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. Both the June 17-20 and August 26, 2020 events 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")[35], a Q/d analysis was performed on each of the three individual Arizona 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 more than 2,000 km away from the western Michigan NAA monitors, daily emissions from any one fire would need to exceed 200,000 tons in order to meet the criteria of a Q/d ≥ 100 tons/km. Michigan's initial Q/d from the Bush Fire Complex (the largest of the three wildfires) was estimated below 0.1 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.

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

Figure 44, Figure 45, and Figure 46 show the MDA8 during 2020 at the Muskegon, Holland (Allegan), and Coloma (Berrien) monitors, respectively, where data exclusion is requested. Increased ozone is evident between June 17-20, 2020, as indicated within the grey columns. As shown later in this document (Table 17), ozone concentrations were elevated at all sites in the western Michigan NAAs during these dates, demonstrating that region was impacted by an area-wide event. All three Michigan monitors in the reviewed NAAs recorded MDA8 ozone concentrations above their 99th percentile values between June 17 and 20, 2020, signifying rare ozone episodes. As previously shown in Table 3, the observations from these four days at the three NAA monitors were in the top days of 2020, on some days they were among the top two.

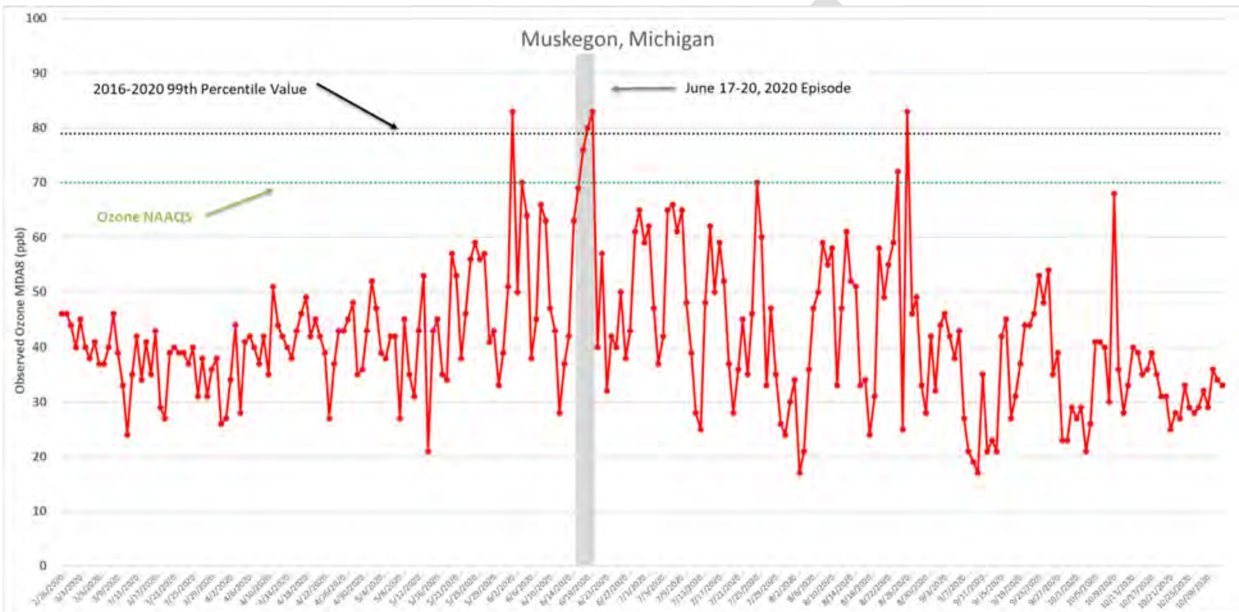

Figure 44. MDA8 ozone concentrations in 2020 at the Muskegon monitor.

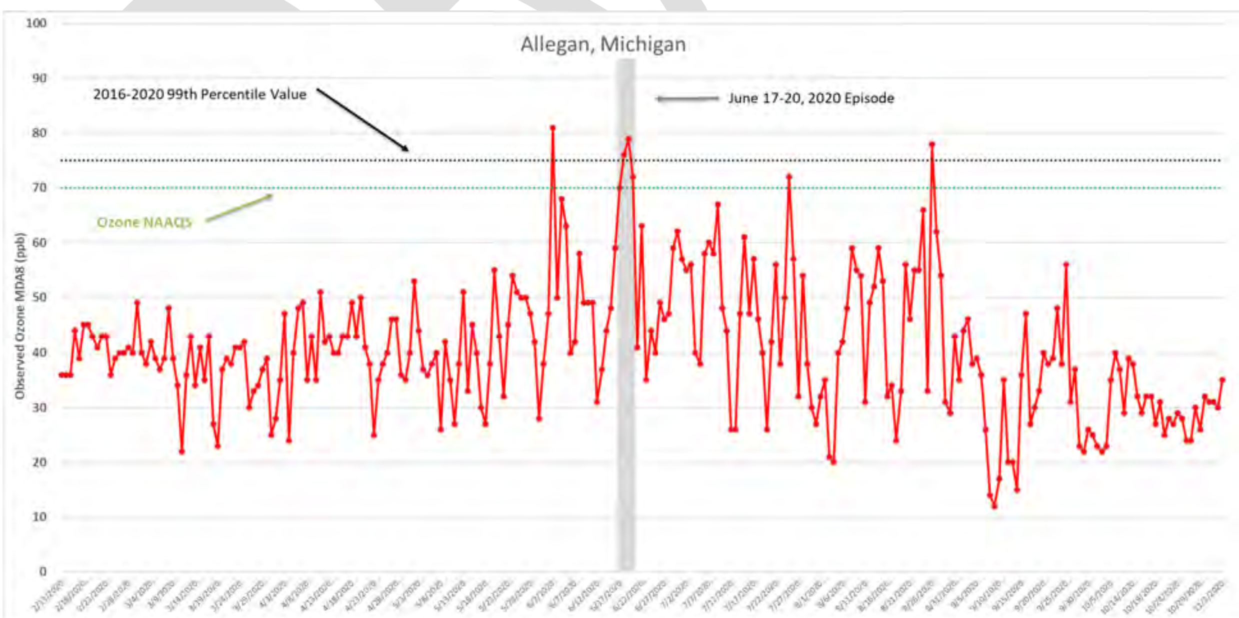

Figure 45. MDA8 ozone concentrations in 2020 at the Holland monitor.

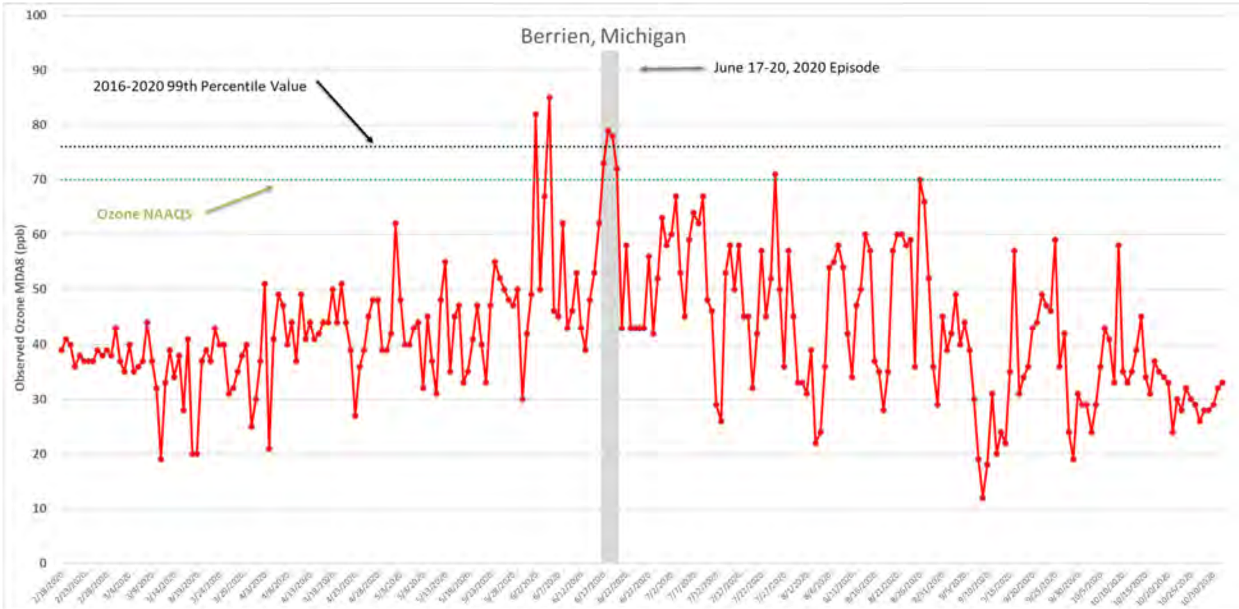

Figure 46. MDA8 ozone concentrations in 2020 at the Coloma monitor.

Figure 47, Figure 48, and Figure 49 provide historical context of ozone concentrations at the monitors and present the MDA8 concentrations across the past five years with the June 17-20, 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.

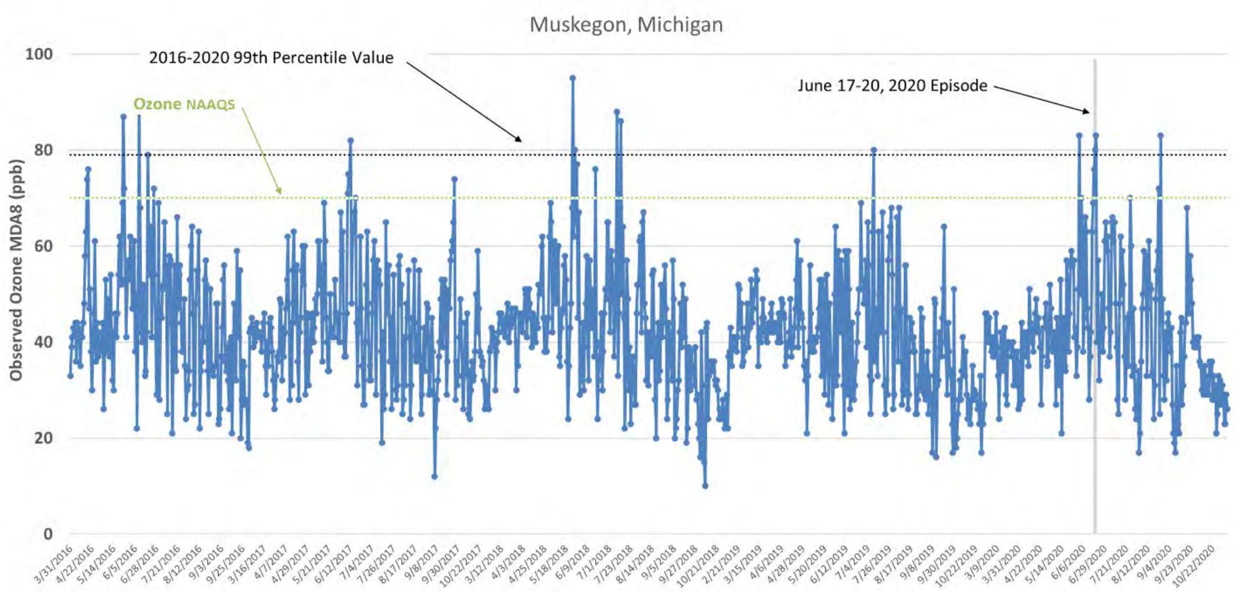

Figure 47. Muskegon MDA8 Ozone, 2016-2020

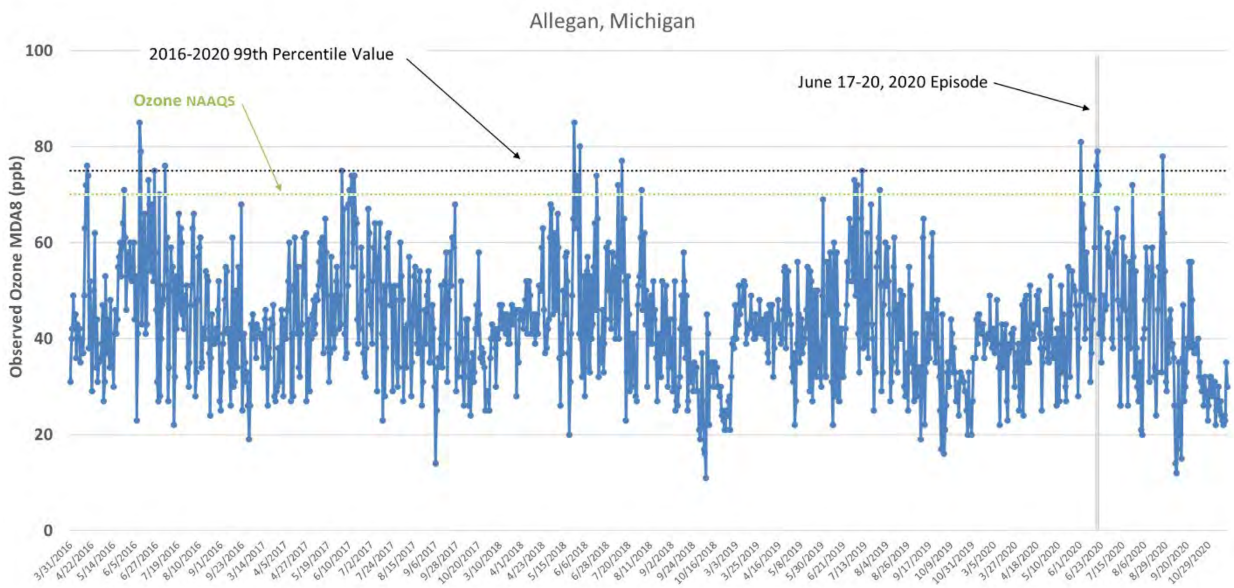

Figure 48. Holland MDA8 Ozone, 2016-2020

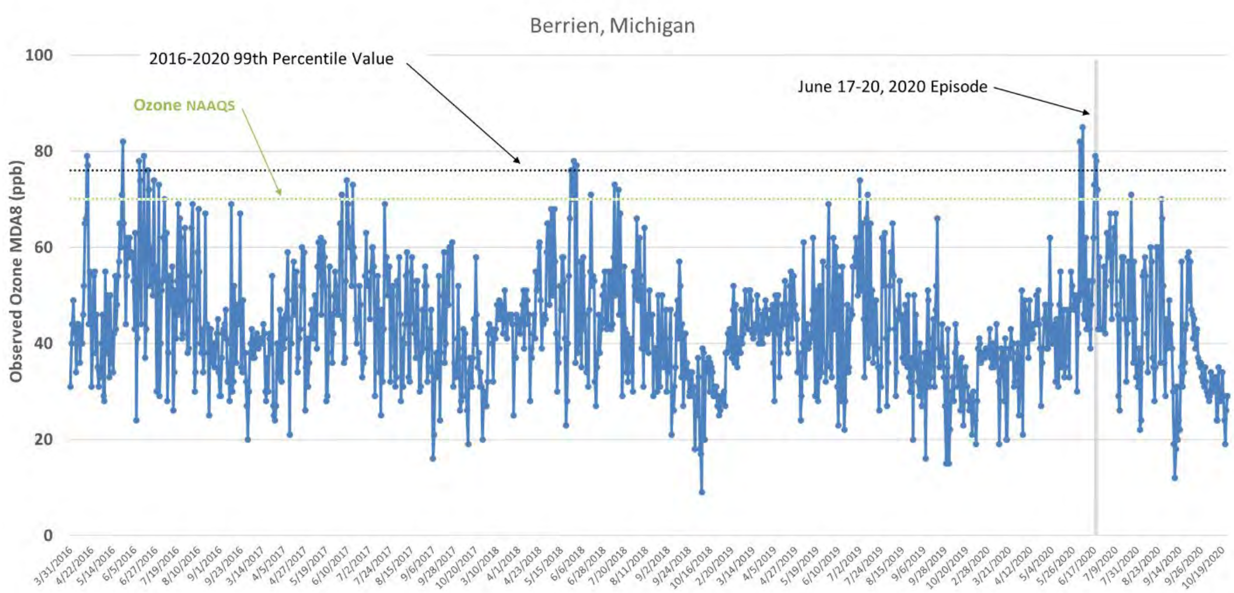

Figure 49. Coloma MDA8 Ozone, 2016-2020

Figure 50, Figure 51, and Figure 52 demonstrate that the June 17-20, 2020 MDA8 observations were unusually high compared to five-year June 2016-2020 average MDA8 concentrations. Figure 50 presents observed June 2020 MDA8 concentrations at the Muskegon monitor compared to five-year monthly averages at the same location. Identified by the red bars, June 18, 19, and 20 were 27.1 ppb, 31.1 ppb, and 34.1 ppb higher, respectively, than the average June MDA8 from 2016-2020. These values also exceeded the standard deviation of observations over this period, as represented by the orange dotted line in the figure.

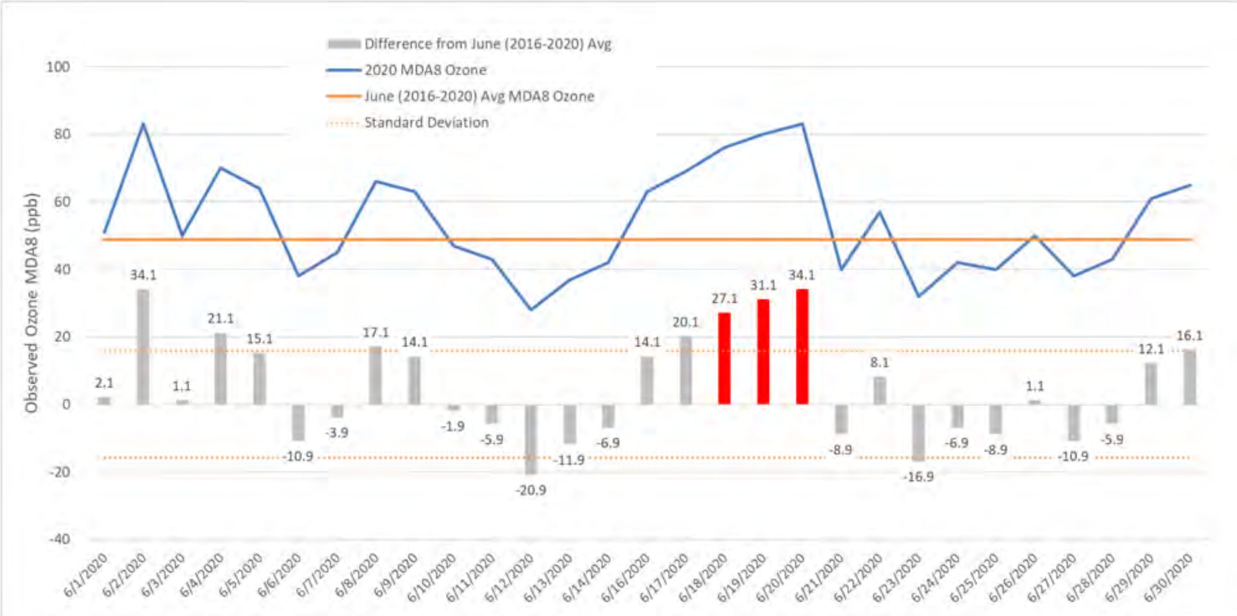

Figure 50. Muskegon June 2020 8-hr Ozone Comparison to June 2016-2020 Average 8-hr.

Similar results are seen in Figure 51 at the Holland monitor where observed June 17-20, 2020 MDA8 concentrations are again significantly higher than the five-year monthly averages at the same location. As shown by the red bars in this figure, June 17 (19.5 ppb), June 18 (25.5 ppb), 19 (28.5 ppb), and 20 (21.5 ppb) were all higher than the average June MDA8 and standard deviation from 2016-2020.

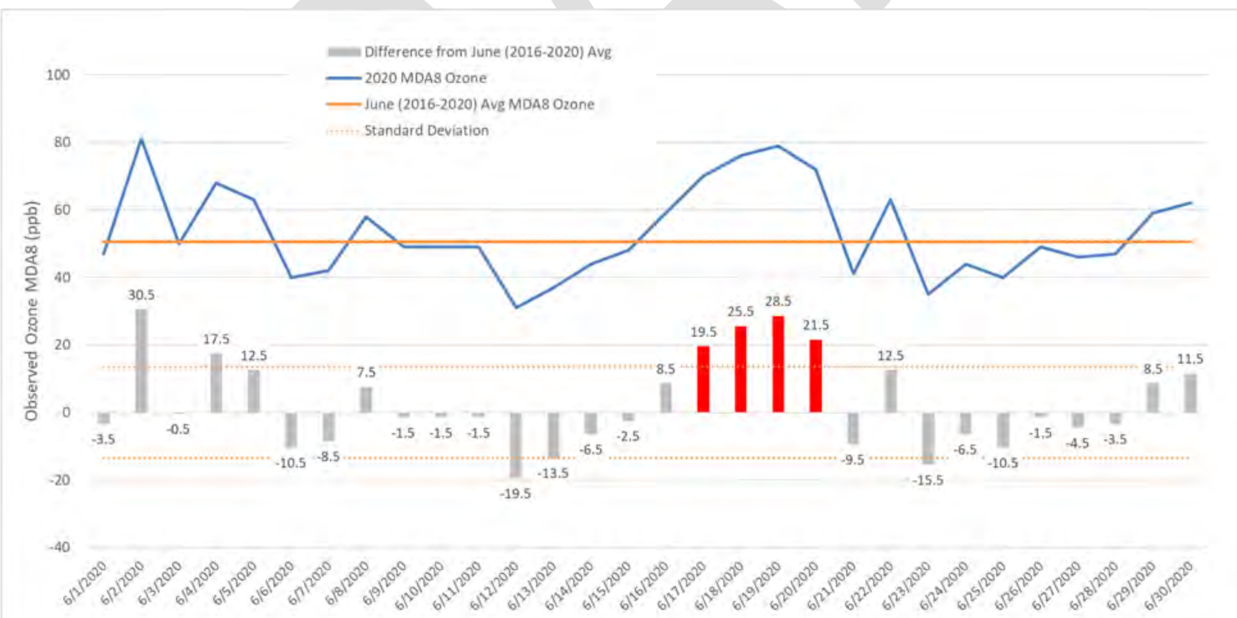

Figure 51. Holland June 2020 8-hr Ozone Comparison to June 2016-2020 Average 8-hr.

Finally, Figure 52 presents June 2020 MDA8 values at the Coloma monitor where June 17 was 22.3 ppb higher, June 18 was 28.3 ppb higher, June 19 was 27.3 ppb higher, and June 20 was 21.3 ppb higher than the five-year June MDA8 average. All values were again above the calculated standard deviation.

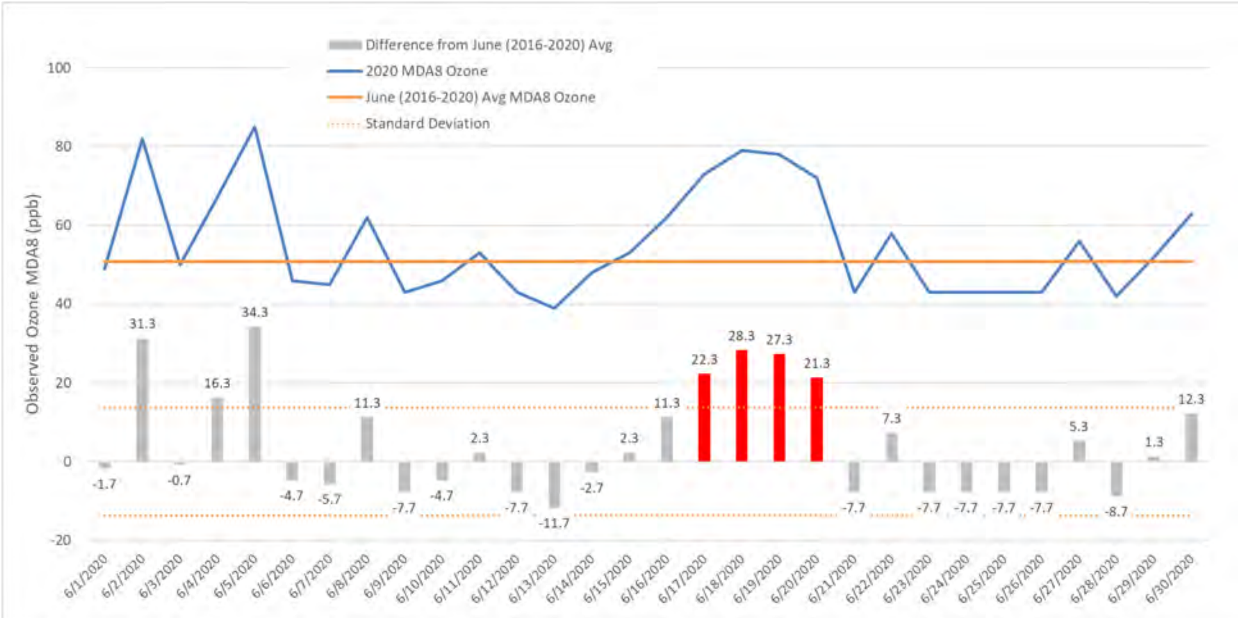

Figure 52. Coloma June 2020 8-hr Ozone Comparison to June 2016-2020 Average 8-hr.

Table 7 shows the MDA8 ozone levels at the West Michigan NAA monitors on June 17-20, 2020 compared with the 99th percentile ranked MDA8 ozone concentrations observed during the last five years.

Table 7. MDA8 Ozone Five-year (2016-2020) 99th Percentile Comparison for Western Michigan Monitors.

			MDA8 Ozone (ppb)				
Monitor ID	**Site Name**	**NAA**	**6/17/20**	**6/18/20**	**6/19/20**	**6/20/20**	**99th Percentile**
26-005-0003	Holland	Allegan	70	76	79	72	75
26-021-0014	Coloma	Berrien	73	79	78	72	76
26-121-0039	Muskegon	Muskegon	69	76	80	83	79

Figure 53 shows a time-series plot of ozone concentrations at the Holland monitor for the ozone season overlaying ozone monitoring data from 2016 through 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 exceptional event-related days of June 17-20, 2020, are represented as red diamonds. Figure 54 and Figure 55 present this same information for the Coloma and Muskegon monitors, respectively.

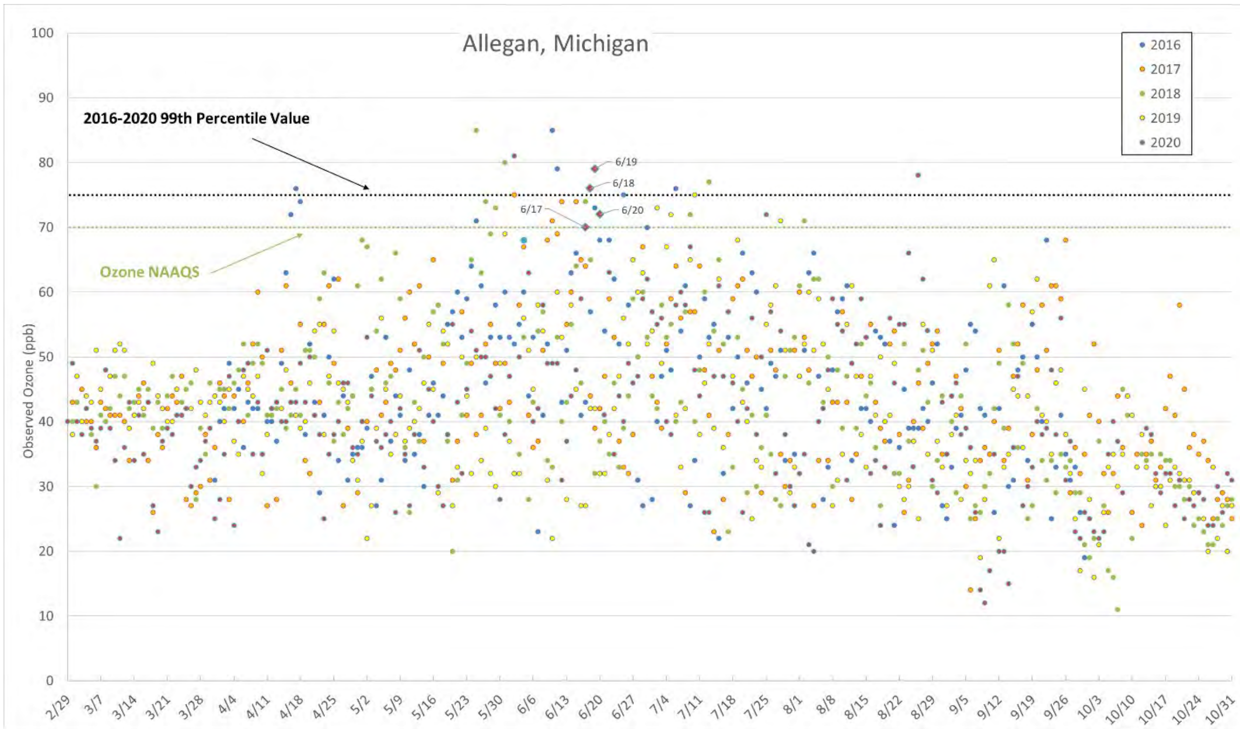

Figure 53. Holland (26-005-0003) MDA8 values; 2016-2020, color-coded by year.

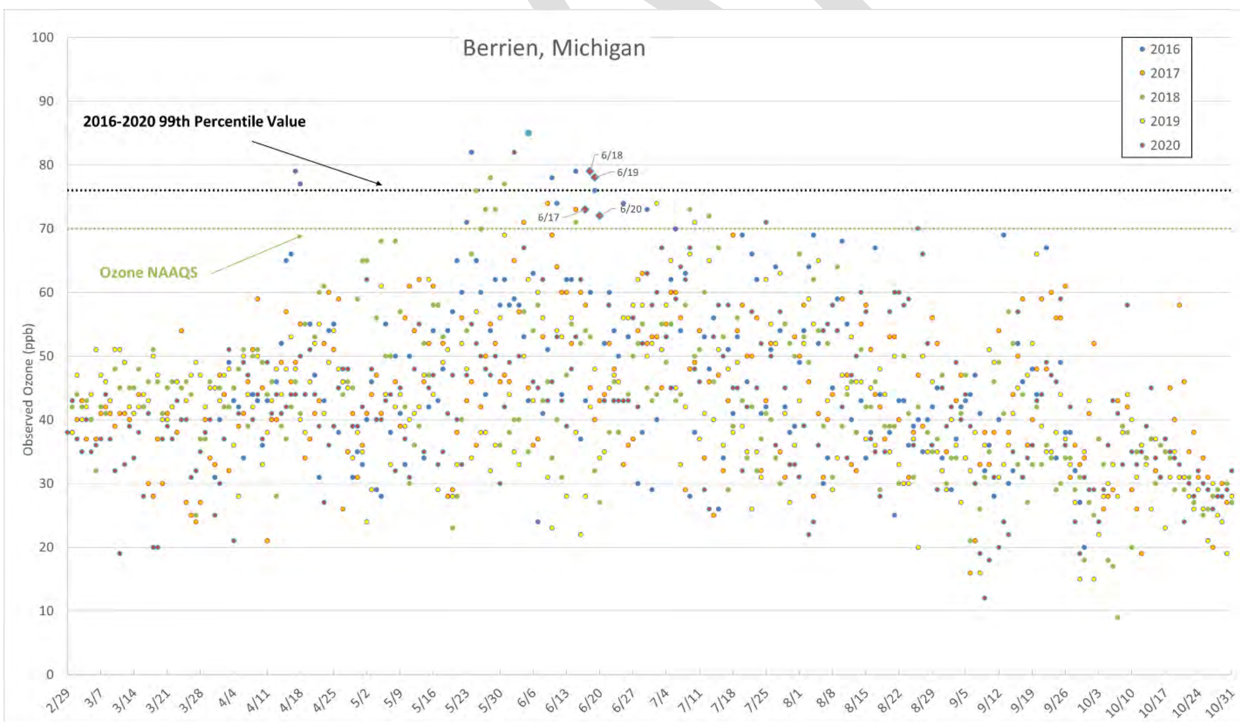

Figure 54. Coloma (26-021-0014) MDA8 values; 2016-2020, color-coded by year.

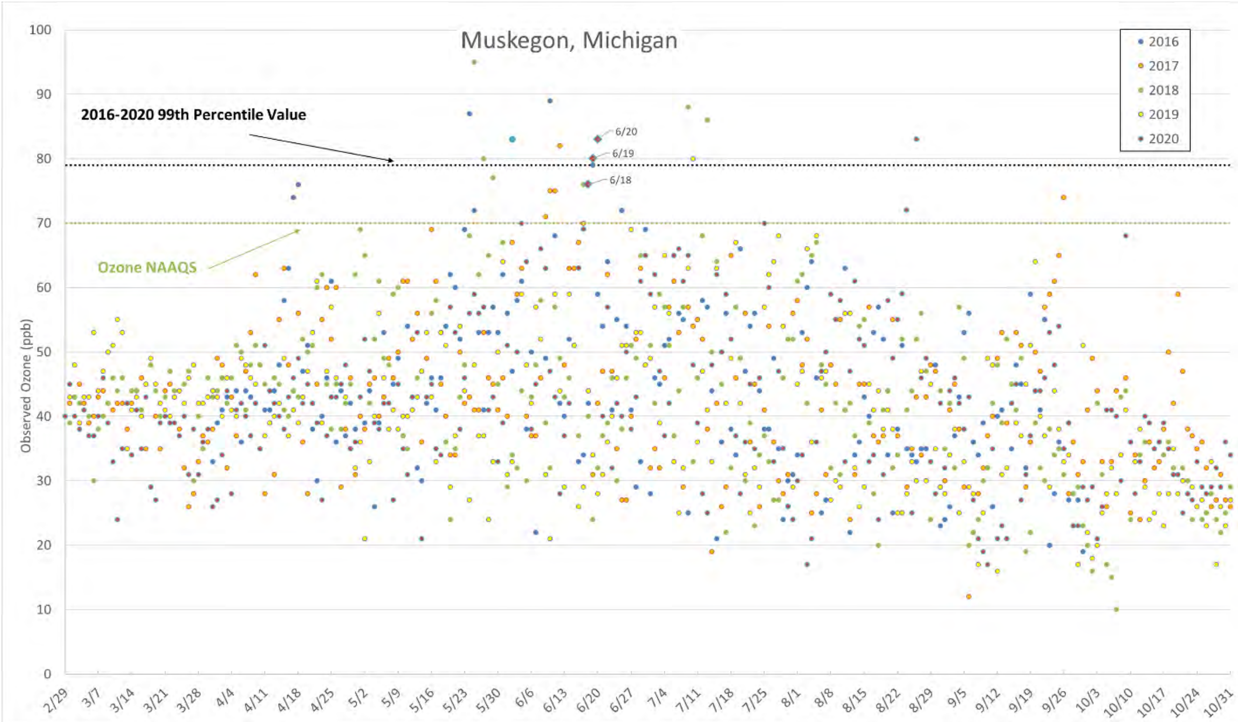

Figure 55. Muskegon (26-121-0039) MDA8 values; 2016-2020, color-coded by year.

As shown in these figures and table, the June 17-20, 2020 ozone values are among the highest concentrations that have occurred at each of the three monitors over the past five years and many of them are above the 99th percentile of such observations. Some 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 and Berrien NAAs 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 Arizona to the central and midwestern United States, including Michigan, between June 17 and June 20, 2020, (Figure 56 through Figure 59) when ozone concentrations were at their highest. The movement of a dense smoke plume east and northeast from Arizona between June 11 and June 18, 2020, is particularly noteworthy as this plume eventually makes its way north from the Gulf of Mexico region to join with the northeastern plume over Lake Michigan and surrounding areas, enhancing ozone concentrations along its path.

The associated smoke text product produced by NOAA for the last day of the episode, June 20, 2020, and represented in Figure 59 notes the following:

> "DESCRIPTIVE TEXT NARRATIVE FOR SMOKE/DUST OBSERVED IN SATELLITE IMAGERY THROUGH 1701Z June 20, 2020
>
> *Large area from the Southwestern U.S. to the Central, Northeastern, and Southeastern U.S./South Central to Southeastern Canada… The pattern continues with a very large leftover mass of thin density smoke present again today emanating from wildfires in the Southwestern U.S. and covering the region from Arizona and southern Utah eastward and northeastward across the Central U.S. and up over South Central and Southeastern Canada as well as the northern part of Maine. Another branch of the leftover thin density smoke extended over a portion of the Southeastern U.S. Within this large area of thin density smoke was a region of moderate to thick density smoke. It was not known if the thin or thicker smoke extended any farther towards the central and northeastward U.S. due to significant cloud cover over the Central Plains. New moderately dense to thick smoke was seen near the Mangum, Bush, and Bighorn Fires in Arizona. Also, two wildfires burning in southeastern Quebec in southeastern Canada were observed producing long plumes of moderate to thick density smoke. This smoke was extending to the east and southeast over northern New Brunswick and Newfoundland and into the North Atlantic."*

The movement of this smoke corresponds to the expansion of elevated ozone values along the pathway of transport to western Michigan as demonstrated in following sections using ozone observations, NOAA HMS smoke products, and Ozone AQI maps. In addition, the transport of smoke northeastward from Arizona 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.

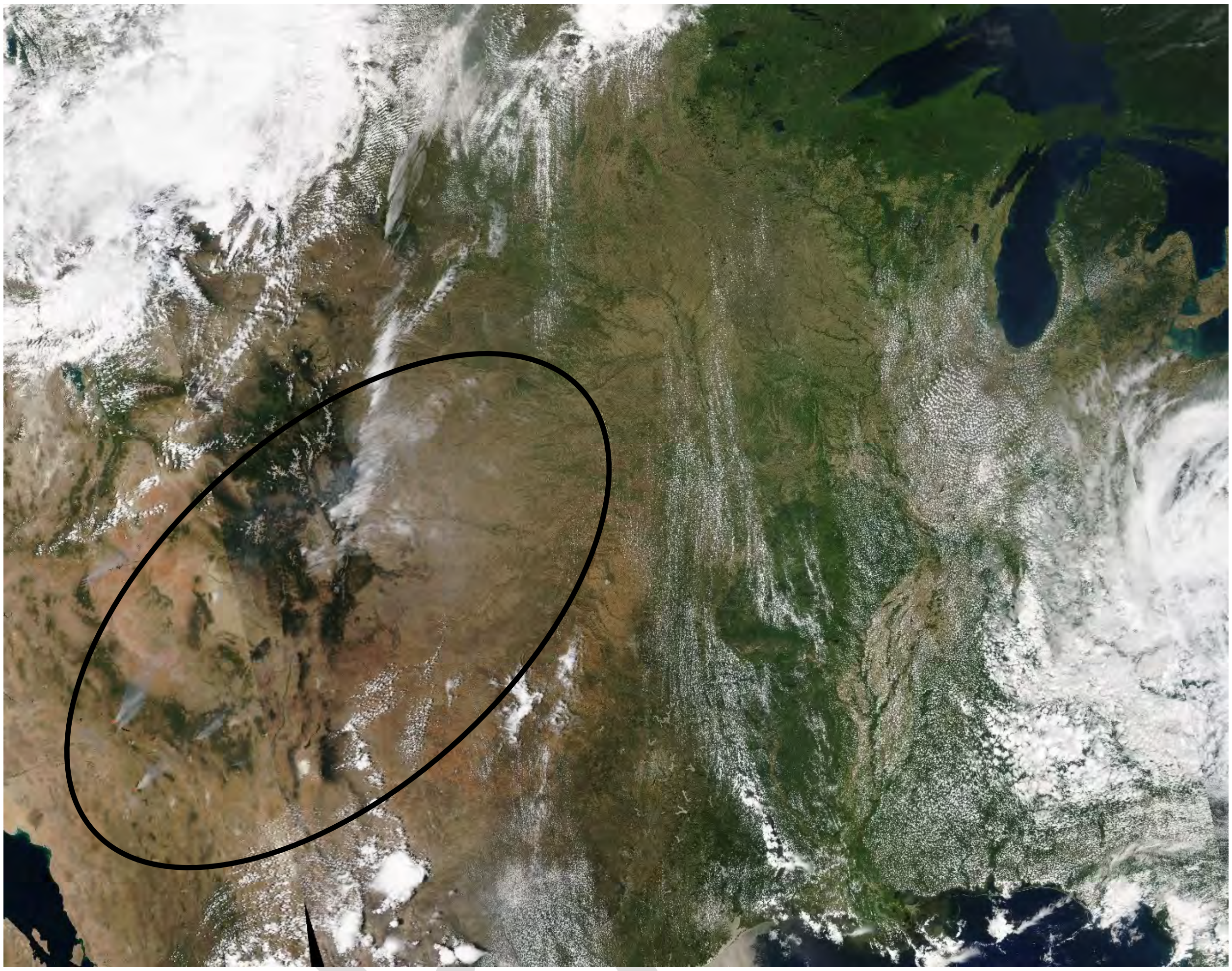

Figure 56. MODIS Aqua true color satellite imagery from June 17, 2020, showing the visible smoke extending eastward with the upper-level jet stream (black circle). Smoke plumes are still seen emanating from the Arizona wildfire complexes.

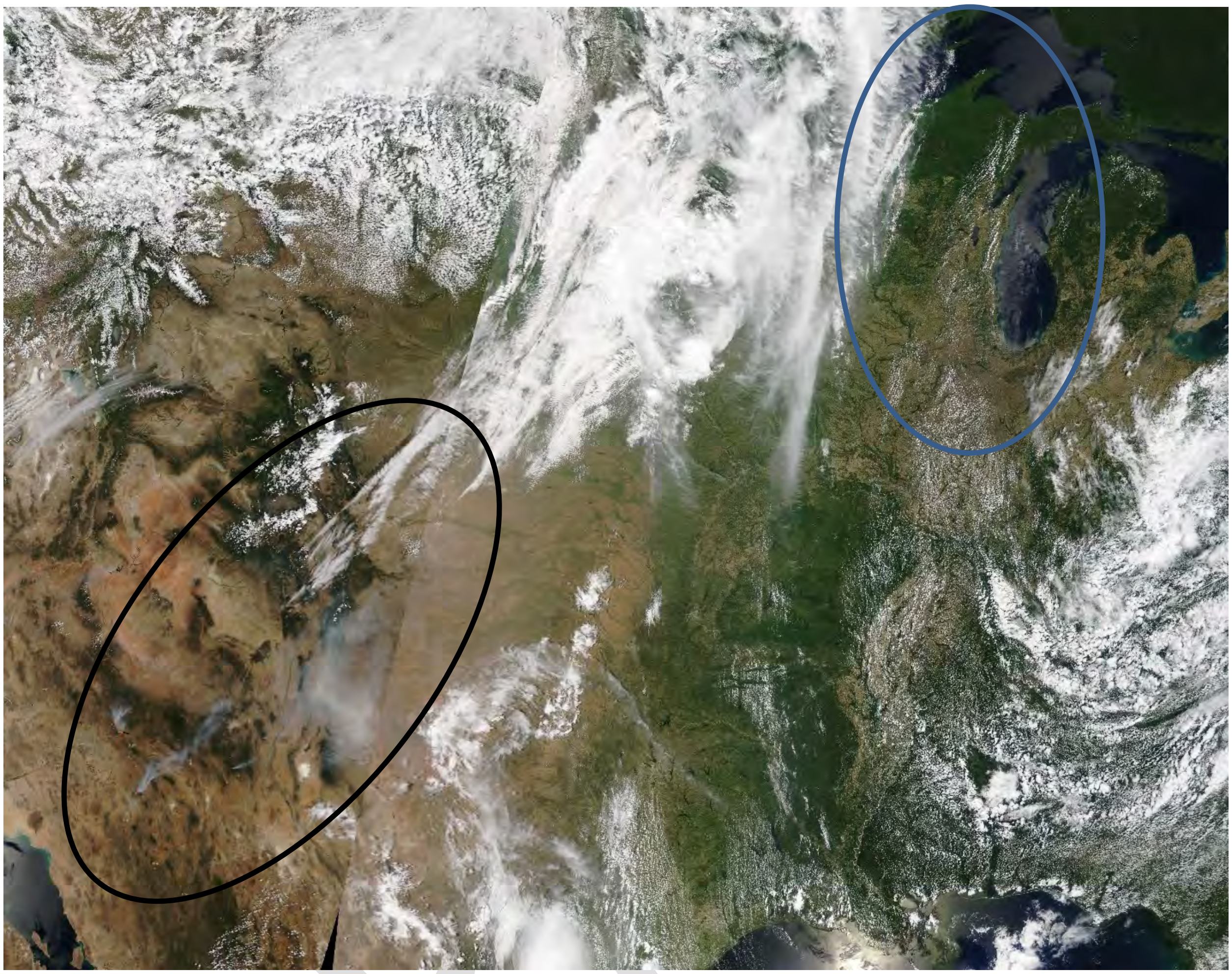

Figure 57. MODIS Terra true color satellite imagery from June 18, 2020, with smoke visible over the Lake Michigan region after being drawn from the south and pushed in from the west ahead of the weather front (blue circle). Smoke plumes are still seen emanating from the Arizona wildfire complexes (black circle).

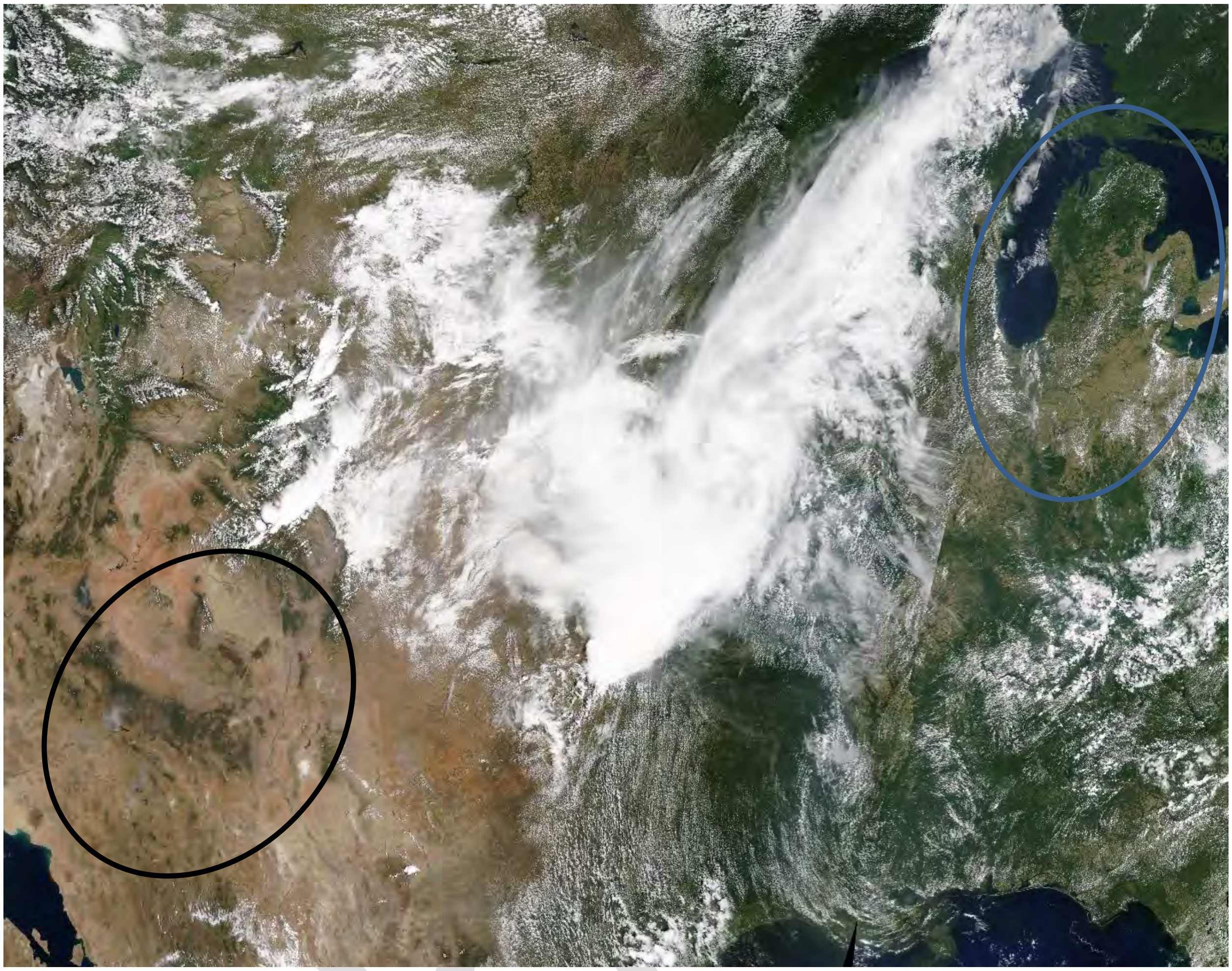

Figure 58. MODIS Terra true color satellite imagery from June 19, 2020, with smoke continuing to be present over the Lake Michigan region as it moves eastward into Michigan and Ohio (blue circle). Smoke plumes are still seen emanating from the Arizona wildfire complexes (black circle).

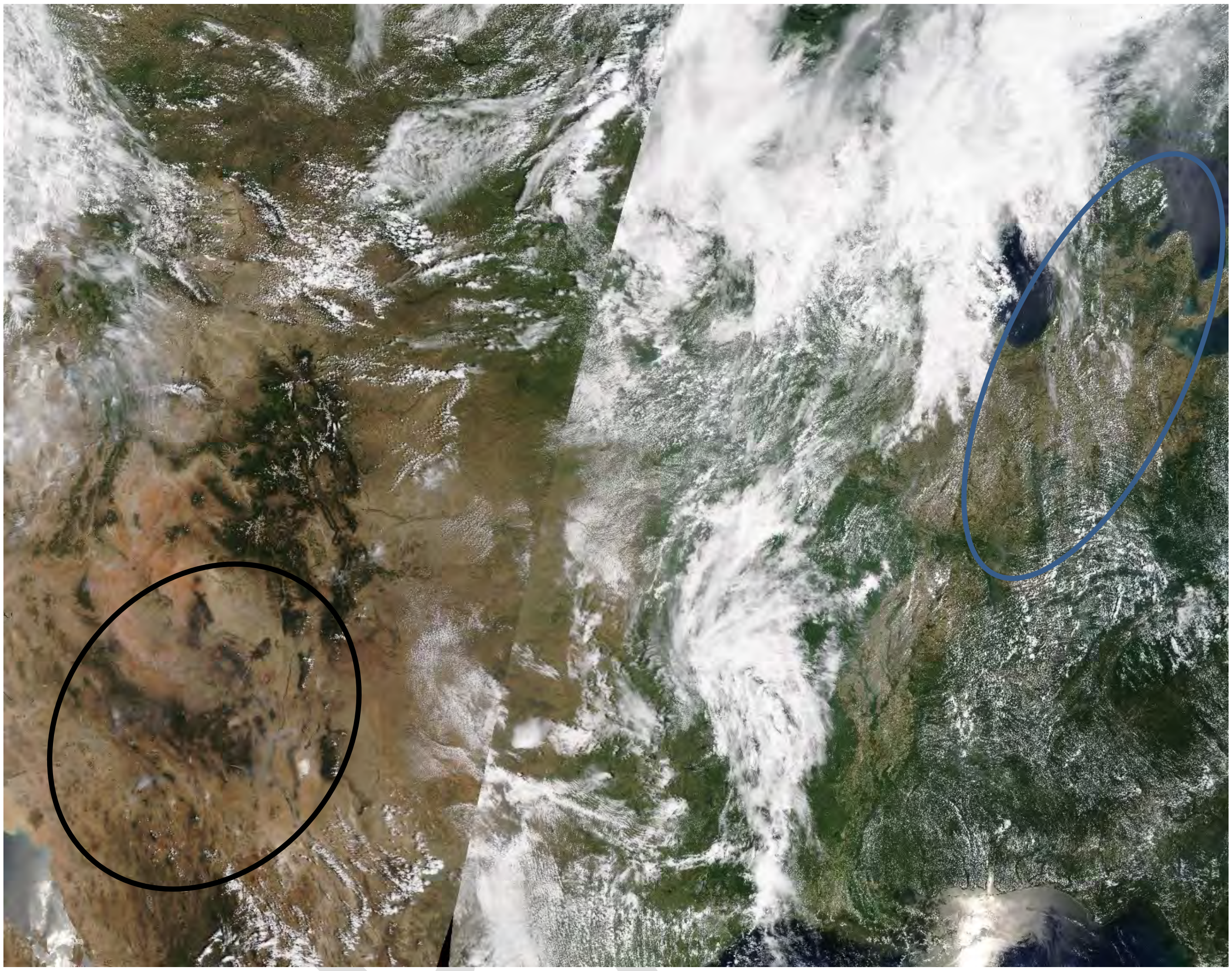

Figure 59. MODIS Terra true color satellite imagery from June 20, 2020, with smoke moving into eastern Michigan and Ohio ahead of the weather front (blue circle). Smoke plumes are still seen emanating from the Arizona wildfire complexes (black circle).

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[36] 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[37], 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 60 and Figure 61 below, obtained from the NRL/Monterey Aerosol page archives[38], present smoke mass mixing ratios (μg/m^3) within the first (surface) model layer, which is 20 m thick.

These images support the claim that in the June 17-20, 2020 episode, there was an increased level of smoke concentration above the Central United States which spread towards the Eastern United States as also seen in the HMS Smoke product. A large portion of the area was covered with a concentration of 2-4 μg/m^3 (shown in Light Blue) with times where the concentration was in the 8-16 μg/m^3 (Light Green) range and even above 32 μg/m^3 (Orange) in some time steps over western Michigan.

[36] https://www.nrlmry.navy.mil/aerosol_web/Docs/globaer_model.html
[37] https://aeronet.gsfc.nasa.gov/new_web/system_descriptions.html
[38] https://www.nrlmry.navy.mil/aerosol/index_frame.html

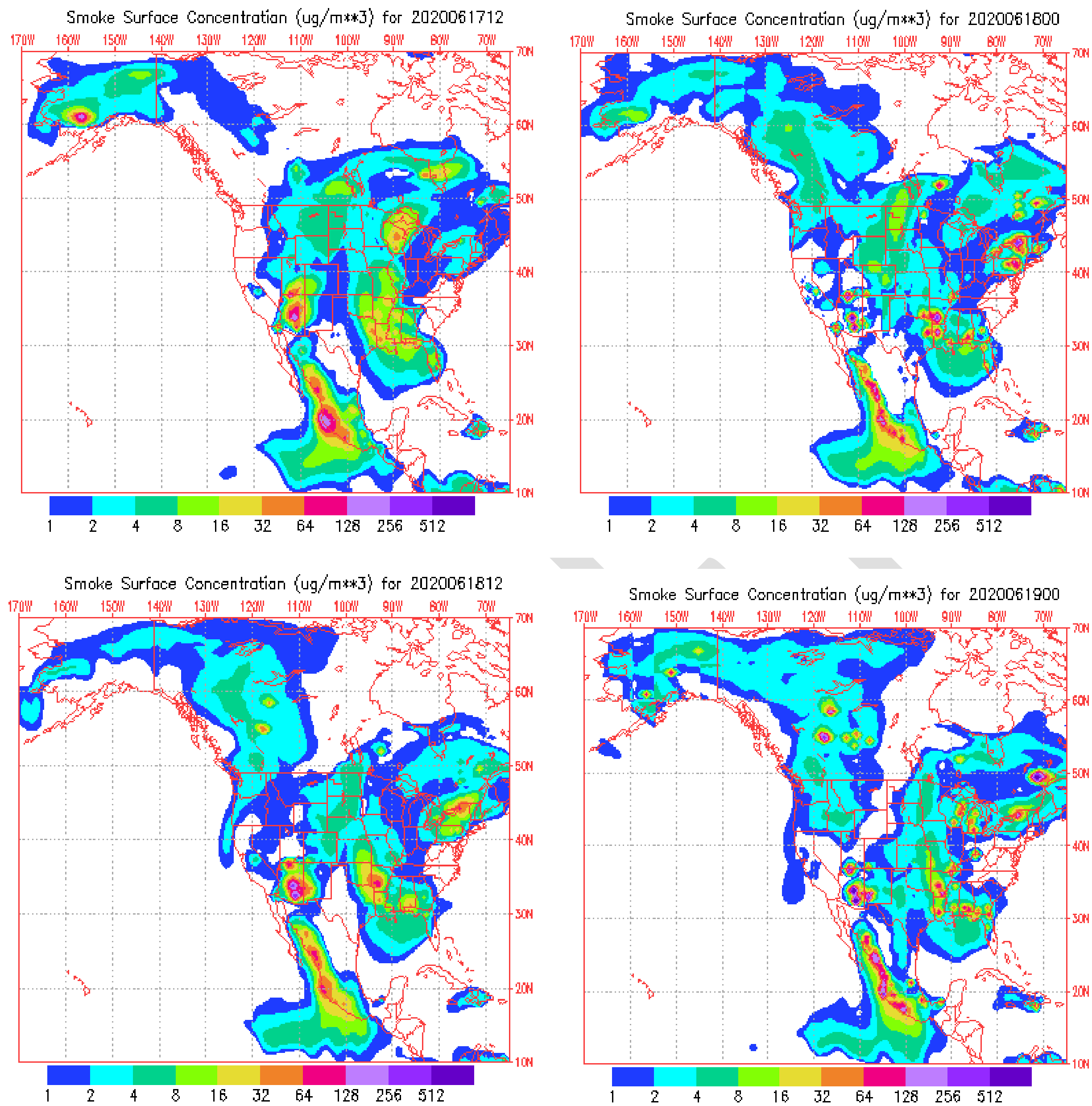

Figure 60. NAAPS smoke surface concentration (µg/m³) on June 17 (top) and June 18 (bottom), 2020 at 8 AM EDT (left) and 8 PM EDT (right).

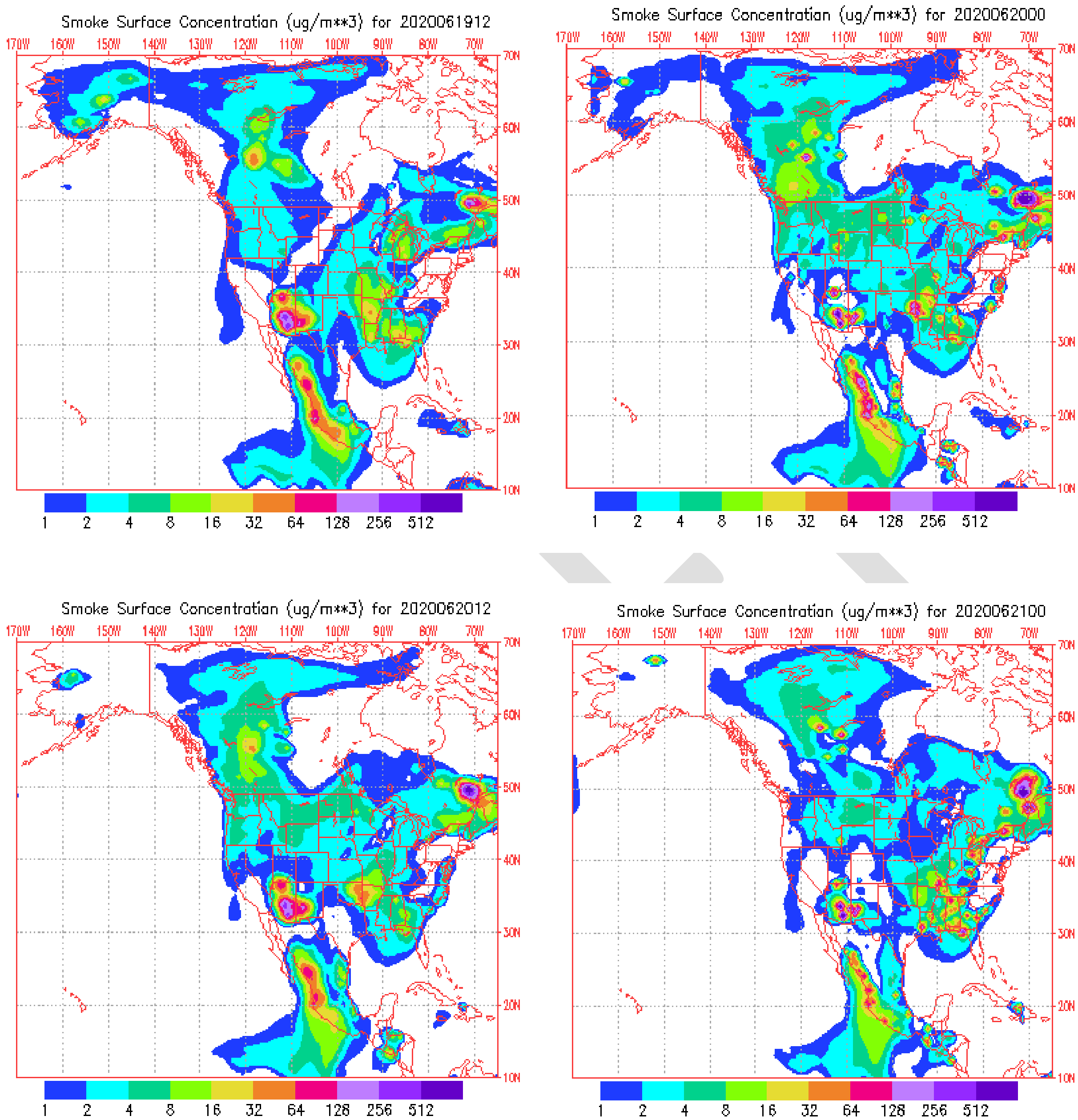

Figure 61. NAAPS smoke surface concentration (µg/m^3) on June 19 (top) and June 20 (bottom), 2020 at 8 AM EDT (left) and 8 PM EDT (right).

NOAA HRRR-Smoke Forecast

NOAA's High Resolution Rapid Refresh-Smoke model[39] (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 Arizona fires reaching into the Lake Michigan region and impacting monitors in western Michigan.

Figure 62 and Figure 63 below presents the forecast for June 17 and June 18, 2020 and predicts the wildlife plume stretching from the Arizona wildfire complexes into the Upper Midwest as it enters the Lake Michigan airshed on the initial dates of the June 2020 episode.

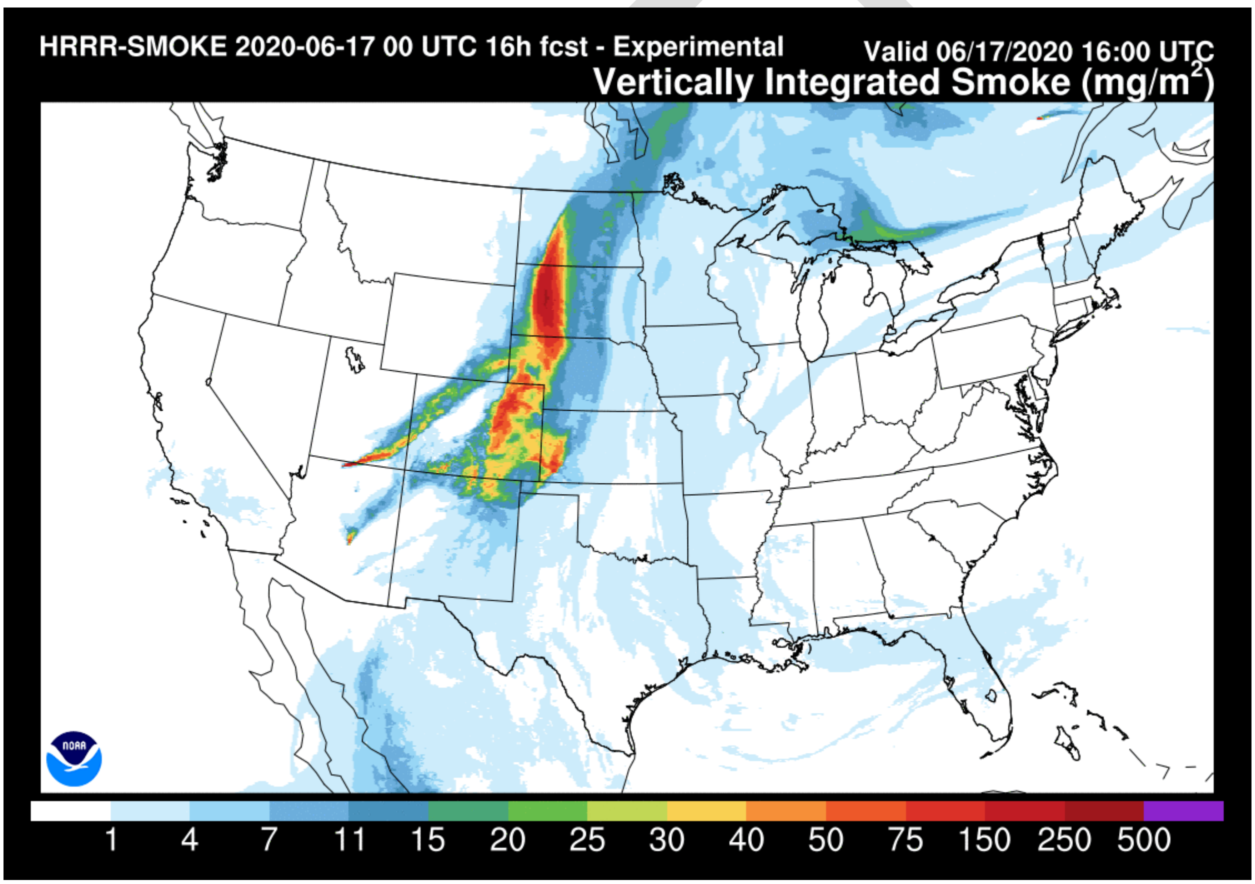

Figure 62. HRRR-Smoke forecast for the distribution of vertically integrated smoke from wildfires at 12 p.m. EDT June 17, 2020.

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

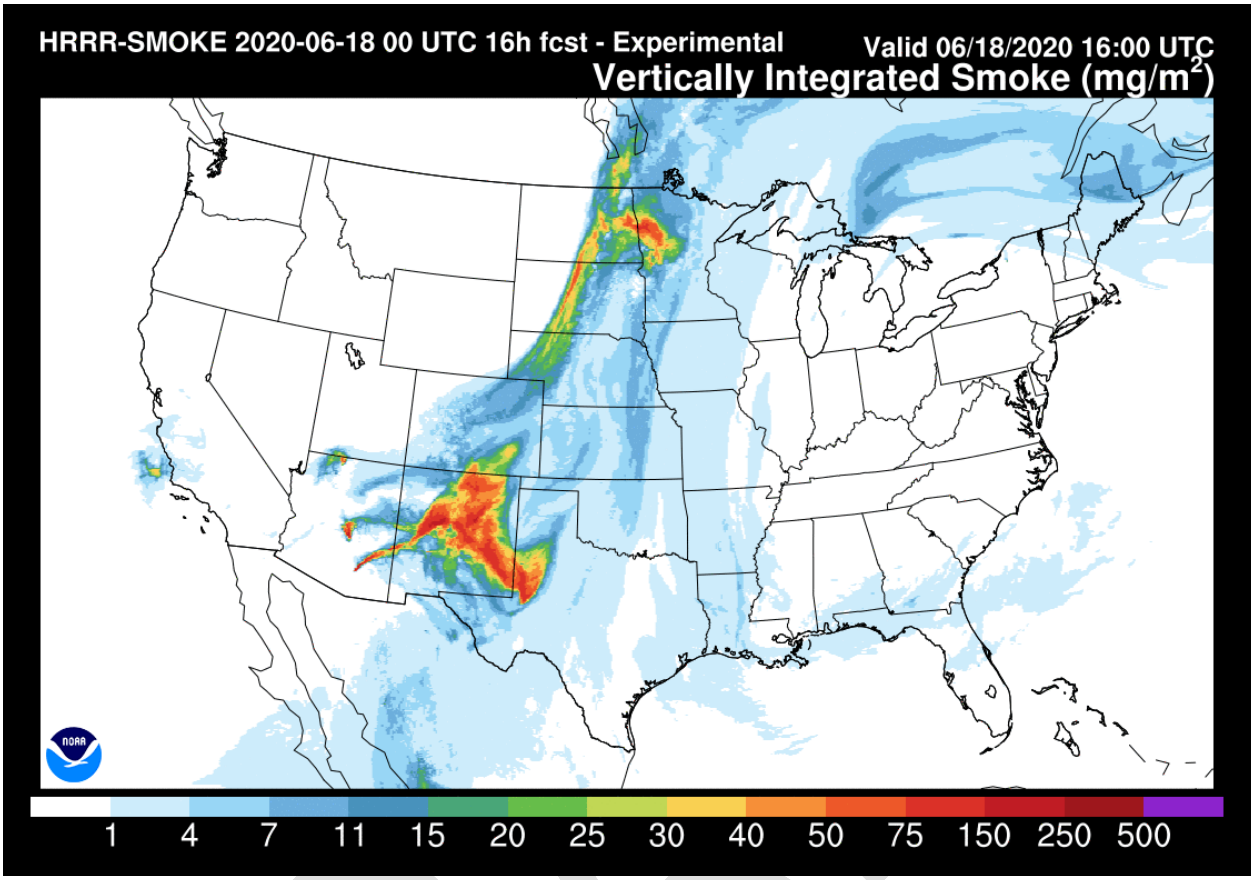

Figure 63. HRRR-Smoke forecast for the distribution of vertically integrated smoke from wildfires at 12 p.m. EDT June 18, 2020.

Figure 64 includes the vertically integrated smoke forecast for June 19, 2020 and demonstrates the eastward trajectory of the smoke plume once it makes its way into the Upper Midwest. Both the northeastern and eastern (along the Gulf of Mexico) plumes are seen in this simulation.

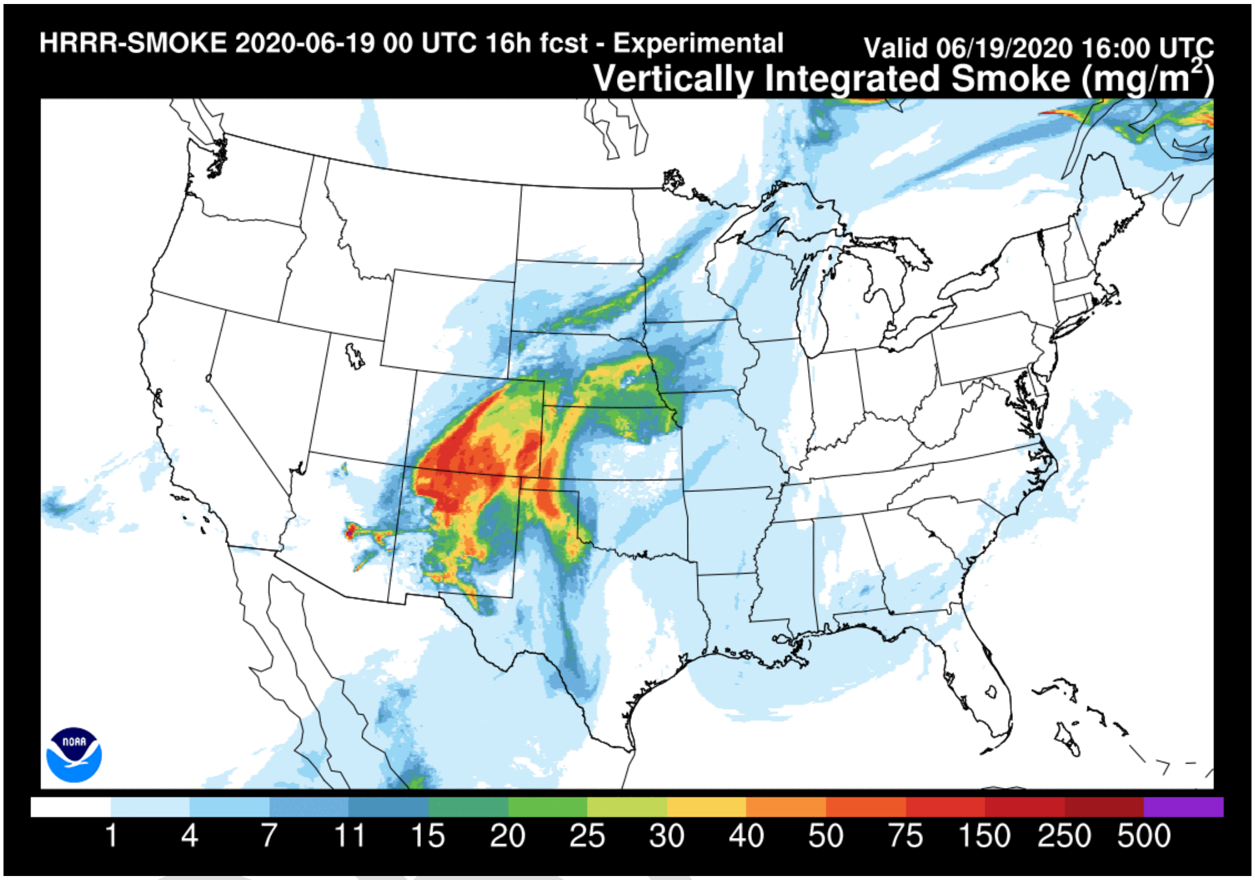

Figure 64. HRRR-Smoke forecast for the distribution of vertically integrated smoke from wildfires at 12 p.m. EDT June 19, 2020.

On June 20, 2020, the HRRR-Smoke forecast (Figure 65) predicts smoke over most of the central states and covering most of Lake Michigan, including portions of western Michigan where the NAAs are located.

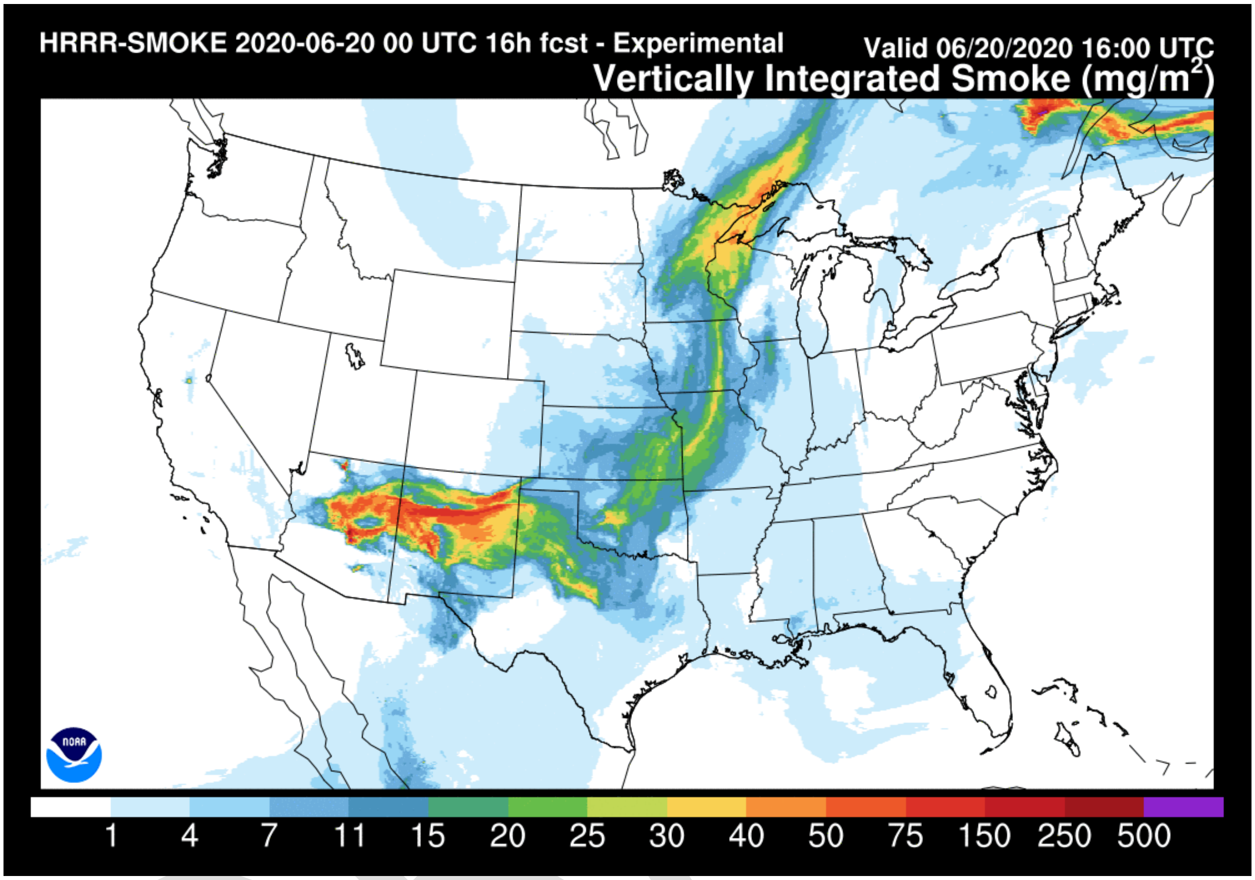

Figure 65. HRRR-Smoke forecast for the distribution of vertically integrated smoke from wildfires at 12 p.m. EDT June 20, 2020.

HMS Fire Detect and Smoke Plume Data and Ozone AQI Maps

Based on the considerable collective size of the Arizona wildfire complexes, significant amounts of ozone and PM2.5 precursors were emitted in addition to other smoke ingredients. As early as June 11, 2020, the plume from the Arizona wildfires began dispersing eastward and north through the Mississippi Valley toward the upper Midwest and Great Lakes region where it would eventually merge with a separate plume from the same fire system and become trapped due to subsidence, atmospheric stability, and light winds associated with a large area of high pressure.

Figure 66 and Figure 67 show the progression of the smoke plumes over North America in June 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 Arizona smoke plumes as a first plume tracks east and then north over the Ohio Valley while a separate plume on June 16, 2020, moves in a northeastern direction. The plumes meet over the western Michigan region during June 17-20, 2020.

As shown in these figures, the Ozone AQI on June 17-20, 2020, showed an impact at monitors in western Michigan and the surrounding areas. Additionally, the Ozone AQI tracks well with the movement of the densest portion of the smoke plume with highest values coinciding with thickest smoke. Figure 66 and Figure 67 corroborate the evidence of smoke over Lake Michigan demonstrated by the visual satellite images (Figure 56 through Figure 59) that enhanced the ozone concentrations during the June 17-20, 2020, episode.

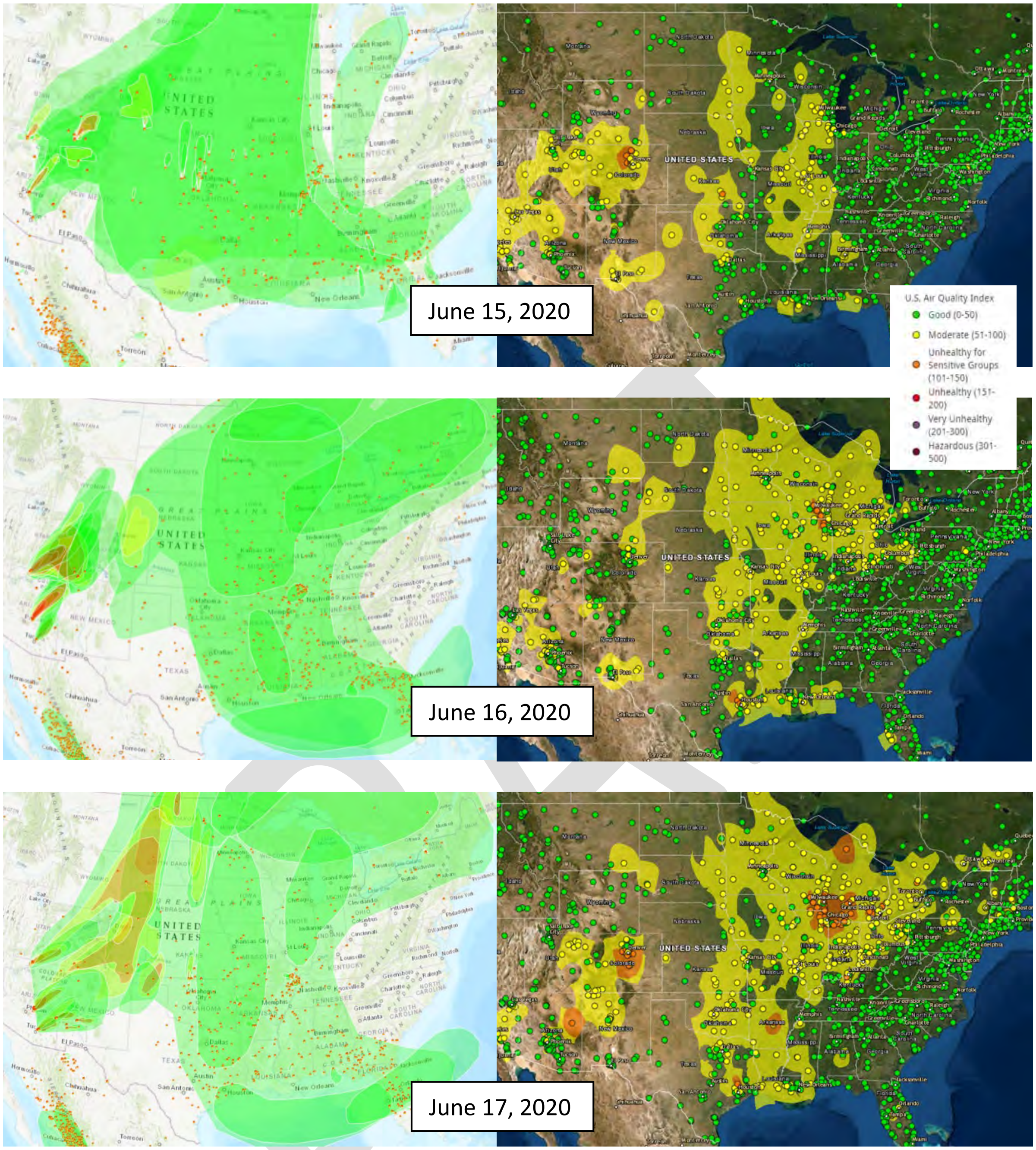

Figure 66. HMS Smoke Analysis (left) and Ozone AQI Maps (right) from June 15-17, 2020.

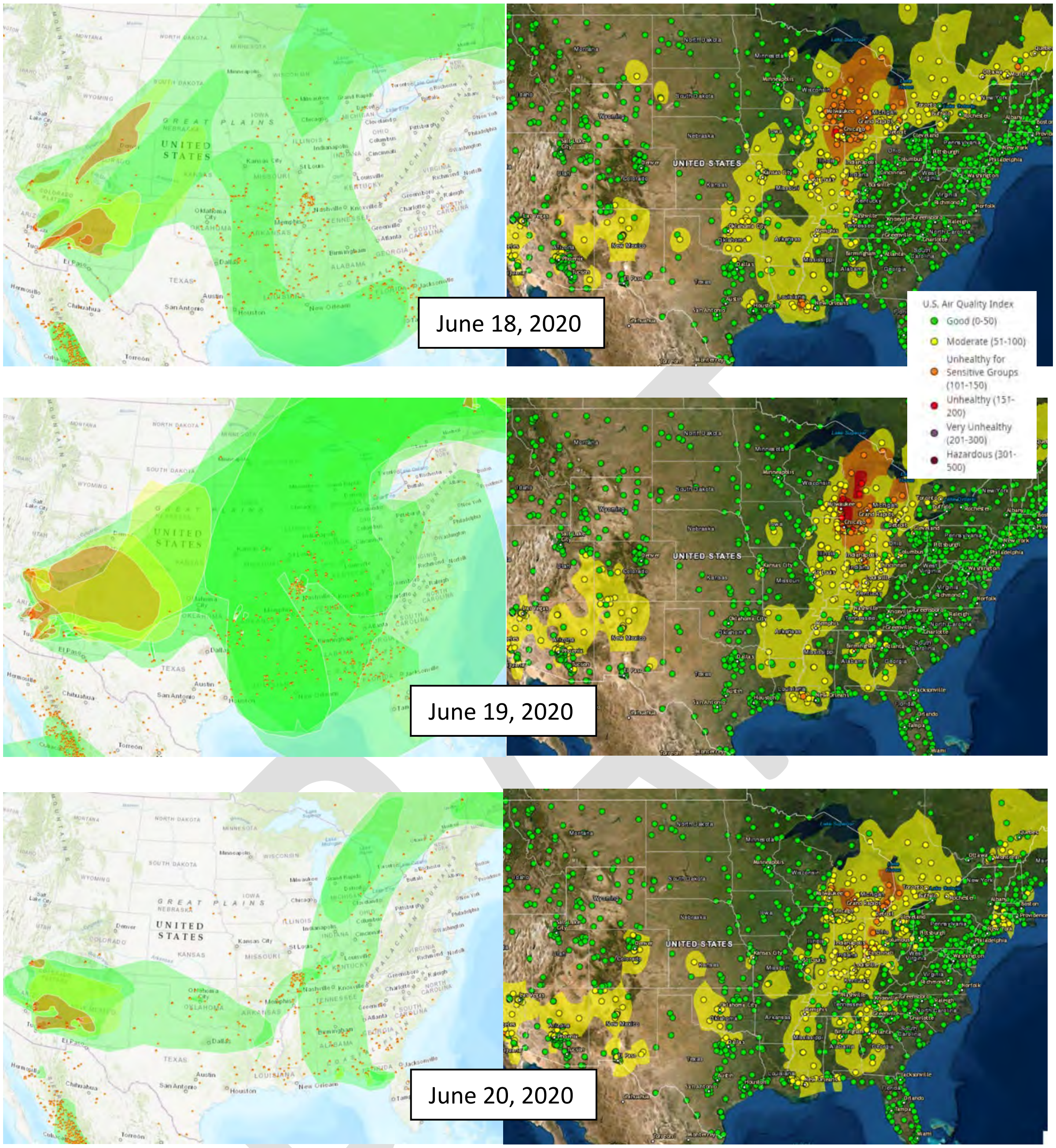

Figure 67. HMS Smoke Analysis (left) and Ozone AQI Maps (right) from June 17-20, 2020.

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[40] to evaluate the presence of smoke plumes on June 17-20, 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 days of June 17-20, 2020.

Figure 68 through Figure 77 show satellite flyover paths and CALIPSO profiles that were collected on episode event days of June 17-20, 2020 in the early morning and afternoon hours. These profiles, along with HMS smoke products and earlier presented mixing height and vertical temperature profile data, show that the location and altitude of smoke plumes observed on June 17-20, 2020 align with the HYSPLIT trajectories presented below and confirm that smoke in the area reached the surface and enhanced the ozone concentrations in the region.

A collection of multiple CALIPSO aerosol profiles collected between June 15 and 20, 2020, confirming the transport of smoke from Arizona is presented in Figure 78.

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

CALIPSO aerosol retrieval across the central U.S. in the early morning of June 17, 2020 is available at 3:47 AM EDT. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 68 and through a portion of the visible smoke plume along the Appalachian Mountain chain. The total attenuated backscatter and vertical profile in Figure 69 shows that a smoke plume (composition polluted dust, clean continental, and polluted continental/smoke) was present in a layer between the surface and about 2,000 m above ground level (AGL).

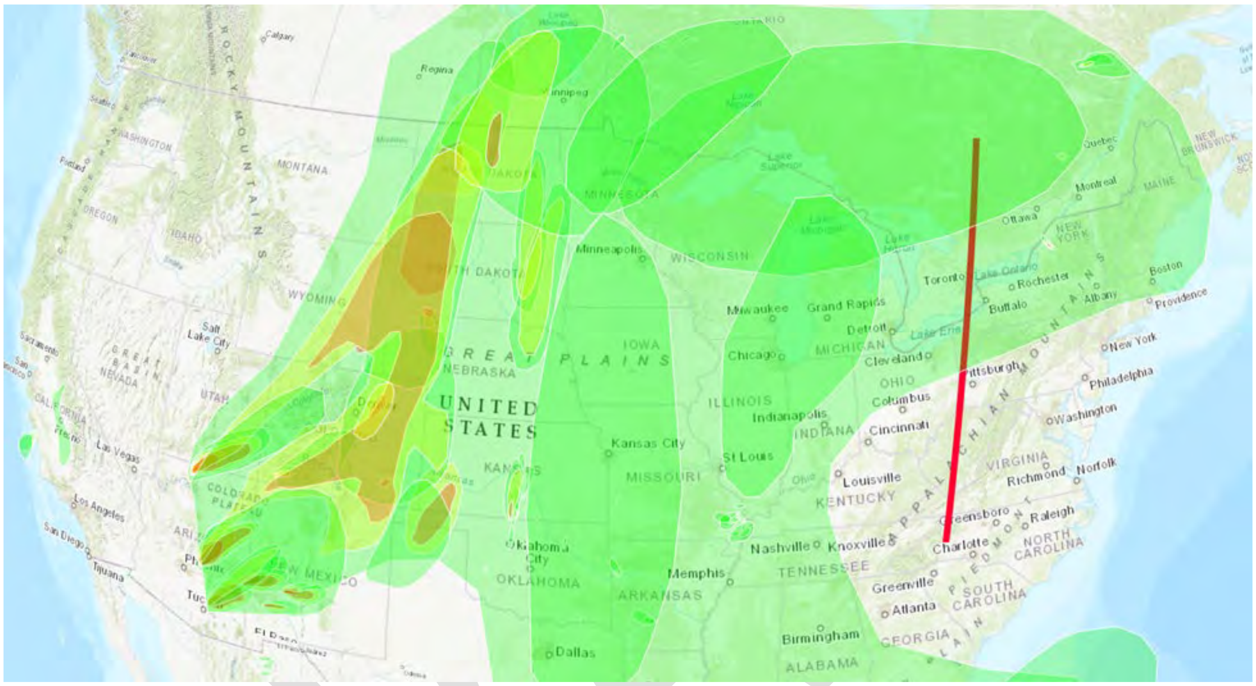

Figure 68. Approximate path of CALIPSO satellite flyover (red line) in early morning of June 17, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 69.

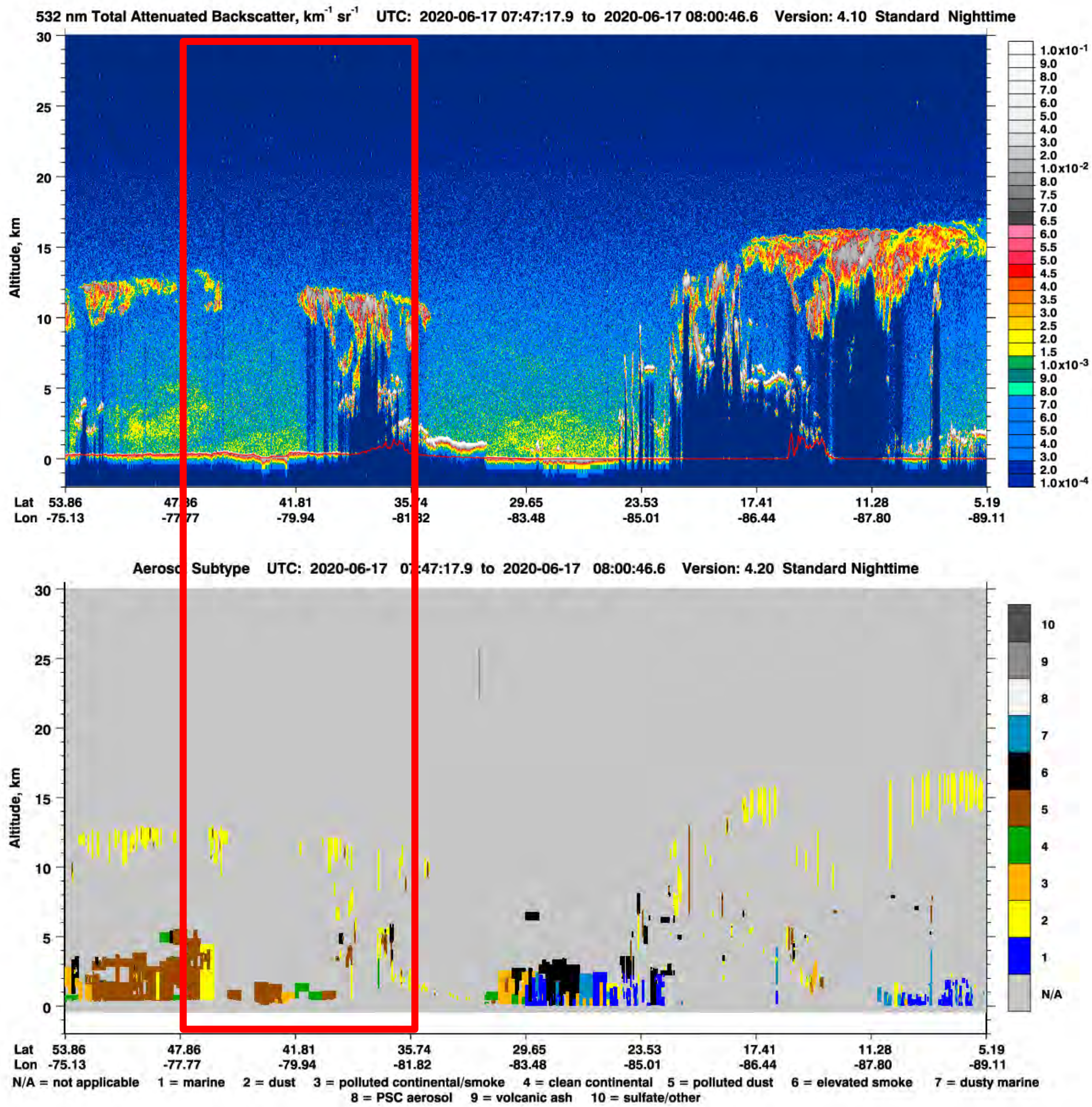

Figure 69. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on June 17, 2020, between 3:47 and 4:00 a.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

CALIPSO aerosol retrieval across the central U.S. in the early morning of June 18, 2020 is available at 4:25 AM EDT. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 70 and through the visible smoke plume along the western shore of Lake Michigan. The total attenuated backscatter and vertical profile in Figure 71 shows that a smoke plume (composition polluted dust and polluted continental/smoke) was present in a layer between the surface and about 2,500 m above ground level (AGL).

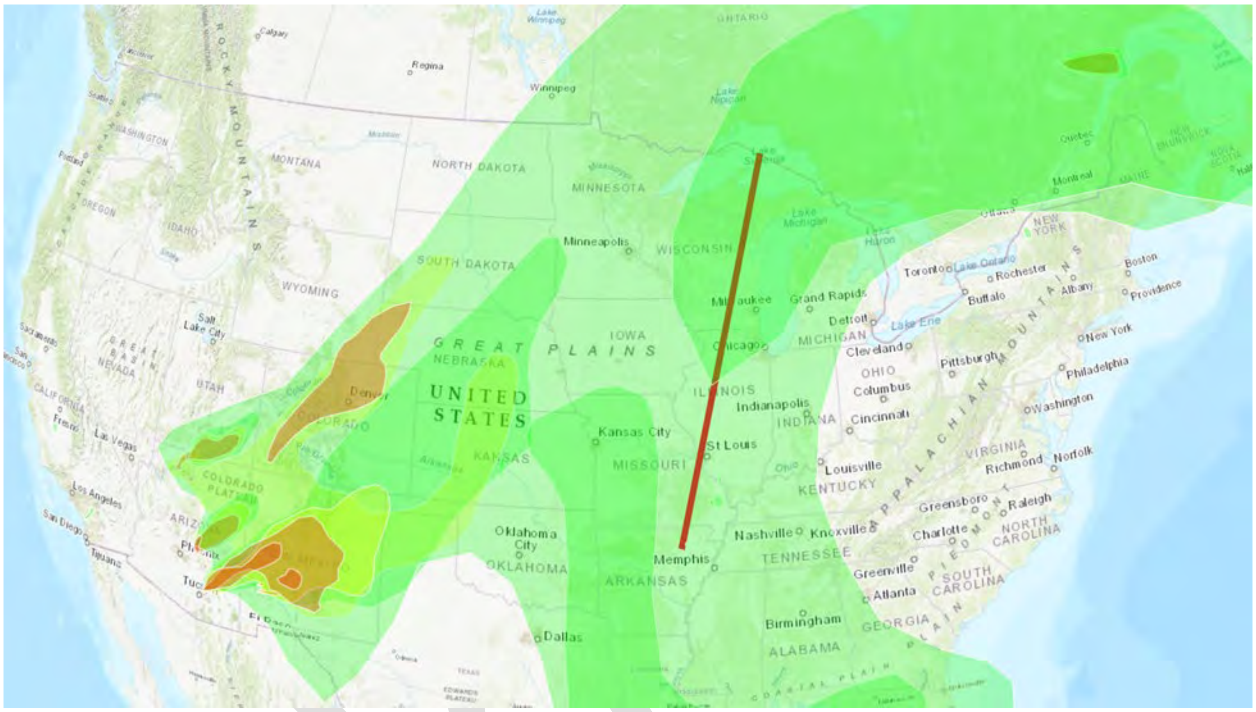

Figure 70. Approximate path of CALIPSO satellite flyover (red line) in early morning of June 18, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 71.

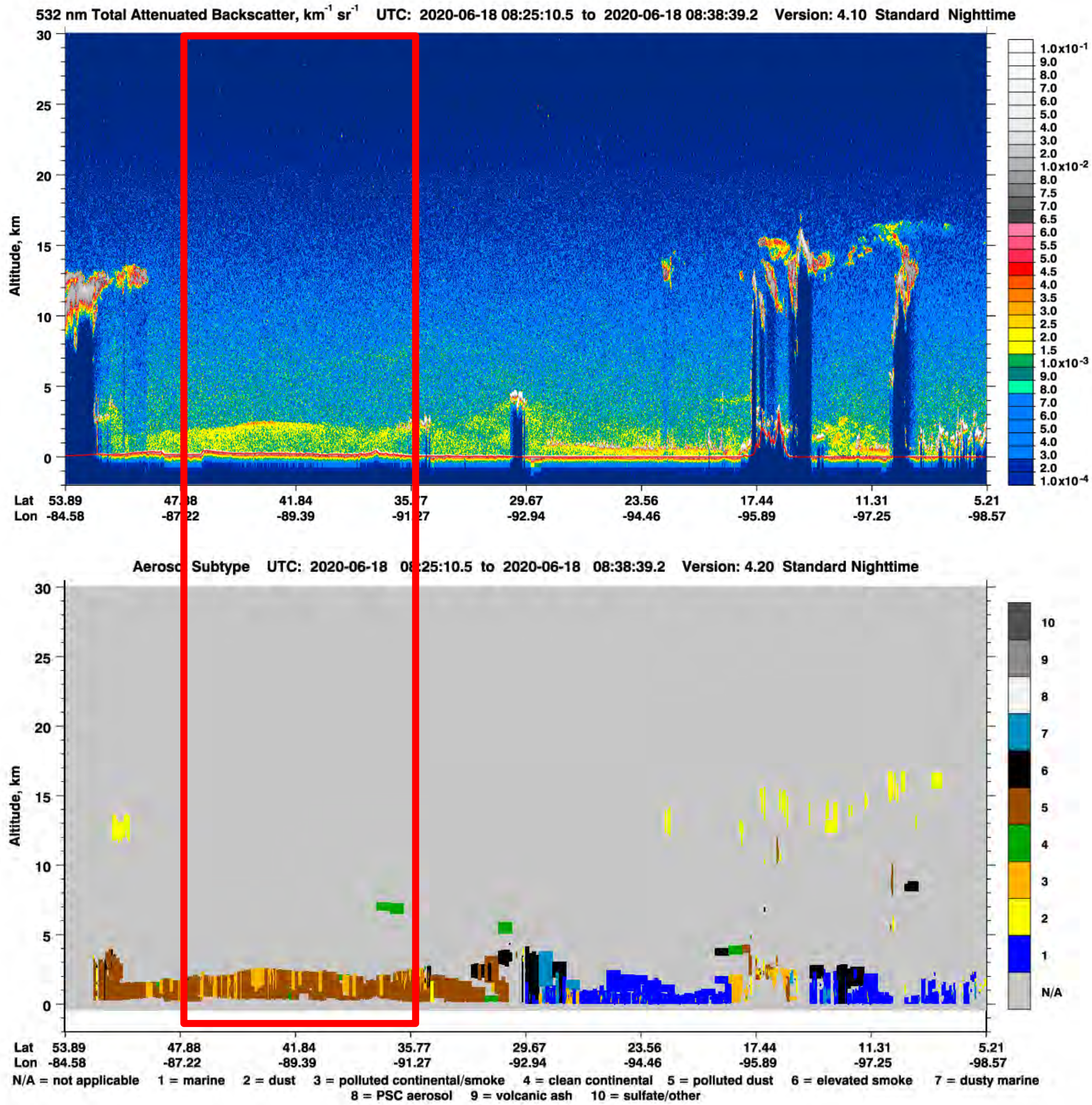

Figure 71. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on June 18, 2020, between 4:25 and 4:38 a.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

CALIPSO aerosol retrieval over southern Ontario on the afternoon of June 19, 2020 is available at 2:28 PM EDT. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 72 and through the visible smoke plume along the northern border of Lake Huron. The total attenuated backscatter and vertical profile in Figure 73 shows that a smoke plume (composition polluted dust and polluted continental/smoke) was present in a layer between the surface and about 2,500 - 3,000 m above ground level (AGL).

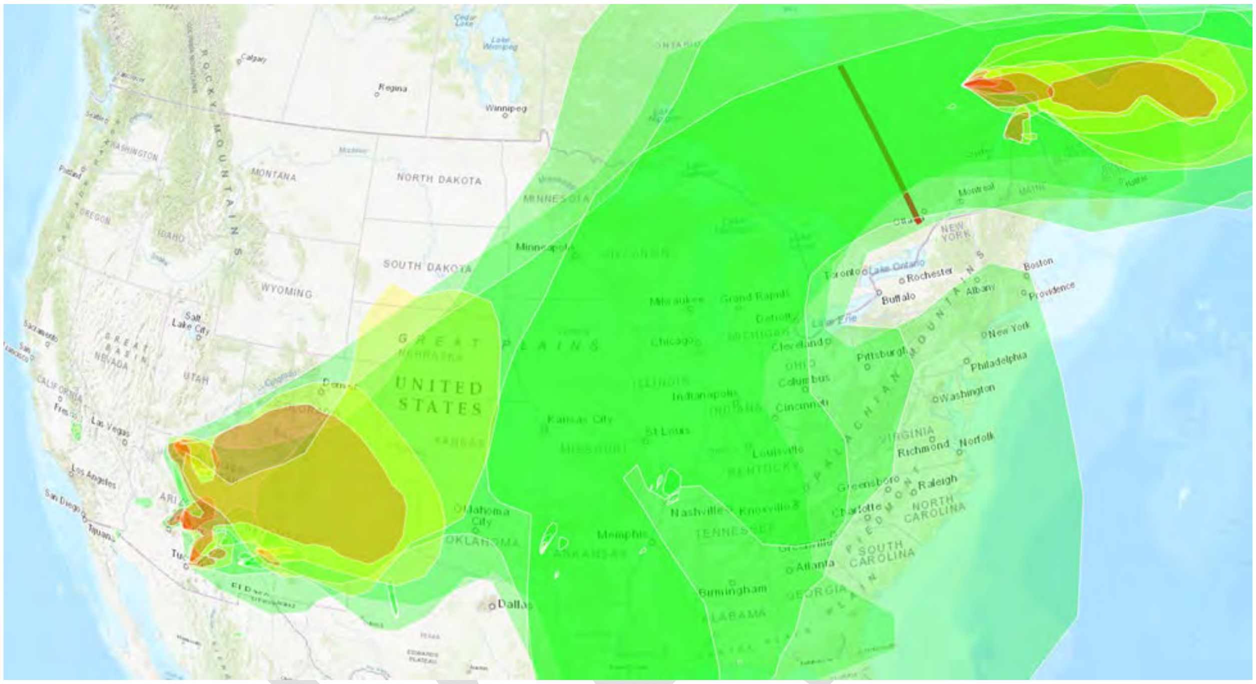

Figure 72. Approximate path of CALIPSO satellite flyover (red line) in the afternoon of June 19, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 73.

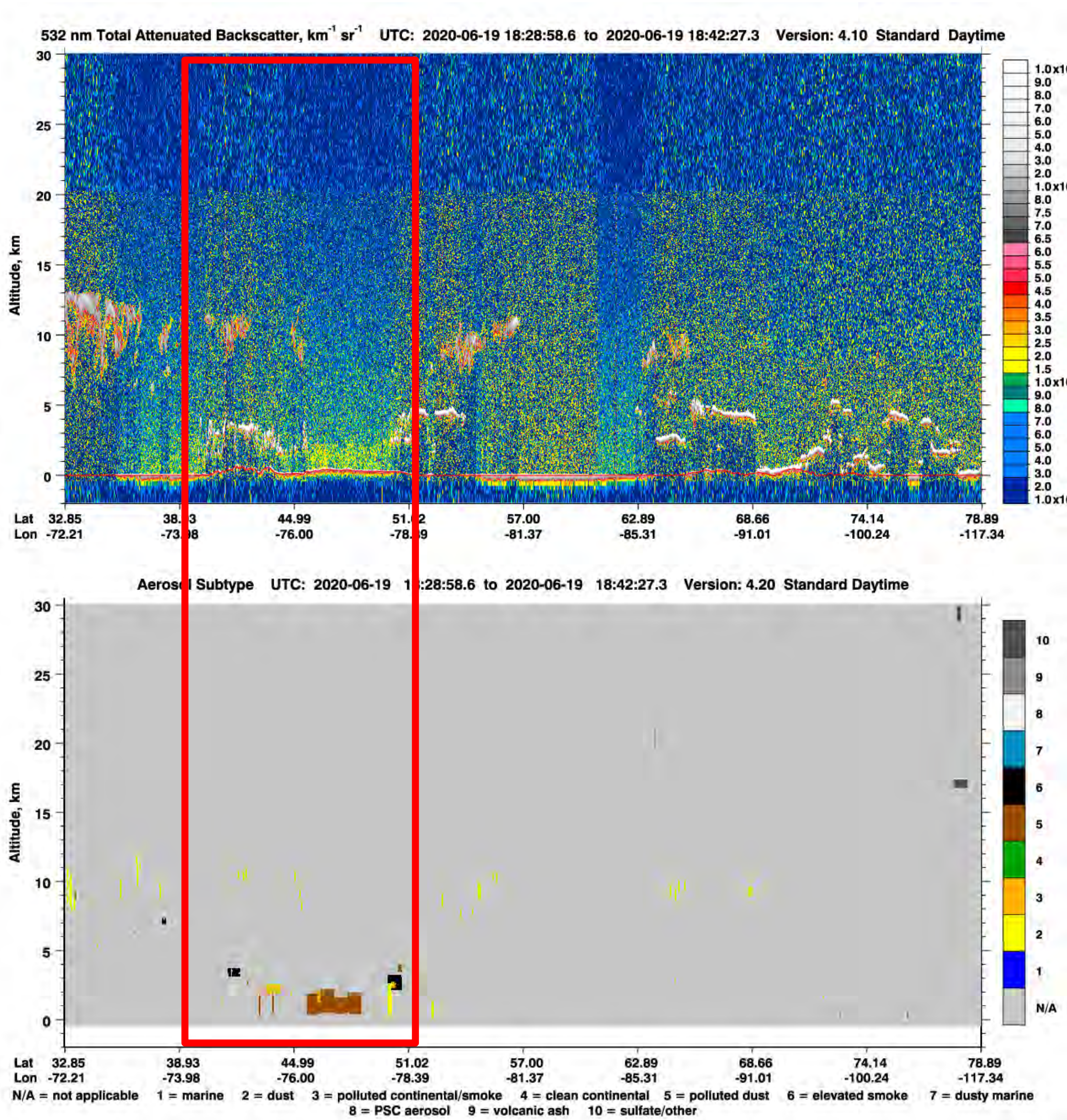

Figure 73. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on June 19, 2020, between 2:28 and 2:42 p.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

CALIPSO aerosol retrieval over the Ohio Valley for the morning of June 20, 2020 is available at 4:02 AM local time. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 74 and travels almost directly over Cincinnati, Detroit, and the visible smoke plume. The total attenuated backscatter and vertical profile in Figure 75 shows that a smoke plume (composition polluted dust and polluted continental/smoke) was present in the morning of June 20 in a layer between the surface and about 3,000 - 3,500 m above ground level (AGL).

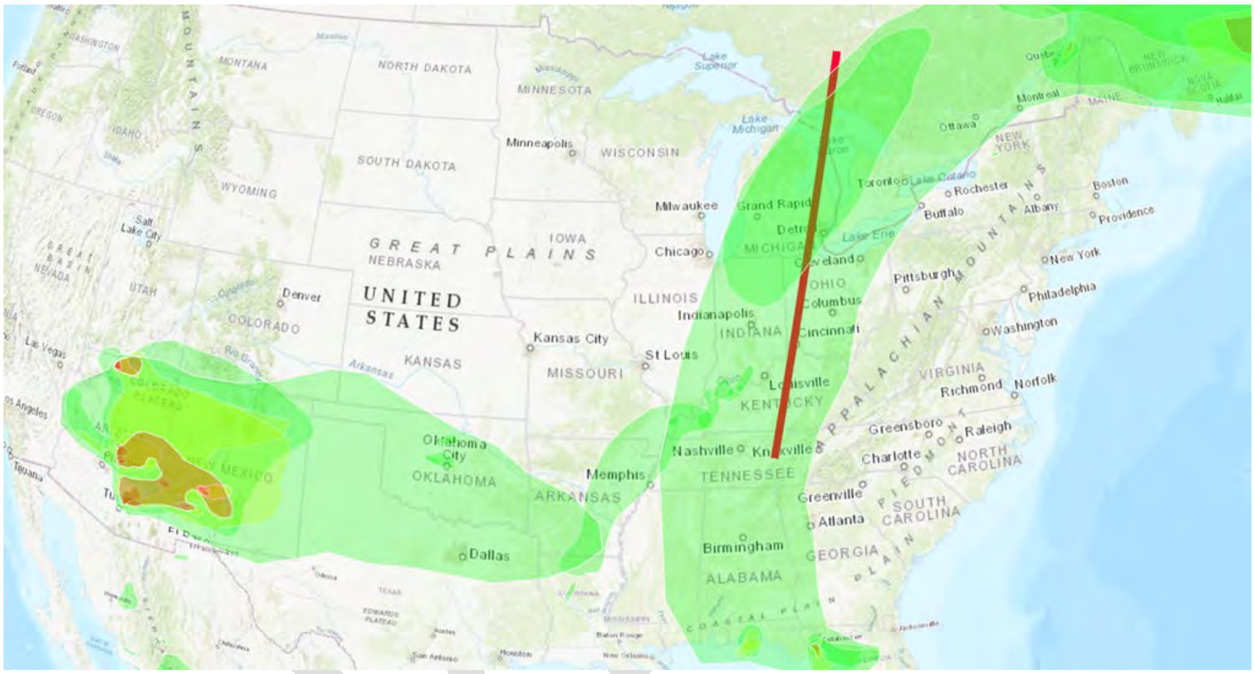

Figure 74. Approximate path of CALIPSO satellite flyover (red line) in early morning of June 20, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 75.

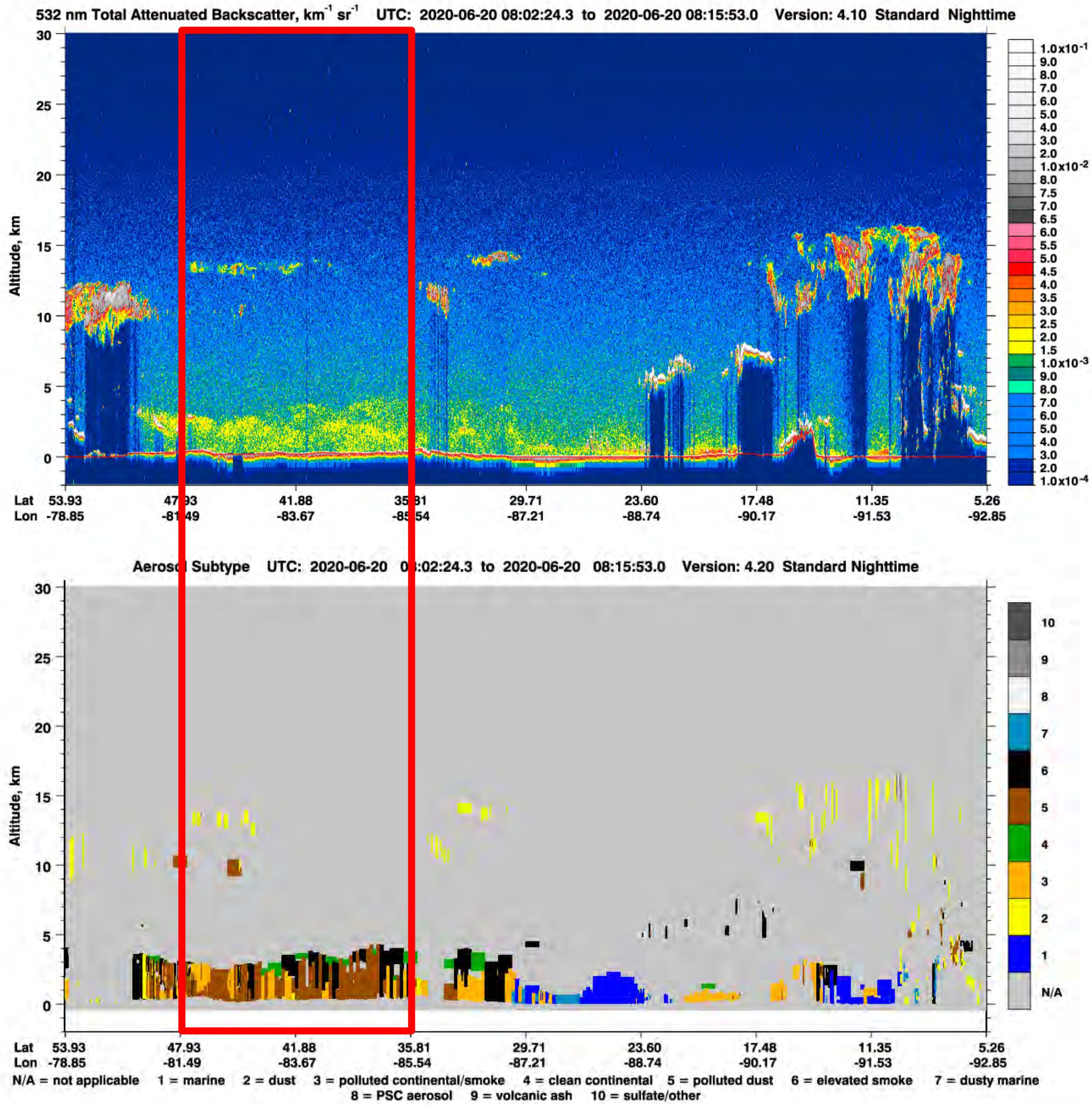

Figure 75. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on June 20, 2020, between 4:02 and 4:15 a.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

CALIPSO aerosol retrieval over the region for the afternoon of June 20, 2020 is available at 3:06 PM local time. The approximate path of the flyover with the HMS smoke overlay is seen in Figure 76. The satellite travels just east of the western Michigan NAAs and is still directly over the expansive visible smoke plume. The total attenuated backscatter and vertical profile in Figure 77 shows that a smoke plume (also a composition of polluted dust and polluted continental/smoke) was present during the day of June 20 in a layer between the surface and about 2,500 - 3,000 m AGL.

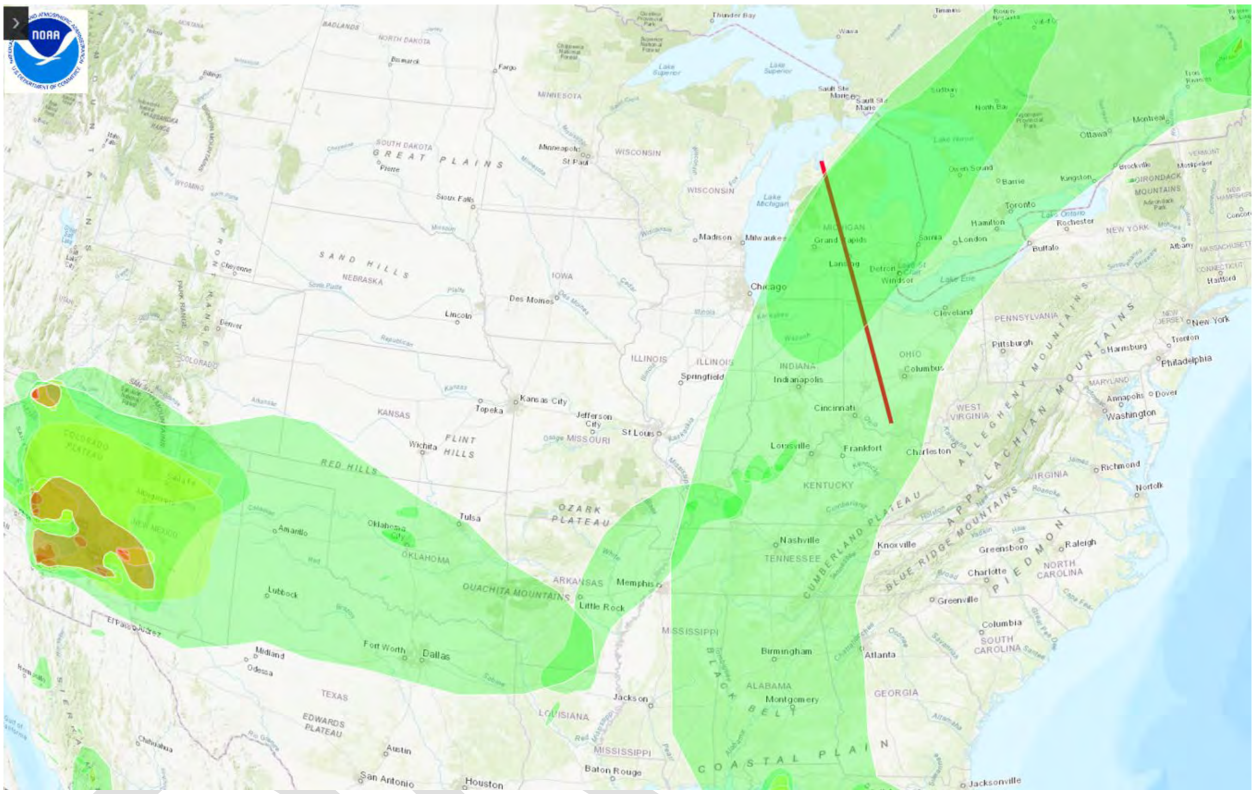

Figure 76. Approximate path of CALIPSO satellite flyover (red line) in the afternoon of June 20, 2020, with HMS smoke overlay. Vertical profiles along the marked path are indicated in Figure 77.

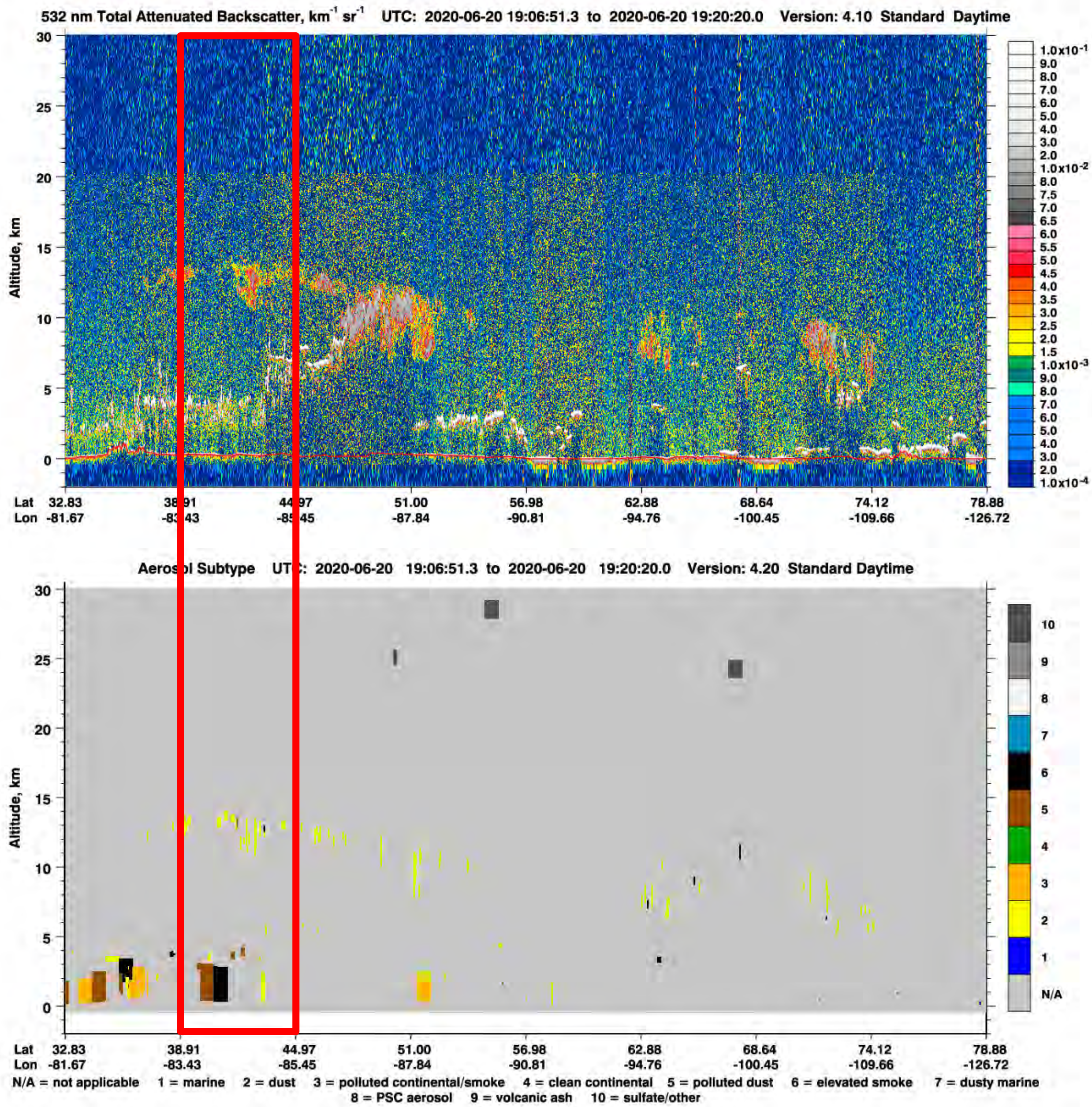

Figure 77. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype at 532 nm, collected on June 20, 2020, between 3:06 and 3:20 p.m. EDT over the northern hemisphere. The area enclosed in the red box corresponds to the path marked by the red line in the previous figure.

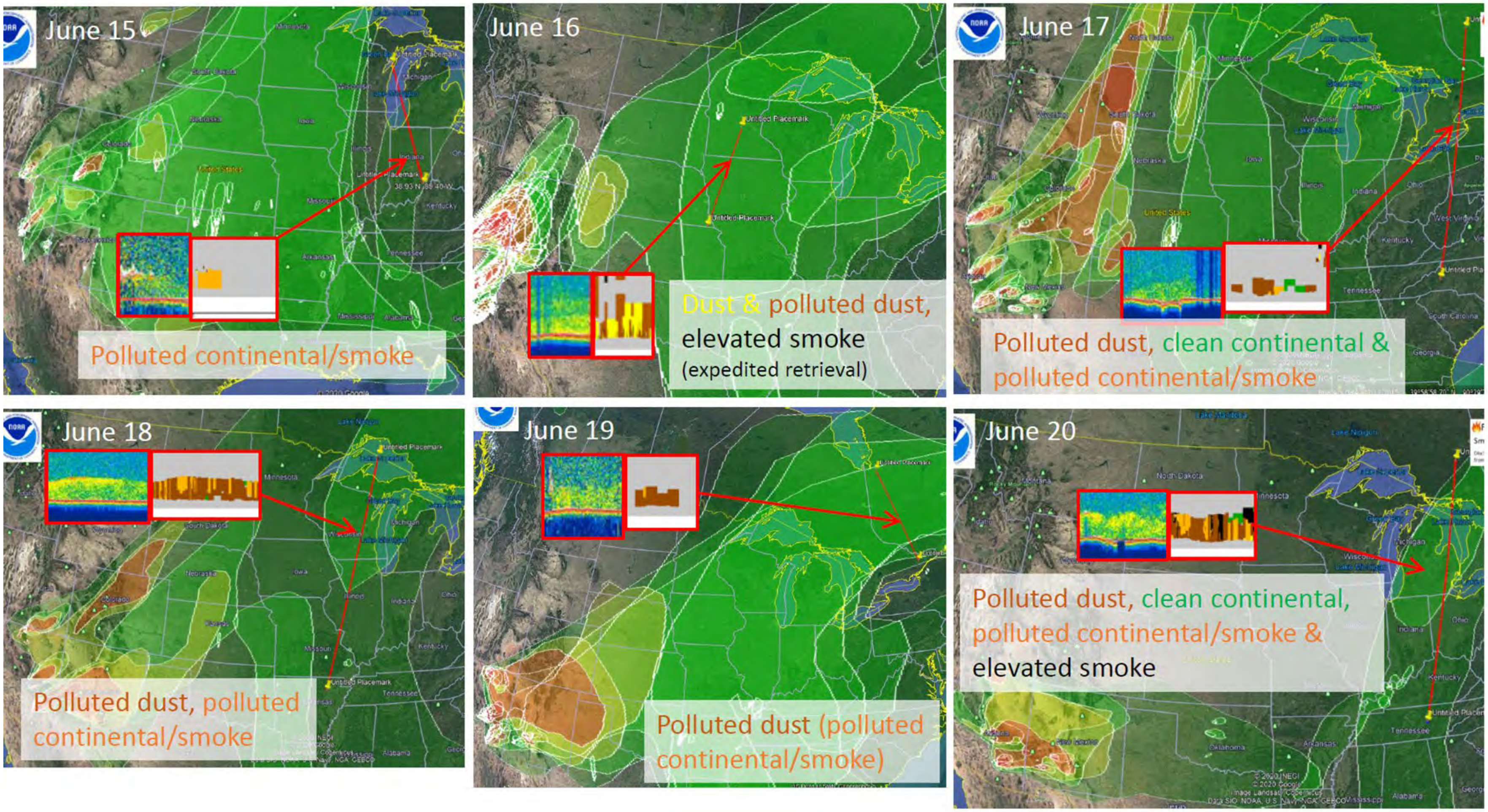

Figure 78. CALIPSO aerosol total attenuated backscatter vertical profile and aerosol subtype summary for June 15-20, 2020. Image source: LADCO presentation.

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 Arizona, the Mississippi Valley, and the western Michigan region during the June 2020 episode. 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 8) 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.

Table 8. Observed 1st - 4th High MDA8 Ozone Concentrations (ppb) at Monitors in the Path of the Arizona Wildfire Smoke Plume during the Period June 14–18, 2020 (highlighted).

			MDA8 Ozone Observations (ppb)							
State	**County**	**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**
Iowa	Linn	19-113-0033	67	06/08/20	64	06/16/20	64	07/03/20	64	08/14/20
Iowa	Scott	19-163-0014	64	06/08/20	63	06/16/20	60	06/17/20	55	06/02/20
Iowa	Van Buren	19-177-0006	66	06/16/20	64	06/08/20	63	06/07/20	59	06/06/20
Kansas	Sedgwick	20-173-0010	72	06/15/20	60	06/13/20	59	06/14/20	57	06/17/20
Kansas	Sedgwick	20-173-0018	62	06/15/20	61	06/05/20	61	06/14/20	60	06/13/20
Kansas	Sumner	20-191-0002	60	06/13/20	60	06/15/20	59	06/14/20	57	04/08/20
Kansas	Trego	20-195-0001	61	06/11/20	61	06/15/20	60	06/26/20	59	06/03/20
Missouri	Andrew	29-003-0001	63	06/03/20	62	06/17/20	60	06/08/20	60	06/18/20
Missouri	Callaway	29-027-0002	66	04/08/20	60	06/16/20	59	06/08/20	59	06/14/20
Missouri	Greene	29-077-0036	61	07/10/20	57	06/15/20	56	06/17/20	55	05/02/20
Missouri	Lincoln	29-113-0004	73	06/07/20	68	06/16/20	65	06/08/20	65	06/17/20
Missouri	Monroe	29-137-0001	65	06/07/20	64	06/16/20	58	04/08/20	56	06/15/20
Missouri	Saint Charles	29-183-1004	70	06/18/20	69	06/07/20	68	06/06/20	65	06/17/20
Oklahoma	Adair	40-001-9009	55	06/17/20	54	06/16/20	53	03/28/20	53	06/22/20
Oklahoma	Canadian	40-017-0101	65	06/17/20	64	08/30/20	62	05/07/20	62	06/13/20
Oklahoma	Carter	40-019-0297	70	06/17/20	69	08/06/20	67	05/01/20	66	05/07/20
Oklahoma	Cleveland	40-027-0049	67	06/17/20	64	05/18/20	64	08/28/20	63	08/30/20
Oklahoma	Oklahoma	40-109-0096	66	06/17/20	65	05/01/20	63	08/30/20	62	08/28/20
Oklahoma	Sequoyah	40-135-9021	58	06/16/20	58	06/17/20	54	06/09/20	53	06/15/20

HYSPLIT Trajectory Analysis

To demonstrate that the Arizona wildfire emissions were transported to the western Michigan ozone network, the HYSPLIT model[41] was used to calculate forward trajectories originating from within the smoke plume at the fire sites and backward trajectories from each monitor in the three western Michigan NAAs. All trajectories utilize NAM 12km data for all meteorological input.

According to HYSPLIT-WEB Short Course materials[42], 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 on June 13 and showing the fire plume transport are shown in Figure 90. Trajectories represent 500 m, 1500 m, and 2000 m starting heights from each of the Bighorn, Bush, and Mangum 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 79 (trajectory start time of 1700 UTC / 1 PM ET on June 13, 2020), the smoke reaches eastern Wisconsin and Lake Michigan as early as June 16, 2020. A trajectory that starts four hours later (top right of Figure 79) shows a comparable track with multiple plumes modeled in vertical layers under 2000m in the region on June 17 and 18, 2020. The image in the lower left of Figure 79 is a trajectory that starts at 2200 UTC (6 PM ET) on June 13 and shows that the smoke plume was over the western shore of Michigan during June 17 and 18, 2020. Finally, as shown in the lower right of Figure 79, a trajectory that started at 0000 UTC on June 14 (10 PM ET, June 13) found its way directly over northern and western Michigan (where all three NAAs are located) during the period of June 17 and 18, 2020, corroborating the satellite measurements and visual observations and HMS smoke product findings that wildfire smoke made its way into the region during the episode of June 17-20, 2020.

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

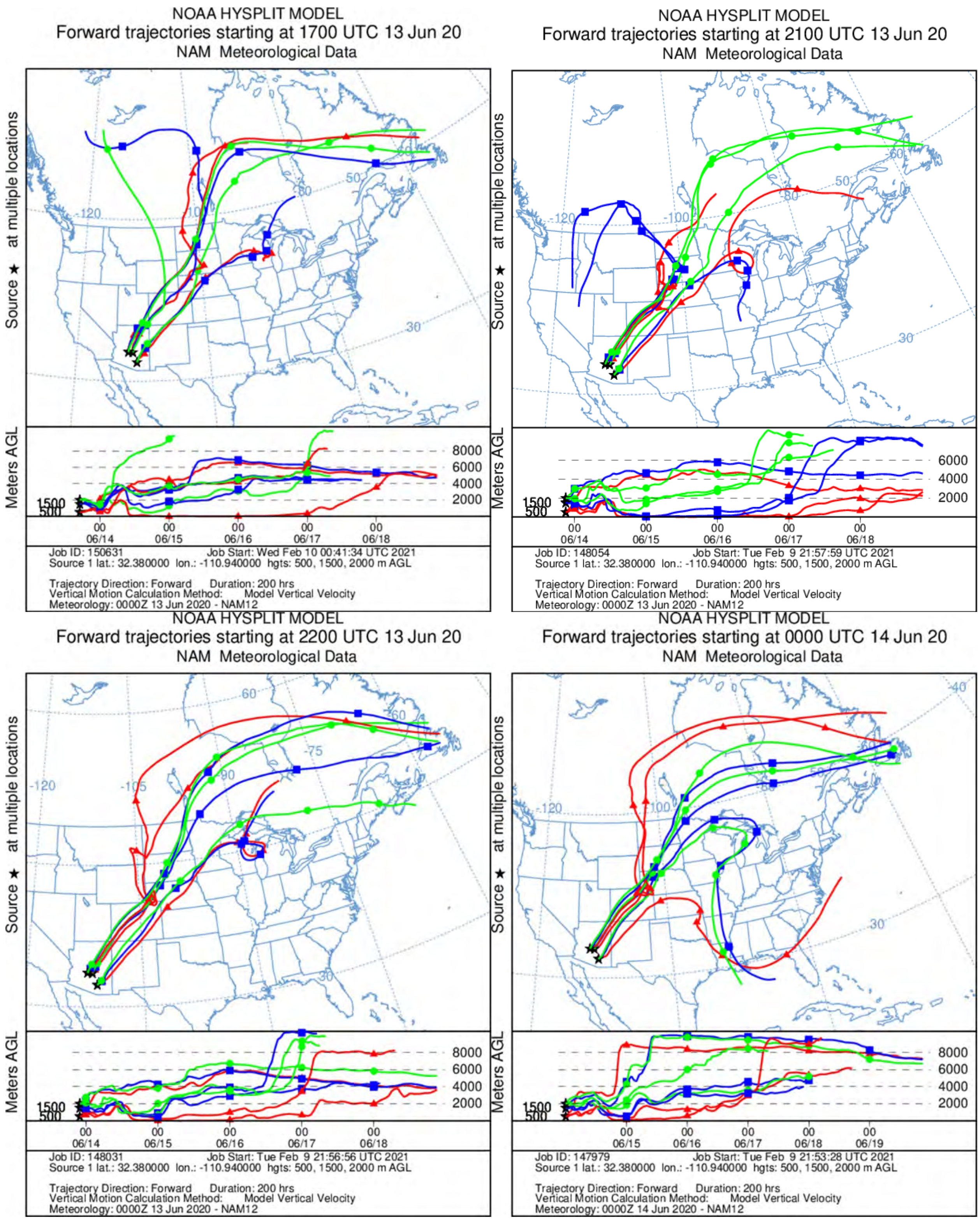

Figure 79. HYSPLIT 200-hour Forward Trajectories Starting June 13, 2020 from Arizona Wildfire Complexes using Multiple Start Times.

Figure 80, Figure 81, Figure 82, and Figure 83 show 48-hour backward trajectories from the Muskegon (top), Holland (middle), and Coloma (bottom) monitors on June 17, 18, 19, and 20, 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 3,000 m. Regional observations of mixing heights at Detroit/Pontiac and modeled soundings at MKG, BIV, and BEH on June 17-20, 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 the Mississippi Valley and upper Midwest just before the June 17-20, 2020 episode was resident over the region and enhanced ozone concentrations on the days leading up to the ozone event.

From these figures, it is easy to see that wildfire smoke which had been transported into the region prior to June 17, 2020 and then was present in the region as meteorological conditions culminated in a recirculation event at the monitor locations during June 17-20, 2020. 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.

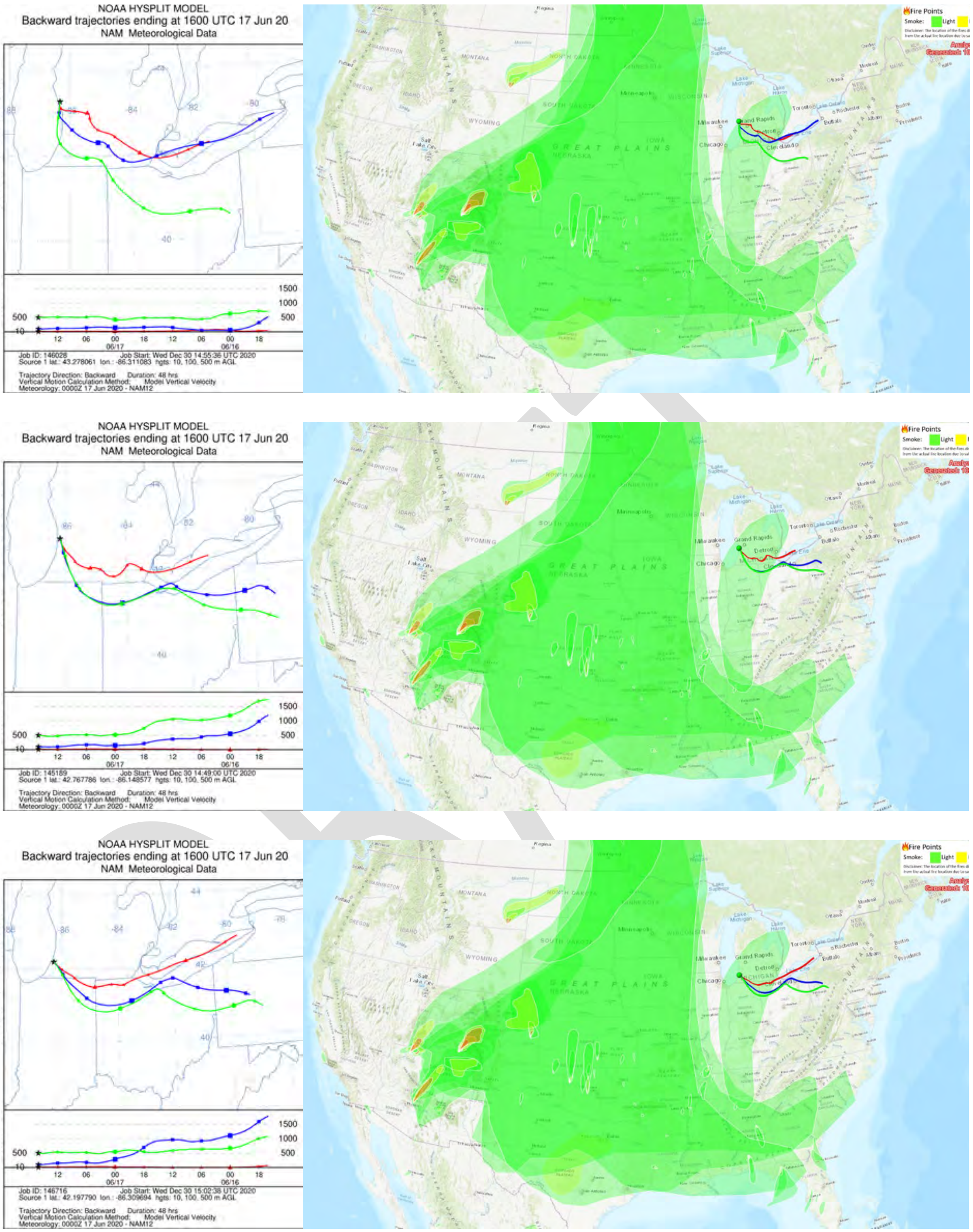

Figure 80. June 17, 2020 HYSPLIT 48-Hour Backward Trajectory from Muskegon (top), Holland (middle), and Coloma (bottom) monitors with HMS Smoke Overlay.

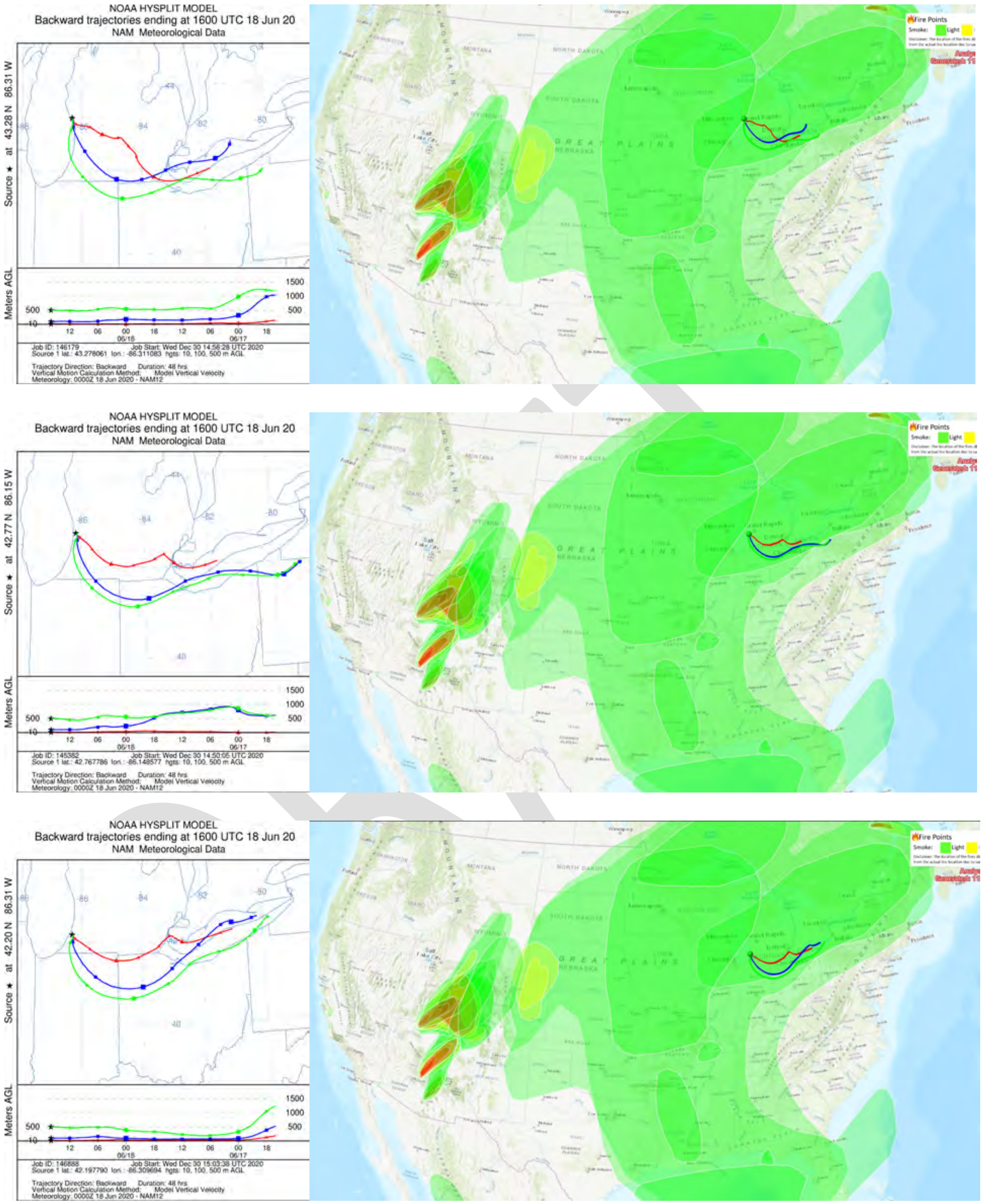

Figure 81. June 18, 2020 HYSPLIT 48-Hour Backward Trajectory from Muskegon (top), Holland (middle), and Coloma (bottom) monitors with HMS Smoke Overlay.

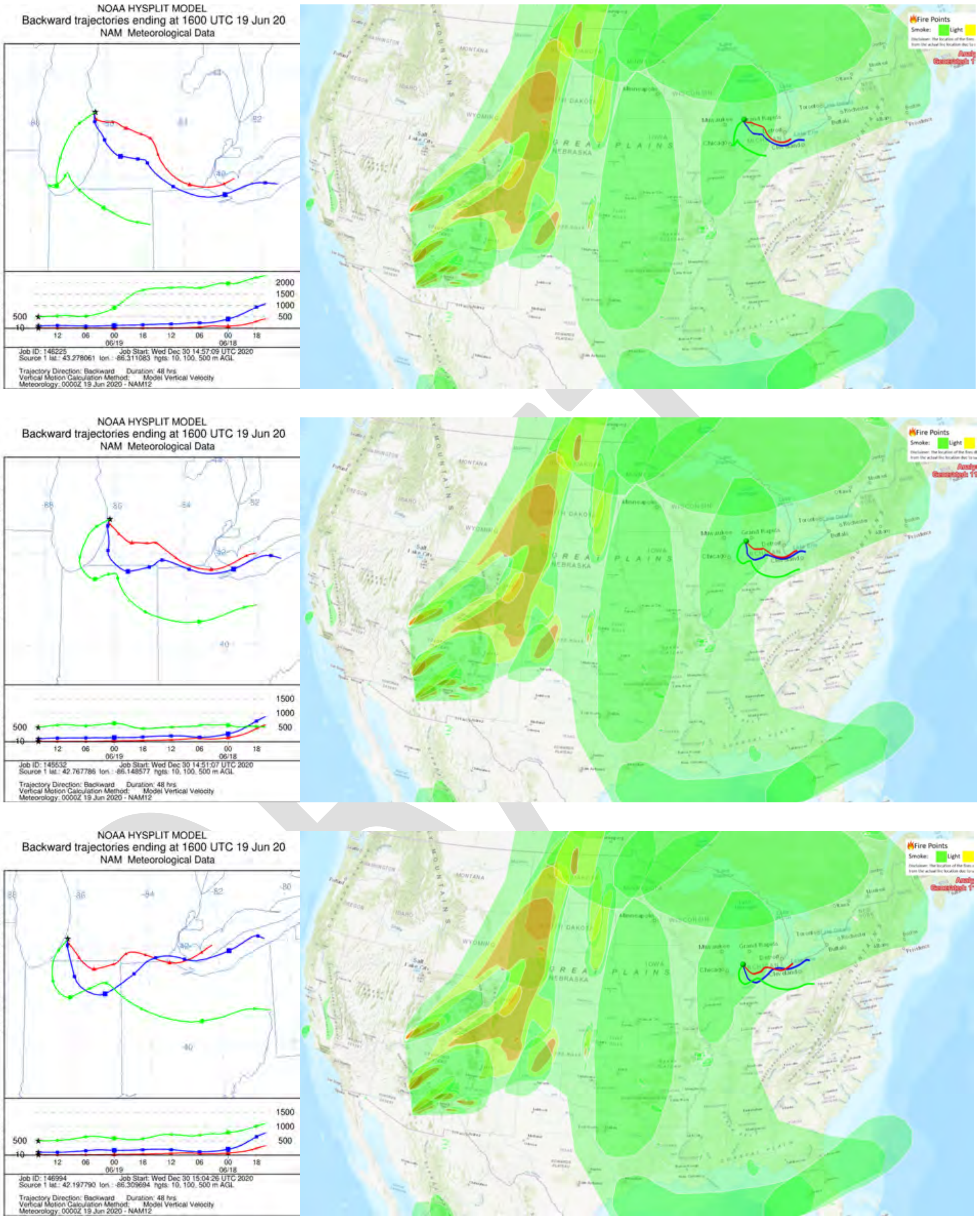

Figure 82. June 19, 2020 HYSPLIT 48-Hour Backward Trajectory from Muskegon (top), Holland (middle), and Coloma (bottom) monitors with HMS Smoke Overlay.

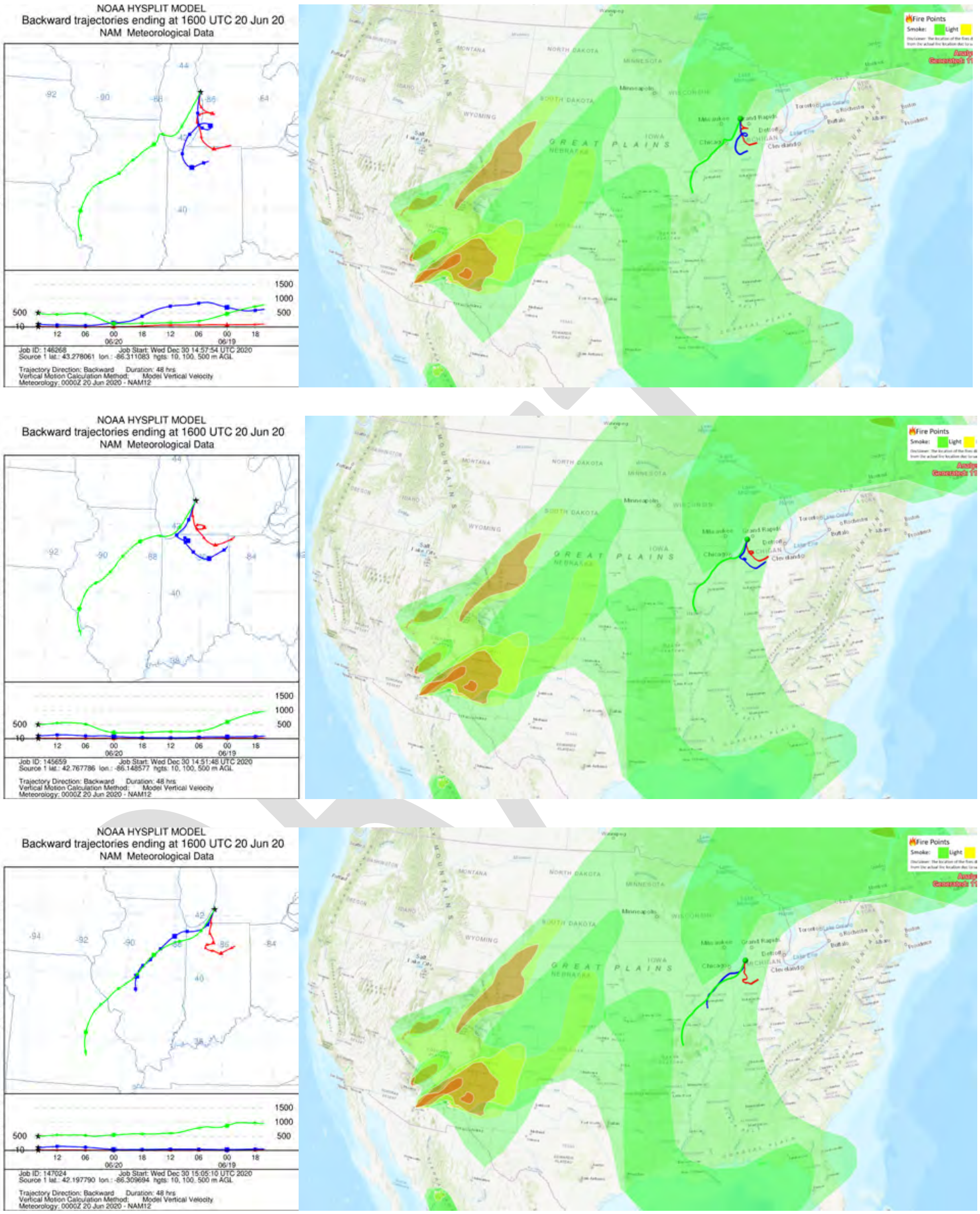

Figure 83. June 20, 2020 HYSPLIT 48-Hour Backward Trajectory from Muskegon (top), Holland (middle), and Coloma (bottom) monitors with HMS Smoke Overlay.

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 June 17-20, 2020, also support smoke transport from the Arizona wildfire complexes to the Allegan, Berrien, 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 MODIS instrument onboard the Aqua and Terra satellites and the Suomi National Polar-orbiting Partnership (NPP) provides evidence to support the transport of smoke from fires in Arizona to the Michigan region, as already demonstrated with visual imagery and trajectories. The following images show relatively high AOD prior to and on the episode days along the transport path and over the western Michigan region and provide further evidence that the smoke plume and associated ozone and PM2.5 precursors were present in the smoke plume in the days leading up to the exceedances, and during the exceedances on June 17-20, 2020.

Figure 84 shows the MODIS combined value-added AOD for June 18, 2020. High AOD values between the Arizona wildfires (red circle) and smoke plume (blue circle) along the transport path to the upper Midwest are evident.

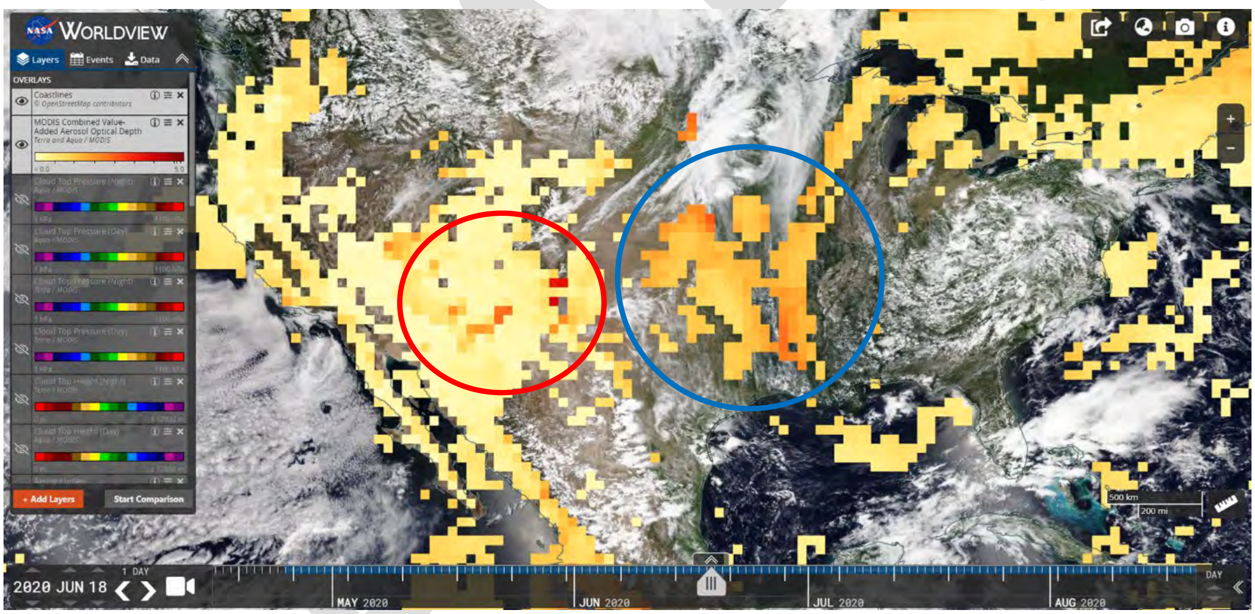

Figure 84. MODIS combined value-added AOD for June 18, 2020

Figure 85 presents the Suomi NPP AOD[43] for June 15-21, 2020 around Lake Michigan. This figure shows increasing aerosol scatter around the corresponding increased presence of smoke during the June 17-20, 2020 episode. AOD scatter is notably lower along the western shore of Michigan and Lake Michigan prior to (June 15-16) and just after (June 21) the smoke has passed through the region in relation to the observed MDA8 levels.

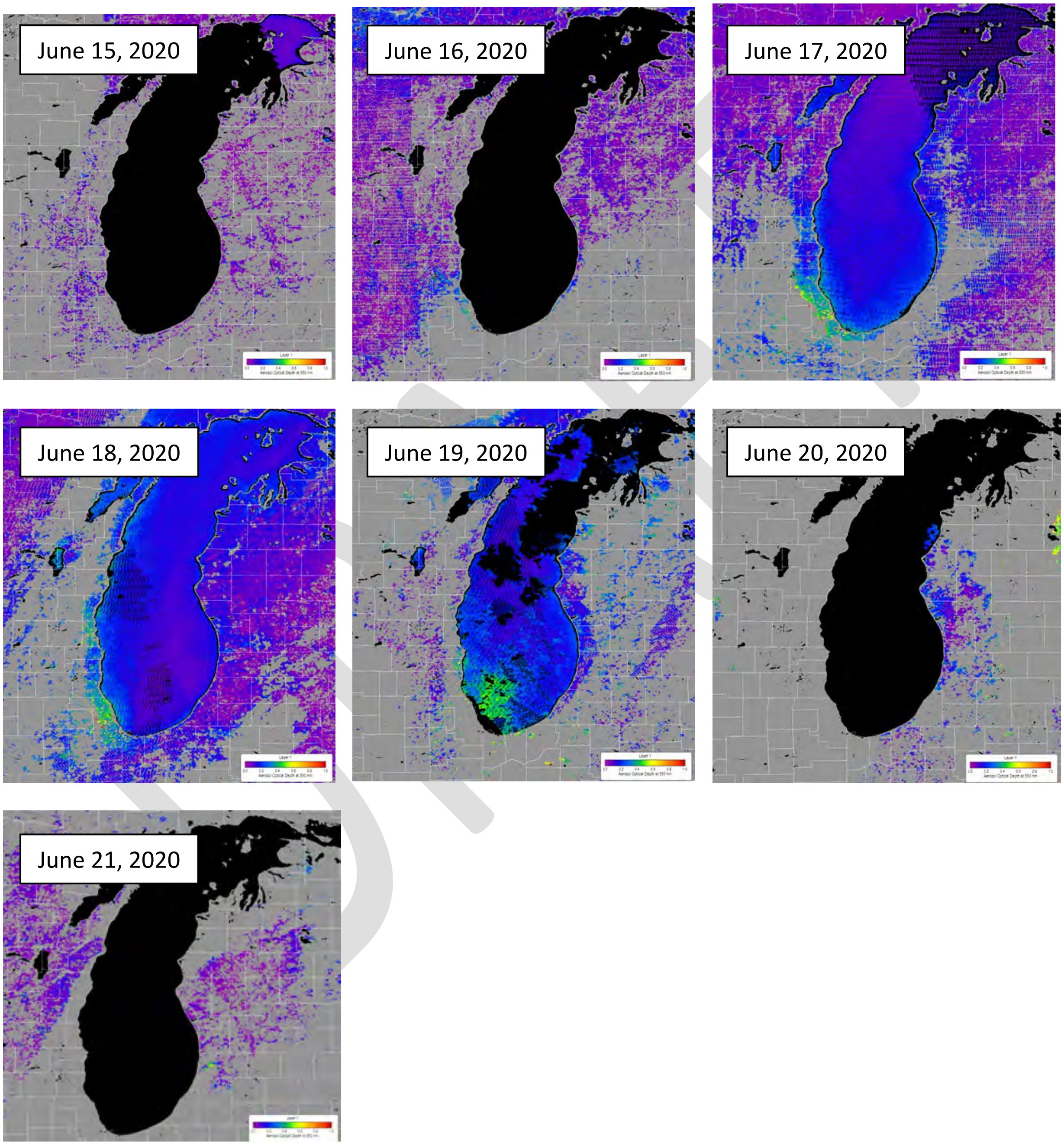

Figure 85. Suomi NPP AOD for June 15-21, 2020

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[43] https://www.star.nesdis.noaa.gov/

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 Arizona to the western Michigan region, as already demonstrated with visual imagery and trajectories described earlier.

CO measurements show the same pattern of smoke plume transport seen in the MODIS AOD data noted above. The maps show smoke transport from the south and southwest through the southern and central United States and into the Lake Michigan region between June 18 and June 20, 2020. June 17, 2020 measurements are not provided as the observed CO was incomplete over the U.S. on that day. The high concentration of CO (yellow), indicating a smoke plume, over northern New Mexico on June 18 (Figure 86) is particularly clear in this imagery. By June 19, the CO plume has been transported northeast with a signature of smoke present in the Mississippi Valley moving northward (Figure 87). By the time this specific plume reaches the Ohio valley on June 20 (Figure 88), concentrations have increased and are seen as higher values along the Lake Michigan border states.

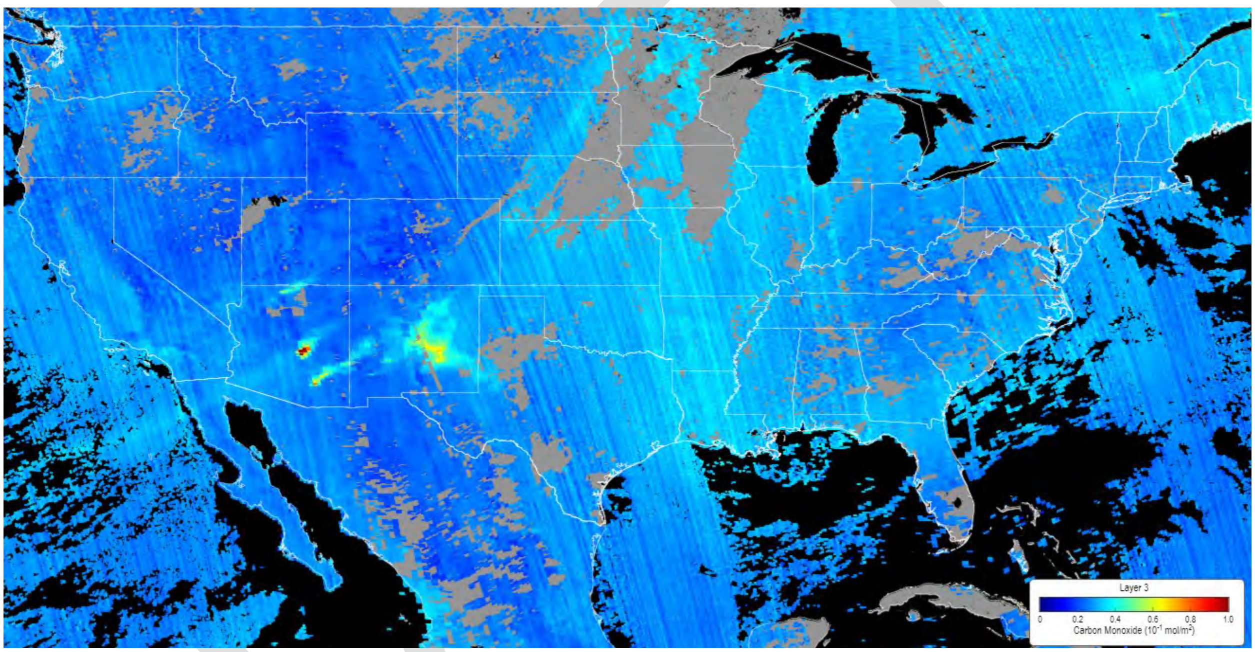

Figure 86. TROPOMI CO Measurement for June 18, 2020

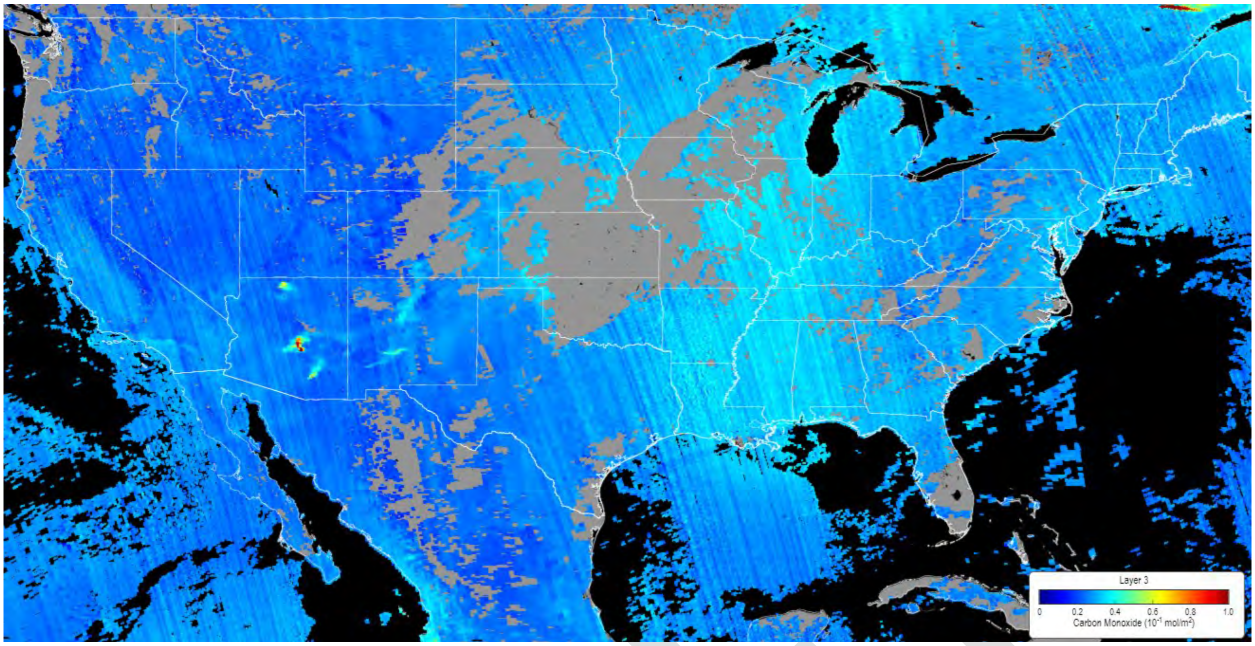

Figure 87. TROPOMI CO Measurement for June 19, 2020

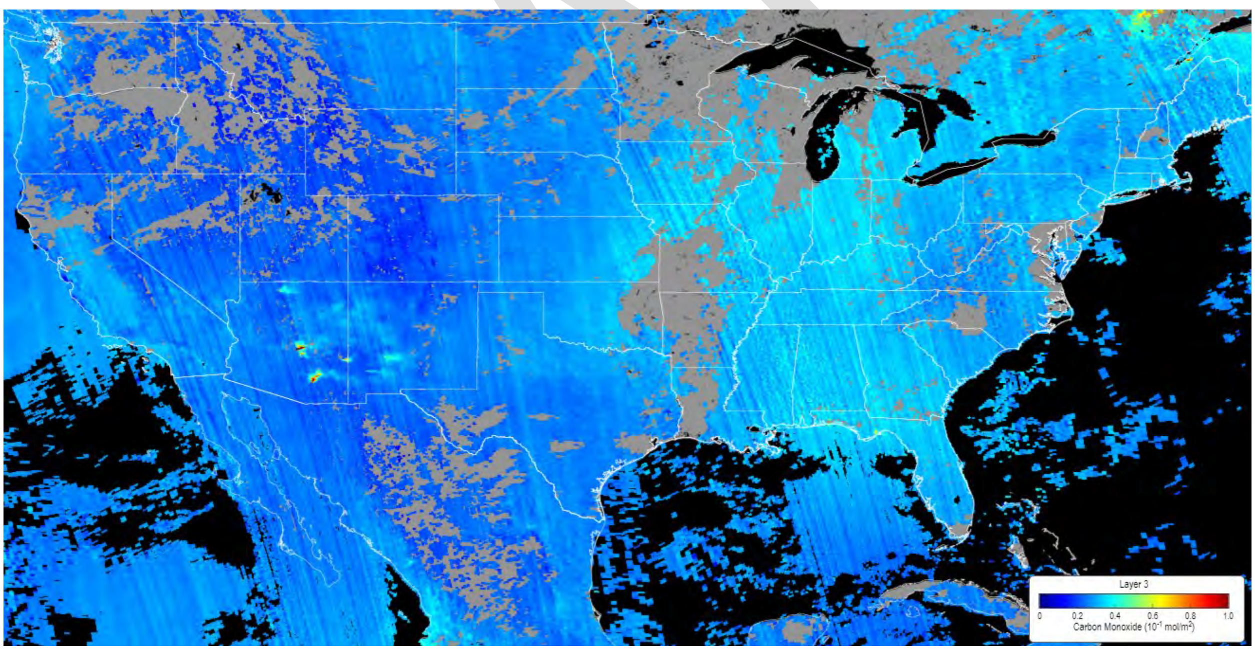

Figure 88. TROPOMI CO Measurement for June 20, 2020

Additionally, TROPOMI retrievals of tropospheric NO_2 (Figure 89 through Figure 92) 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.

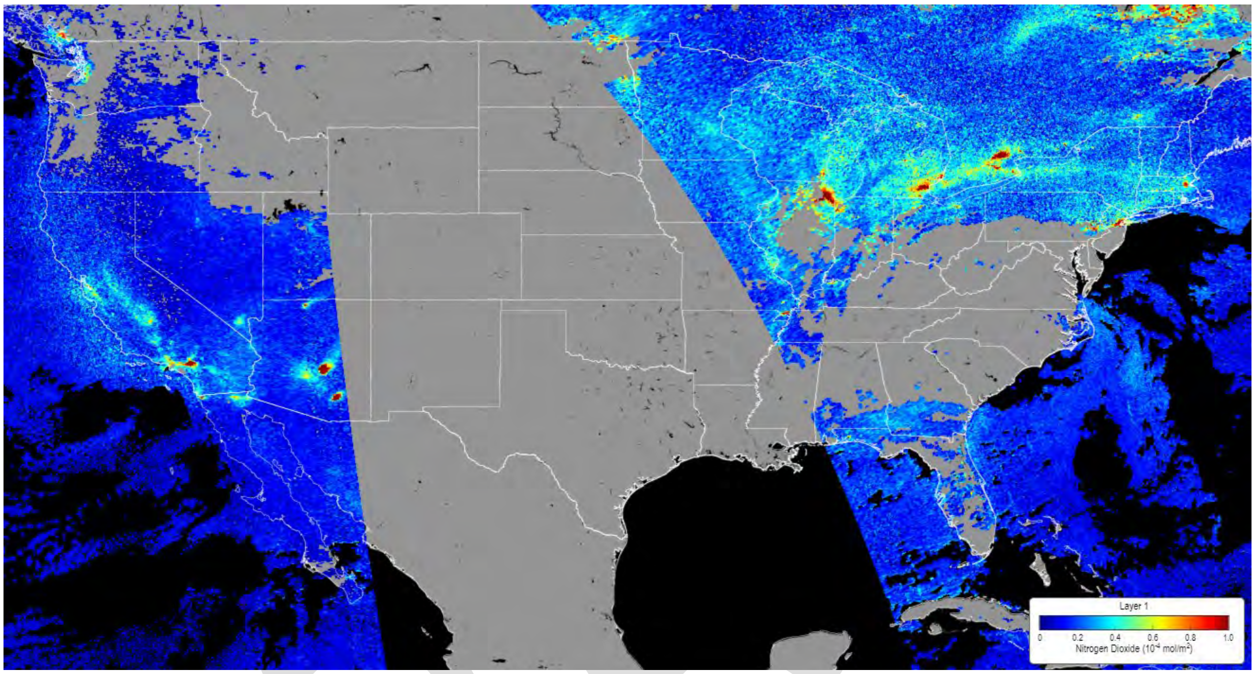

Figure 89. TROPOMI Nitrogen Dioxide Tropospheric Column for June 17, 2020.

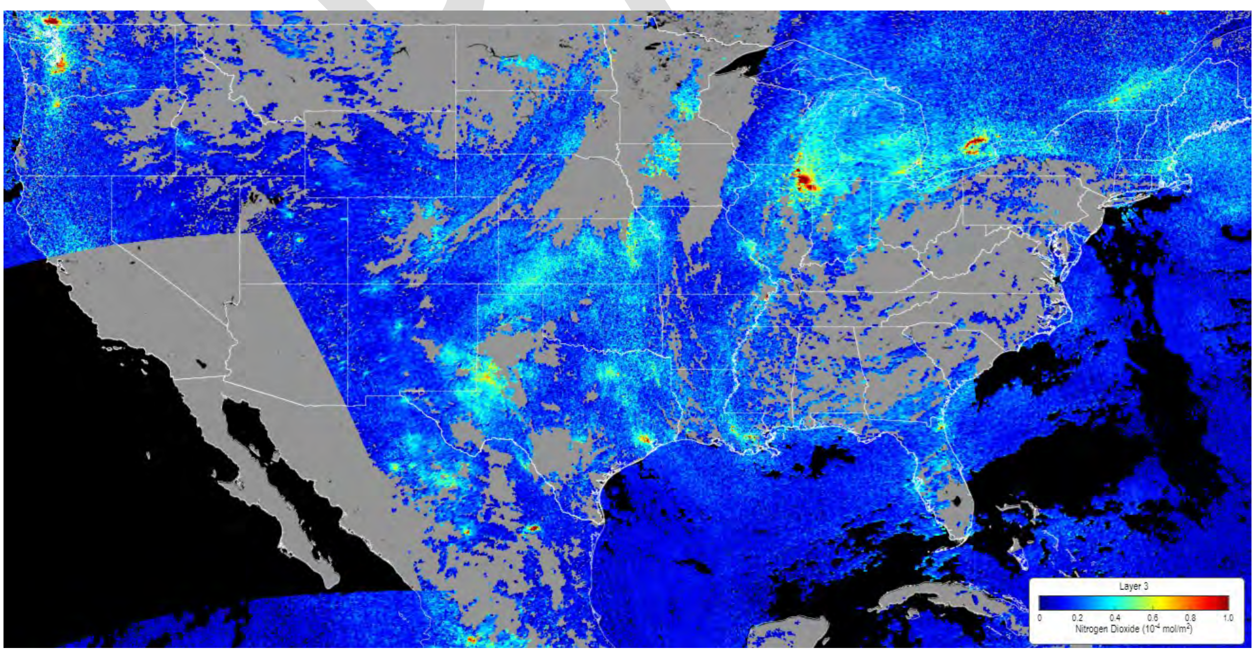

Figure 90. TROPOMI Nitrogen Dioxide Tropospheric Column for June 18, 2020.

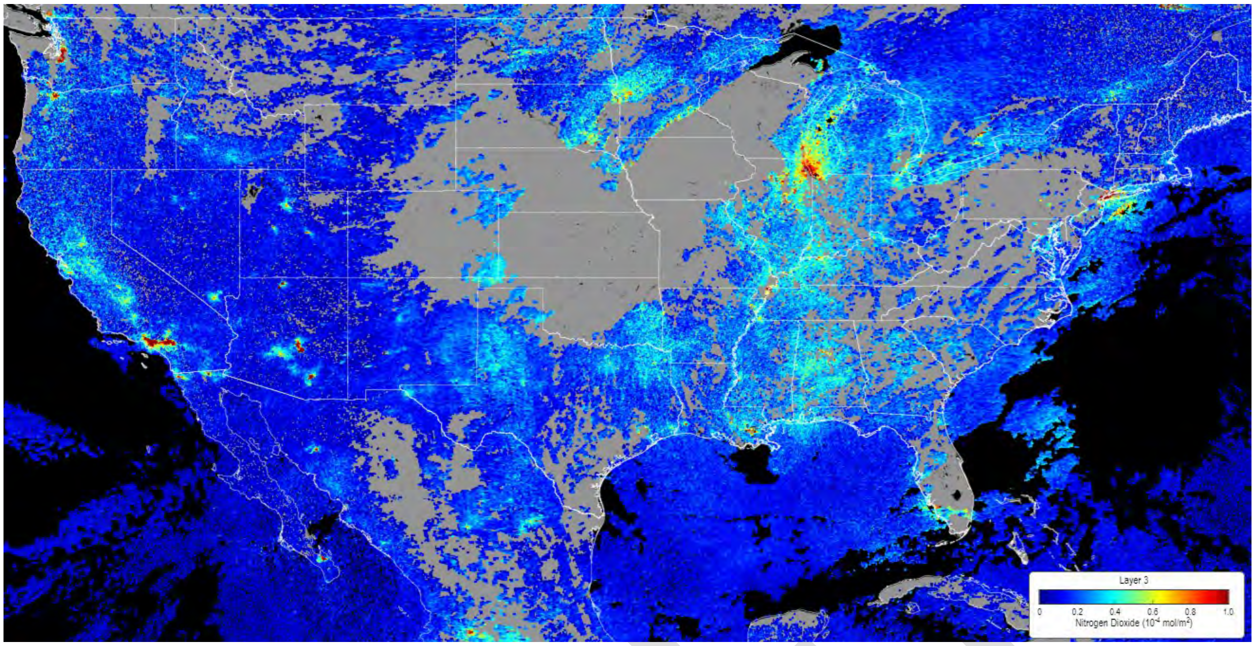

Figure 91. TROPOMI Nitrogen Dioxide Tropospheric Column for June 19, 2020.

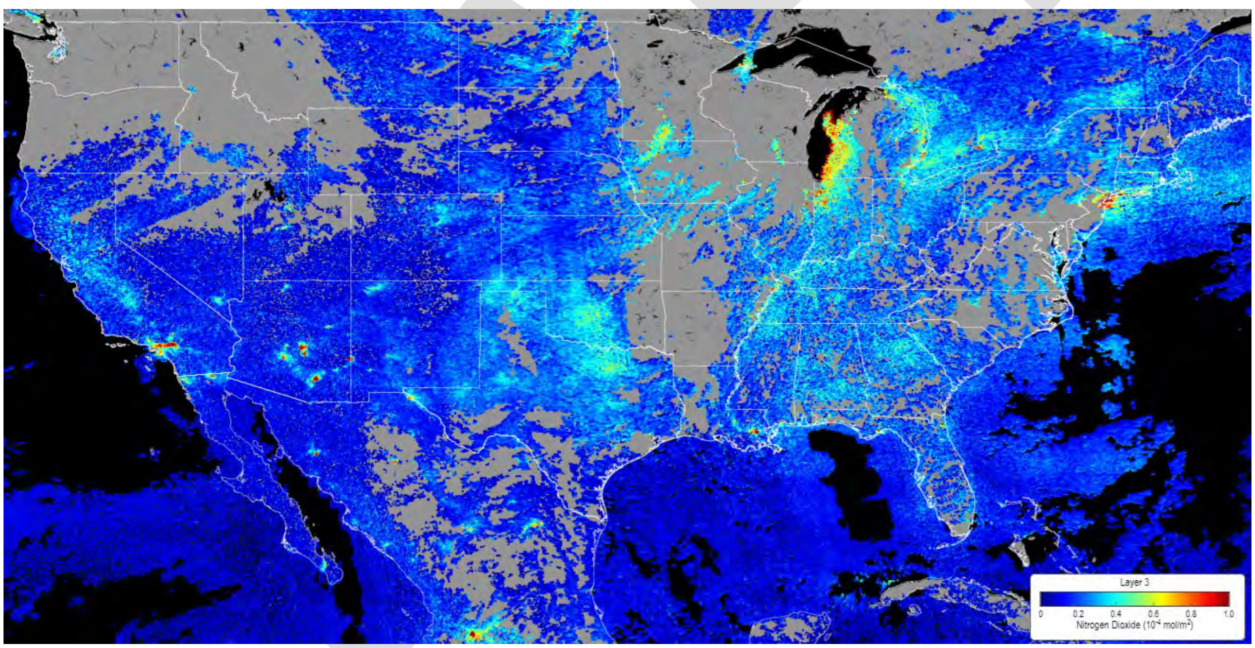

Figure 92. TROPOMI Nitrogen Dioxide Tropospheric Column for June 20, 2020.

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, Grand Rapids, and upper peninsula located Seney (26-153-0001) 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, Holland, and Coloma monitors were the only to have regulatory significance at this time. 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 93 to spike at the Muskegon monitor between June 17-20, 2020. As shown in Figure 94, these observations are consistent with the Holland monitor and in Figure 95 with the Coloma monitor during the smoke impact events.

The Grand Rapids (Figure 96) and Seney (Figure 97) monitors also experienced a noted increase in daily maximum and average 1-hour ozone in the days of the smoke impact events indicating broad geographic effects from the plumes.

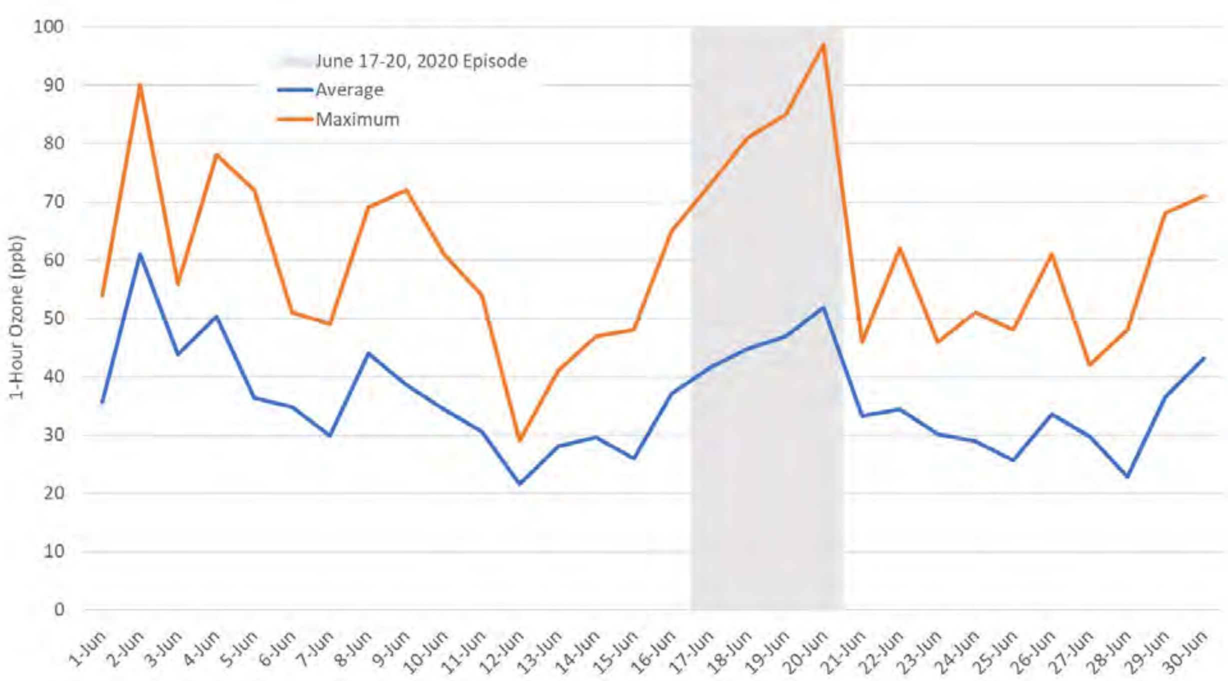

Figure 93. Average and maximum 1-hour ozone concentrations June 2020 at the Muskegon monitor.

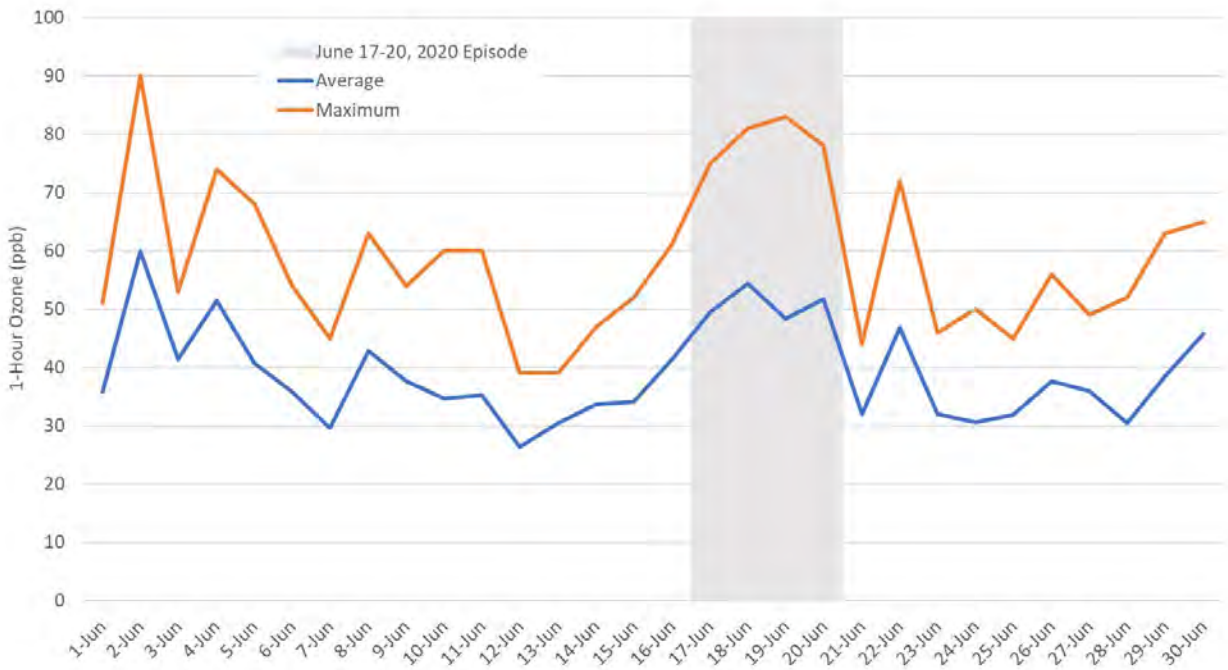

Figure 94. Average and maximum 1-hour ozone concentrations June 2020 at the Holland monitor.

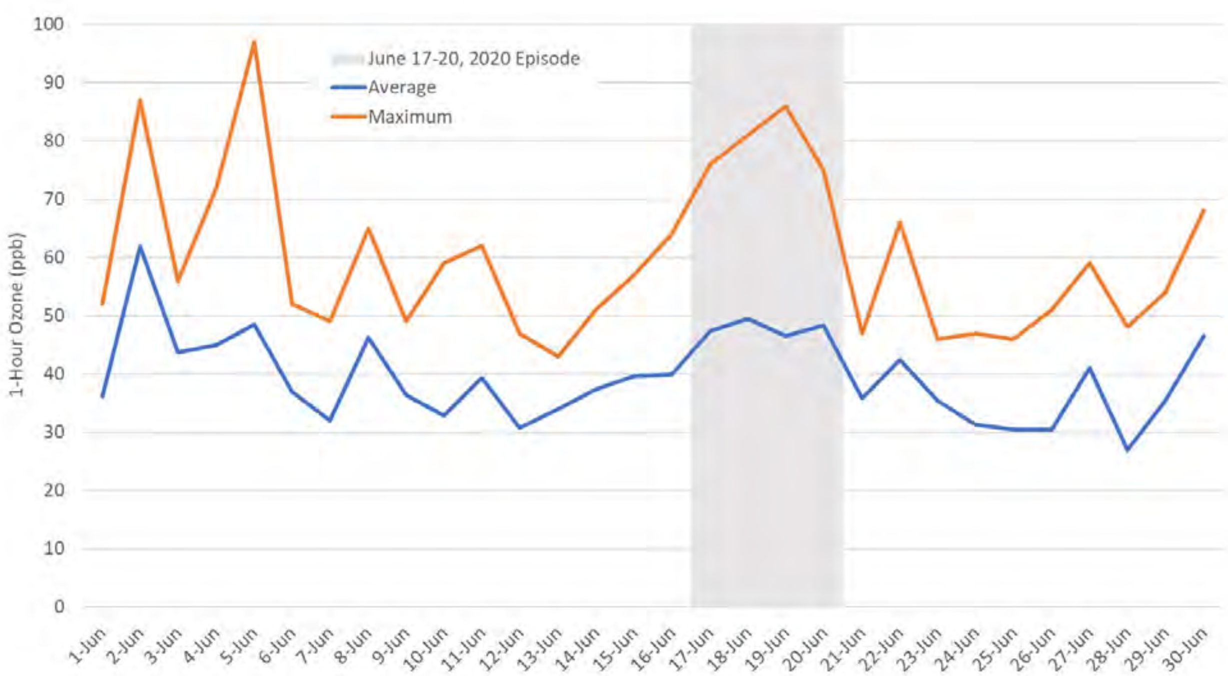

Figure 95. Average and maximum 1-hour ozone concentrations June 2020 at the Coloma monitor.

Figure 96. Average and maximum 1-hour ozone concentrations June 2020 at the Grand Rapids monitor.

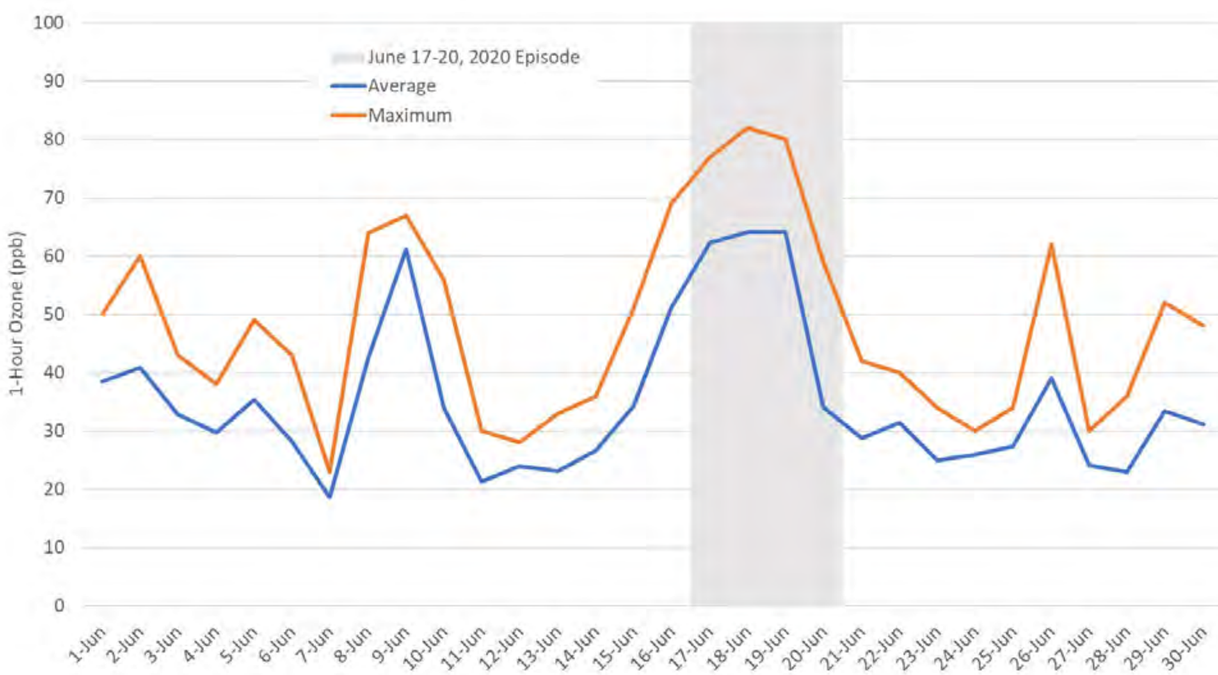

Figure 97. Average and maximum 1-hour ozone concentrations June 2020 at the Seney monitor.

The Holland (Figure 98), Grand Rapids (Figure 99), and northern Seney (Figure 100) monitors also experienced increases in daily maximum and average 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.

We see the multi-day buildup of ozone and PM2.5 concentrations at these monitors consistent with the earlier demonstration of increasing smoke presence in the days leading up to the June 17-20, 2020 episode days.

A Saharan dust impact event is also observed in the PM2.5 observations in late June 2020. As is shown in these figures, this well documented[44,45] dust cloud arrived from the Gulf of Mexico region and caused significantly high PM2.5 concentrations in parts of Michigan.

Figure 98. Average and maximum 1-hour PM2.5 concentrations June 2020 at the Holland monitor.

44 https://www.wxyz.com/news/saharan-dust-migrating-toward-the-great-lakes
45 https://earthsky.org/earth/saharan-dust-cloud-us-sunsets-june2020

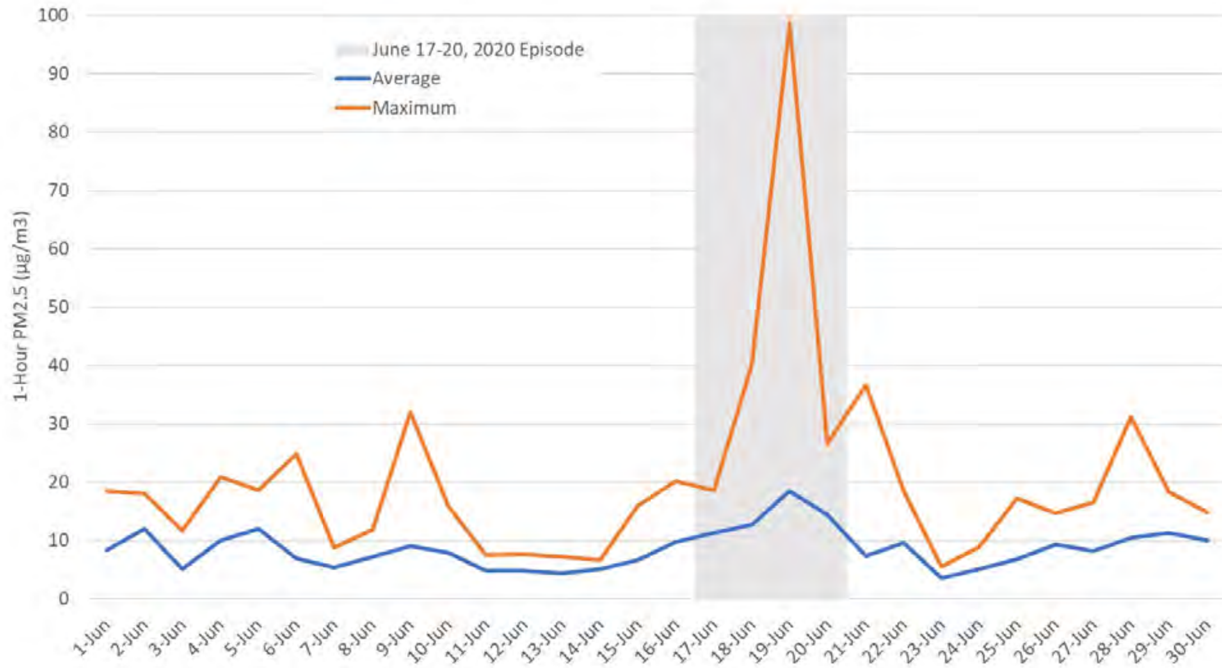

Figure 99. Average and maximum 1-hour PM2.5 concentrations June 2020 at the Grand Rapids monitor.

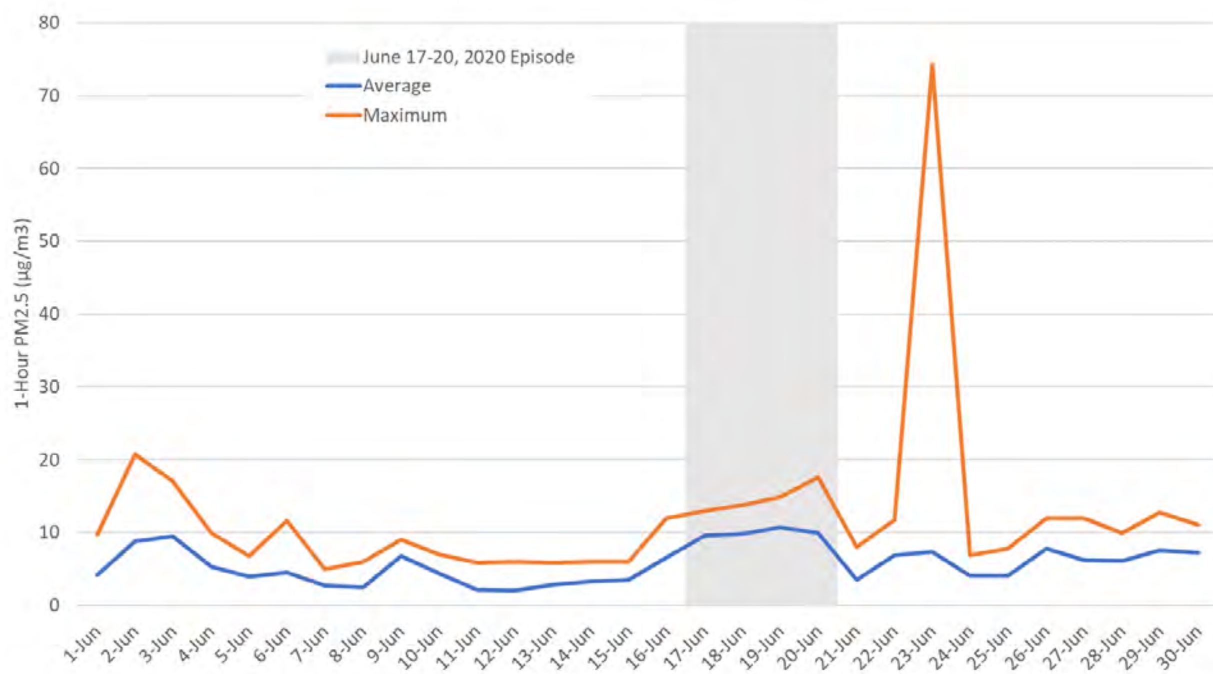

Figure 100. Average and maximum 1-hour PM2.5 concentrations June 2020 at the Seney monitor.

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 between June 17-20, 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.[46]

Particularly on June 17 and 20, 2020 (days that are part of the three-day observation schedule), the magnitude of K+ was the highest for the month of June at the Grand Rapids (Figure 101) monitor, demonstrating influence by the wildfire smoke in the geographic area. A highest peak is noted on July 4, 2020 associated with fireworks displays.

Figure 102 shows that K+, along with OC (Figure 103), increased around the time of the elevated ozone during the June 17-20, 2020 episode at the Allen Park monitor, days in which smoke was 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 104.

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.

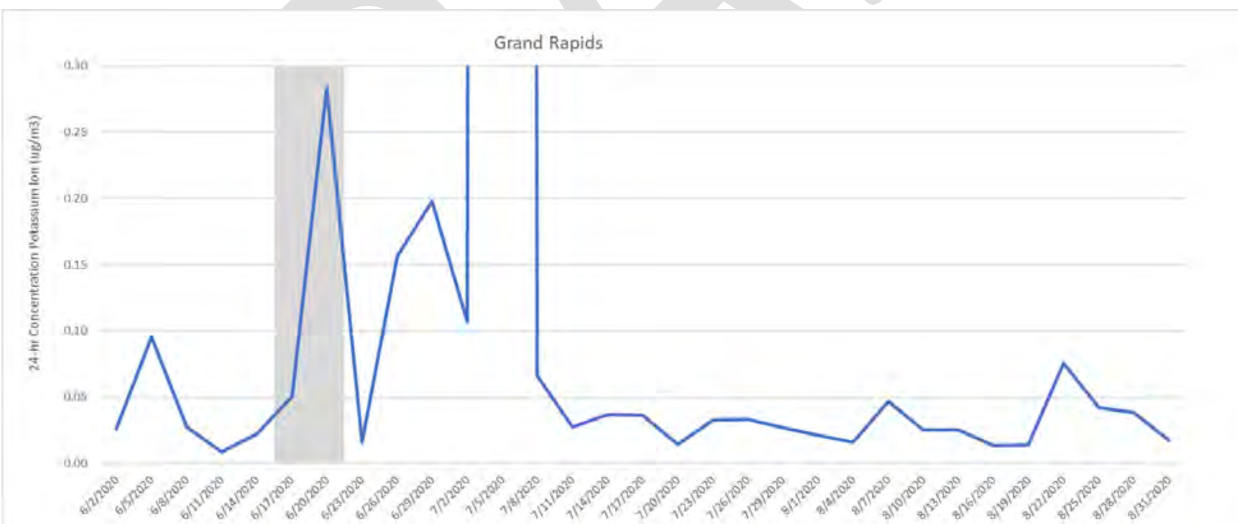

Figure 101. 24-hour K+ Concentration June-August 2020 at the Grand Rapids Monitor.

[46] 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.

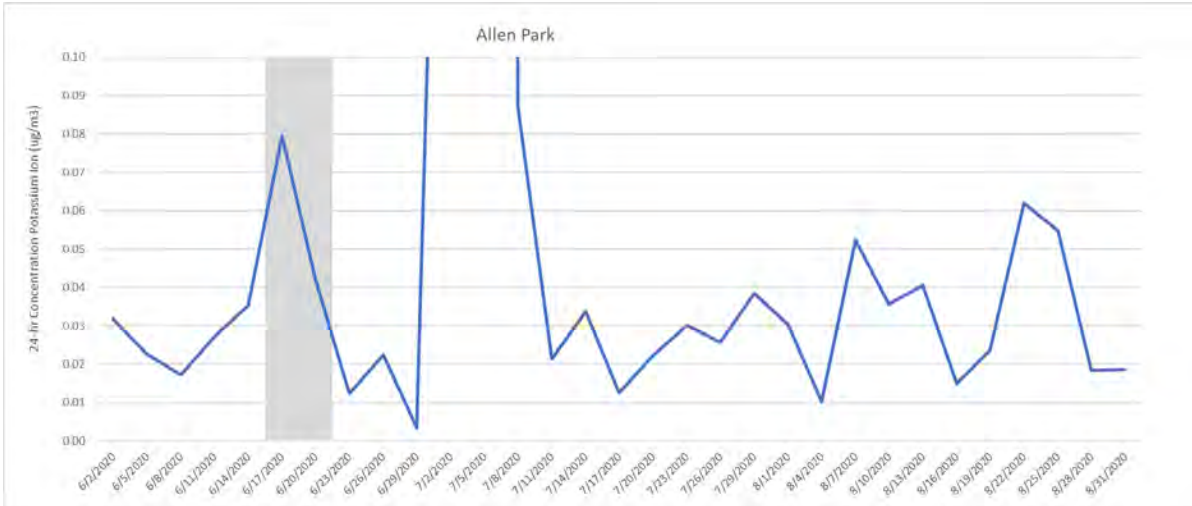

Figure 102. 24-hour K+ Concentration June-August 2020 at the Allen Park Monitor.

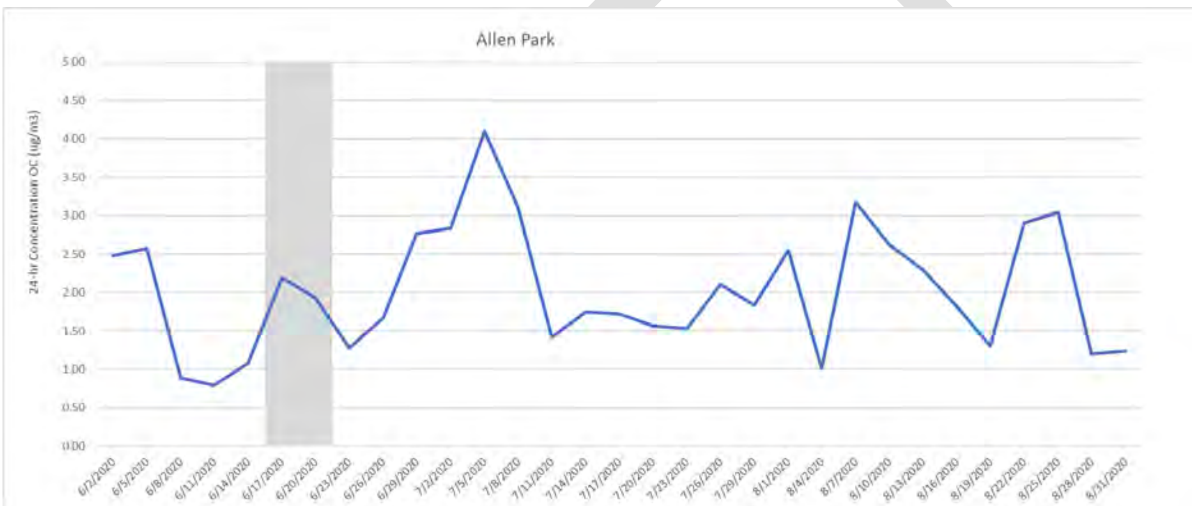

Figure 103. 24-hour OC Concentration June-August 2020 at the Allen Park Monitor.

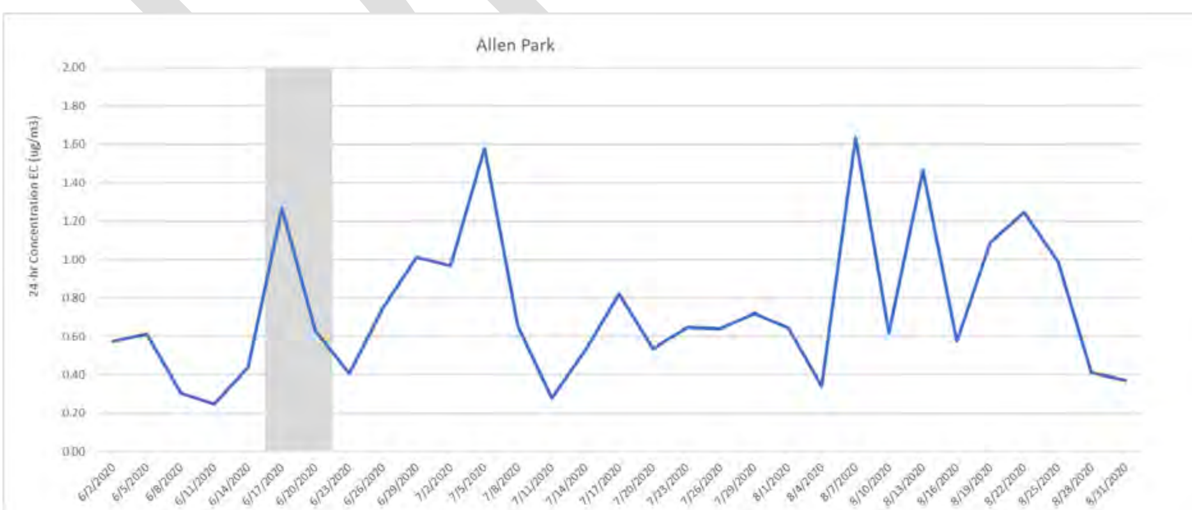

Figure 104. 24-hour EC Concentration June-August 2020 at the Allen Park Monitor.

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.

June 17-20, 2020 at the Muskegon, Holland, and Coloma 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 June 17-20, 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, surface maps show high-pressure system-dominated meteorological conditions during the June 17-20, 2020 event with a surface level wind direction shift from the east-northeast to the west-southwest during the days of the episode. Moving through the episode period, meteorological conditions indicated the transport of air from the east-northeast until June 19 and 20, 2020 when air stagnation and light surface winds were observed and the local airmass initiated a recirculation pattern. Maximum temperatures rose during the event period, peaking on June 20.

For each of three monitors, a set of ranges across multiple meteorological conditions that were reported during the episode of June 17-20, 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 (^{o}F), average wind speed (mph), wind direction (degrees), and relative humidity (%) between 9 AM and 9 PM generated the values in Table 9 for inclusion in the analyses.

Table 9. Meteorological Conditions for Comparison by Monitor

Monitor	Local Airport	Max Temp Range (^{o}F)	Wind Speed Range (Avg mph)	Wind Dir Range (degrees)	Average Relative Humidity Range (%)
Muskegon	MKG	80-90	< 5.0 mph	220-300	55-65
Holland	BIV	80-90	< 5.0 mph	220-300	50-60
Coloma	BEH	80-90	< 5.0 mph	160-260	50-60

Using the meteorological ranges presented in Table 9, 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 10, Table 11, and Table 12 below.

From the list of all days from 2016-2020, ten 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 10 along with conditions on June 17-20, 2020 (highlighted in bold font).

Of these days, only one, June 8, 2020, had an MDA8 ozone observation above 60 ppb. Six of the days had MDA8 values less than 50 ppb, and three of the days had MDA8 observations below 35 ppb. On average, these ten days had an MDA8 ozone concentration of 45 ppb, 31 ppb lower than the June 18, 2020 MDA8 value at the monitor and 38 ppb lower than the 83 ppb observed on June 20, 2020. Average maximum temperature across the ten days was 84°F, average wind speed was 4.6 mph out of the southwest (214 degrees) and average relative humidity was 55%. Skies were reported as mainly clear with some broken and scattered cloud days observed.

Table 10. 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
7/5/2017	57	83	4.7	226	59	CLR
7/7/2018	44	80	5.0	242	52	M
7/14/2019	33	85	3.6	248	50	M
7/31/2019	29	80	5.0	225	58	CLR
8/13/2019	32	85	4.9	199	56	CLR
6/8/2020	66	87	4.8	179	50	M
6/28/2020	43	85	3.6	215	59	FEW
7/1/2020	59	89	4.8	184	55	BKN
7/4/2020	37	89	4.8	229	59	FEW
7/14/2020	48	81	4.8	190	57	M
6/17/2020	**69**	**82**	**4.9**	**239**	**60**	**FEW**
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**
Average without 6/17 – 6/20	**45**	**84**	**4.6**	**214**	**55**	**M**

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 11 along with conditions on June 17-20, 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 53 ppb, 17 ppb lower than the June 17, 2020 MDA8 value at the monitor and 26 ppb lower than the 79 ppb observed on June 19, 2020. Average maximum temperature for the three days was 84^{o}F, average wind speed was 4.0 mph out of the west (265 degrees) and average relative humidity was 56%. Skies were reported as clear across all days.

Table 11. Comparable Meteorological Day Analysis: MDA8 Ozone Levels at Holland Monitor and Associated Meteorological Conditions at BIV

Date	Holland MDA8 (ppb)	Max Temp (^{o}F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
6/18/2016	57	86	3.7	280	59	CLR
6/14/2018	55	81	4.0	277	58	CLR
7/11/2018	48	85	4.2	237	51	CLR
6/17/2020	**70**	**83**	**3.5**	**265**	**57**	**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**
Average without 6/17 – 6/20	**53**	**84**	**4.0**	**265**	**56**	**CLR**

From the list of all days from 2016-2020, eight days met the meteorological range for the Coloma monitor comparison. A list of those days, the observed MDA8 ozone observations at the monitor and meteorological observations at BEH are presented in Table 12 along with conditions on June 17-20, 2020 (highlighted in bold font).

Two of the days, August 4, 2016 and July 18, 2017 had MDA8 ozone concentrations of 69 ppb. All the other days had MDA8 values ranging from 56 ppb to 61 ppb. The average MDA8 ozone concentration for these comparable meteorological days is 61 ppb, 11 ppb lower than MDA8 on June 20, 2020 and 18 ppb lower than the 79 ppb MDA8 on June 18, 2020. Average maximum temperature across the eight days was 83^{o}F, average wind speed was 3.0 mph out of the west-southwest (238 degrees) and average relative humidity was 63%. Skies were reported as clear across all days.

Table 12. Comparable Meteorological Day Analysis: MDA8 Ozone Levels at Coloma Monitor and Associated Meteorological Conditions at BEH

Date	Coloma MDA8 (ppb)	Max Temp (^{o}F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
6/18/2016	60	85	3.1	238	55	CLR
8/4/2016	69	91	3.7	232	62	CLR
8/9/2016	59	84	3.0	262	63	CLR
7/5/2017	60	85	3.7	221	59	CLR
7/6/2017	60	86	4.2	264	63	CLR
7/18/2017	69	82	3.1	268	63	CLR
9/26/2017	61	90	4.9	229	64	CLR
6/26/2019	56	84	3.0	225	63	CLR
6/17/2020	**73**	**83**	**3.0**	**238**	**63**	**CLR**
6/18/2020	**79**	**82**	**2.9**	**275**	**63**	**CLR**
6/19/2020	**78**	**88**	**2.7**	**292**	**60**	**CLR**
6/20/2016	**72**	**88**	**8.1**	**233**	**63**	**CLR**
Average without 6/17 – 6/20	**61**	**85**	**3.6**	**244**	**62**	**CLR**

Based on the similar day analysis, no other day since 2016 which had similar meteorological characteristics produced similar levels of ozone at any of the three monitor locations analyzed. Of the days selected for comparison, only two came within a few ppb to measured exceedances of 71 ppb and most days had ozone levels 10 to 30 ppb lower than were observed between the episode days of June 17-20, 2020.

This evidence suggests the June 17-20, 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 June 17-20, 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, Holland, and Coloma monitors. A list of those days and meteorological conditions is presented in Table 13, Table 14, and Table 15. June 17-20, 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 days of June 17-20, 2020, twenty-two 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 seventeen 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 across both sets of days in Table 9 (smoke enhanced and non-enhanced) is identical at 84 ^{o}F, average wind speed is similarly moderate (6.2 mph for smoke enhanced days and 6.7 mph for non-enhanced days), and wind direction is typically out of the S-SSW across both sets of days.

Table 13. Comparison of Meteorology and MDA8 Ozone Levels at Muskegon on Typical Non-Event Ozone Exceedance Days

Date	MDA8 (ppb)	Max Temp (^{o}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

Date	MDA8 (ppb)	Max Temp (°F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
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 days of June 17-20, 2020, twenty-seven 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-two 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 (6.1 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 14. Comparison of Meteorology and MDA8 Ozone Levels at Holland on Typical Non-Event Ozone Exceedance Days

Date	MDA8 (ppb)	Max Temp (°F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
4/16/2016	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

Date	MDA8 (ppb)	Max Temp (°F)	Wind Speed (Avg mph)	Wind Dir (degrees)	Average Relative Humidity (%)	Sky
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
6/17/2020	**70**	**83**	**3.5**	**265**	**57**	**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

Finally, at the Coloma monitor, excluding the episode days of June 17-20, 2020, there were also twenty-seven days found to have an MDA8 value of greater than 70 ppb between 2016-2020. Of those days, ten were found to be absent of regional HMS smoke coverage on or in the previous 48-hours. The average MDA8 value across the seventeen exceedance days with potential smoke enhancement is 74 ppb. On days where no smoke was observed in the HMS smoke product, the average MDA8 value was 76 ppb. The calculated average maximum temperature on potential smoke enhanced days is 88 °F, while the average maximum temperature on typical non-smoke ozone exceedance days is 82 °F. Average wind speed is similarly moderate (5.2 mph for smoke enhanced days and 5.0 mph for non-enhanced days and wind direction is typically out of the SW across both sets of days.

Table 15. Comparison of Meteorology and MDA8 Ozone Levels at Coloma 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	79	77	3.2	173	42	CLR
4/18/2016	77	77	3.3	129	49	CLR
5/23/2016	71	80	3.7	174	54	CLR
5/24/2016	82	83	5.2	242	43	CLR
6/10/2016	78	91	5.7	219	53	CLR
6/11/2016	74	88	6.3	268	56	CLR
6/15/2016	79	86	3.9	242	72	CLR
6/19/2016	76	89	4.9	254	53	CLR
6/20/2016	72	88	8.1	233	63	CLR
6/25/2016	74	87	5.4	161	56	CLR
6/30/2016	73	80	5.6	263	55	CLR
6/4/2017	71	85	5.5	238	64	CLR
6/9/2017	74	77	4.8	240	56	CLR
6/15/2017	73	82	6.0	259	75	CLR
5/25/2018	76	85	5.4	234	56	CLR
5/27/2018	73	90	3.8	272	70	CLR
5/28/2018	78	95	4.0	196	64	CLR
5/29/2018	73	90	3.3	187	73	CLR
5/31/2018	77	86	6.8	242	70	CLR
6/15/2018	71	86	3.9	158	60	CLR
7/9/2018	73	86	5.8	241	64	CLR
7/13/2018	72	88	5.1	243	59	CLR
7/2/2019	74	91	6.3	254	70	CLR
7/10/2019	71	91	5.4	243	77	CLR
6/2/2020	82	89	9.4	208	51	CLR
6/5/2020	85	83	4.4	270	84	CLR
6/17/2020	**73**	**83**	**3.0**	**238**	**63**	**CLR**
6/18/2020	**79**	**82**	**2.9**	**275**	**63**	**CLR**
6/19/2020	**78**	**88**	**2.7**	**292**	**60**	**CLR**
6/20/2020	**72**	**91**	**5.6**	**220**	**57**	**CLR**
7/25/2020	71	86	3.3	287	79	CLR

While the analysis presented for Holland and Coloma based on Table 14 and Table 15 are not as conclusive as for Muskegon, we present further analysis of the rates of ozone formation for both potentially smoke-enhanced and non-smoke days that more definitively indicate a significant smoke influence on all three monitors.

Figure 105, Figure 106, and Figure 107 below present averaged diurnal profiles of 1-hour ozone for the June 17-20, 2020 episode days and the potential smoke enhanced and typical exceedance days listed in Table 13, Table 14, and Table 15 for the Muskegon, Holland, and Coloma 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 averaged June 17-20, 2020 episode (green line), as well as the hourly difference between the smoke enhanced days (grey bar) and June 17-20, 2020 episode (green bar) compared to typical non-event exceedance observations.

The buildup of smoke-enhanced ozone is clearly seen in Figure 105 where a distinctly greater gradient of ozone change occurs between the early morning hours (hours 0 – 6) and dawn (hour 7). Ozone concentrations observed at the Muskegon monitor on June 18-20, 2020 (green line) are 14 ppb higher (green bar) than average typical non-event ozone exceedance day ozone observations (blue line) by late morning. This 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 this same period of the day, smoke enhanced observations (grey line) are consistently higher than averaged typical non-event ozone exceedance day hourly observations (blue line) but not as high as seen during this June 18-20, 2020 episode.

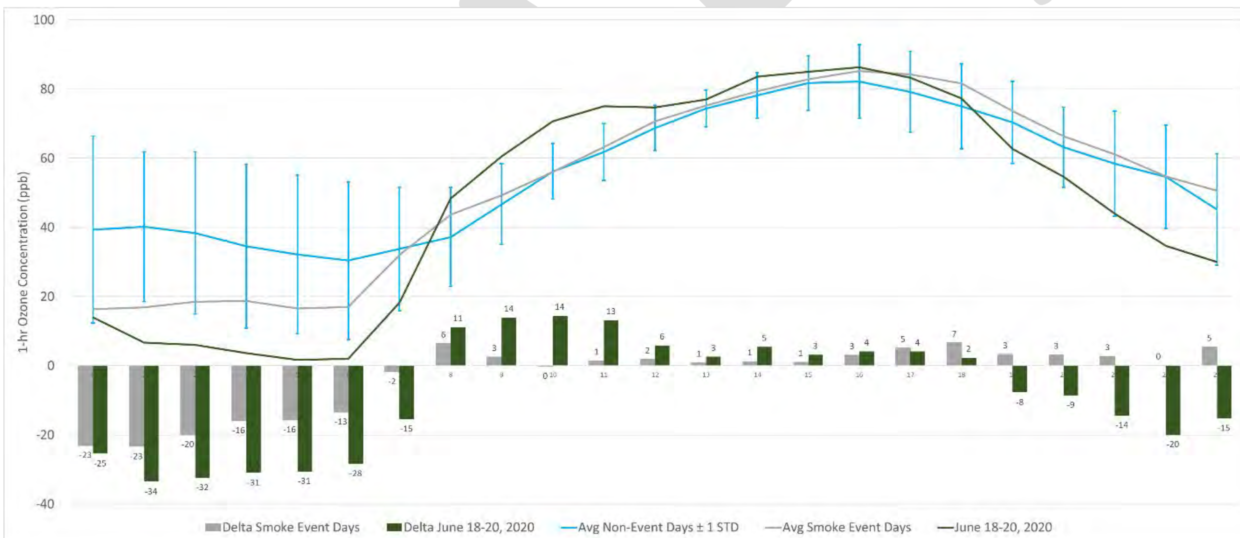

Figure 105. Diurnal ozone (ppb) profiles for Muskegon monitor.

Figure 106 presents similar conditions at the Holland monitor and shows the same buildup concentration during the early morning hours of June 17-20, 2020 and increased ozone formation in the morning hours of the day. Like the Muskegon monitor, morning differences in ozone measurements were greater than 13 ppb as photolysis in the morning sunlight hours formed ozone in higher concentrations than normal for a typical non-event ozone exceedance day.

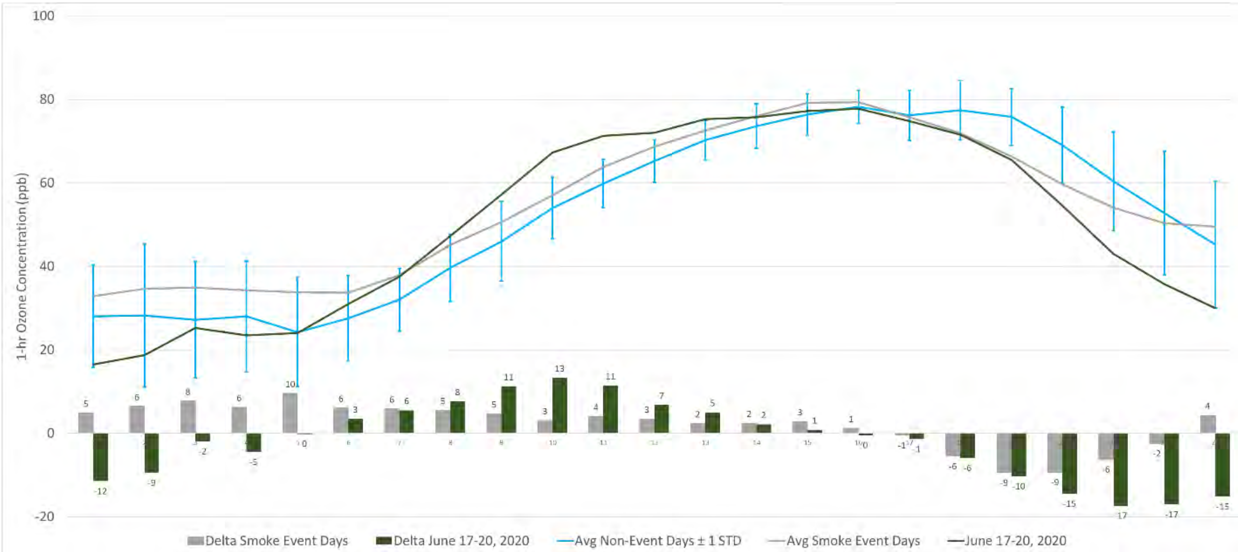

Figure 106. Diurnal ozone (ppb) profiles for Holland monitor.

Similarly, as seen in Figure 107, the Coloma monitor exhibits the concentration gradient during the morning hours of the June 17-20, 2020 event. In this figure, morning differences in ozone measurements were also greater than 13 ppb as photolysis in the morning sunlight hours formed ozone in higher concentrations than normal for either a typical non-event ozone exceedance day (blue line) or the averaged smoke enhanced event days (grey line).

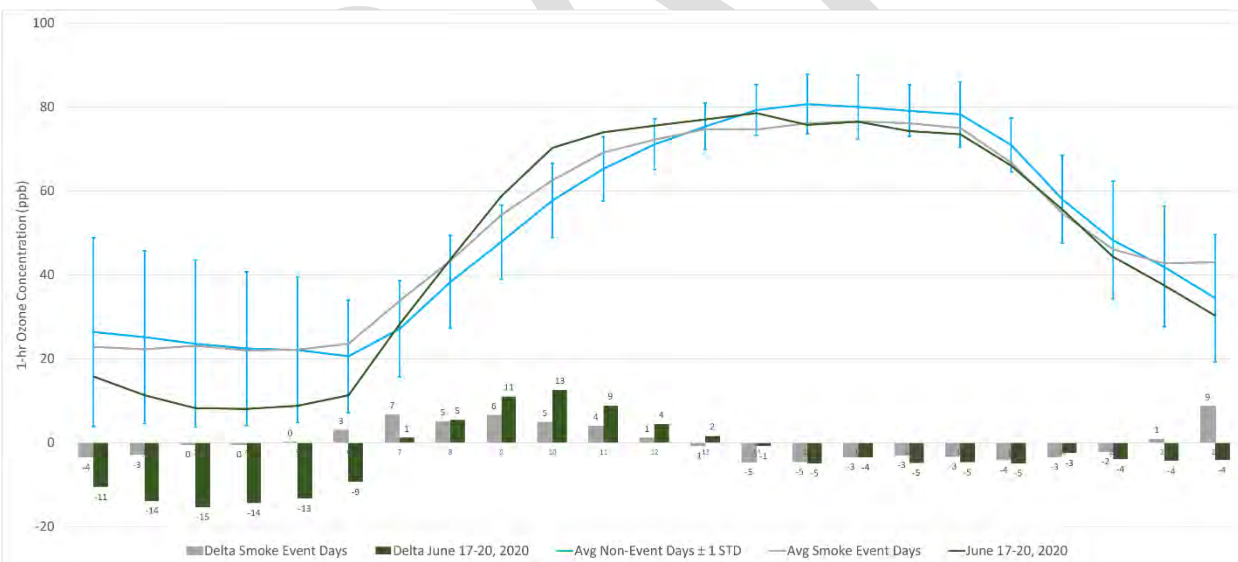

Figure 107. Diurnal ozone (ppb) profiles for Coloma monitor.

When these data are viewed from a multi-day buildup perspective, the data indicate that the buildup/carryover is more significant during the June 17-20, 2020 event (orange line) than during a typical non-event ozone exceedance (blue line). As seen in Figure 108, Figure 109, and Figure 110, the June 17-20, 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).

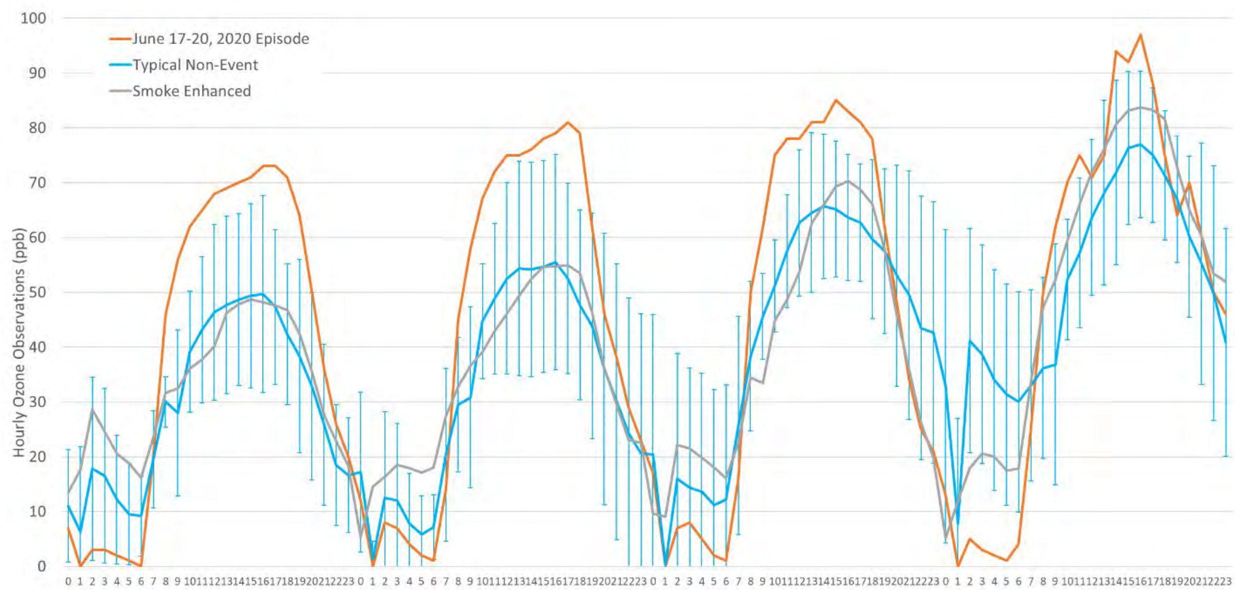

Figure 108. Multi-day diurnal ozone (ppb) profiles for Muskegon monitor.

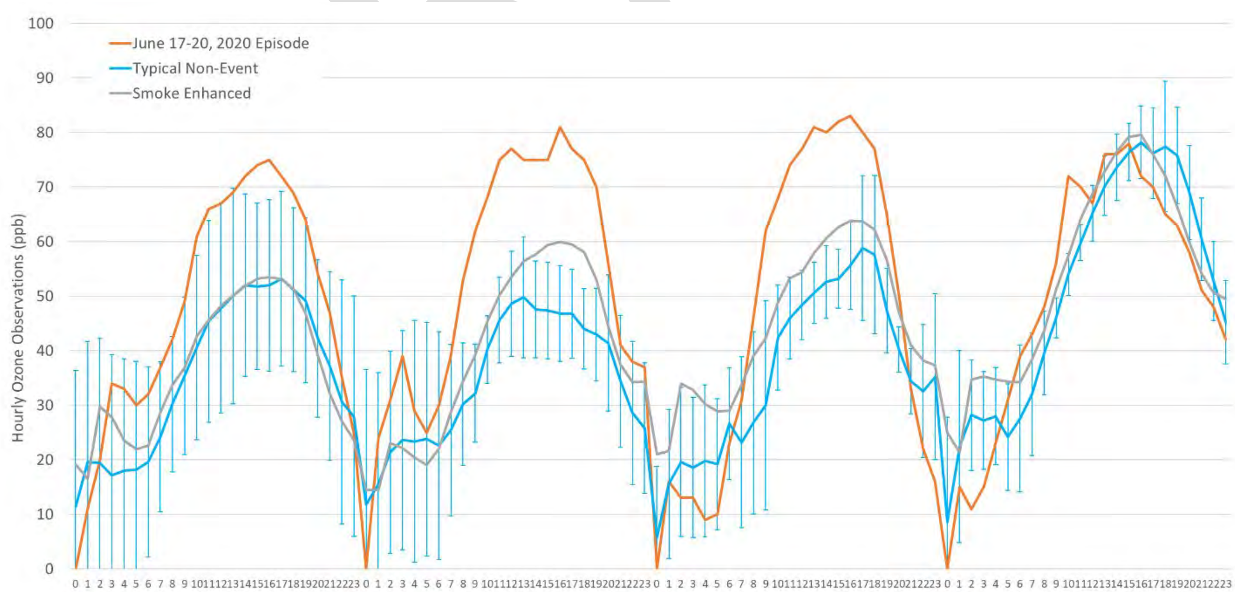

Figure 109. Multi-day diurnal ozone (ppb) profiles for Holland monitor.

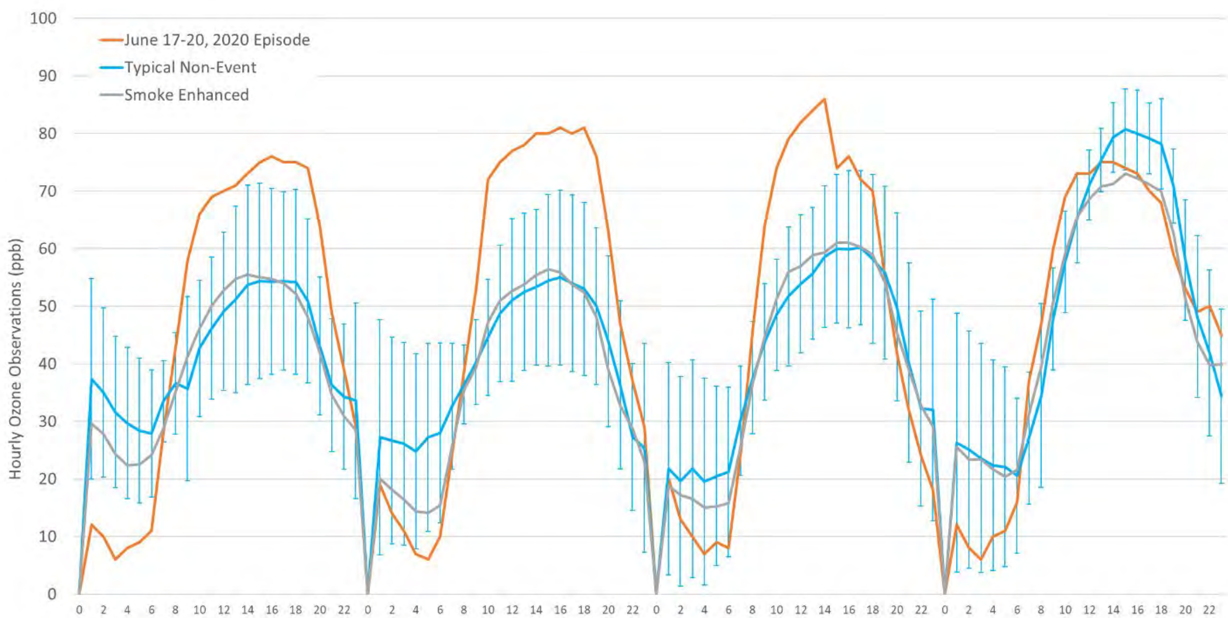

Figure 110. Multi-day diurnal ozone (ppb) profiles for Coloma monitor.

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 all three monitors. These data were also assigned the potentially enhanced and non-enhanced days classifications. Table 16 below provides a comparison with days on the three-day reporting cycle where observations were made for the PM2.5 species.

Table 16. Comparison of MDA8 Ozone and Key PM2.5 Species Concentrations

	MDA8 Ozone (ppb)			Grand Rapids			
Date	**Muskegon**	**Holland**	**Coloma**	**MDA8 (ppb)**	**K+ (µg/m^3)**	**EC (µg/m^3)**	**OC (µg/m^3)**
04/18/16	76	74	77	75	0.040	1.277	4.035
05/24/16	87	64	82	79	0.080	0.908	3.264
06/11/16	68	79	74	69	0.010	0.289	1.350
06/20/16	59	68	72	62	0.050	-	-
06/09/17	71	68	74	68	0.020	0.668	2.598
06/12/17	82	74	60	62	0.010	0.609	2.737
06/15/17	63	74	73	63	0.010	0.404	1.798
05/29/18	77	73	73	75	0.010	0.881	3.981
07/13/18	86	77	72	71	0.010	1.006	5.354
07/02/19	57	73	74	55	0.060	0.564	2.020
06/02/20	83	81	82	83	0.026	0.543	2.843
06/05/20	64	63	85	64	0.095	-	-
06/17/20	**69**	**70**	**73**	**78**	**0.051**	**-**	**-**
06/20/20	**83**	**72**	**72**	**76**	**0.284**	**1.120**	**3.833**
Smoke Enhanced	**76**	**72**	**74**	**73**	**0.067**	**0.914**	**3.636**
Typical Non-Event Exceedance	**70**	**72**	**75**	**66**	**0.037**	**0.558**	**2.399**

On days where smoke was present on or just before an observation (including June 17 and 20, 2020), K+ concentrations tended to be higher than on days when smoke was not seen in the region. As seen in Table 16, 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). On June 20, 2020, this value was measured at 0.284 µg/m^3, 4.2 times as high as the average measurements when smoke was present and 7.7 times higher than days when smoke was not observed.

From a long-term comparison perspective, K+ concentrations at the Grand Rapids monitor were the second highest values observed (omitting July 4th firework event dates) across the past five years. Figure 111 below presents this information and demonstrates that the episode event of June 17-20, 2020 (highlighted with a grey column) was only lower than measurements taken on November 25, 2018 (excluding July 4th observations each year) indicating the distinct conditions of this episode.

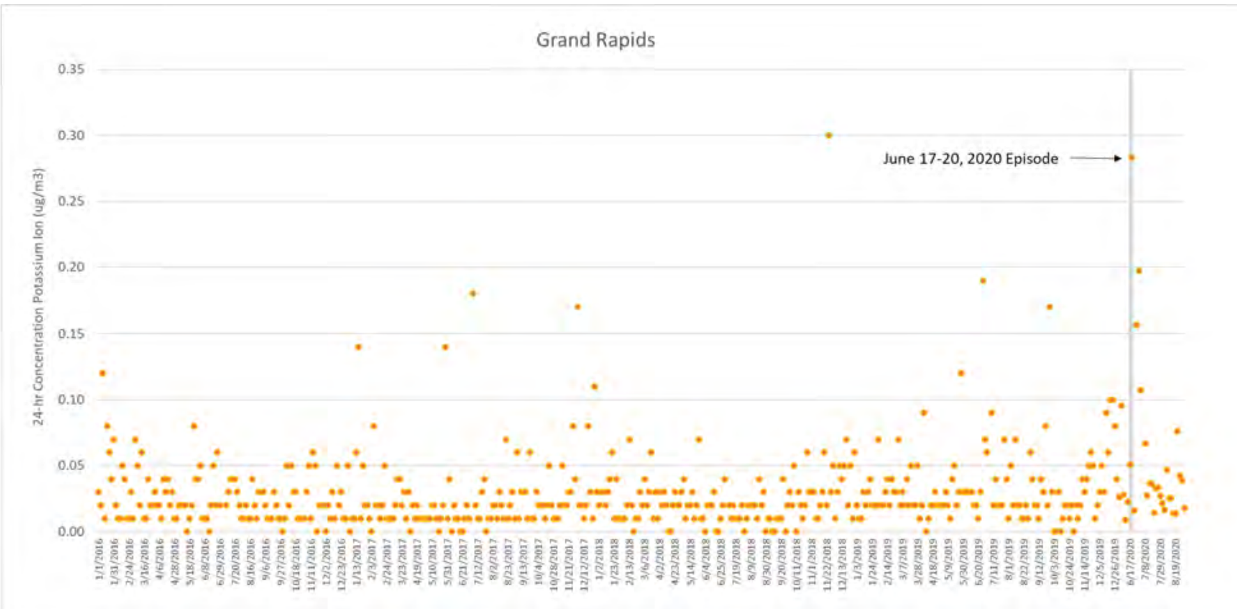

Figure 111. 24-hour K+ Concentration 2016- 2020 at the Grand Rapids Monitor.

Finally, a review of the regional scale of the episodes was conducted to differentiate the June 17-20, 2020 episode days from more typical non-event ozone exceedances.

Qualitatively, ozone episodes in western Michigan are caused by a natural lake-land breeze circulation pattern along the lakeshore of Lake Michigan. This pattern is driven by surface temperature gradients between the lake and the land. Areas in closer proximity to the lake shoreline display the most frequent and most elevated ozone concentrations and exceedances are limited to geographically proximal monitors along the lake.

During the June 17-20, 2020 episode, high ozone concentrations were observed across most of the state, not just along the lakeshore. Table 17 below provides a summary of the preliminary top ten MDA8 observations at each monitor in 2020. As is seen in this table, of the twenty-six monitors that had complete, preliminary 2020 ozone observations at the time of the development of this demonstration, fourteen of the monitors had all four days of the June 17-20, 2020 episode among the top ten MDA8 values. Twenty-four of the monitors had three or more of the four days from the June 17-20, 2020 episode within the top ten MDA8s. All represented monitors had at least one of the days from the June 17-20, 2020 episode among its top four MDA8 values.

The episode had a wide, regional impact beyond just the western Michigan NAAs of Muskegon, Allegan, and Berrien Counties, and further lends support to the conclusion that the influence of wildfire smoke created the ozone exceedances on June 17-20, 2020.

This collection of evidence suggests the June 17-20, 2020 exceedance event was influenced by factors not definitively explained by a typical, non-event exceedance day analysis.

Table 17. Preliminary top ten MDA8 ozone measurements from Michigan monitors in 2020. Episode days of June 17-20, 2020 highlighted in grey.

	Top Ten MDA8 Ozone - Date (MDA8)									
Monitor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
260050003	06/02 (81)	06/19 (79)	08/26 (78)	06/18 (76)	06/20 (72)	07/25 (72)	06/17 (70)	06/04 (68)	07/09 (67)	08/24 (66)
260190003	06/19 (91)	06/18 (78)	06/17 (69)	06/02 (68)	07/25 (65)	06/30 (64)	08/26 (64)	06/08 (63)	06/09 (63)	06/16 (61)
260210014	06/05 (85)	06/02 (82)	06/18 (79)	06/19 (78)	06/17 (73)	06/20 (72)	07/25 (71)	08/26 (70)	07/09 (68)	06/04 (67)
260370002	07/07 (68)	06/02 (67)	06/19 (65)	06/17 (64)	06/09 (63)	06/05 (61)	06/20 (61)	06/04 (60)	06/18 (59)	07/06 (59)
260490021	06/09 (78)	06/17 (69)	06/20 (68)	06/02 (67)	06/08 (67)	07/15 (67)	06/18 (66)	08/22 (66)	06/19 (65)	07/06 (65)
260492001	06/02 (70)	08/22 (69)	06/17 (68)	06/20 (68)	07/06 (68)	06/09 (67)	06/19 (66)	06/18 (65)	07/15 (65)	06/04 (63)
260630007	06/20 (85)	07/06 (83)	07/09 (78)	07/15 (75)	06/18 (74)	05/26 (72)	06/19 (72)	06/09 (67)	06/02 (64)	06/22 (64)
260650012	07/07 (64)	06/02 (62)	06/17 (62)	06/20 (62)	06/09 (61)	07/06 (61)	06/18 (59)	06/26 (57)	06/29 (56)	07/09 (56)
260650018	07/07 (64)	07/15 (63)	06/02 (62)	06/17 (62)	06/20 (62)	06/09 (61)	07/06 (61)	09/25 (60)	06/18 (59)	08/08 (59)
260770008	06/17 (75)	06/18 (74)	06/19 (73)	06/02 (72)	07/07 (72)	06/20 (70)	07/09 (69)	06/05 (67)	06/29 (65)	07/08 (65)
260810020	06/02 (83)	06/18 (80)	06/19 (79)	06/17 (78)	06/20 (76)	08/26 (72)	06/04 (69)	06/16 (69)	07/08 (69)	07/25 (68)
260810022	06/02 (76)	06/19 (72)	06/18 (71)	06/17 (70)	06/20 (66)	08/26 (65)	06/04 (64)	06/09 (63)	06/16 (60)	06/29 (57)
260910007	06/09 (77)	07/07 (71)	06/20 (68)	06/17 (67)	07/06 (65)	07/09 (65)	06/02 (64)	09/25 (64)	06/18 (63)	06/29 (63)
260990009	06/04 (78)	07/09 (76)	06/18 (75)	06/20 (74)	07/06 (74)	07/17 (74)	08/21 (74)	07/07 (73)	06/17 (72)	08/22 (72)
260991003	07/06 (77)	06/20 (71)	06/09 (70)	07/02 (70)	07/09 (70)	07/07 (69)	06/02 (67)	06/04 (67)	06/05 (64)	07/15 (64)
261050007	06/19 (89)	06/18 (74)	10/09 (74)	06/02 (68)	06/17 (68)	07/25 (68)	06/20 (63)	08/20 (63)	08/26 (63)	06/30 (62)
261130001	06/09 (72)	06/18 (69)	06/19 (69)	06/02 (68)	06/08 (65)	06/17 (65)	10/09 (64)	06/20 (61)	06/04 (60)	06/05 (60)
261210039	06/02 (83)	06/20 (83)	08/26 (83)	06/19 (80)	06/18 (76)	08/24 (72)	06/04 (70)	06/17 (70)	07/25 (70)	10/09 (67)
261390005	06/18 (85)	06/02 (81)	06/19 (77)	06/17 (75)	06/20 (73)	08/26 (73)	07/25 (70)	06/04 (67)	06/16 (66)	06/29 (66)
261470005	06/20 (72)	07/17 (70)	08/12 (70)	07/06 (69)	07/09 (69)	06/17 (68)	06/19 (68)	06/02 (67)	07/18 (67)	06/18 (66)
261530001	06/18 (80)	06/19 (76)	06/17 (73)	07/25 (67)	06/16 (65)	06/08 (63)	06/09 (62)	09/25 (62)	05/21 (60)	08/09 (57)
261579991	06/18 (71)	06/19 (71)	06/17 (70)	06/20 (67)	06/02 (66)	06/09 (65)	08/22 (65)	07/15 (63)	06/04 (62)	07/06 (62)
261610008	07/09 (74)	06/17 (73)	06/09 (72)	07/07 (72)	06/20 (71)	06/18 (67)	07/06 (67)	07/15 (67)	07/01 (66)	06/02 (65)
261619991	06/17 (78)	06/09 (72)	06/20 (68)	06/02 (67)	06/18 (67)	07/07 (66)	08/12 (62)	07/15 (61)	06/16 (60)	06/08 (59)
261630001	07/09 (73)	07/07 (71)	06/09 (70)	06/20 (70)	07/06 (69)	07/02 (68)	07/05 (66)	07/25 (66)	06/02 (65)	06/17 (65)
261659991	06/18 (70)	06/19 (69)	06/17 (68)	06/20 (67)	06/09 (66)	06/02 (64)	10/09 (64)	08/26 (61)	07/25 (60)	06/16 (59)

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 112 shows 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.

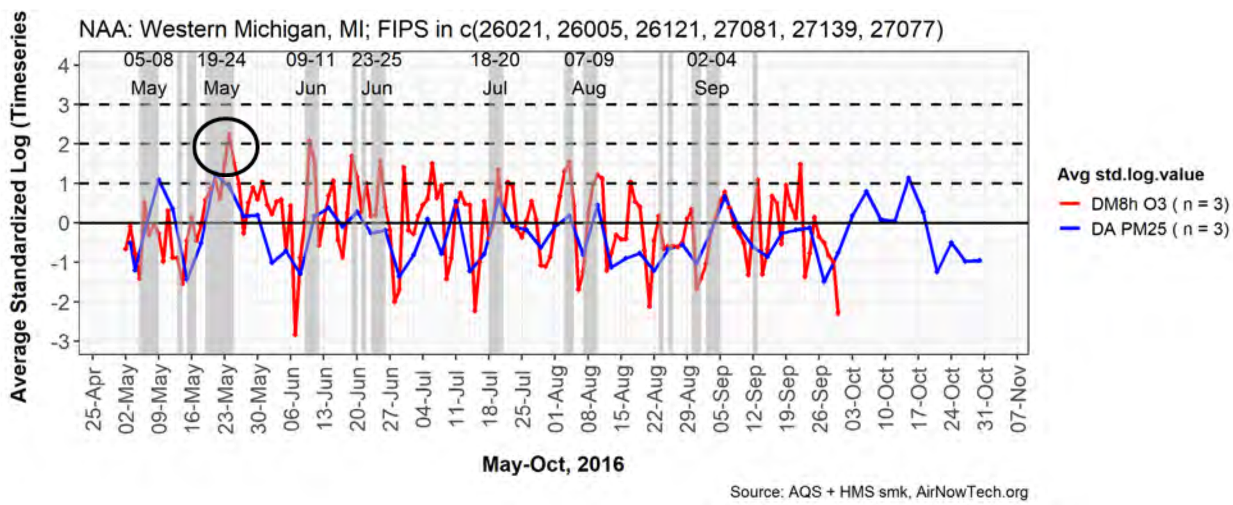

Figure 112. Average anomaly plots for the Standardized Log Timeseries of daily maximum 8-hour ozone and daily average 24-hour PM2.5 concentrations measured from the western Michigan Monitors based on historical Ozone Season Concentrations. Ft. McMurray wildfire episode circled in black.

The western Michigan anomaly plot in Figure 113 shows a similar irregularity for the June 17-20, 2020 episode and are consistent with results from the Ft. McMurray fire in western Michigan.

Figure 113 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.

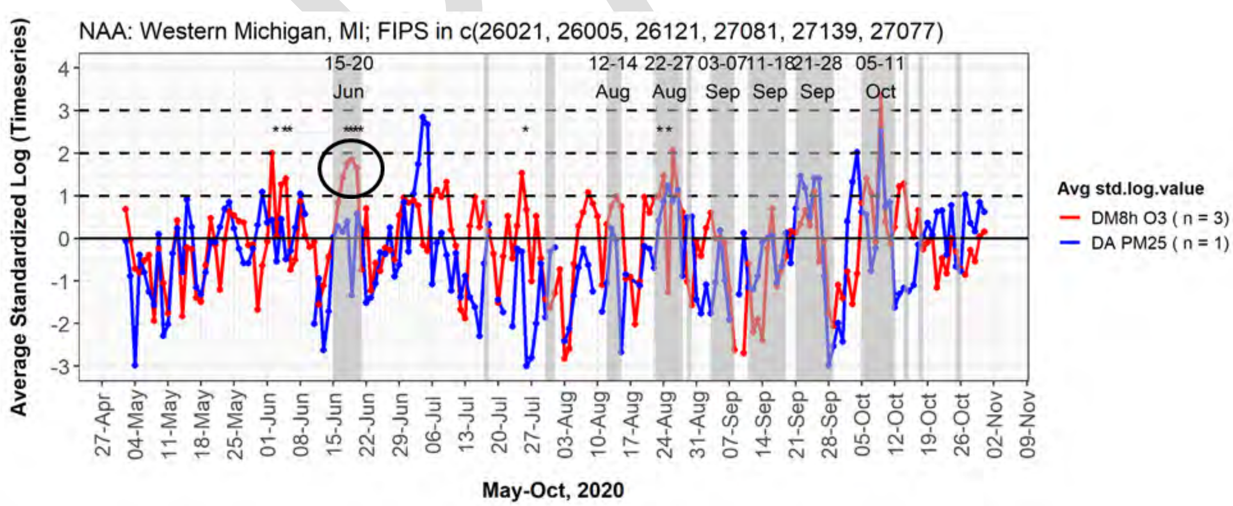

Figure 113. Average anomaly plots for the daily maximum 8-hour ozone and daily average PM2.5 concentrations measured in western Michigan. June 17-20, 2020 episode circled in black.

As can be seen in this figure, the period around June 17-20, 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

Three large wildfires in Arizona were identified that were part of the largest wildfire season the state had on record, where over 955,000 acres burned through November 2020. From the three fires - the Bush, Mangum, and Bighorn wildfires - close to 385,000 acres burned between June 5 and July 27, 2020, on Arizona wildlands generating ozone, PM2.5, and their precursors. These 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 three western Michigan NAAs between June 17-20, 2020. The monitored ozone concentrations on these days were unusually high, especially given recent trends. The instances for which ozone data exclusion is requested were among the highest ozone concentrations in 2020 and most were above the 99^{th} percentile among data from 2016 to 2020.

Although the meteorological conditions that existed during the events could have potentially caused elevated ozone at usual summer season levels without the increased burden of the additional wildfire-related precursor emissions, the influence of the Arizona 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, Holland, and Coloma monitors between June 17-20, 2020 and show that (1) a considerable amount of smoke was transported from wildfires in Arizona across the United States into the Lake Michigan region in the days leading up to June 17-20, 2020; (2) smoke aloft was transported to the surface on these days; and (3) smoke impacted ground-level pollution measurements at these monitors between June 17-20, 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 and Ohio Valley in the days prior to the June 2020 episode. In visible imagery and in measurements from satellite, the movement of smoke from Arizona to the western Michigan region is clear. These data show that wildfire smoke was present over the monitors on the days of the event, June 17-20, 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 episodes. On June 17-20, 2020, CALIPSO aerosol data show that smoke was present in Michigan 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 between June 17-20, 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 June 17-20, 2020, impacted air quality in western Michigan NAAs. Exceptionally high area-wide ozone concentrations were observed on those days. In addition, 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, Holland, and Coloma monitoring sites were impacted between June 17-20, 2020, by wildfire smoke transported from fires in Arizona.

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 Bush, Bighorn, and Mangum Arizona 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."

The exact cause of the Mangum fire remains under investigation; however, fire officials have confirmed it was human-caused and burned in the Kaibab National Forest of Arizona. The Bush Fire was a human-caused wildfire that started in the Tonto National Forest northeast of Phoenix, Arizona. Lightning has been identified as the cause of the Bighorn fire in the Santa Catalina Mountains north of Tucson, Arizona. 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 June-July 2020 Bush, Bighorn, and Mangum 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 either lightning or unplanned ignition likely due to human activities 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, 2020, and flagged the June 17-20, 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 the Bush, Bighorn, and Mangum wildfires in Arizona adversely affected ozone data in a regulatory significant way, such that ozone data between June 17-20, 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 Arizona wildfire events that caused the violations at the Holland, Coloma, and Muskegon ozone monitors, and how emissions from those events reached the affected monitor, 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 one of Arizona's largest recorded wildfire years, which was then transported into Michigan over several days in June 2020.
2. Meteorological conditions (at the surface and aloft) were favorable for transport of smoke from the wildfires in Arizona into the region, including Michigan, during June 2020.
3. Ozone concentrations during the June 17-20, 2020 episodes at the Muskegon, Holland, and Coloma 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 Air Quality Index (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 June 17-20, 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 June 17-20, 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 both the June 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 June 17-20, 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 June 17-20, 2020 event.
12. Comparable meteorological and typical non-event ozone exceedance day analyses suggests that the June 17-20, 2020 exceedance event was influenced by factors not explained by meteorology alone and indicated a wide, regional impact beyond just the western Michigan NAAs, lending support to the conclusion that the influence of wildfire smoke created the ozone exceedances on June 17-20, 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 June 17-20, 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 June 17-20, 2020 episodes.
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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