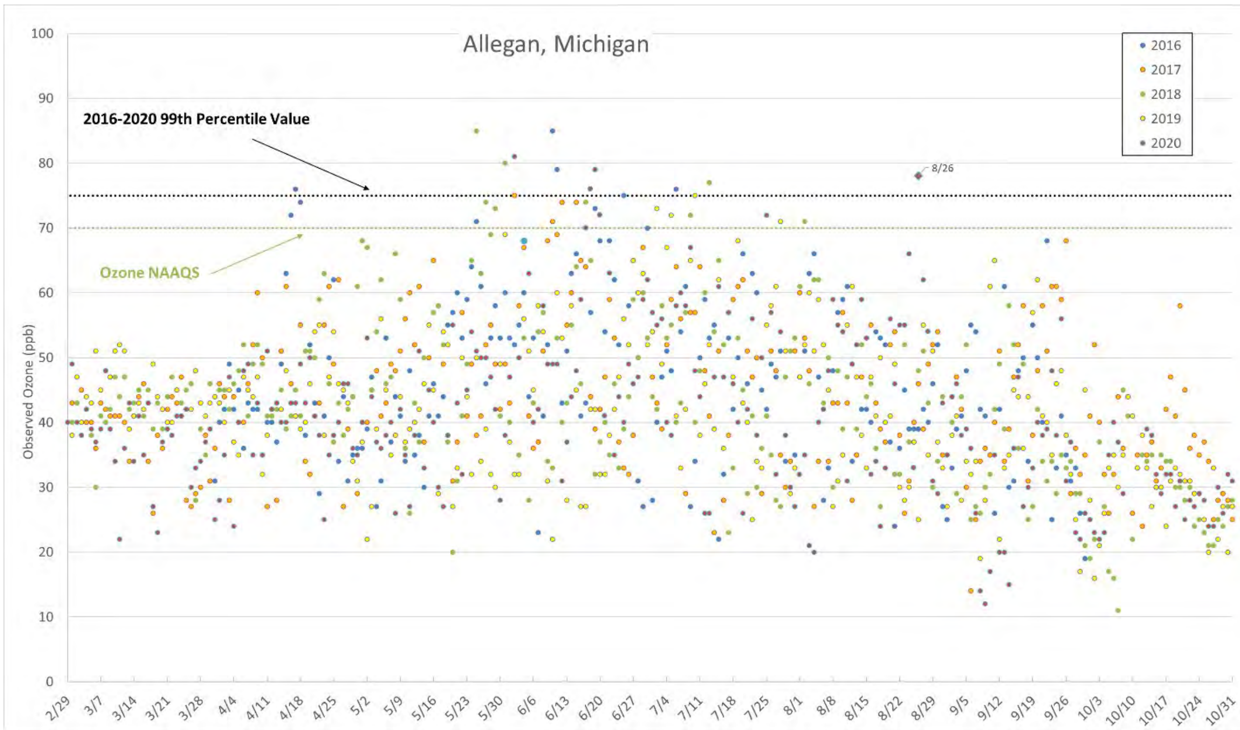

Figure 39. Holland (26-005-0003) MDA8 values; 2016-2020, color-coded by year.

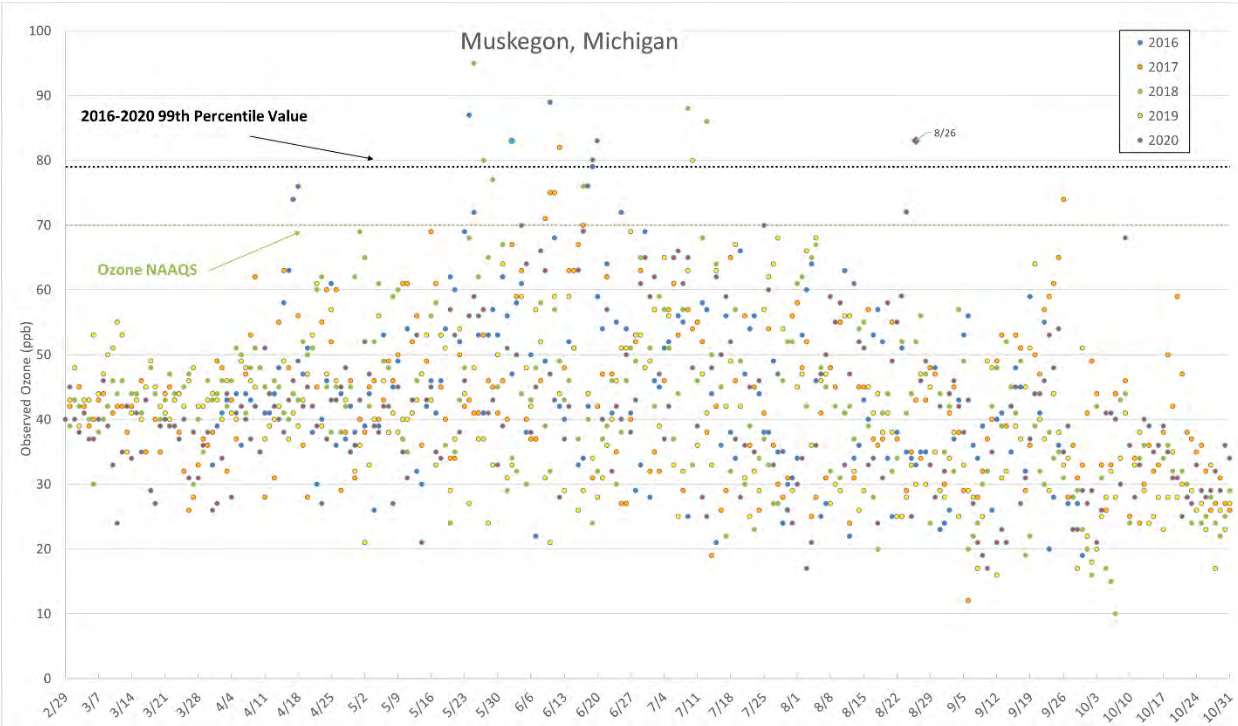

Figure 40. Muskegon (26-121-0039) MDA8 values; 2016-2020, color-coded by year.

As shown in these figures and table, the August 26, 2020 ozone values are among the highest concentrations that have occurred at both monitors over the past five years, are above the 99th percentile of such observations, and were among the highest ozone concentrations in 2020, thereby meeting the criteria for considering these data outliers. As noted previously, exclusion of these data from these dates may bring the Allegan NAA into attainment with the 2015 ozone NAAQS or qualify the Muskegon NAA for a 1-year attainment date extension under the 2015 ozone standard.

Evidence of Transport of Fire Emissions from the Fire to the Monitor

Visible Satellite Imagery

Visible satellite imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua and Terra satellites plainly show transport of smoke from fires burning in northern California to the central and midwestern United States, including Michigan, between August 24 and 26, 2020, (Figure 41 through Figure 43) when ozone concentrations were at their highest. The movement of a dense smoke plume along the Canadian border is clearly visible as it makes its way toward Lake Michigan and further east.

The movement of this smoke corresponds to the expansion of elevated ozone values along the pathway of transport to Lake Michigan as demonstrated in following sections using ozone observations, NOAA HMS smoke products, and Ozone AQI maps. In addition, the transport of smoke eastward from California is consistent with transport patterns seen in the HYSPLIT trajectory analysis and satellite measurements of smoke associated species presented in later sections of this demonstration.

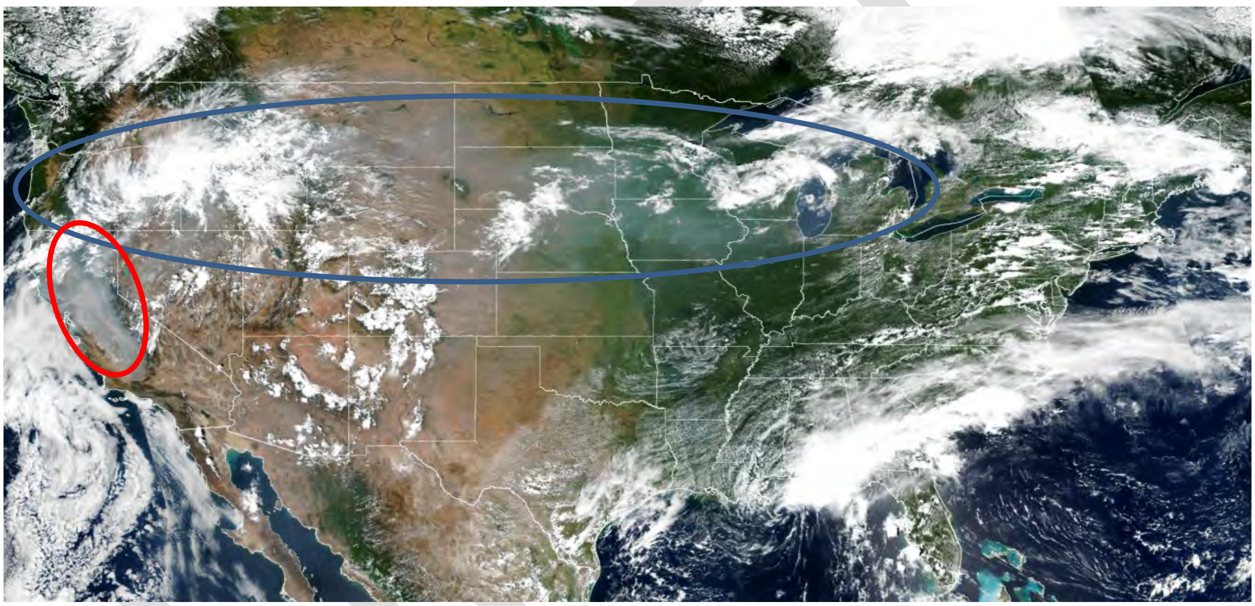

Figure 41. MODIS Terra true color satellite imagery from August 24, 2020, with smoke clearly visible over much of the northern half of the U.S. extending to Lake Michigan (blue circle). Smoke plumes are seen emanating from the California wildfire complexes (red circle).

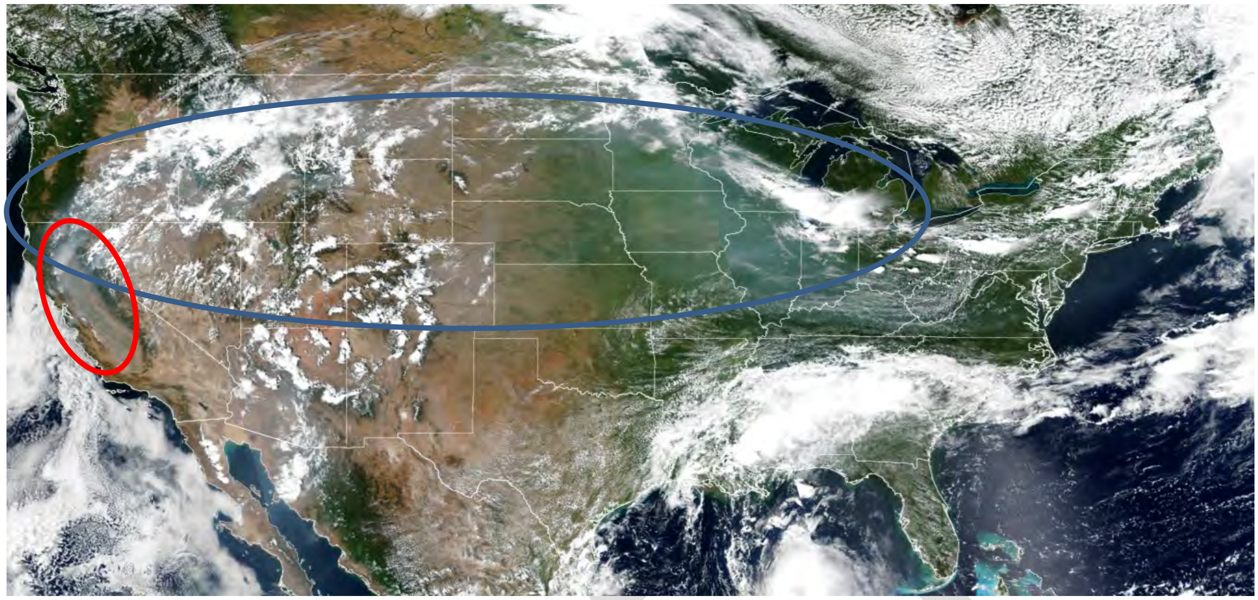

Figure 42. MODIS Terra true color satellite imagery from August 25, 2020, with smoke clearly visible over much of the northern half of the U.S. (blue circle). Smoke plumes are seen emanating from the California wildfire complexes (red circle).

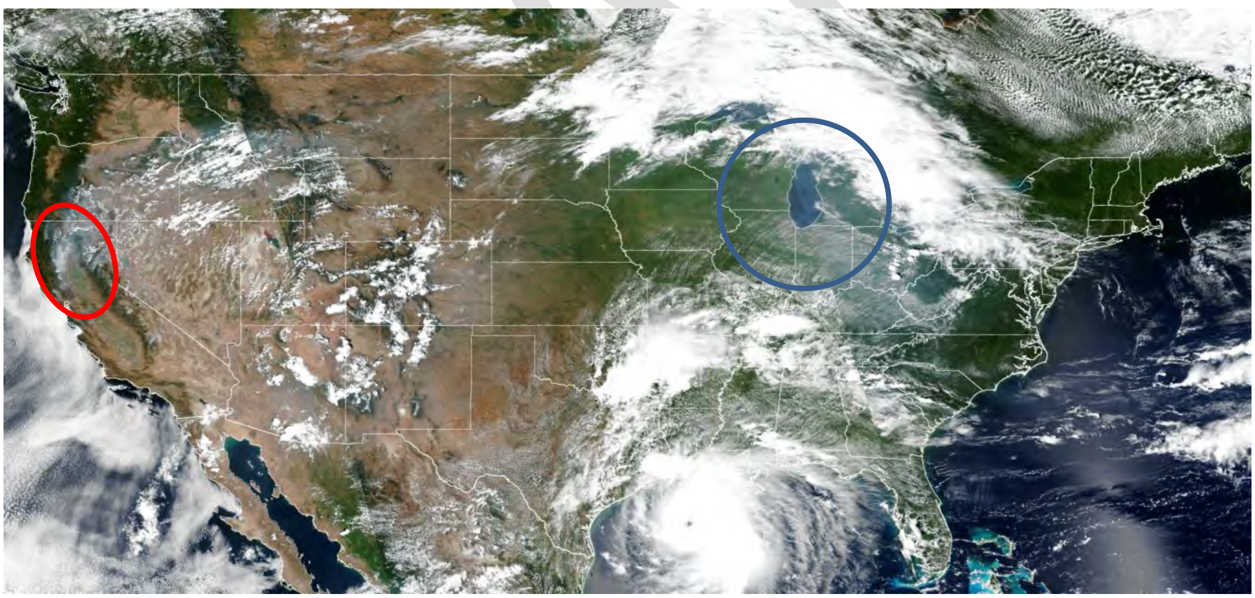

Figure 43. MODIS Terra true color satellite imagery from August 26, 2020, with smoke clearly present over the Lake Michigan region (blue circle). Smoke plumes are still seen emanating from the California wildfire complexes (red circle). Hurricane Laura seen in the Gulf of Mexico.

Navy Aerosol Analysis and Prediction System (NAAPS)

Originally in response to U.S. Navy needs, the Naval Research Laboratory (NRL) has developed a global, multi-component aerosol analysis and modeling capability (NAAPS: Navy Aerosol Analysis and Prediction System) that combines satellite data streams with other available data and the global aerosol simulation and prediction model[42] for predicting the distribution of tropospheric aerosols. Specifically, this system investigates and evaluates satellite-based aerosol retrievals and implements those that are relevant and practical. They utilize the unique processing capabilities within NRL's remote sensing section to develop one of the most complete suites of aerosol retrieval products in the world.

NAAPS utilizes several sources of surface-based aerosol measurements. These include surface synoptic reports of visibility and current and past weather. These data have been used by NRL in previous studies to follow large dust storms and smoke plumes. Data from the AERONET aerosol monitoring network[43], a federation of ground-based remote sensing aerosol networks, are utilized and yield optical depth at eight wavelengths every minute and are available in near real-time via satellite link. The aerosol size distribution is then inferred from the wavelength dependence of optical depth.

Figure 44 below, obtained from the NRL/Monterey Aerosol page archives[44], presents smoke mass mixing ratios (μg/m^3) within the first (surface) model layer, which is 20m thick.

These images support the claim that there was an increased level of smoke concentration present over western Michigan on August 24, that moved south with the weather on August 25, and then returned on August 26, 2020, consistent with images provided elsewhere. Concentrations range from of 2-8 μg/m^3 (shown in Light Blue and Dark Green) over western Michigan on August 24 and reach levels of 8-16 μg/m^3 (Light Green) on August 26, 2020.

[42] https://www.nrlmry.navy.mil/aerosol_web/Docs/globaer_model.html
[43] https://aeronet.gsfc.nasa.gov/new_web/system_descriptions.html
[44] https://www.nrlmry.navy.mil/aerosol/index_frame.html

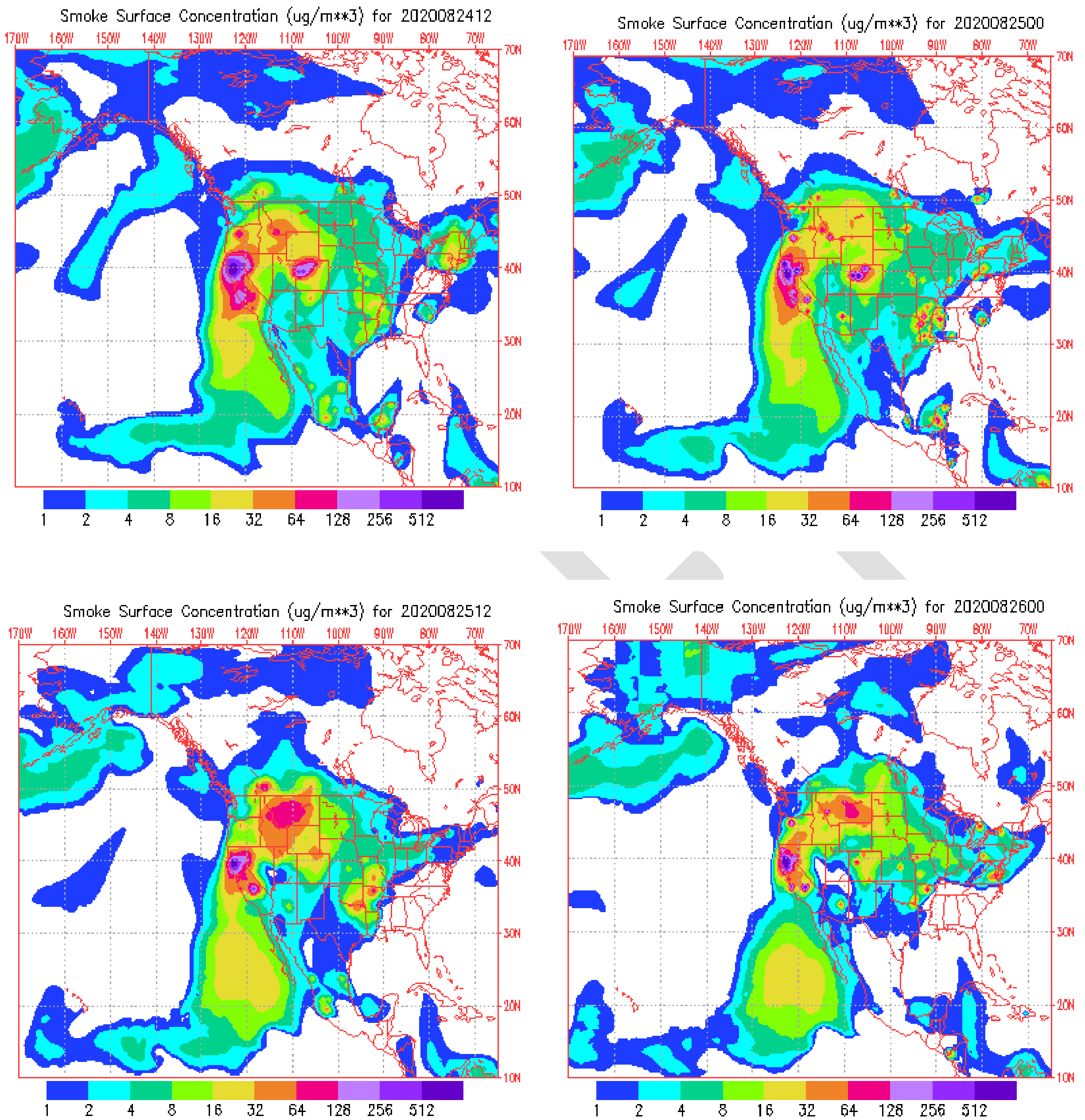

Figure 44. NAAPS smoke surface concentration (µg/m³) on August 24 (top) and August 25 (bottom), 2020 at 8 AM EDT (left) and 8 PM EDT (right).

NOAA HRRR-Smoke Forecast

NOAA's High Resolution Rapid Refresh-Smoke model[45] (HRRR-Smoke) is a numerical weather prediction model in the U.S. that forecasts smoke's impact on several weather variables. Based on satellite observations of fire location and intensity, HRRR-Smoke predicts the movement of smoke in three dimensions across the country over 48 hours, simulating how the weather will impact smoke movement and how smoke will affect visibility, temperature, and wind.

Smoke forecasts using this model shows the presence of predicted wildfire smoke from the California fires reaching into the Lake Michigan region and impacting monitors in western Michigan.

Figure 45 represents the HRRR-Smoke forecast for August 26, 2020. In this figure, a smoke plume from the northern California fires is clearly seen moving across the entire northern U.S. with significant coverage over Lake Michigan and the Allegan and Muskegon NAAs.

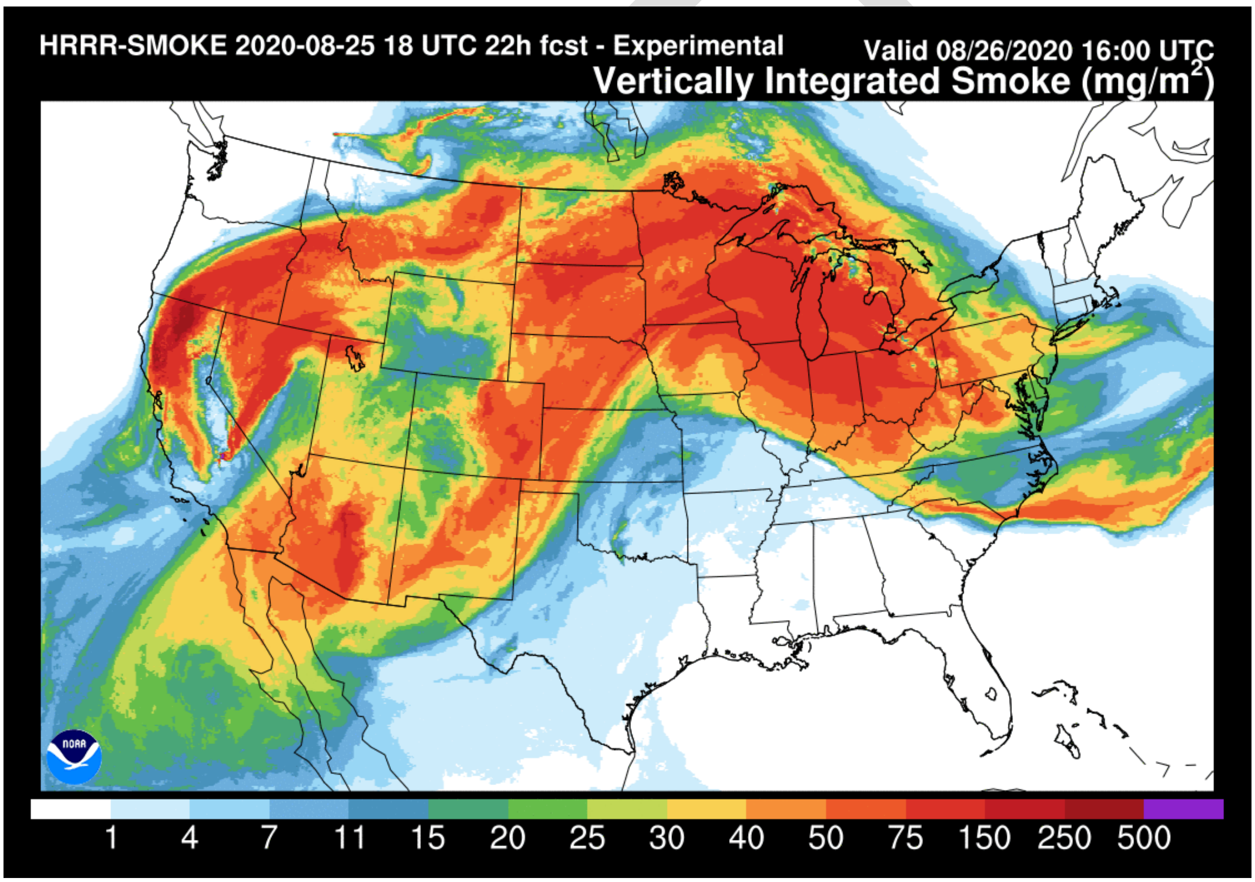

Figure 45. HRRR-Smoke forecast for the distribution of vertically integrated smoke from wildfires at 12 p.m. EDT August 26, 2020.

[45] https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/HRRR-Smoke_desc.html

HMS Fire Detect and Smoke Plume Data and Ozone AQI Maps

Based on the considerable collective size of the California wildfire complexes, significant amounts of ozone and PM2.5 precursors were emitted in addition to other smoke ingredients. The plumes from these fires traveled eastward along the border with Canada eventually making its way to the Great Lakes region and impacted the western Michigan NAA monitors.

Figure 46 presents the progression of the smoke plume over the U.S. in late August 2020 as analyzed by the HMS staff at NOAA, using the satellite images and the Ozone AQI. This series of maps shows the movement of the smoke plumes and the associated impact at monitors on the path to western Michigan and the surrounding areas. The Ozone AQI tracks well with the movement of the densest portion of the smoke plume with highest values coinciding with thickest smoke or on days just after the plume clears, leaving residual concentrations that may not influence ozone peaks until a day or so later due to light attenuation and lower temperatures resulting from the significant coverage of smoke. Figure 46 corroborates the evidence of smoke over Lake Michigan demonstrated by the visual satellite images (Figure 41 through Figure 43) that enhanced the ozone concentrations during the August 26, 2020 episode day.

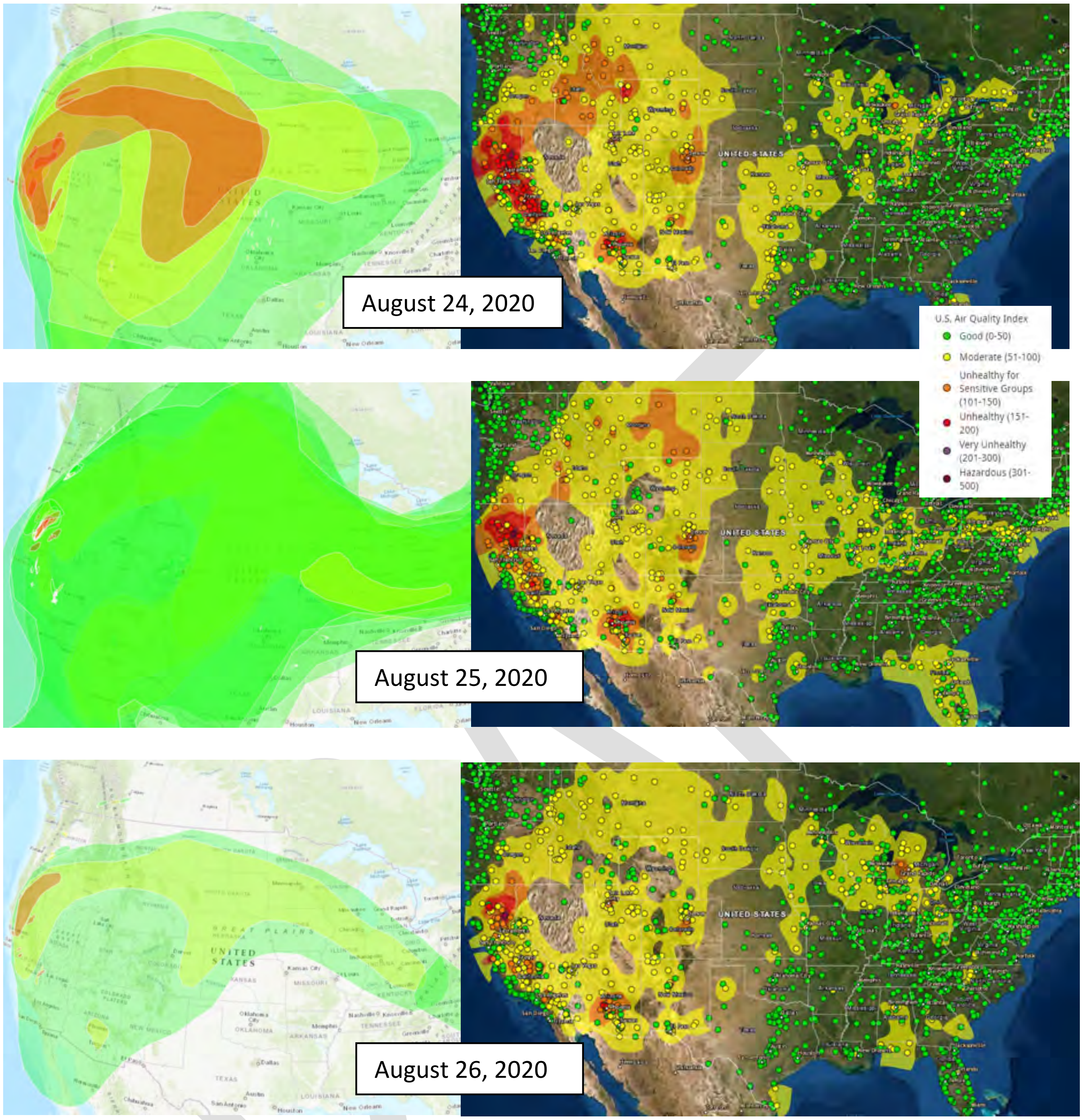

Figure 46. HMS Smoke Analysis (left) and Ozone AQI Maps (right) from August 24-26, 2020.

CALIPSO Analyses

The CALIPSO satellite provides information about the vertical distribution of visible and measured smoke components. CALIPSO combines an active lidar instrument with passive infrared and visible imagers to probe the vertical structure and properties of thin clouds and aerosols over the globe. Detected aerosols are classified into marine, marine mixture, dust, dust mixture, clean/background, polluted continental, smoke, and volcanic aerosol types. Aerosol vertical profiles were retrieved[46] to evaluate the presence of smoke plumes on August 26, 2020.

The CALIPSO retrievals presented below indicate that a mixture of dust, polluted continental, and smoke associated with wildfire plumes were present at the surface layer during the episode day of August 26, 2020.

Figure 48 and Figure 50 show profiles that were collected by CALIPSO on August 24 and 25, 2020 in the early morning hours. These profiles, along with HMS smoke products show that the location and altitude of smoke plumes observed on August 24 and 25, 2020 align with the HYSPLIT trajectories presented below and confirm that smoke moving into the area included components that enhanced the ozone concentrations in the region. The transport of smoke from California was confirmed by these CALIPSO aerosol profiles collected to the west of the Lake Michigan region in the days leading up to the ozone exceedance event.

CALIPSO aerosol retrieval over western Michigan was not available for August 26, 2020 as the flight pattern of the satellite did not coincide with the region on this day. The approximate path of the flyovers presented with the HMS smoke overlays are seen in Figure 47 and travel to the west of the region and directly over the visible smoke plume. The total attenuated backscatter and vertical profile in Figure 48 shows that a smoke plume (composition polluted dust and polluted continental/smoke) was present in the morning of August 24 in a layer between 1,000 m and 6,000 m above ground level (AGL). Figure 48 shows that the smoke plume composition was also polluted dust and polluted continental/smoke and found in a layer between the surface and about 6,000 m AGL.

[46] https://www-calipso.larc.nasa.gov/products/index.php

CALIPSO aerosol retrieval across the central U.S. in the early morning of August 24, 2020 is available at 5:36 AM EDT. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 47 and through a portion of the densest visible smoke plume to the north of the Rocky Mountain chain through Wyoming and eastern Montana. The total attenuated backscatter and vertical profile in Figure 48 shows that a smoke plume (composition of dust, polluted continental, polluted dust, and smoke) was present in a layer between 1,000 and 6,000 m AGL.

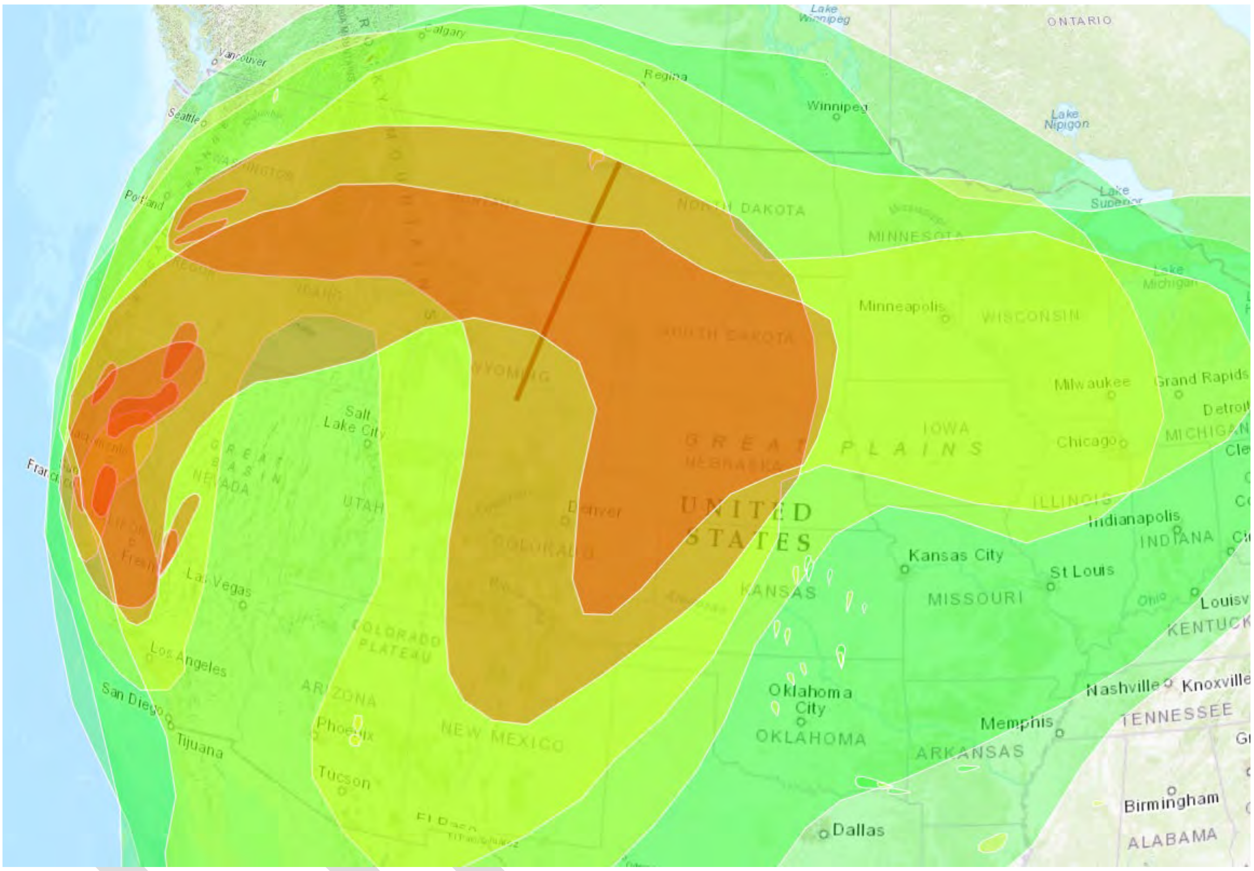

Figure 47. Approximate path of CALIPSO satellite flyover (red line) in early morning of August 24, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 48.

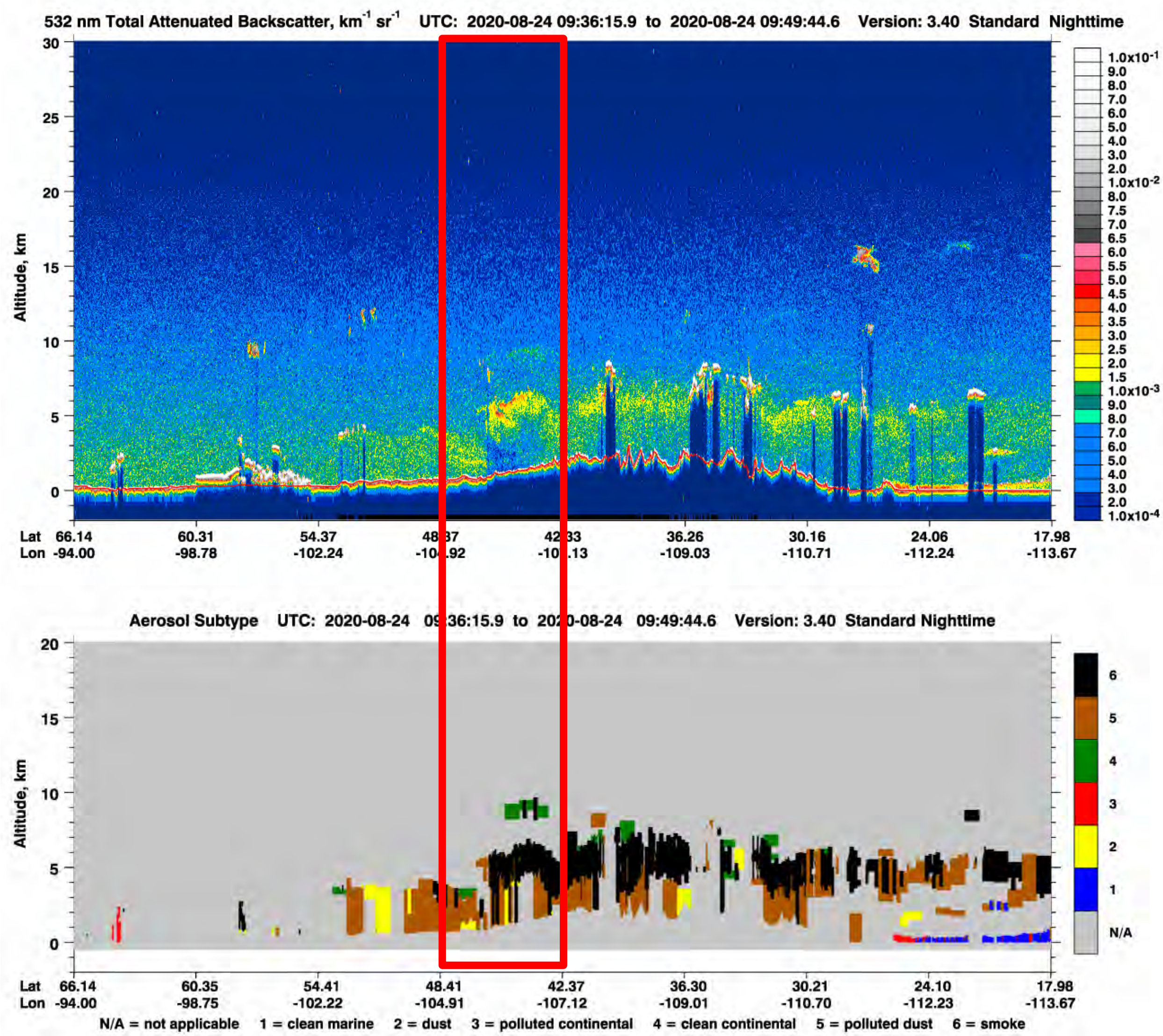

Figure 48. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on August 24, 2020, between 5:36 a.m. and 5:49 a.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

CALIPSO aerosol retrieval across the central U.S. in the early morning of August 25, 2020 is available at 4:35 AM EDT. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 49 and through the visible smoke plume along a line into the upper Midwest. The total attenuated backscatter and vertical profile in Figure 50 shows that a smoke plume (composition of dust, polluted continental, polluted dust, and smoke) was present in a layer between the surface and about 6,000 m above ground level (AGL). Cloud cover between 4,000 and 6,000 m AGL over central Wisconsin obscured the observations in some places along the flight path.

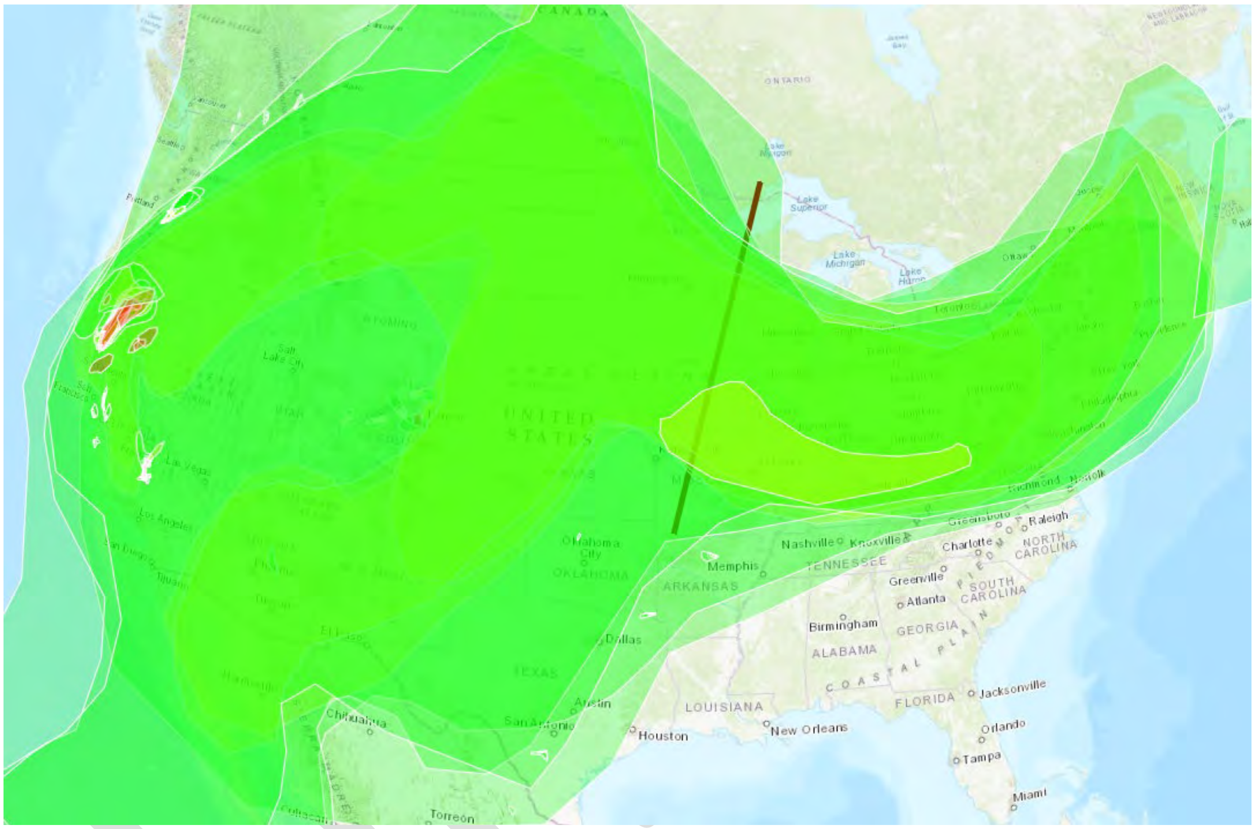

Figure 49. Approximate path of CALIPSO satellite flyover (red line) in early morning of August 25, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 50.

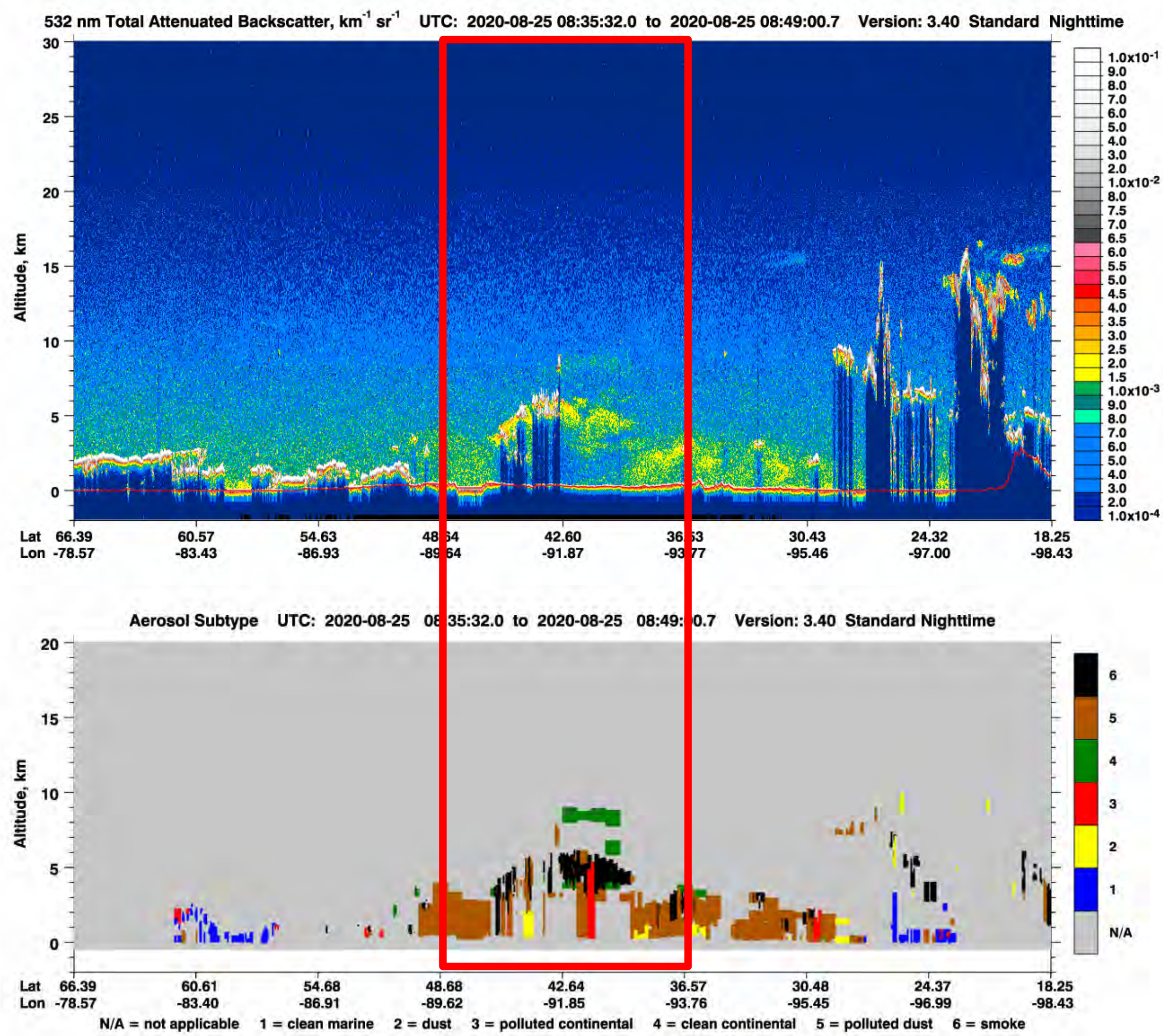

Figure 50. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on August 25, 2020, between 4:35 a.m. and 4:49 a.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

Regional Upwind Supporting Measurements

Additionally, the comparison of the HMS smoke plumes with MDA8 ozone concentrations shows that ozone concentrations increased at monitors along the paths of the smoke plumes between northern California and the western Michigan region during the August 2020 episode. Figure 51 below shows the smoke plume and enhanced MDA8 ozone concentrations as it moves across the northern continental U.S. during the period of August 21-24, 2020. This impact is even clearer based on examination of the four highest ozone concentrations at these sites. Ozone concentrations on many of these dates (Table 7) were within the four highest annual concentrations at many of the monitors along the pathway of the smoke plume. While many of these sites may not have exceeded the level of the ozone NAAQS during this period, it is clearly seen that during the episode of the smoke transport, these sites had unusually high MDA8 ozone concentrations.

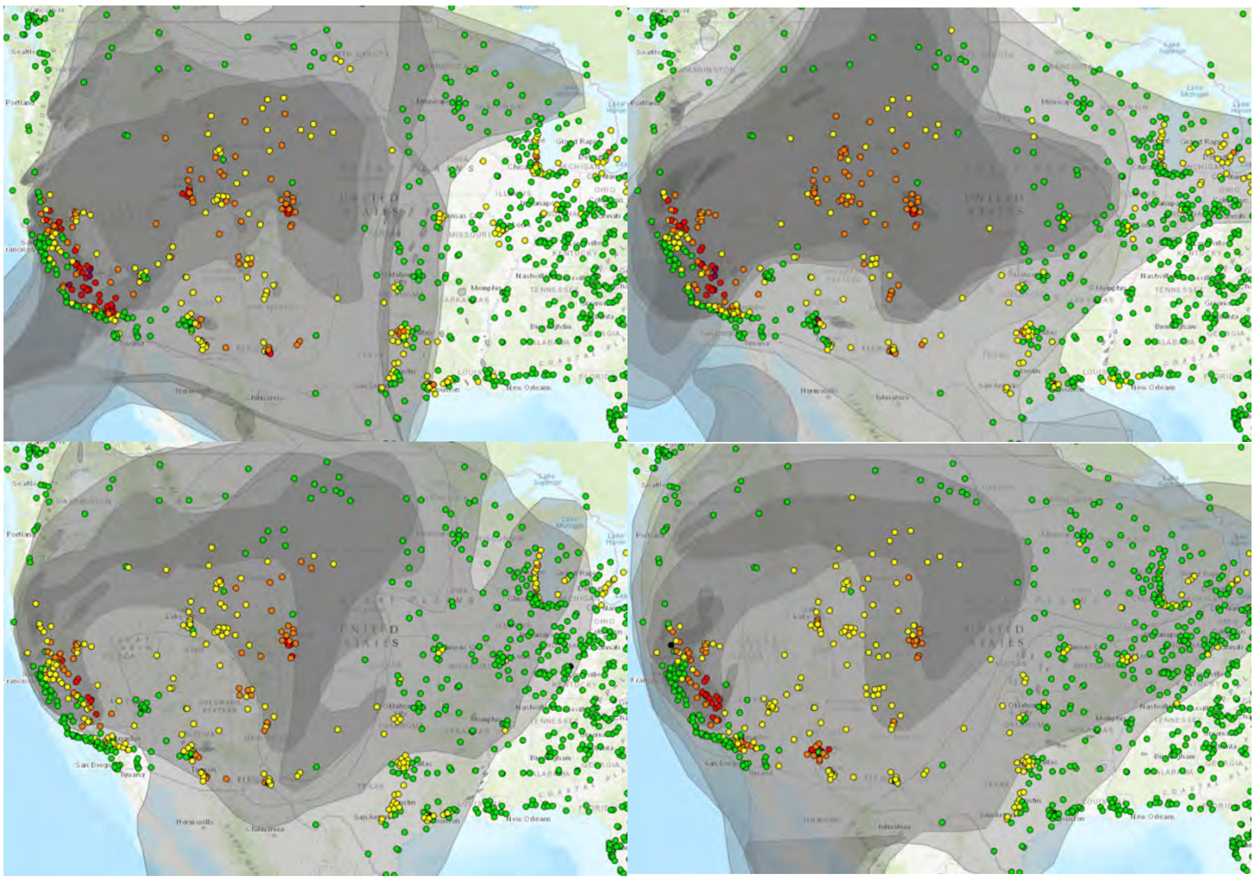

Figure 51. HMS smoke product coverage and MDA8 ozone values in path of California wildfire smoke plume; August 21 (top left), 22 (top right), 23 (bottom left), and 24 (bottom right).

Table 7. Observed 1st - 4th High MDA8 Ozone Concentrations (ppb) at Monitors in the Path of the California Wildfire Smoke Plume during the Period August 20-25, 2020.

			MDA8 Ozone Observations (ppb)							
State	Site	Monitor ID	1st Max Value	1st Max Date	2nd Max Value	2nd Max Date	3rd Max Value	3rd Max Date	4th Max Value	4th Max Date
MT	Broadus	300750001	68	08/21	65	08/22	60	08/29	60	09/22
MT	Sidney 201	300830002	59	06/13	56	04/27	56	08/25	54	03/22
MT	Birney	300870001	68	08/22	62	08/24	61	08/25	59	08/21
ND	Theodore Roosevelt NP	380070002	56	07/02	55	08/25	54	06/13	54	08/21
ND	Bismarck Residential	380150003	59	08/21	51	07/03	51	07/04	51	08/07
ND	Beulah North	380570004	58	06/13	56	08/21	52	06/29	52	08/07
ND	Hannover	380650002	62	08/21	57	06/13	56	08/07	55	06/07
ND	RYDER	381010003	54	08/20	54	08/21	52	08/07	51	06/14
ND	Lake Ilo	8403802500	57	06/13	54	06/16	54	07/02	54	08/21
SD	WIND CAVE	460330132	76	08/23	69	08/25	63	08/06	62	08/07
SD	Badlands	460710001	67	08/23	63	08/25	62	07/07	61	06/13
SD	Black Hawk	460930001	65	09/23	63	08/23	63	09/19	62	09/22
WY	Centennial	560019991	81	08/22	73	08/23	72	08/21	66	08/24
WY	Basin	560030002	78	08/22	73	08/21	61	08/24	58	04/28
WY	Thunder Basin	560050123	71	08/21	68	08/22	64	08/25	62	09/22
WY	Converse County Long-Term	560090010	79	08/23	75	08/21	74	08/22	71	08/24
WY	South Pass	560130099	81	08/22	72	08/21	71	08/23	66	08/24
WY	Johnson County	560190004	68	08/22	65	08/21	64	08/24	64	08/25
WY	Casper Gaseous	560250100	76	08/22	71	08/23	67	08/21	64	08/24
WY	Sheridan	560330004	68	08/22	62	08/24	61	08/21	58	04/28
WY	Boulder	560350099	78	01/21	78	02/22	74	08/22	69	02/21
WY	Daniel South	560350100	76	08/22	69	08/23	68	03/07	67	08/24
WY	Pinedale Gaseous	560350101	76	08/22	69	08/23	66	06/29	65	08/24
WY	Big Piney	560350700	73	08/21	73	08/22	68	08/23	67	08/24
WY	Pinedale	560359991	79	08/22	74	08/23	69	08/20	69	08/24
WY	Hiawatha	560370077	73	08/22	67	08/21	65	08/23	61	08/08
WY	Wamsutter	560370200	77	08/22	67	08/21	65	08/23	63	08/24
WY	Moxa Arch	560370300	73	08/21	73	08/22	67	03/07	66	06/06
WY	Grand Teton NP	560390008	67	08/22	66	08/23	64	08/20	60	08/24
WY	Yellowstone NP	560391011	80	08/22	76	08/20	67	08/24	66	08/23
WY	Murphy Ridge	560410101	77	08/21	76	08/22	69	08/03	68	07/09
WY	NewCastle	560450003	76	08/23	67	08/22	67	08/25	66	08/24
WY	Riverton Mobile	8405601300	68	08/22	59	08/23	59	08/24	51	08/27
WY	James Town Mobile	8405603700	74	08/21	71	08/22	65	08/23	64	07/09

HYSPLIT Trajectory Analysis

To demonstrate that the California wildfire emissions were transported to the western Michigan ozone network, the HYSPLIT model[47] was used to calculate forward trajectories originating from within the smoke plume at the three largest California fire sites (LNU Lightning Complex, SCU Lightning Complex, and August Complex) and backward trajectories from both monitors in the western Michigan NAAs. All trajectories utilize NAM 12km data for all meteorological input.

According to HYSPLIT-WEB Short Course materials[48], the total error associated with a given trajectory calculation is estimated to be anywhere from 15 to 30% of the travel distance. The trajectory calculation is an integration using discrete data points (gridded values in space and time) to represent a continuous function. How well the gridded data can be used to represent the flow depends upon the size of the flow features and their speed through the domain versus the number of grid points that sample those features. Too coarse data in space and time adds the greatest uncertainty to the calculation. As a result, any forward or backward trajectory that travel a significant distance over the U.S., as is used in this demonstration, will have some error composed of multiple components, including the inadequacy of the data's representation of the atmosphere in space and time.

Accounting for this error and those additional error components associated with the numerical inaccuracies of the computation, the measurement errors in creating the meteorological data fields, and the forecast error when using forecast meteorology, it is recognized that the error associated with the model runs and presented in this document are difficult to quantify. All trajectories included in this document are assumed to have error in the plume forecast and back trajectories and are used in a comparative sense to determine general direction and elevation of smoke plume transport and air packet initiation. It is not presumed that the smoke plume only moves along the single line of the forward transport path nor that the back trajectory does the same and instead should be viewed in combination with HMS smoke overlays and satellite measurements and imagery.

Multi-day forward trajectories starting in time increments starting at 0200 UTC on August 21 and showing the fire plume transport are shown in Figure 52. Trajectories represent 500 m, 1500 m, and 2000 m starting heights from each of the wildfire complexes. The start height trajectories at 500 m AGL are represented as red lines, 1500 m as blue lines, and 2000 m as green lines. Each square along the line represents 0000 UTC at the start of each new day so each change in the line from square to square indicates the movement of the plume across 24-hours.

As is demonstrated in the image on the top left of Figure 52 (trajectory start time of 0200 UTC August 21, 2020 / 10 PM ET on August 20, 2020), the smoke reaches eastern Lake Michigan during a period between August 24 and 25, 2020. This is corroborated by visual imagery (Figure 41) as seen in earlier areas of this document. A trajectory that starts one hour later (top right of Figure 52) shows a comparable track plumes modeled in vertical layers under 2000 m in the region during this same period.

The image in the lower left of Figure 52 is a trajectory that starts at 0400 UTC (midnight ET) on August 21 and shows that the smoke plume was over the western shore of Michigan late August 24 and early August 25, 2020. Finally, as shown in the lower right of Figure 52, trajectories that started at 0500 UTC on August 21 (1 AM ET) found their way both just north of the NAAs in the early morning of August 25

[47] https://www.ready.noaa.gov/HYSPLIT.php
[48] https://www.arl.noaa.gov/documents/workshop/NAQC2007/HTML_Docs/index.html

and another just to the south on August 26, 2020, the day of the exceedance episode. These trajectories again corroborate the satellite measurements and visual observations and HMS smoke product findings that wildfire smoke made its way into the region during the episode of August 26, 2020.

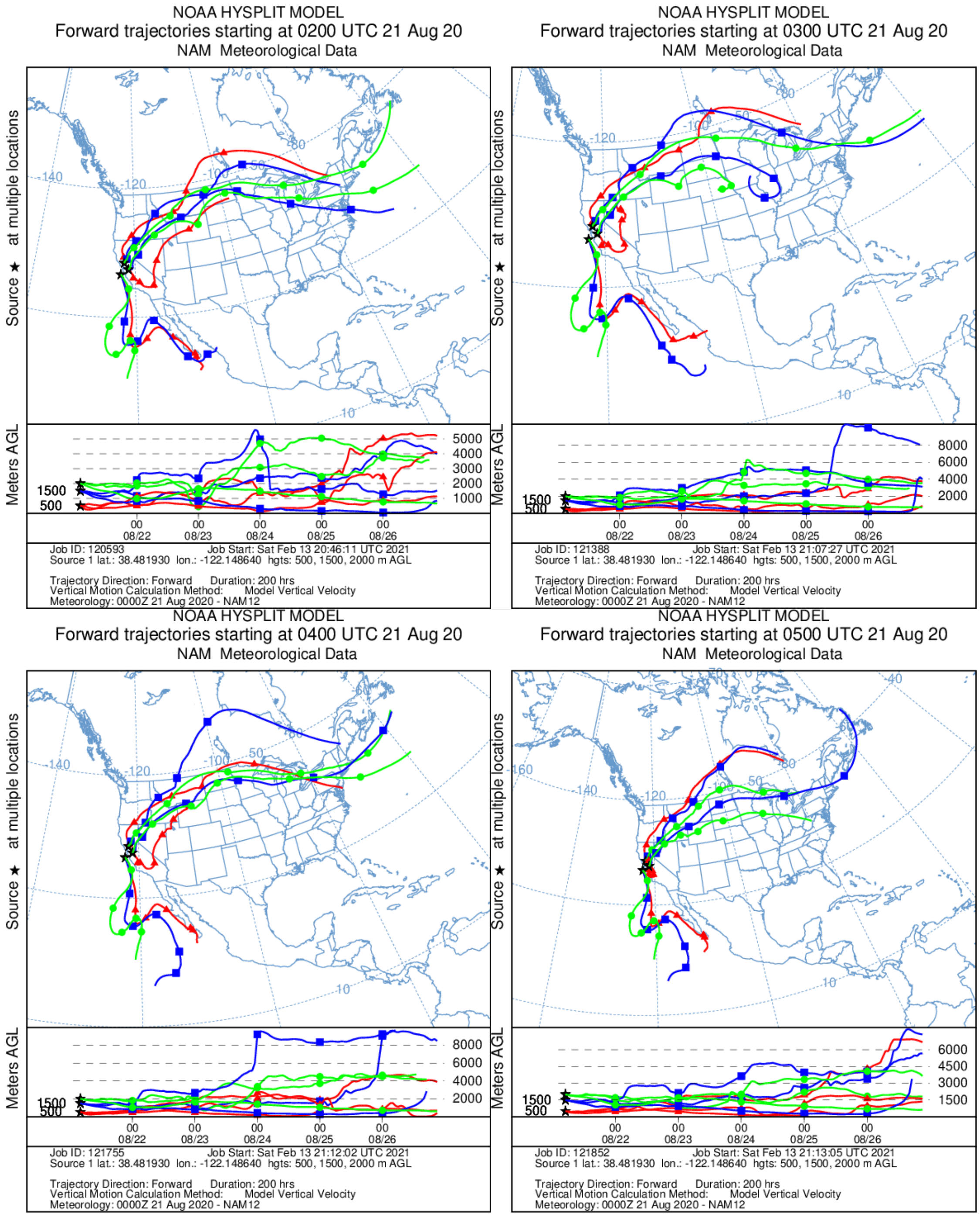

Figure 52. HYSPLIT 200-hour Forward Trajectories August 20-21, 2020 from California Wildfire Complexes using Multiple Start Times.

Figure 53 shows 48-hour backward trajectories from the Muskegon (top) and Holland (bottom) monitors on August 26, 2020, respectively. The left side of each figure shows back-trajectories at three starting heights: 10 m AGL (red), 100 m (blue), and 500 m (green) from each monitor location. These trajectories were initiated at different starting heights to capture transport throughout the mixed boundary layer, as ozone precursors were transported aloft and influence concentrations at the surface through vertical mixing. On the days of the events, as shown in the earlier CALIPSO analysis, smoke was present over the region at altitudes from ground level up to about 6,000 m. Regional observations of mixing heights at Detroit/Pontiac and modeled soundings at MKG and BIV on August 26, 2020, provide evidence that smoke mixed into the lower levels of the atmosphere during this episode.

The right-side image represents the backward trajectory with the HMS smoke overlay from 48-hours prior to demonstrate how the transport plume associated with the fire made its way to individual monitors. These figures demonstrate that wildfire smoke which had moved in from western U.S. before the August 26, 2020 episode was resident over the region and enhanced ozone concentrations on the days leading up to the ozone event.

From this figure, it is easy to see that wildfire smoke which had been transported into the region prior to August 26, 2020 and then was present in the region as meteorological conditions culminated in an event at the monitor locations during the episode. Varying back trajectory starting heights were used to demonstrate the transport of ozone precursor emissions throughout the mixed boundary layer, where vertical mixing of the plume to surface levels enhanced ozone concentrations at the monitor.

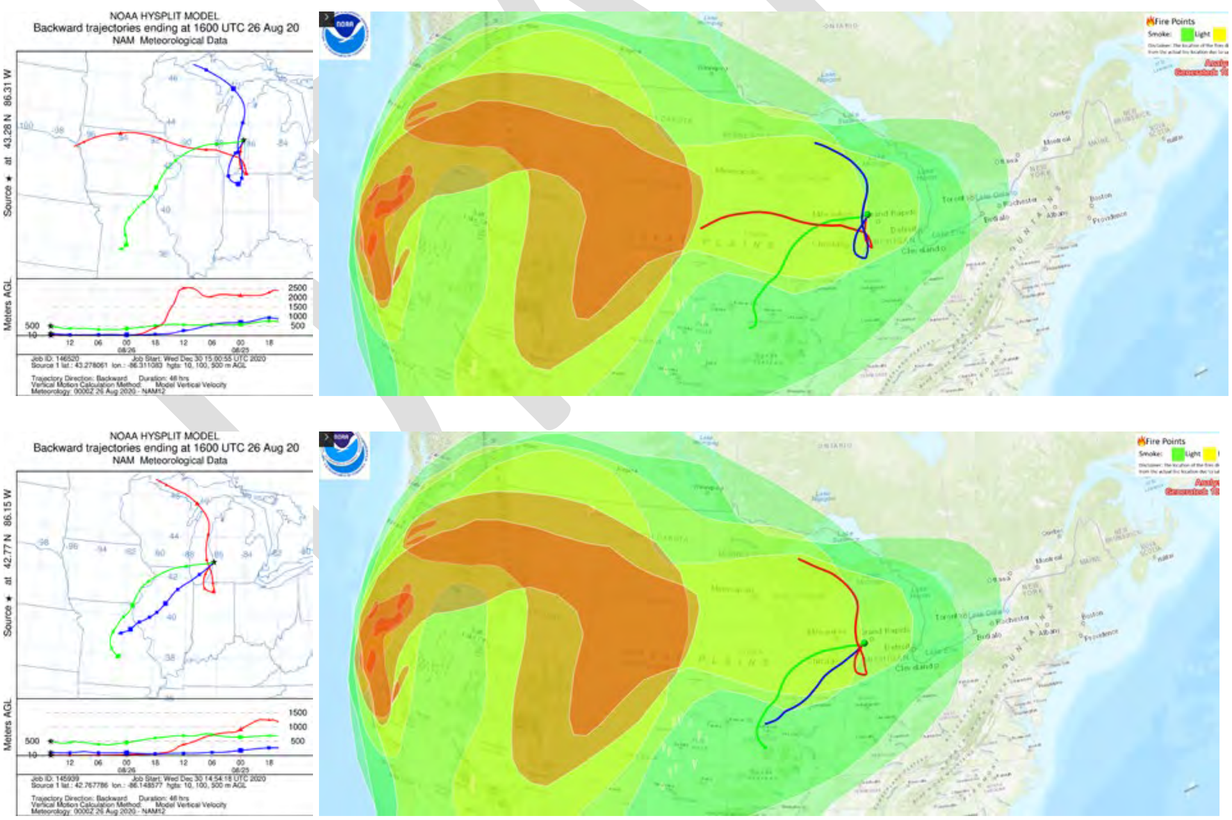

Figure 53. August 26, 2020 HYSPLIT 48-Hour Backward Trajectory from Muskegon (top) and Holland (bottom) monitors with August 24, 2020 HMS Smoke Overlay.

Aerosol Optical Depth, CO, and NO_2 Column Retrievals

Observational data which show the elevated presence of aerosols and gases in the Lake Michigan area during August 26, 2020, also support smoke transport from the California wildfire complexes to the Allegan and Muskegon monitors. Aerosols are particles in the air which scatter and absorb sunlight. Sources of aerosols include pollution from factories, smoke from fires, dust from dust storms, sea salt, volcanic ash, and smog. Aerosol optical depth (AOD) indicates the degree to which particles in the air (aerosols) prevent light from traveling through the atmosphere. Examining maps of AOD from the Suomi National Polar-orbiting Partnership (NPP) provides evidence to support the transport of smoke from fires in California to the Michigan region, as already demonstrated with visual imagery and trajectories.

High AOD is seen during the period leading up the August 26, 2020 episode as is demonstrated in Figure 54 through Figure 57. In these images, we see the increased AOD as it is transported from the northern California wildfires starting on August 23, 2020 and makes its way along the southern edge of the Canadian border. By the time the plume has reached the western Michigan NAAs on August 26, 2020 (Figure 57), AOD is measured at its highest level for the episode commensurate with the significantly high daily maximum ozone concentrations observed at the same time.

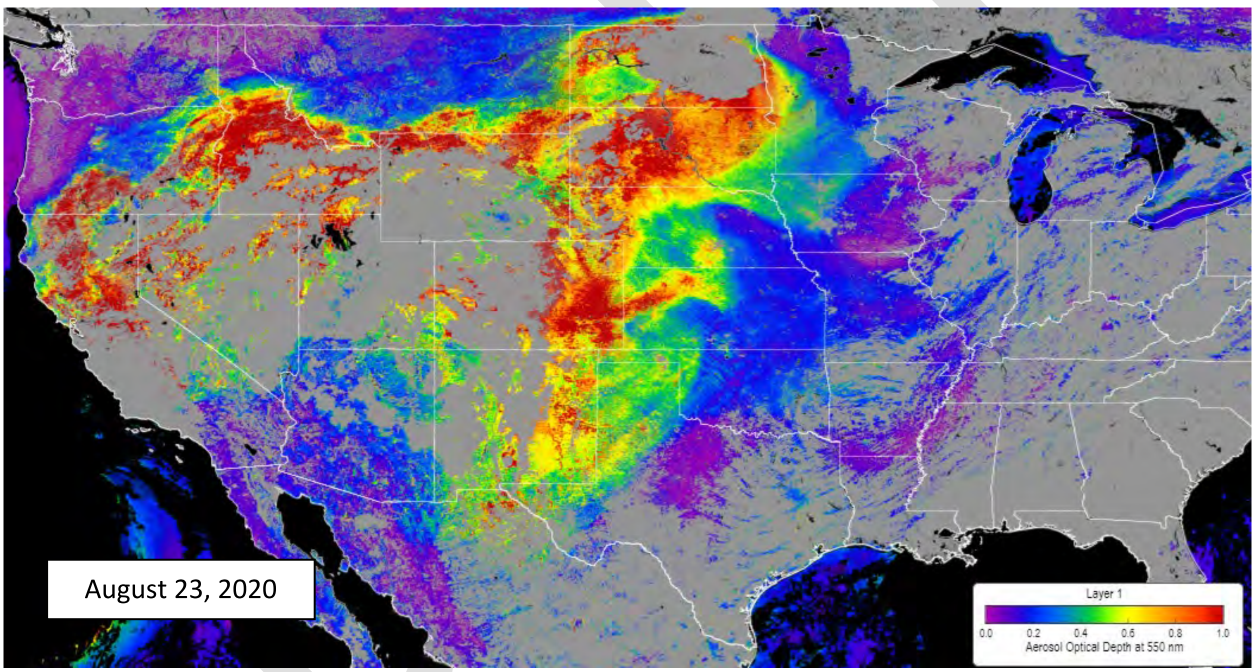

Figure 54. Suomi NPP AOD for August 23, 2020.

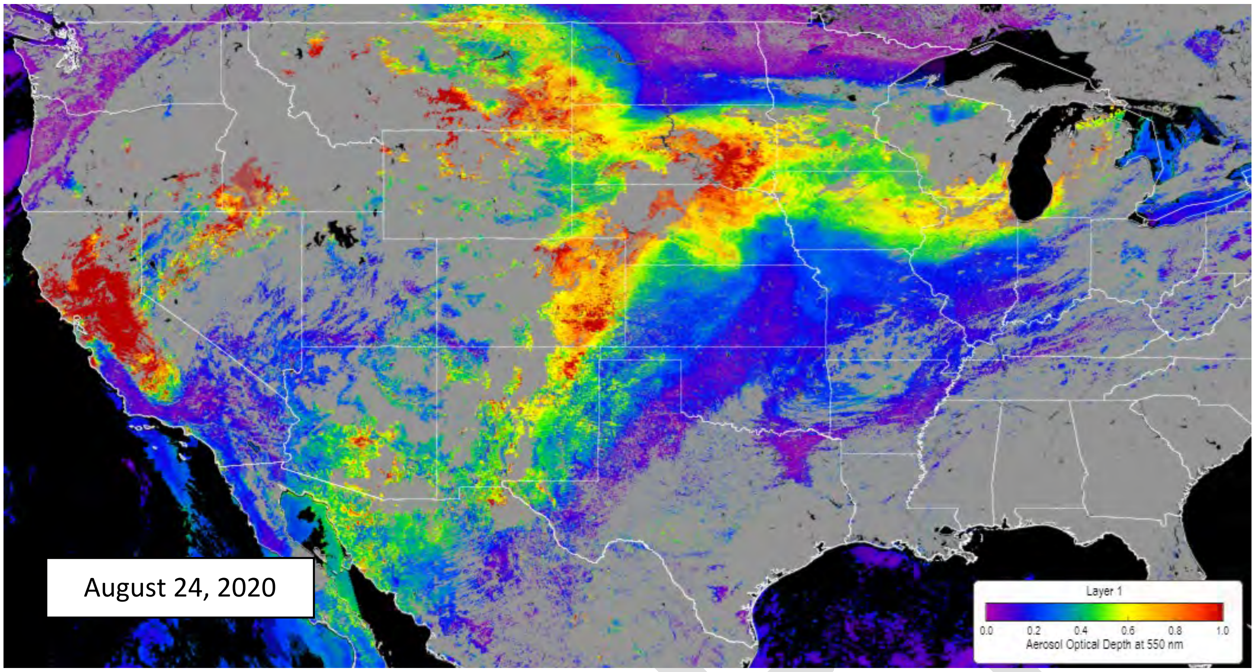

Figure 55. Suomi NPP AOD for August 24, 2020.

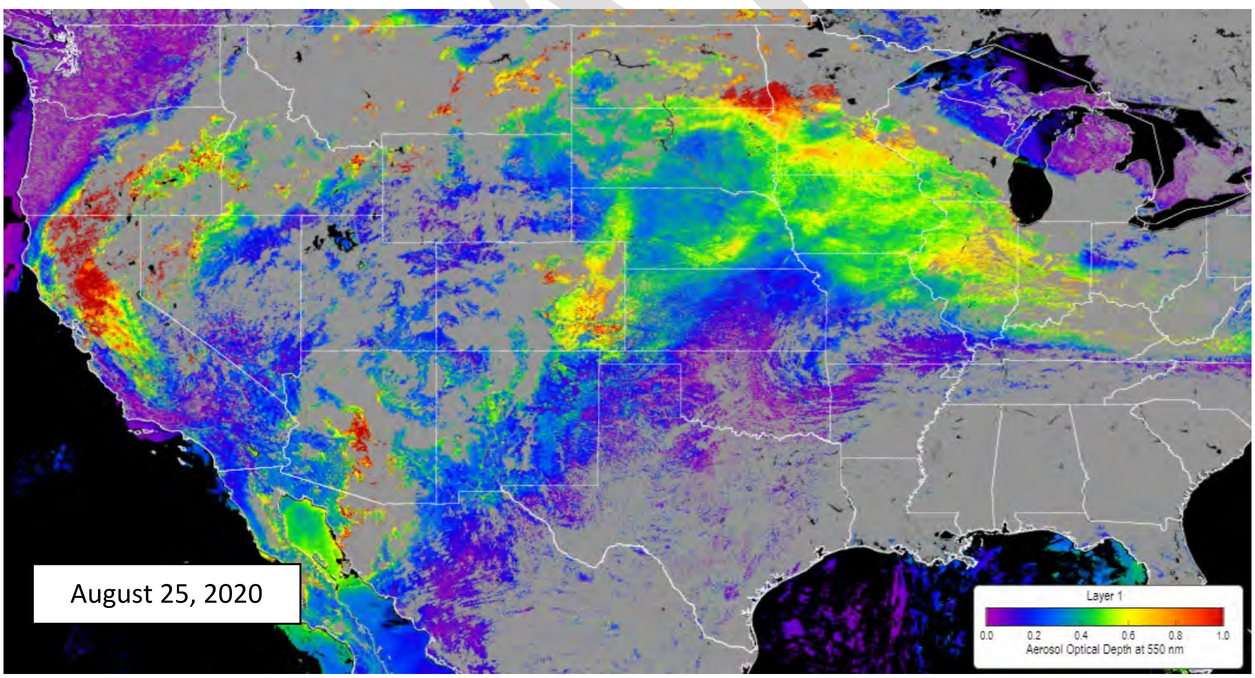

Figure 56. Suomi NPP AOD for August 25, 2020.

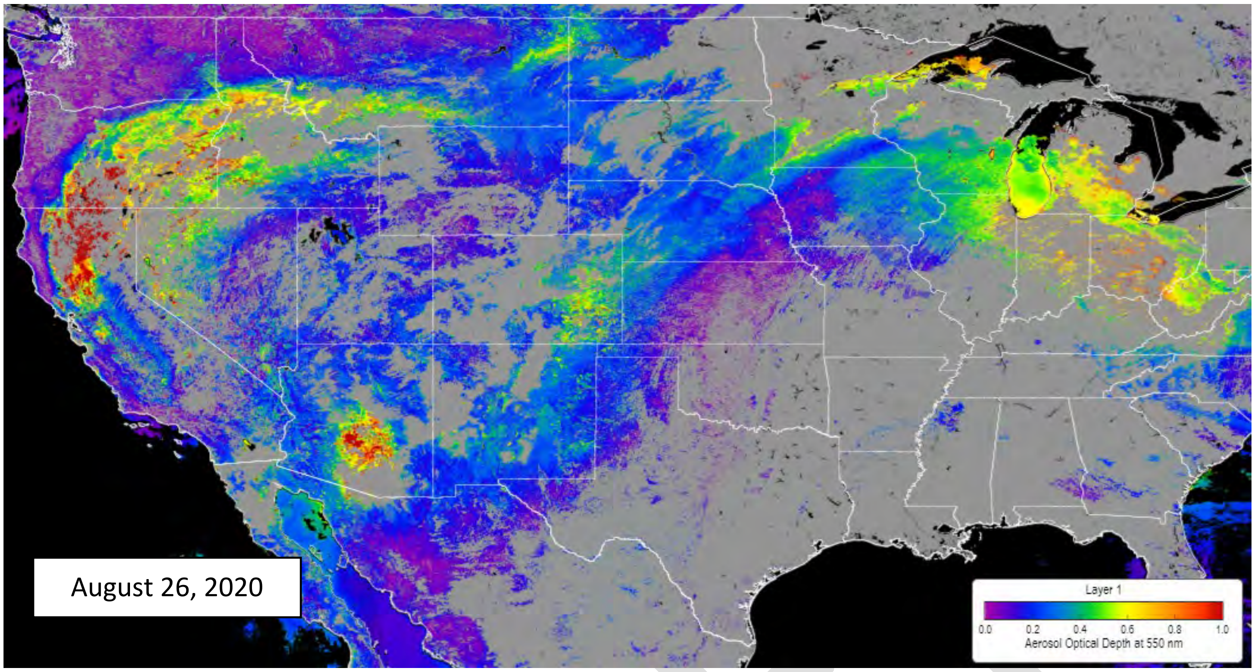

Figure 57. Suomi NPP AOD for August 26, 2020.

These images show relatively high AOD on the episode days and provide further evidence that the smoke plume and associated ozone and PM2.5 precursors were present in the smoke plume and in the Lake Michigan region in the days leading up to the exceedances, and during the exceedances on August 26, 2020.

CO and NO_2 retrievals from the TROPOspheric Monitoring Instrument (TROPOMI) were also examined. These maps indicate the presence of both gases and provide additional evidence to support the transport of smoke from fires in California to the western Michigan region, as already demonstrated with visual imagery and trajectories described earlier.

Measurements of the smoke plumes from the California fires in August 2020 are prominent in the images presented in Figure 58 through Figure 60. In these figures, the wildfire signatures are clearly seen in red on the left side of each image and a long tail of CO associated with the smoke plume is present along the Canadian border. On August 26, 2020 (Figure 60), a broad swath of smoke is identifiable by the high CO concentrations present over Lake Michigan.

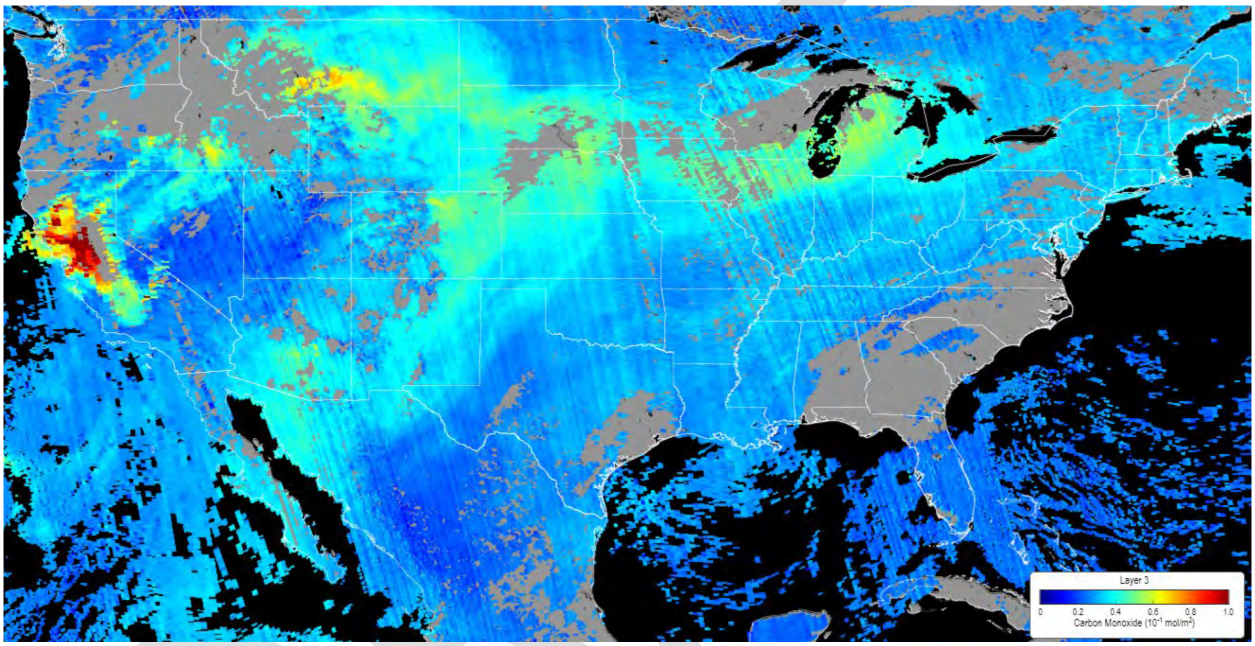

Figure 58. TROPOMI CO Measurement for August 24, 2020

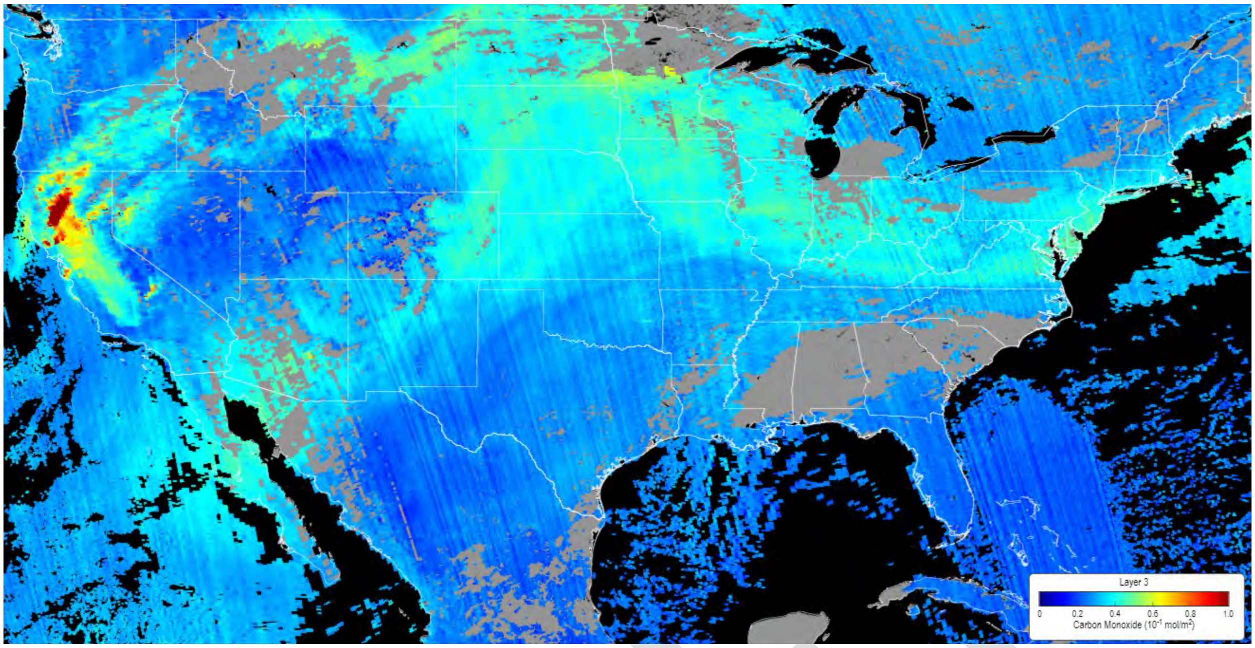

Figure 59. TROPOMI CO Measurement for August 25, 2020

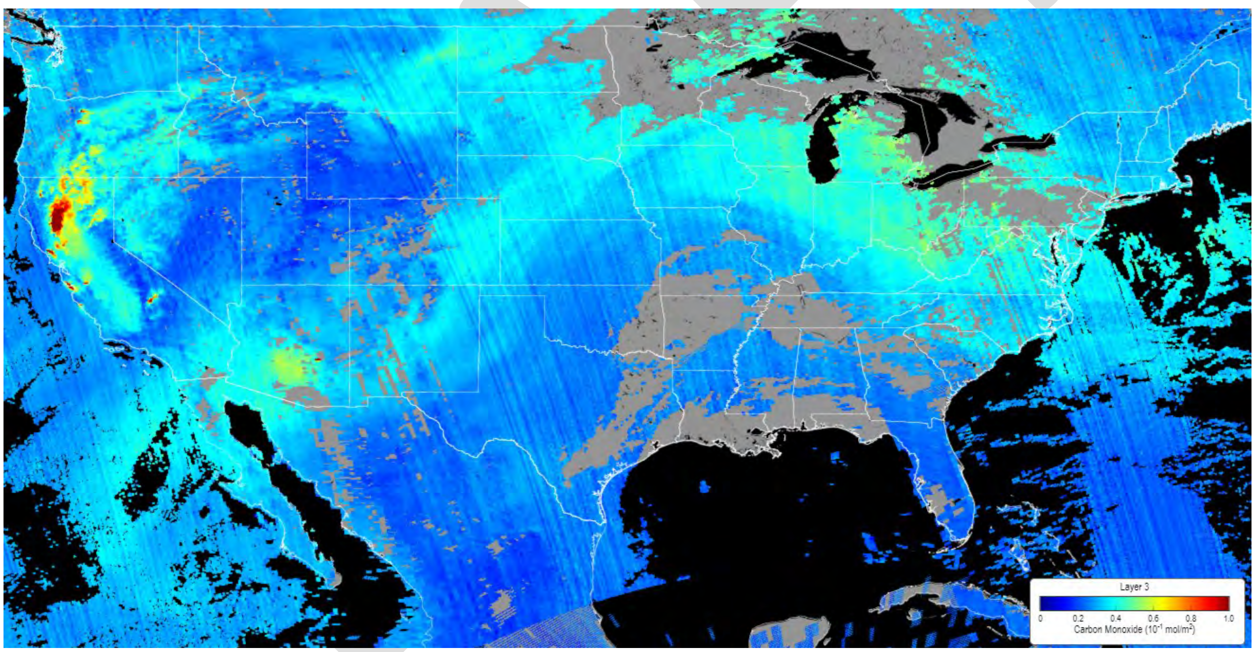

Figure 60. TROPOMI CO Measurement for August 26, 2020

Additionally, TROPOMI retrievals of tropospheric NO_2 (Figure 61 through Figure 63) were examined. 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 nominal increase in measured NO_2 and are consistent with urban measurements during non-event days. Therefore, it was determined that column NO_2 does not provide strong evidence for or against smoke impacts in western Michigan.

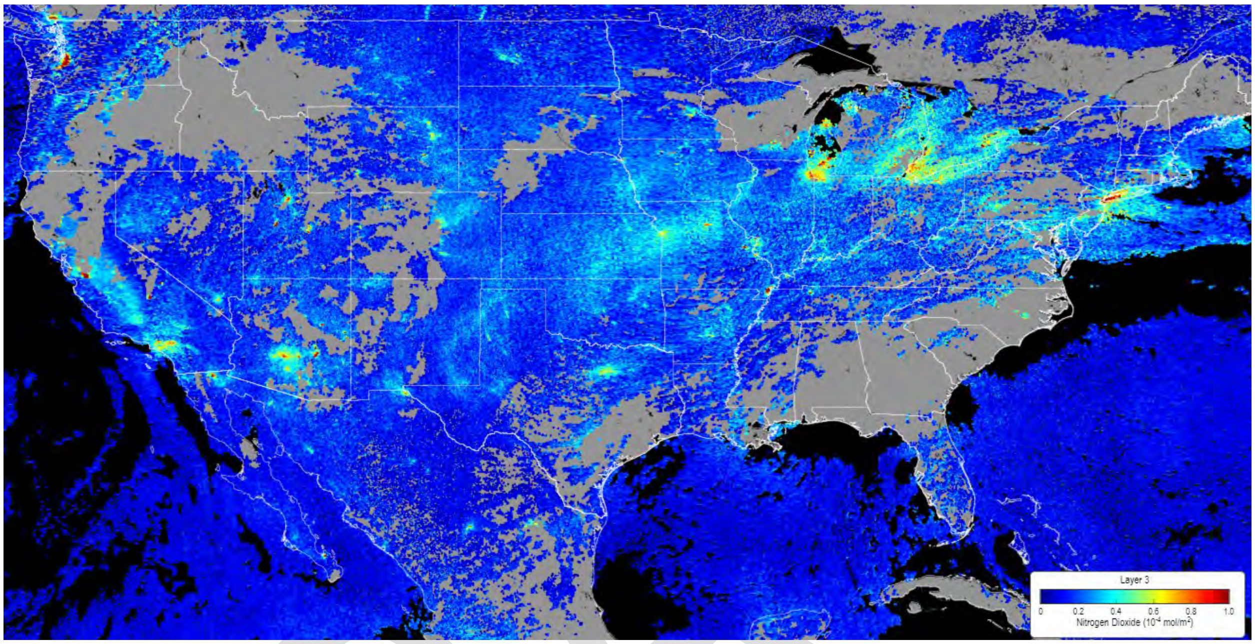

Figure 61. TROPOMI Nitrogen Dioxide Tropospheric Column for August 24, 2020.

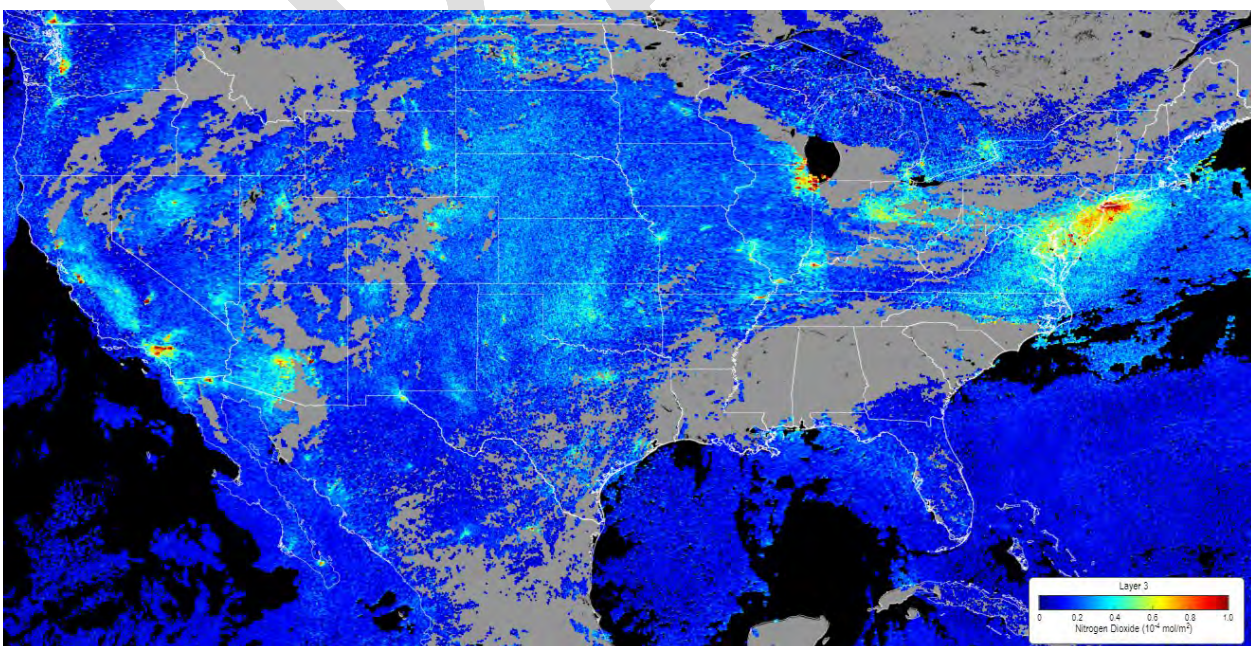

Figure 62. TROPOMI Nitrogen Dioxide Tropospheric Column for August 25, 2020.

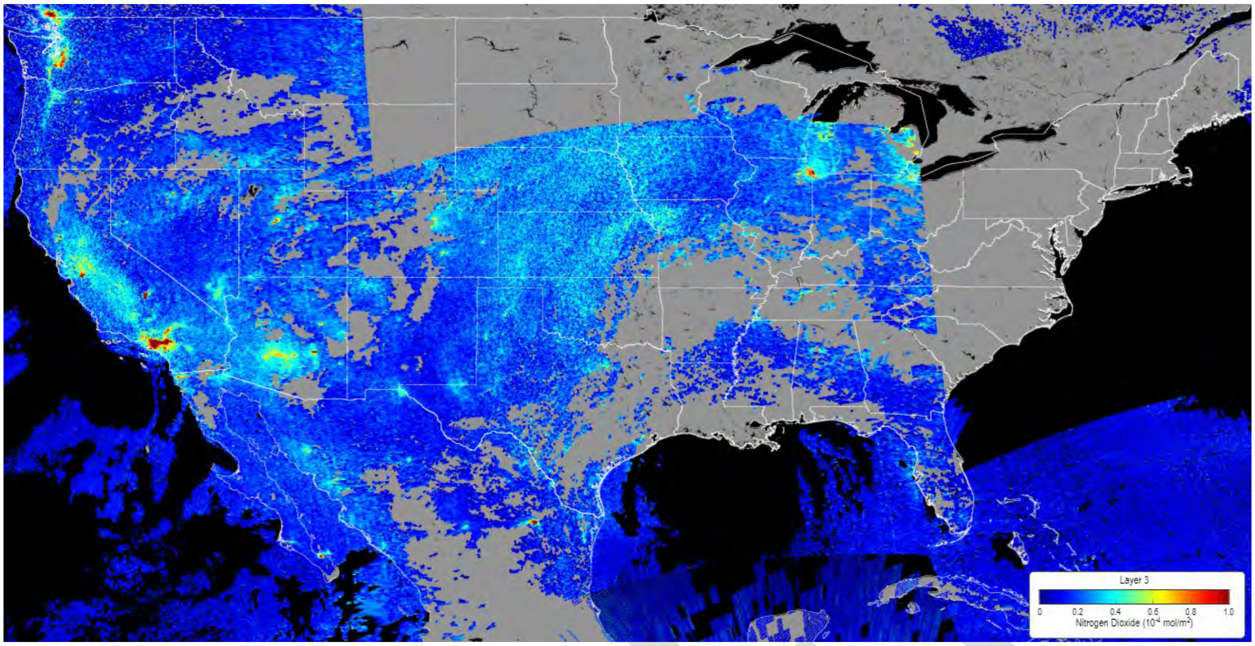

Figure 63. TROPOMI Nitrogen Dioxide Tropospheric Column for August 26, 2020.

Evidence that the Fire Emissions Affected the Western Michigan Monitors

Ground level multi-pollutant and alternate species corroboration

Michigan EPA's monitoring network observes both total PM2.5 mass and speciated compounds such as ionic potassium (K+), organic carbon (OC), and black carbon (EC) which can act as tracers of wildfire emissions.

The hourly ozone concentrations at the Muskegon, Holland, Coloma, and nearby Grand Rapids (26-081-0020) monitors, hourly PM2.5 at the Holland and Grand Rapids monitors, daily K+ concentrations at the Grand Rapids, Allen Park (26-163-0001) and Southwestern High School (26-163-0015) monitors, and daily EC and OC concentrations at the Allen Park monitor (26-163-0001) in Michigan were examined.

None of the listed receptors monitor for all pollutants and species, so the additional monitors are being used as regional alternates. Although all monitors were affected by the event, the impact on the Muskegon and Holland monitors were the only to have regulatory significance. However, the analysis of the hourly ozone and PM2.5 and daily K+, EC, and OC in the days around the events is illustrative of the impact to the monitors in the NAAs.

Both maximum and average 1-hour ozone concentrations are shown in Figure 64 to spike at the Muskegon monitor on August 26, 2020. As shown in Figure 65, these observations are consistent with the Holland monitor and in Figure 66 with the Coloma monitor during the smoke impact events.

The Grand Rapids (Figure 67) monitor also experienced a noted increase in maximum and average daily 1-hour ozone in the days of the smoke impact events indicating broad geographic effects from the plumes.

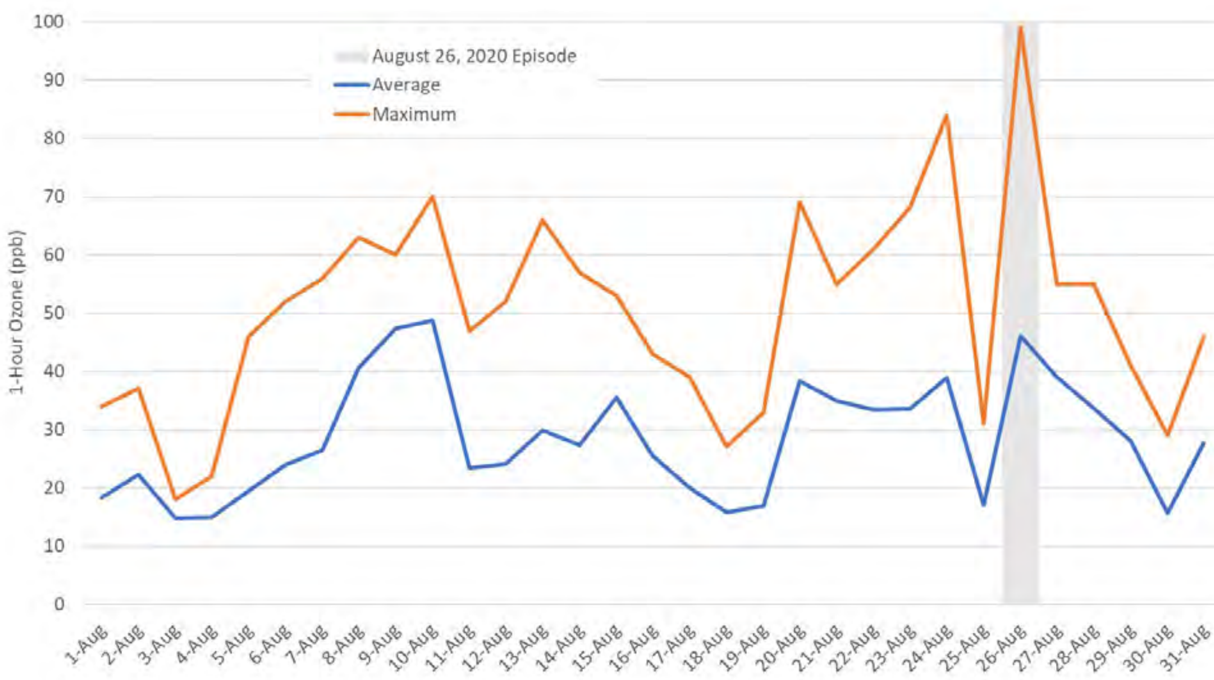

Figure 64. Average and maximum 1-hour ozone concentrations August 2020 at the Muskegon monitor.

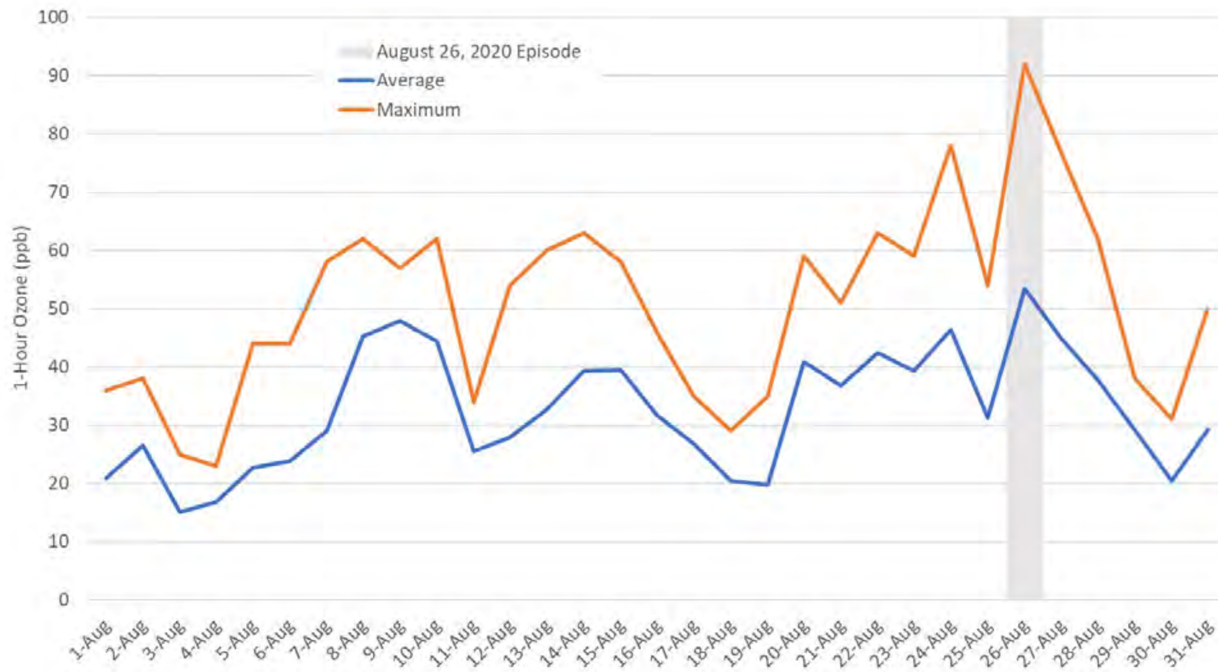

Figure 65. Average and maximum 1-hour ozone concentrations August 2020 at the Holland monitor.

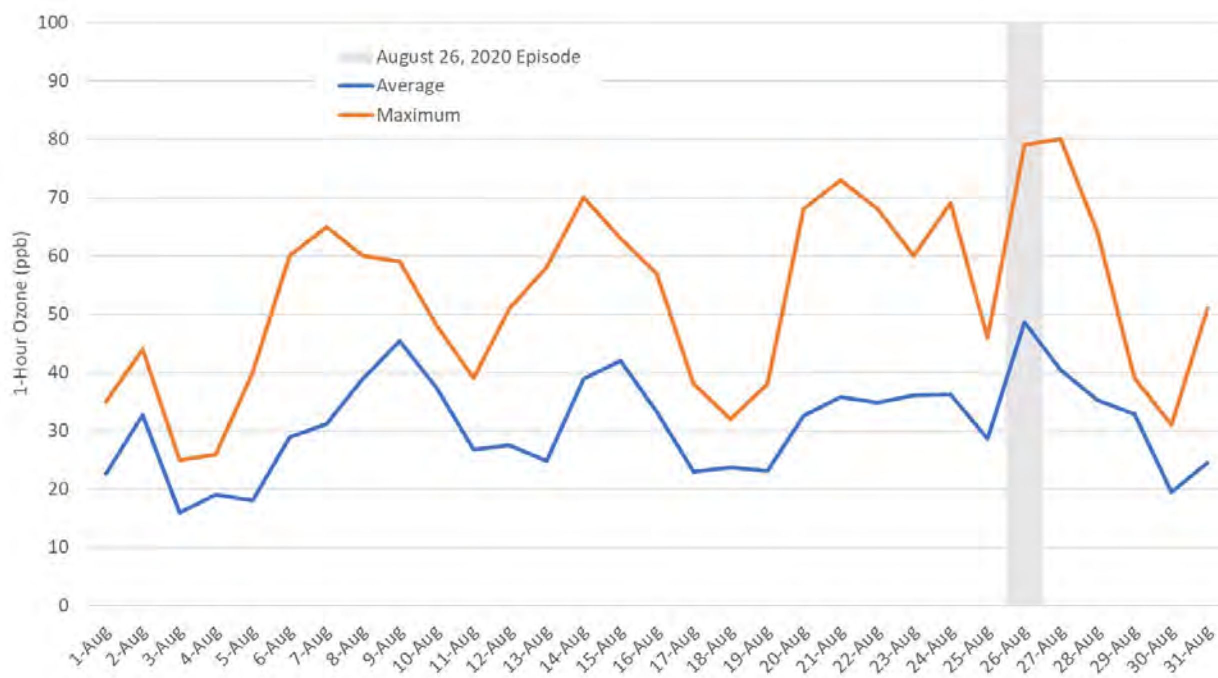

Figure 66. Average and maximum 1-hour ozone concentrations August 2020 at the Coloma monitor.

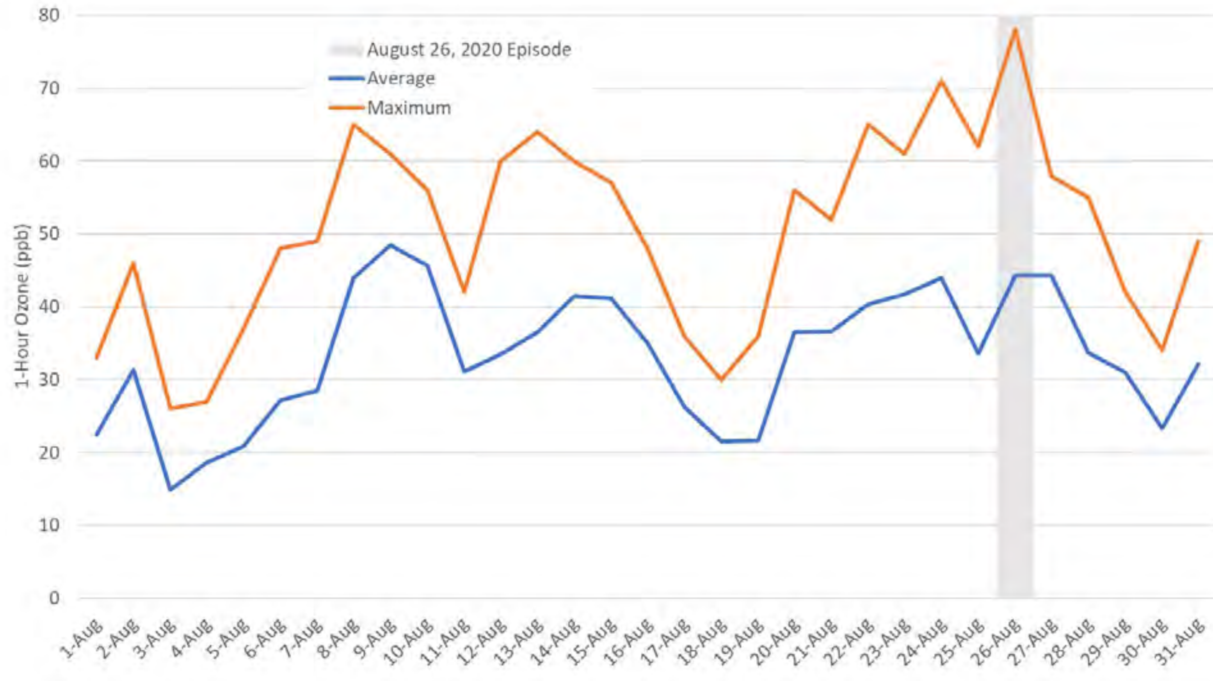

Figure 67. Average and maximum 1-hour ozone concentrations August 2020 at the Grand Rapids monitor.

The Holland (Figure 68) and Grand Rapids (Figure 69) monitors also experienced increases in maximum and average daily 1-hour PM2.5 in the days of the smoke impact event which is indicative of the arrival of the smoke plume and associated ozone precursors. As the smoke plume had arrived in the region in the days leading up to the August 26, 2020 ozone exceedance event, we also see increases in monitored pollutants during these days.

The multi-day buildup of ozone and PM2.5 concentrations at these monitors is consistent with the earlier demonstration of increasing smoke presence in the days leading up to the August 26, 2020 episode days.

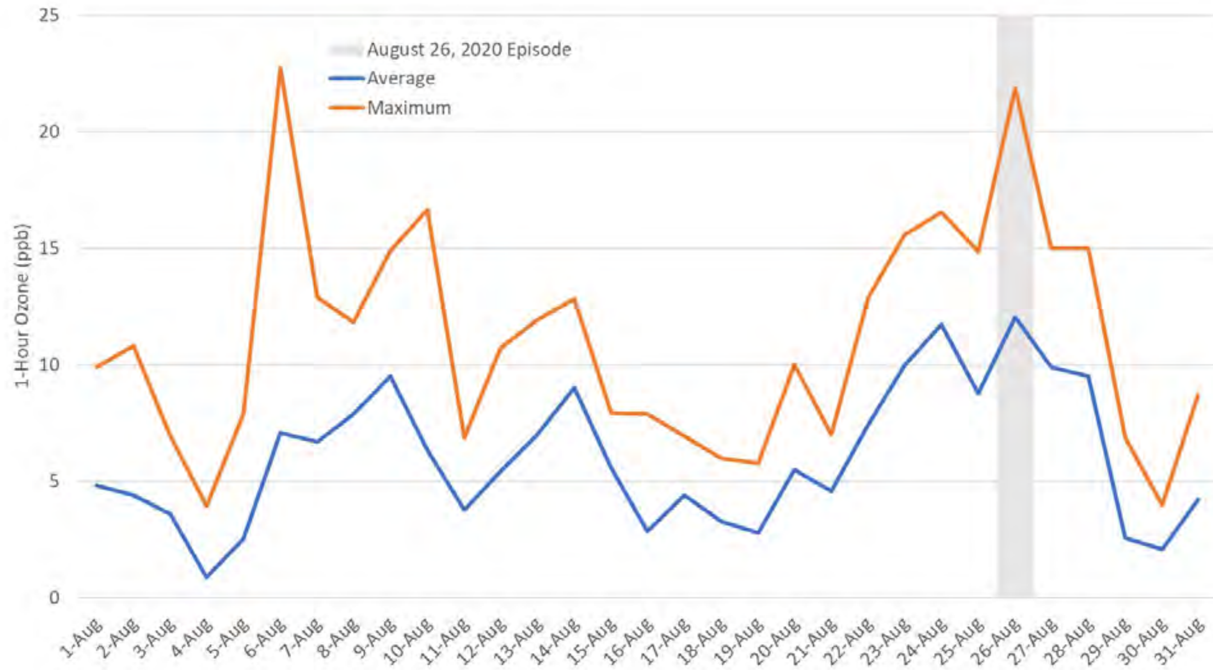

Figure 68. Average and maximum 1-hour PM2.5 concentrations August 2020 at the Holland monitor.

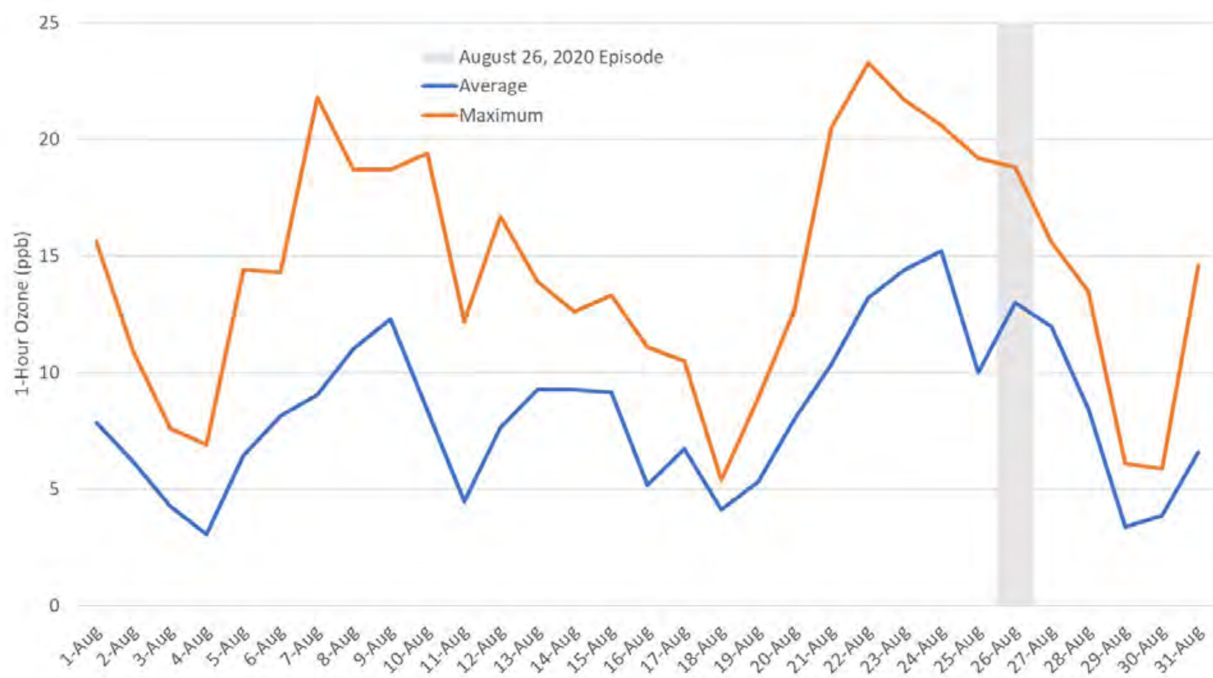

Figure 69. Average and maximum 1-hour PM2.5 concentrations August 2020 at the Grand Rapids monitor.

OC and K+ are most associated with wildfire emissions, so comparing these chemical compounds against the monitored 8-hour maximums for these days can provide evidence regarding the impact of such emissions. Speciated data (run every 3 or 6 days) retrieved from the Grand Rapids (western Michigan) and Allen Park and Southwestern High School (both in Wayne County, near Detroit) monitors showed increased concentrations of these species around August 26, 2020, consistent with the track of the smoke plume analyzed by HMS and observed increases in the ozone concentrations. K+ acts as a useful tracer of wildfire smoke because there are few anthropogenic sources, and concentrations above background levels are a signature of wildfire emissions.[49] As August 26, 2020 was not on the three-day recording cycle for these species, we have identified August 22 through August 29 with grey bars in the following figures to reference the episode period.

Particularly on August 22, 2020 (a day that is part of the three-day observation schedule), the magnitude of K+ was the highest for the month of August at the Grand Rapids (Figure 70) monitor, demonstrating influence by the wildfire smoke in the geographic area just before the ozone exceedance.

Figure 71 shows that K+, along with OC (Figure 73), increased around the same time of the elevated ozone episode of August 26, 2020 at the Allen Park monitor, and in the earlier days in which smoke was already visibly present over the location, providing further support that this was an event with a clear indicator of wildfire influence. This is also supported by an increase in EC as shown in Figure 74.

Since the K+ and OC are specific wood combustion markers, these speciated PM2.5 data provide conclusive evidence that the ozone affecting the airmass in western Michigan developed in areas under the heavy influence of smoke related emissions.

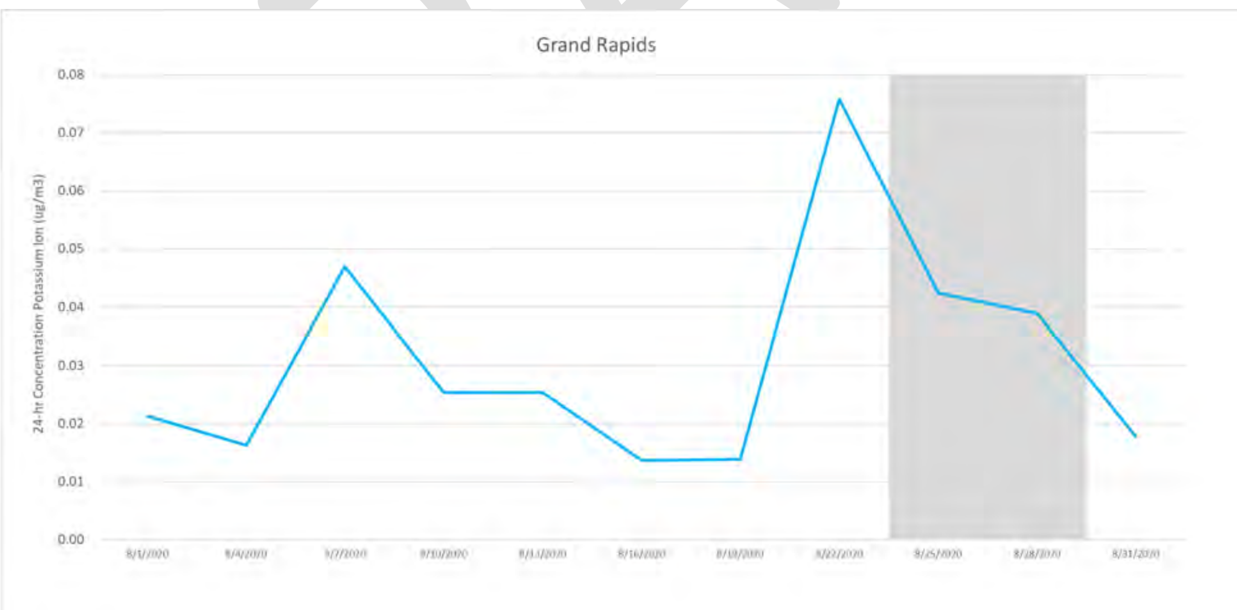

Figure 70. 24-hour K+ Concentration August 2020 at the Grand Rapids Monitor.

[49] Lee, T., A.P. Sullivan, L. Mack, J.L. Jimenez, S.M. Kreidenweis, T.B. Onasch, and D.R. Worsnop, Chemical smoke marker emissions during flaming and smoldering phases of laboratory open burning of wildland fuels. Aerosol Science and technology 44(9): i–v, 2010.

Figure 71. 24-hour K+ Concentration August 2020 at the Allen Park Monitor.

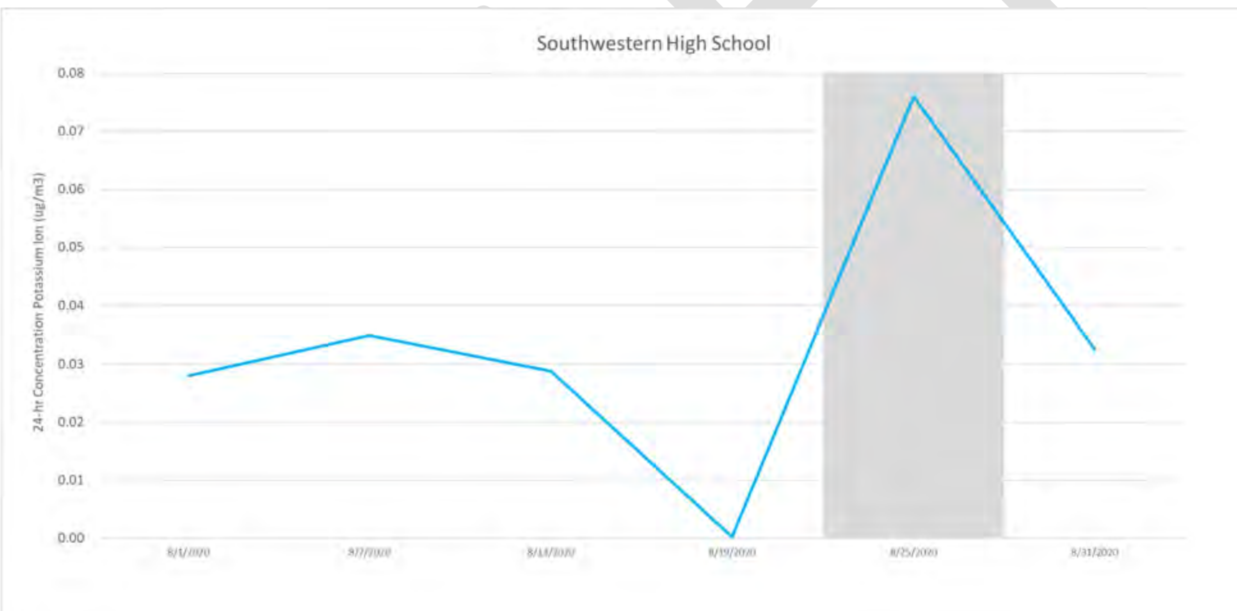

Figure 72. 24-hour K+ Concentration August 2020 at the Southwestern High School Monitor.

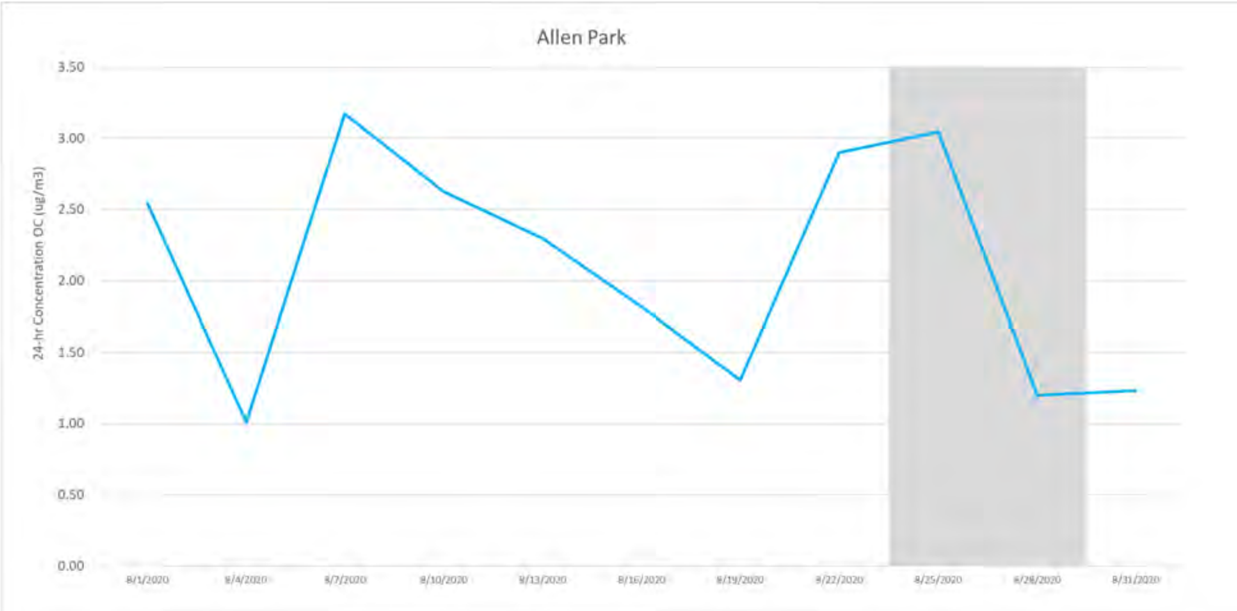

Figure 73. 24-hour OC Concentration August 2020 at the Allen Park Monitor.

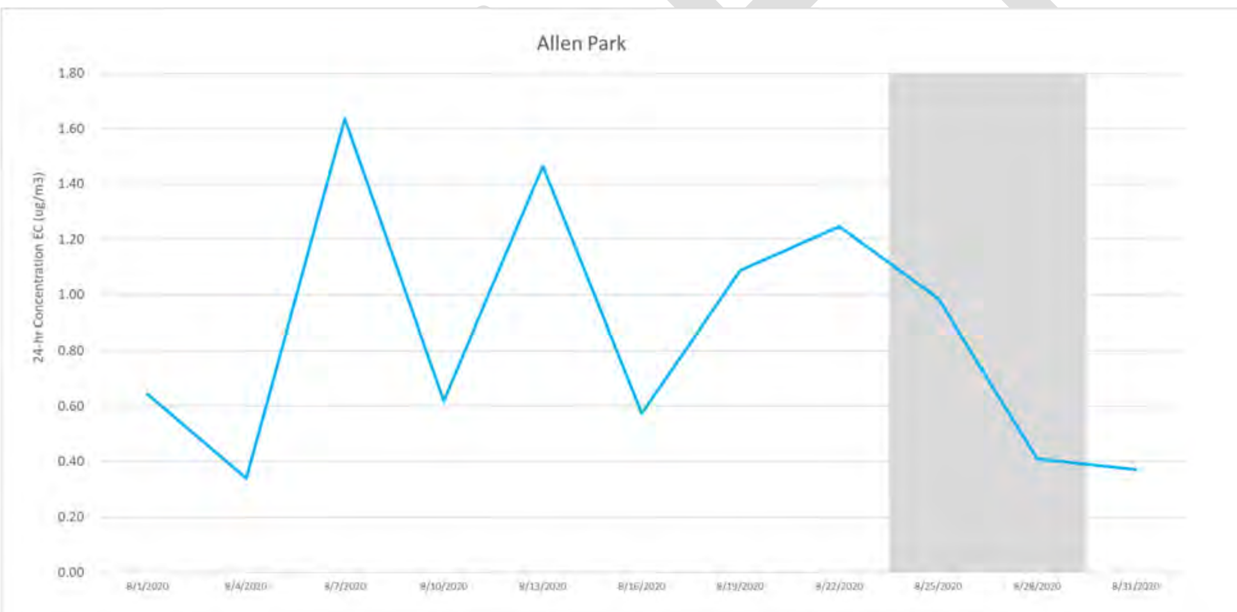

Figure 74. 24-hour EC Concentration August 2020 at the Allen Park Monitor.

Additional Evidence that the Fire Emissions Caused the Ozone Exceedances

Comparable Meteorological Day Analysis

A comparable meteorological day analysis is used to identify days which are similar in pattern and characteristics (temperatures, winds, transport regime) but are without the burden of smoke on ozone production. In a comparison of such days, affected monitors should show substantially less ozone when not impacted by smoke.

August 26, 2020 at the Muskegon and Holland monitors were used in this comparison. Because the monitors at these locations do not measure all the compared meteorological variables, measurements from the local airports are used as surrogates. In this analysis, we compared the days in two ways; first, by comparing each day across the average of all typical non-event ozone exceedance days in the past five years, and second, by reviewing a comparable multi-day ozone event with noted increases in temperature and changes in other meteorological conditions similarly found in the August 26, 2020 episode. For this demonstration, typical non-event days are identified as those without an HMS smoke product plume located directly over the receptor on or in the previous 48-hours of the exceedance day. Days when HMS smoke was present on or in the previous 48 hours are classified as potential smoke event days and are analyzed separately from the typical non-event exceedance day.

As noted earlier, synoptic patterns from August 22 through August 26, 2020 show weak forcing over much of the Continental United States with some influence of the outflow of Hurricane Laura on August 25. The outflow caused a weak surface cold front to drop south and at upper levels, a trough sank in producing a northwesterly flow, lighter at the surface but more prevalent at upper levels. This was short lived, but strong enough to bring in clouds and scattered precipitation for one day keeping ozone levels lower on August 25, 2020. Again, this was short lived because by the morning of August 26, 2020, the boundary lifted back with all levels back to a weaker, but southerly flow.

Throughout the period a weakening blocking structure over Northern Utah and surrounding areas is diverting flows from southern California to the east where they are captured in the more northerly winds toward the Upper Midwest. Conversely, the winds from Northern California are directed to the north, where they meet more westerly winds toward the Upper Midwest near the Canadian border.

For each of the monitors, a set of ranges across multiple meteorological conditions that were reported during the episode day of August 26, 2020 were developed. Using the conditions observed at local airports on those days, ranges of the min and max value across each day for reported maximum temperature (°F), average wind speed (mph), wind direction (degrees), and relative humidity (%) between 9 AM and 9 PM generated the values in Table 8 for inclusion in the analyses.

Table 8. Meteorological Conditions for Comparison by Monitor

Monitor	Local Airport	Max Temp Range (°F)	Wind Speed Range (Avg mph)	Wind Dir Range (degrees)	Average Relative Humidity Range (%)
Muskegon	MKG	80-90	6.0 – 10 mph	145-170	65-75
Holland	BIV	80-90	6.0 – 10 mph	190-215	60-70

Using the meteorological ranges presented in Table 8, a list of days that fell with each parameters' ranges was developed and those conditions and associated MDA8 ozone concentration from the associated monitor are presented in Table 9 and Table 10 below.

From the list of all days from 2016-2020, four days met the constraints listed above for the Muskegon monitor in the Muskegon NAA for each of the meteorological parameters. A list of those days, the observed MDA8 ozone observations at the Muskegon monitor and meteorological observations at MKG are presented in Table 9 along with conditions on August 26, 2020 (highlighted in bold font).

Of these days, only one of four comparable days, July 28, 2019, had an MDA8 ozone observation above 60 ppb. On average, these four days had an MDA8 ozone concentration of 60 ppb, 23 ppb lower than the August 26, 2020 MDA8 value at the monitor. Average maximum temperature across the four days was 84°F, average wind speed was 7.4 mph out of the south-southeast (152 degrees) and average relative humidity was 70%. Skies were mixed clouds across all days.

Table 9. Comparable Meteorological Day Analysis: MDA8 Ozone Levels at Muskegon Monitor and Associated Meteorological Conditions at MKG

Date	Muskegon MDA8 (ppb)	Max Temp (°F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
5/18/2019	53	80	6.4	147	73	FEW
7/28/2019	68	84	6.5	148	69	CLR
5/25/2020	59	83	7.0	165	66	M
7/26/2020	60	90	9.6	148	71	SCT
8/26/2020	**83**	**86**	**7.8**	**155**	**71**	**M**
Average without 8/26/2020	**60**	**84**	**7.4**	**152**	**70**	**Mixed**

From the list of all days from 2016-2020, only three days met the meteorological range for the Holland monitor comparison. A list of those days, the observed MDA8 ozone observations at the monitor and meteorological observations at BIV are presented in Table 10 along with conditions on August 26, 2020 (highlighted in bold font).

Of these days, none had an observed MDA8 ozone concentration above 60 ppb. On average, these three days had an MDA8 ozone concentration of 57 ppb, 21 ppb lower than the August 26, 2020 MDA8 value at the monitor. Average maximum temperature for the three days was 83°F, average wind speed was 7.2 mph out of the south-southwest (210 degrees) and average relative humidity was 67%. Skies were reported as clear across all days.

Table 10. Comparable Meteorological Day Analysis: MDA8 Ozone Levels at Holland Monitor and Associated Meteorological Conditions at BIV

Date	Holland MDA8 (ppb)	Max Temp (°F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
9/19/2016	55	82	6.7	207	68	CLR
6/22/2017	59	85	8.4	213	69	CLR
7/26/2019	58	83	6.5	210	66	CLR
8/26/2020	**78**	**88**	**7.2**	**209**	**65**	**CLR**
Average without 8/26/2020	**57**	**83**	**7.2**	**210**	**67**	**CLR**

Based on the similar day analysis, no other day since 2016 which had similar meteorological characteristics produced similar levels of ozone at either of the monitor locations analyzed. Of the days selected for comparison, only one came within a few ppb to measured exceedances of 71 ppb and most days had ozone levels 15 to 30 ppb lower than were observed between the episode day of August 26, 2020.

This evidence suggests the August 26, 2020 exceedance event was influenced by factors not definitively explained by a comparable meteorological day analysis and lends support to the conclusion that the influence of wildfire smoke created the ozone exceedances during the episode of August 26, 2020.

Typical Non-Event Ozone Exceedance Day Analysis

A typical non-event ozone exceedance day analysis is used to compare conditions on exceedance days without the burden of smoke to demonstrate differences in the episode event and typical ozone exceedances. On these days, conditions may show differences in temperature, wind direction or speed, presence of precipitation, diurnal profiles, multi-day carryovers, and PM2.5 species analyses that would lead to differing observed ozone concentrations.

In this analysis, we investigated days in the past five years (2016-2020) with MDA8 ozone observations greater than 70 ppb at the Muskegon and Holland monitors. A list of those days and meteorological conditions is presented in Table 11 and Table 12. August 26, 2020 is identified in bold font for each of the monitors. Days which were determined to have observed HMS smoke over the region on or just before (48 hours earlier) are highlighted in grey and are considered as days with potential smoke enhancement of ozone concentrations.

Excluding the episode day of August 26, 2020, twenty-four days were found to have an MDA8 value of greater than 70 ppb between 2016-2020 at the Muskegon monitor and of those days, only five were found to be absent of regional HMS smoke coverage on or in the previous 48-hours. The average MDA8 value across the nineteen exceedance days with potential smoke enhancement is 80 ppb while the average MDA8 for the five days when smoke was not present is 77 ppb, a potential enhancement difference of 3 ppb. The calculated average maximum temperature for the smoke enhanced days was 85 ^{o}F and for typical non-event ozone exceedance days was 84 ^{o}F. Average wind speed is similarly moderate (5.9 mph for smoke enhanced days and 6.7 mph for typical non-event ozone exceedance days), and wind direction is typically out of the SSW across both sets of days.

Table 11. Comparison of Meteorology and MDA8 Ozone Levels at Muskegon on Typical Non-Event Ozone Exceedance Days

Date	MDA8 (ppb)	Max Temp (°F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
4/17/2016	74	76	3.9	216	39	SCT
4/18/2016	76	76	4.0	260	47	BKN
5/24/2016	87	82	5.6	199	43	M
5/25/2016	72	83	4.3	220	62	M
6/10/2016	89	85	6.1	176	67	M
6/19/2016	79	85	5.7	198	59	M
6/25/2016	72	87	6.6	186	56	CLR
6/9/2017	71	77	5.0	244	65	M
6/10/2017	75	84	11.1	197	57	M
6/11/2017	75	86	9.3	197	52	CLR
6/12/2017	82	87	6.5	196	57	SCT
9/26/2017	74	88	5.5	200	65	M
5/25/2018	95	81	5.3	202	53	M
5/27/2018	80	86	4.2	229	66	FEW
5/29/2018	77	95	6.2	104	56	M
6/17/2018	76	88	8.2	107	69	CLR
7/9/2018	88	84	7.0	190	62	M
7/13/2018	86	86	7.8	153	57	M
7/10/2019	80	87	6.6	176	66	FEW
6/2/2020	83	82	7.0	167	64	M
6/18/2020	76	84	4.1	252	54	CLR
6/19/2020	80	88	3.5	219	52	FEW
6/20/2020	83	89	5.8	168	56	CLR
8/24/2020	72	85	5.2	220	75	FEW
8/26/2020	**83**	**86**	**7.8**	**155**	**71**	**M**

At the Holland monitor, excluding the episode day of August 26, 2020, thirty days were found to have an MDA8 value of greater than 70 ppb between 2016-2020. Of those days, only five were found to be absent of regional HMS smoke coverage on or in the previous 48-hours. The average MDA8 value across both the twenty-five exceedance days with potential smoke enhancement and the five days when smoke was not present is 75 ppb. The calculated average maximum temperature on potential smoke enhanced days is 86 °F, while the average maximum temperature on typical non-smoke ozone exceedance days is 83 °F. Average wind speed is similarly moderate (5.8 mph for smoke enhanced days and 6.2 mph for non-enhanced days). There is a slight wind direction difference as average winds are typically out of the SW on potentially smoke enhanced days and from the WSW on typical non-event ozone exceedance days.

Table 12. Comparison of Meteorology and MDA8 Ozone Levels at Holland on Typical Non-Event Ozone Exceedance Days

Date	MDA8 (ppb)	Max Temp (ºF)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
4/16/2016	72	78	4.4	203	48	CLR
4/17/2016	76	79	3.2	132	43	CLR
4/18/2016	74	78	4.3	272	48	CLR
5/25/2016	71	83	4.7	232	68	CLR
6/10/2016	85	88	5.5	188	65	CLR
6/11/2016	79	84	6.4	258	64	CLR
6/19/2016	73	88	6.4	223	56	CLR
6/25/2016	75	89	6.1	177	56	CLR
7/6/2016	76	84	5.8	243	73	CLR
6/2/2017	75	79	5.3	271	46	CLR
6/10/2017	71	88	11.5	223	50	CLR
6/12/2017	74	90	9.7	224	51	CLR
6/15/2017	74	80	6.2	253	79	CLR
5/25/2018	85	83	5.8	221	59	CLR
5/27/2018	74	89	3.8	263	66	CLR
5/29/2018	73	93	4.8	115	65	CLR
5/31/2018	80	83	6.5	260	79	CLR
6/17/2018	74	91	7.2	225	67	CLR
7/9/2018	72	85	6.2	241	63	CLR
7/13/2018	77	88	6.3	229	59	CLR
8/2/2018	71	81	6.4	251	76	BKN
7/2/2019	73	88	5.8	234	81	CLR
7/5/2019	72	87	4.8	251	80	CLR
7/10/2019	75	90	6.0	227	72	CLR
7/28/2019	71	88	7.3	232	68	CLR
6/2/2020	81	85	8.8	224	59	CLR
6/18/2020	76	85	4.0	238	54	CLR
6/19/2020	79	89	3.2	257	56	CLR
6/20/2020	72	89	5.7	221	57	CLR
7/25/2020	72	85	4.0	250	70	CLR
8/26/2020	**78**	**88**	**7.2**	**209**	**65**	**CLR**

MDA8 ozone, 24-hour K+, EC, and OC concentrations at the Grand Rapids monitor were also reviewed for the combined exceedance day list and compared to the MDA8 values for exceedance days at both NAA monitors. These data were also assigned the potentially enhanced and typical non-event ozone exceedance days classifications.

Table 13 below provides a comparison with days on the three-day cycle where observations were made for the PM2.5 species.

Table 13. Comparison of MDA8 Ozone and Key PM2.5 Species Concentrations

	MDA8 Ozone (ppb)		**Grand Rapids**			
Date	**Muskegon**	**Holland**	**MDA8 (ppb)**	**K+ (µg/m^3)**	**EC (µg/m^3)**	**OC (µg/m^3)**
04/18/16	76	74	75	0.040	1.277	4.035
05/24/16	87	64	79	0.080	0.908	3.264
06/11/16	68	79	69	0.010	0.289	1.350
06/20/16	59	68	62	0.050	-	-
06/09/17	71	68	68	0.020	0.668	2.598
06/12/17	82	74	62	0.010	0.609	2.737
06/15/17	63	74	63	0.010	0.404	1.798
05/29/18	77	73	75	0.010	0.881	3.981
07/13/18	86	77	71	0.010	1.006	5.354
07/02/19	57	73	55	0.060	0.564	2.020
06/02/20	83	81	83	0.026	0.543	2.843
06/05/20	64	63	64	0.095	-	-
06/17/20	69	70	78	0.051	-	-
06/20/20	83	72	76	0.284	1.120	3.833
Smoke Enhanced	**76**	**72**	**73**	**0.067**	**0.914**	**3.636**
Typical Non-Event Exceedance	**70**	**72**	**66**	**0.037**	**0.558**	**2.399**

On days where smoke was present on or just before an observation, K+ concentrations tended to be higher than on days when smoke was not seen in the region. As seen in Table 13, at the Grand Rapids monitor, K+ concentrations on days with observed smoke plumes were on average higher (0.067 µg/m^3) than on days without the presence of smoke (0.037 µg/m^3). Combined EC and OC concentrations are also higher on potentially smoke enhanced days with an additive concentration of 4.550 µg/m^3 compared to typical non-event ozone exceedance days with 2.957 µg/m^3. As August 26, 2020 was not on the three-day observation cycle of PM2.5 species, direct comparisons to that day could not be calculated.

From a long-term comparison perspective, K+ concentrations at the Grand Rapids monitor on August 22, 2020 (just before the episode event) was among the larger values observed (omitting July 4th firework event dates) across the past five years. Figure 75 below presents this information and demonstrates that the K+ concentration (0.076 µg/m^3) on the day of the event (highlighted with a diamond) was more than twice the average value (0.030 µg/m^3) for this monitor across the past five years when removing values from 4th of July firework events.

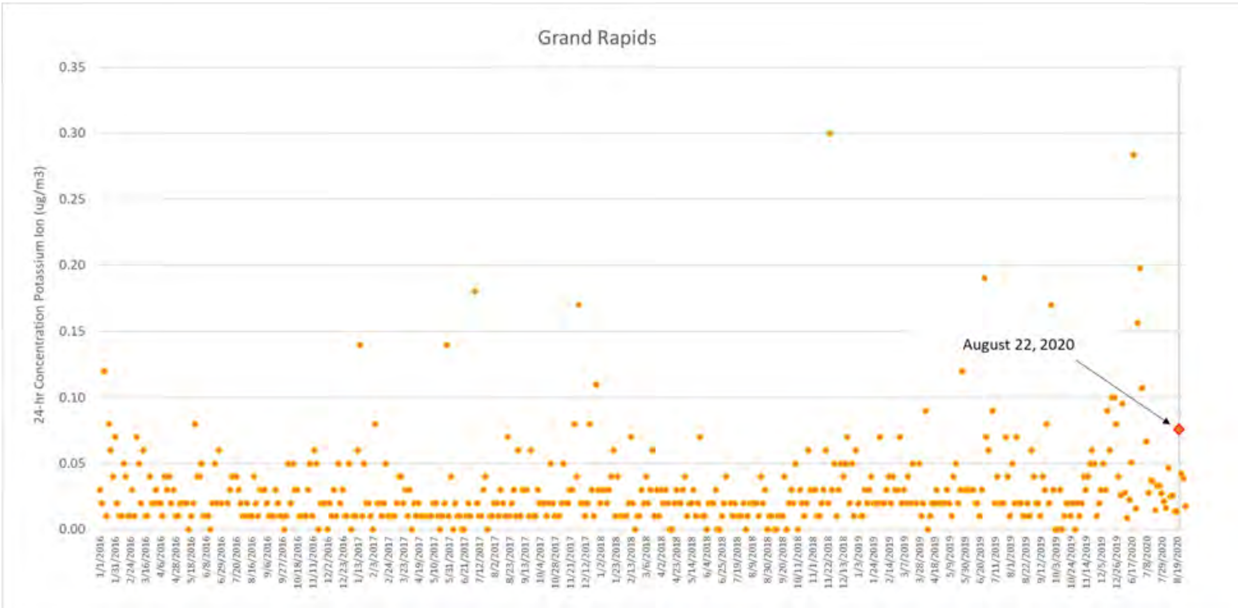

Figure 75. 24-hour K+ Concentration 2016-2020 at the Grand Rapids Monitor.

Further review was conducted on the buildup days leading to ozone exceedances identified as non-smoke influenced days.

Figure 76 and Figure 77 below present averaged diurnal profiles of 1-hour ozone for the August 26, 2020 episode day and the potential smoke enhanced and typical exceedance days listed in Table 11 and Table 12 for the Muskegon and Holland monitors, respectively. Each figure presents average hourly ozone observations across the smoke enhanced days (grey line), typical non-event ozone exceedance days (blue line with ± 1 standard deviation bars), and the August 26, 2020 episode (orange line), as well as the hourly difference between the smoke enhanced days (grey bar) and August 26, 2020 episode (orange bar) compared to typical non-event exceedance observations.

The impact of smoke-enhanced ozone is clearly seen in Figure 76 where a significantly greater gradient of ozone change occurs between the early morning hours (hours 0 – 6) and afternoon (hours 15-17). Ozone concentrations observed at the Muskegon monitor on August 26, 2020 (orange line) are 17 ppb higher (orange bar) than average typical non-event ozone exceedance day ozone observations (blue line) by afternoon. Additionally, this difference between typical non-event ozone exceedances is attributed to the significant rise in 1-hour ozone between the early morning hours and the afternoon. On a potentially smoke enhanced day (grey line), this increase is more dramatic than on a typical non-event ozone exceedance day as the concentration delta continues to rise higher during the early morning hours and leads to more rapid ozone formation in the late morning and early afternoon and delays ozone decay in the late afternoon. During the August 26, 2020 episode, this rise is pointedly heightened as it moves from 38 ppb below typical conditions at hour 2 to 17 ppb above typical conditions at hour 16, a swing of 55 ppb in fourteen hours.

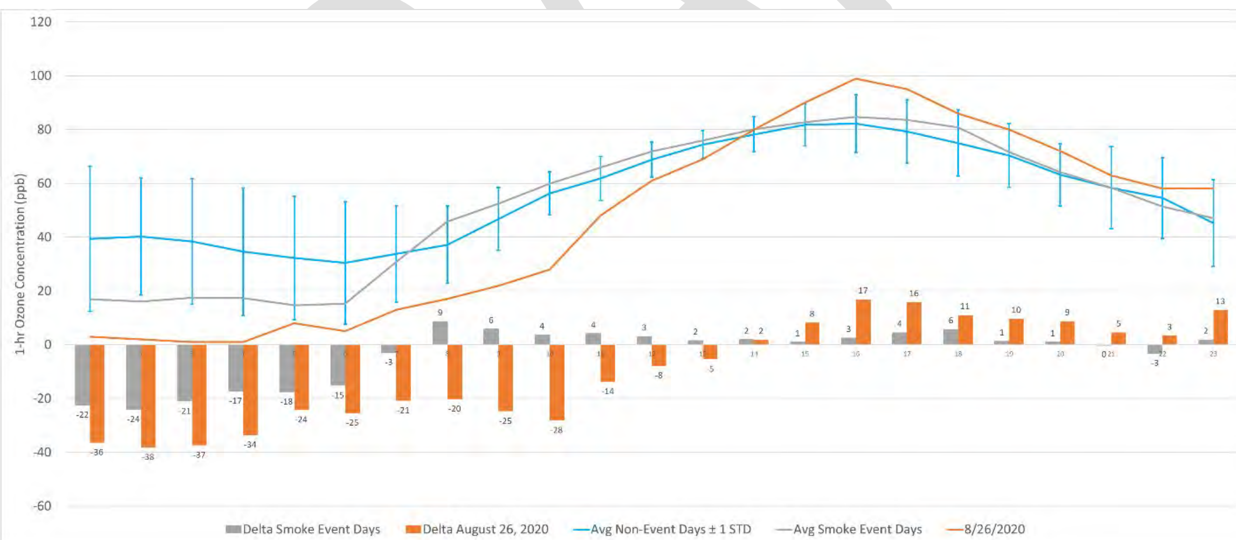

Figure 76. Diurnal ozone (ppb) profiles for Muskegon monitor.

Figure 77 presents similar conditions at the Holland monitor and shows the same dramatic concentration increase during the early morning hours into the afternoon on August 26, 2020. Like the Muskegon monitor, afternoon differences in ozone measurements were greater than 16 ppb as photolysis in the morning sunlight hours formed ozone in higher concentrations than normal for a typical non-event ozone exceedance day.

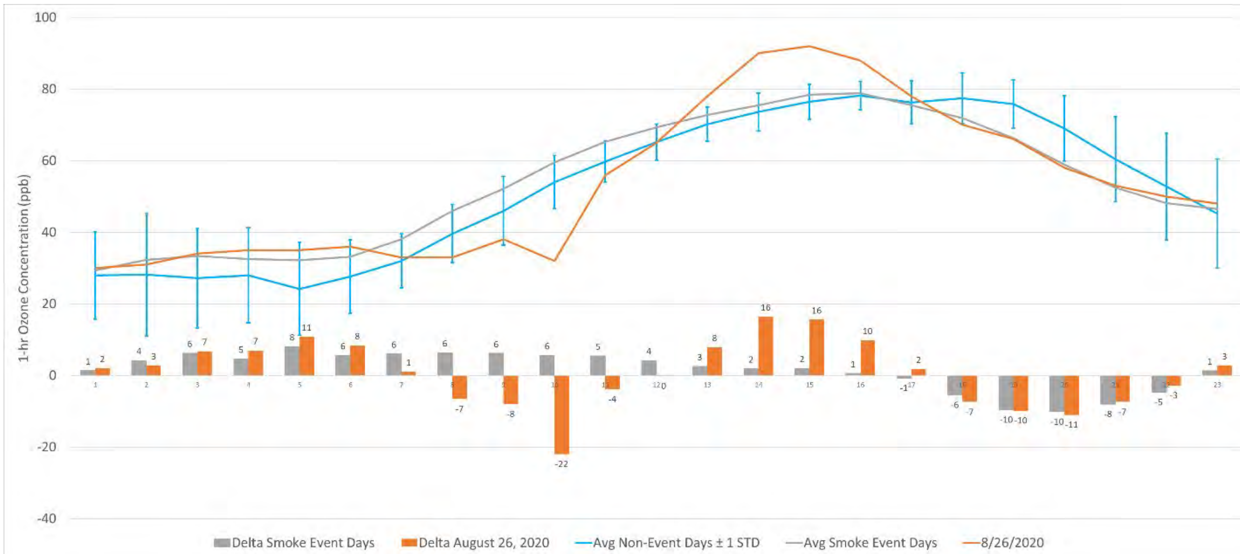

Figure 77. Diurnal ozone (ppb) profiles for Holland monitor.

When these data are viewed from a multi-day buildup perspective, the data indicate that the buildup/carryover is more significant during the August 26, 2020 event (orange line) than during a typical non-event ozone exceedance (blue line). As seen in Figure 78 and Figure 79, the August 26, 2020 event had much more significant ozone concentrations across each day of the episode (orange line) as opposed to either typical non-event ozone exceedance events (blue line) or historical averaged potentially smoke enhanced (grey line) event days which tended to show ozone exceedances only on the exceedance day (peak represented on the far right of each figure).

An interesting feature of this episode is the precipitous drop in ozone on August 25, 2020 associated with the shifting winds and outflow boundaries of Hurricane Laura as the unstable airmass moves into the area and pushes the air mass offshore. Clouds were observed to be present in the region along the outflow boundary preventing the ultraviolet photolysis from generating ozone. Prior to the drop, the influence of wildfire smoke that was in the area on August 24, 2020 can be seen in the MDA8 peak on the day before the ozone drop. With the return of onshore winds and clearing skies on August 26, 2020 with the local resident smoke plume, ozone concentrations again rise to levels exceeding the NAAQS. This is yet another indicator of the unique feature of this exceedance episode and demonstrates the difference between it and typical non-event ozone exceedance events which demonstrate less aggressive changes in ozone.

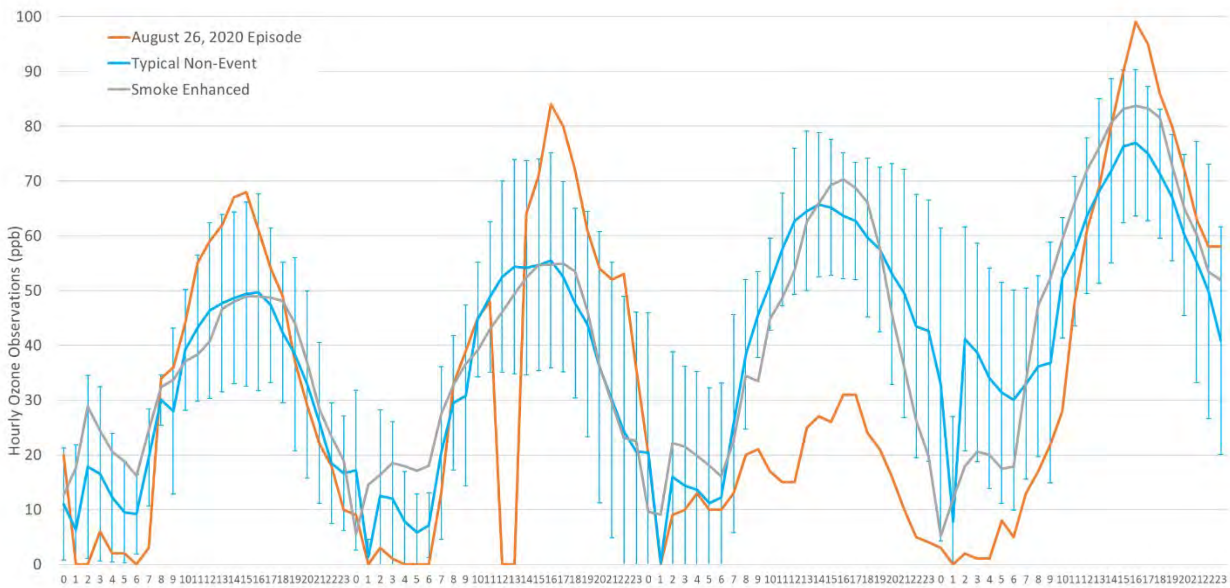

Figure 78. Multi-day diurnal ozone (ppb) profiles for Muskegon monitor.

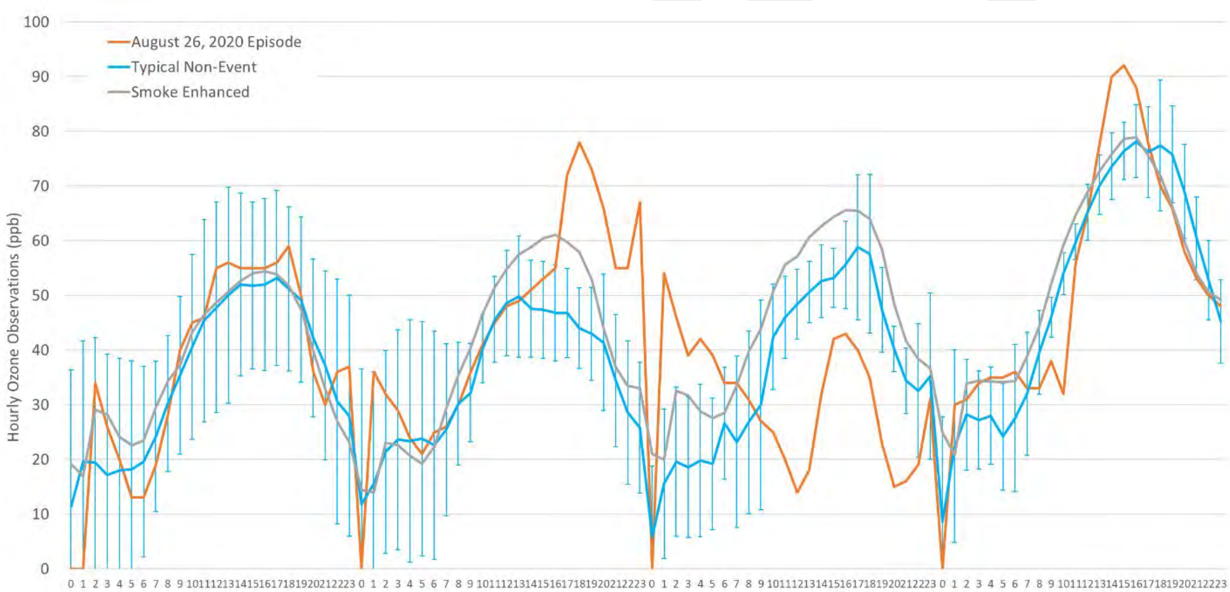

Figure 79. Multi-day diurnal ozone (ppb) profiles for Holland monitor.

This evidence suggests the August 26, 2020 exceedance event was influenced by factors not definitively explained by a typical, non-event exceedance day analysis and lends support to the conclusion that the influence of wildfire smoke created the ozone exceedance on August 26, 2020.

Average Standardized Log-transformed Timeseries

LADCO developed a screening analysis that focused on finding signals in standard surface monitoring data to identify when there is potential for smoke influences on surface air quality conditions during the ozone season (April 1 – October 31). In this analysis, they looked at associations between Air Quality System (AQS) observations of MDA8 ozone and Clean Air Status and Trends Network (CASTNet) daily average total PM2.5. The working hypothesis was that coincident peaks in both pollutants may indicate smoke influence in a NAA.

As part of the analysis, ozone and PM2.5 concentration anomaly plots were developed to identify potential smoke enhancements to surface ozone within the Great Lakes region. The anomaly plots present time series of log-normalized, standardized measurements in units of standard deviation. LADCO identifies periods with both pollutants above one standard deviation of the five-year average monthly mean as being impacted by smoke.

The anomalies are derived from five-year averages of monthly average measurements from multiple sites within a NAA (e.g., the five-year average of the June monthly average concentrations). The ambient concentration data are log normalized to transform them to a normal distribution. Normalizing the distributions of the data allows for the inter-comparison across the three pollutants. The data are standardized to both support the inter-comparison between pollutants, and to attenuate the inter-annual variability in the data.

A factor in the standardization method is to divide by the five-year monthly standard deviation for each pollutant. By dividing a measurement for a given day by the five-year standard deviation for that same month, this metric normalizes the measurement to account for 68% of the variability in the data, which includes meteorological differences. Standardizing with the monthly five-year standard deviation, rather than the entire ozone season five-year year standard deviation, further attenuates the impacts of longer term, seasonal variability in the meteorology.

LADCO first applied the hypothesis as a proof of concept to the May 24-25, 2016 Fort McMurray fire and reviewed its impact on monitors in the western Michigan region. Figure 80 ozone (red) and PM2.5 (blue) concentration anomalies using the LADCO concentration anomaly plot for the western Michigan region in 2016. Grey bars indicate days when smoke was present in the region. Ozone is above two standard deviations (each incremental standard deviation is represented by dotted horizontal black line) for the May 2016 episode and PM2.5 is above one standard deviation, with some individual monitors exceeding 1.5 standard deviations. Standardization (i.e., normalization) was done using the monthly mean and standard deviation of the log-transformed observed values at each site within the region over a historical period.

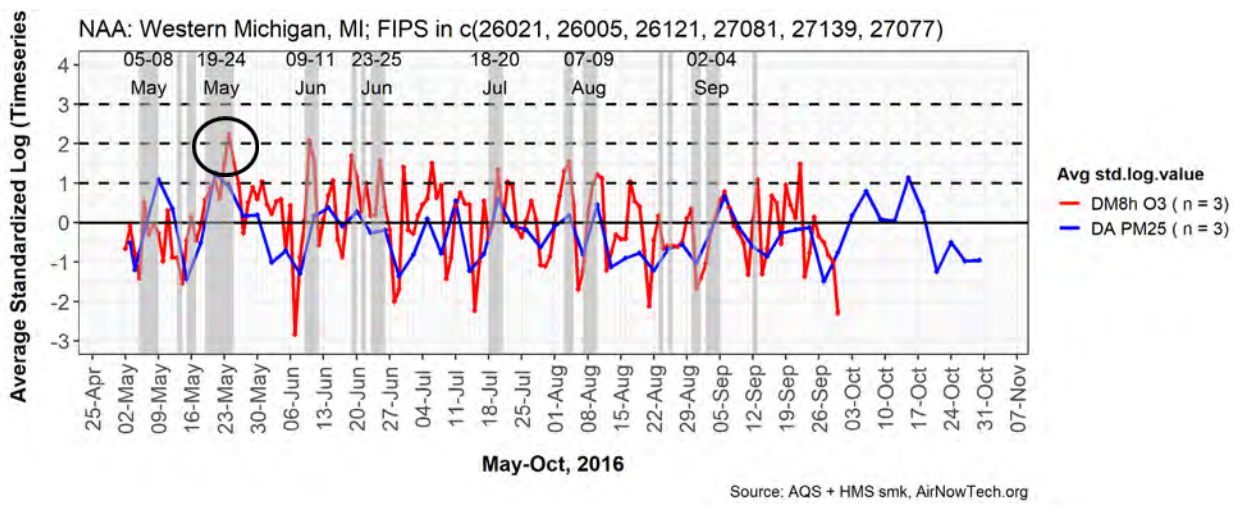

Figure 80. Average anomaly plots for the Standardized Log Timeseries of daily maximum 8-hour ozone and daily average 24-hour PM2.5 concentrations measured from the western Michigan Monitors based on historical Ozone Season Concentrations. Ft. McMurray wildfire episode circled in black.

The western Michigan anomaly plot in Figure 81 shows a similar irregularity for the August 26, 2020 episode and are consistent with results from the Ft. McMurray fire in western Michigan.

Figure 81 below is an average standardized log-transformed timeseries plot that shows ozone and PM2.5 concentration anomalies in western Michigan during the 2020 ozone season. Grey bars indicate that smoke was present in the region and asterisks denote days when ozone exceeded the level of the NAAQS. Standardization (i.e., normalization) was done using the monthly mean and standard deviation of the log-transformed observed values at each site in the region over the 2016-2020 period.

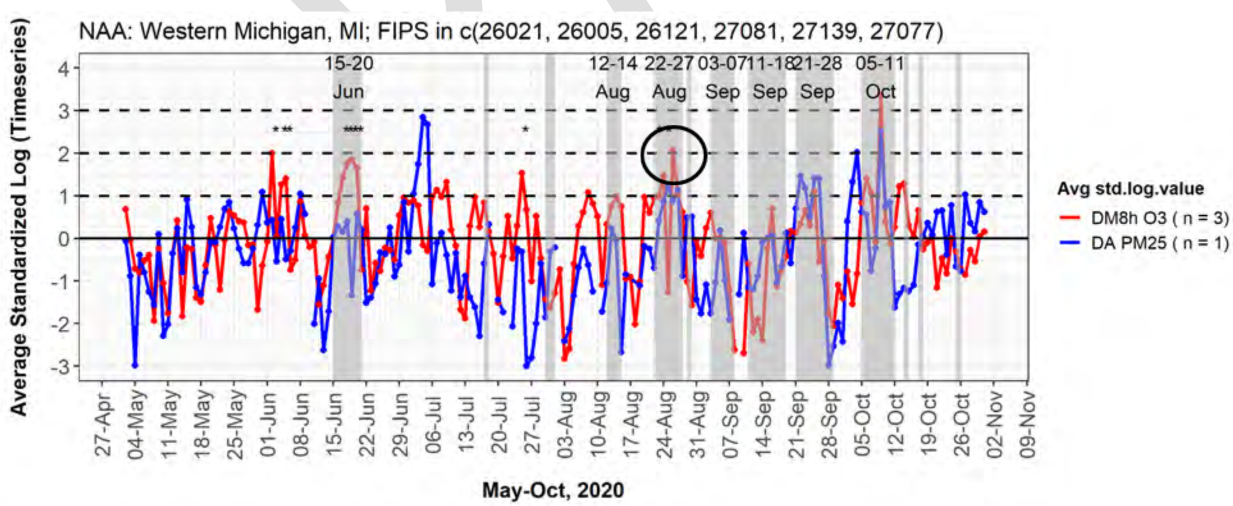

Figure 81. Average anomaly plots for the daily maximum 8-hour ozone and daily average PM2.5 concentrations measured in western Michigan. August 26, 2020 episode circled in black.

As can be seen in this figure, August 26, 2020 shows anomalous concentrations compared to the log normalized remainder of the ozone season. This is an indicator that smoke was present and enhanced the ozone concentrations on those days.

D. Conclusion - Clear Causal Relationship

On August 16 and August 17, a series of highly unusual thunderstorms rolled through most of northern California, which came from the moisture of the diminishing Tropical Storm Fausto. About 2,500 cloud-to-ground lightning strikes were recorded during a 12-hour period. These lightning strikes were responsible for the ignition of dozens of wildfires. These wildfires were part of the largest wildfire season the state had ever recorded, and by of the end of the year nearly 10,000 fires had burned over 4.2 million acres, more than 4% of the state's roughly 100 million acres of land. These fires generated significant amounts of ozone, PM2.5, and their precursors. The wildfire complexes emitted large plumes of smoke that were visible in satellite images and measurements. The transport of these pollutants within the plumes resulted in elevated concentrations at the monitors in western Michigan NAAs on August 26, 2020. The monitored ozone concentration on this day was unusually high, especially given recent trends. The instances for which ozone data exclusion is requested were among the highest ozone concentrations in 2020 and were above the 99^{th} percentile among data from 2016 to 2020.

Although the meteorological conditions that existed during the events were conducive to ozone formation without the increased burden of the additional wildfire-related precursor emissions, the influence of the California wildfire smoke plume emissions caused significant additional impact that elevated ozone levels beyond normal expectations. As the smoke plumes aged and mixed with anthropogenic NOx, ozone concentrations accumulated to levels likely not possible without the smoke.

The analyses conducted provide evidence supportive of smoke impacts on ozone concentrations at the Muskegon and Holland monitors on August 26, 2020 show that (1) a considerable amount of smoke was transported from wildfires in California across the northern United States into the Lake Michigan region in the days leading up to August 26, 2020; (2) smoke aloft was transported to the surface on this day; and (3) smoke impacted ground-level pollution measurements at these monitors on August 26, 2020.

These images and measurements show that the smoke was transported over many days' time to Michigan. Additionally, HYSPLIT trajectories show that the smoke was transported from these wildfires to the upper Midwest in the days prior to the August 2020 episode. In visible imagery and in measurements from satellite, the movement of smoke from California to the western Michigan region is clear. These data show that wildfire smoke was present over the monitors on the day of the event, August 26, 2020. This is further corroborated by the NOAA HMS smoke and Ozone AQI overlays during the episode period which also demonstrate a clear upwind path of smoke impacts on ozone concentrations.

Additional analyses show that vertical mixing and downward transport of smoke aloft to the surface occurred over the episode. In the days prior to August 26, 2020, CALIPSO aerosol data show that smoke was present in the region at near surface levels. The low elevation of the smoke is additionally supported by meteorological evidence. Radiosonde mixing height measurements show that vertical mixing from the altitude at which the smoke was present occurred on August 26, 2020. Evidence is strong that smoke aloft over Michigan was mixed downward to the surface during this episode.

The arrival of smoke at the surface on August 26, 2020, impacted air quality in western Michigan NAAs. Supporting measurement of PM2.5 concentrations and speciated PM2.5 compounds of potassium ions and elemental carbon clearly indicate the presence of smoke. The exceedances at the monitoring sites represent the only regulatory significant observations in the NAA. Together, these analyses demonstrate that ozone concentration at the Muskegon and Holland monitoring sites were impacted on August 26, 2020 by wildfire smoke transported from fires in California.

The comparisons and analyses provided within this document support Michigan's conclusion that the wildfire event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedances specified in Table 1, and thus satisfy the clear causal relationship criterion.

E. Not reasonably Controllable or Preventable

The California wildfires were not reasonably controllable and not reasonably preventable.

The Exceptional Events Rule presumes that wildfire events on wildland are not reasonably controllable or preventable [40 CFR §50.14(b)(4)]. 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. A wildfire that predominantly occurs on wildland is a natural event." Wildland is defined in 40 CFR §50.1(o) as "an area in which human activity and development are essentially nonexistent, except for roads, railroads, power lines, and similar transportation facilities. Structures, if any, are widely scattered."

A series of highly unusual thunderstorms rolled through most of northern California, which came from the moisture of the diminishing Tropical Storm Fausto generating about 2,500 cloud-to-ground lightning strikes during a 12-hour period. These lightning strikes were responsible for the ignition of dozens of wildfires which ultimately contributed to the largest wildfire season in California's recorded history. Each of these wildfires predominantly occurred on wildland.

There is no evidence clearly demonstrating that prevention or control efforts beyond those made would have been reasonable. Therefore, emissions from these wildfires were not reasonably controllable or preventable.

F. A Natural Event

The August 2020 California wildfires were natural events. The definition of “wildfire” at 40 CFR §50.1(n) states, “A wildfire that predominantly occurs on wildland is a natural event.” The events qualify as wildfires because lightning caused the unplanned wildfire events. The EPA generally considers the emissions of precursors from wildfires on wildland to meet the regulatory definition of a natural event at 40 CFR 50.1(k), defined as one “in which human activity plays little or no direct causal role.” These wildfire events occurred on wildland, and accordingly, it has been shown that the events are natural events and may be considered for treatment as exceptional events.

G. Notification and Mitigation Requirements

Public Notification of the Event

The Exceptional Events Rule [40 CFR 50.14(c)(1)(i)] requires air agencies to “notify the public promptly whenever an event occurs or is reasonably anticipated to occur which may result in the exceedance of an applicable air quality standard.” Michigan EGLE posts daily air quality forecasts available at: http://www.deqmiair.org/ and submits information to the National Weather Service when a Clean Air Action Day is called.

Initial Notification of Potential Exceptional Event

The Exceptional Events Rule [40 CFR 50.14(c)(2)(i)] requires air agencies to notify U.S. EPA of its intent to request exclusion data due to an exceptional event by creating an initial event description and flagging the associated data in the AQS database. Michigan EGLE tendered the requisite notice in writing on February 9, 2021, and flagged the August 26, 2020, data in the AQS database.

Mitigation Plan

The Exceptional Events Rule [40 CFR 51.930(b)] requires states having areas with historically documented or known seasonal events to develop and submit a mitigation plan. According to the Rule, historically documented or known seasonal events include events of the same type and pollutant that recur in a three-year period and involve three events or event seasons for which a State submits an Exceptional Event Demonstration or which are the subject of an initial notification for a potential exceptional event. In such cases, U.S. EPA would notify the State that it is subject to the Mitigation Plan requirements. Michigan does not have historically documented or known seasonal events and U.S. EPA has not notified the State that it is subject to these requirements. As such, Michigan is not required to develop and submit a mitigation plan.

Summary

This Exceptional Event demonstration shows that wildfires in California adversely affected ozone data in a regulatory significant way, such that ozone data on August 26, 2020 for the monitors identified in Table 1 meets the rules as an Exceptional Event and should be excluded from regulatory determinations.

This report:

1. Contains the required narrative conceptual model describing the California wildfire event that caused violations at the Holland and Muskegon ozone monitors and how emissions from those events reached the affected monitors, leading to elevated measured ozone concentrations on the specific days in question.
2. Demonstrates that there was a clear causal relationship between smoke and the maximum daily average 8-hour (MDA8) ozone exceedances.
3. Contains analyses comparing the ozone concentrations during the event-influenced days to concentrations at the same monitor at other times on days with similar meteorological conditions.
4. Demonstrates that the wildfires causing smoke were not reasonably controllable or preventable and are unlikely to recur, and that they were considered natural events.

Key findings and evidence supporting these assertions include the following:

1. Considerable ozone was created upstream of Michigan due to the presence of wildfire smoke generated during California's largest recorded wildfire year, which was then transported into Michigan over several days in August 2020.
2. Meteorological conditions (at the surface and aloft) were favorable for transport of smoke from the wildfires in California into the region, including Michigan, during August 2020.
3. Ozone concentrations during the August 26, 2020 episode at the Muskegon and Holland monitors were measured above the 99th percentile of the 5-year distribution of ozone monitoring data at the sites.
4. Satellite images captured visual smoke plumes that were transported into the Lake Michigan region on days when the ozone concentrations were highest.
5. Analysis of the National Oceanic and Atmospheric Administration's (NOAA) Hazard Mapping System (HMS) smoke product and Ozone AQI shows an enhanced ozone concentration impact at monitors along the wildfire smoke transport path that eventually culminates with excess ozone observations in western Michigan.
6. Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) retrievals identified smoke among the classified aerosols at the surface in the region during the August 26, 2020, episode.
7. Regional upwind measurements identify multiple monitors with unusually high ozone concentrations during the dates when the transported smoke plume passes through the region prior to the August 26, 2020 episode event.
8. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model forward and backward trajectory analyses demonstrate that wildfire smoke was transported into the region and was then transported into the western Michigan area during the August 2020 event.
9. Additional satellite retrievals demonstrate the transport of wildfire smoke into the region and provide additional evidence that the smoke plume and associated ozone precursor emissions were present during the August 26, 2020 episode.

10. Fine particulate matter (PM2.5), was elevated during the event, consistent with a wildfire smoke plume.
11. PM2.5 speciated data (organic carbon and potassium ion) showed elevated wildfire attributable concentrations during the August 26, 2020 event.
12. Comparable meteorological and typical non-event ozone exceedance day analyses suggests that the August 26, 2020 exceedance event was influenced by factors not explained by meteorology alone, lending support to the conclusion that the influence of wildfire smoke created the ozone exceedances on August 26, 2020.
13. A multi-day buildup of both wildfire smoke and ozone precursor concentrations in the Michigan area enhanced ozone concentrations in the days building up to the August 26, 2020 episode.
14. A screening analysis of average standardized log-transformed timeseries concentrations of key pollutants provides supporting evidence for smoke influence in the western Michigan region during the August 26, 2020 episode.
15. Q/d analyses, while not meeting specific U.S. EPA thresholds for clear causal influence, are consistent with other previous long-range smoke and ozone transport events approved by U.S. EPA.

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