Maryland
Department of
the Environment

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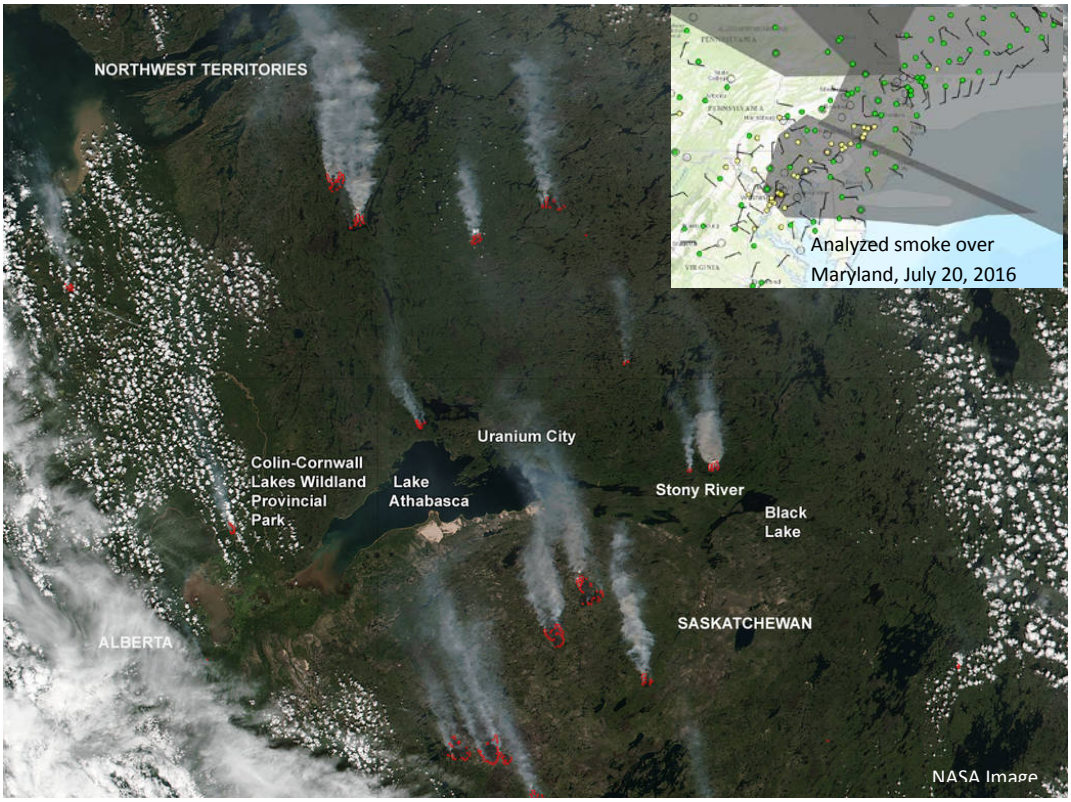
State of Maryland
Exceptional Event Demonstration and Analysis of the Northwestern Canada Wildfires' Impact on Maryland's Air Quality
July 21 and 22, 2016



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1. Overview

1.1. Introduction

A preponderance of fires across northwestern Canada produced smoke covering a wide area of North America for much of the month of July, 2016. During a period of extensive burning across the region, particularly within and around the Northwest Territories of Canada, a combined smoke plume was transported several thousand kilometers within the free atmosphere (well above the surface air) and subsided over the northern Mid-Atlantic States of the Continental United States (CONUS). Maximum daily 8-hour average ozone (MD8AO) concentrations across Pennsylvania and Maryland on July 21 and 22, 2017 exceeded of the 2005 and 2008 ozone National Ambient Air Quality Standards (NAAQS) after the precursor-rich smoke plume[1] subsided to the surface (Figure 1). Maryland MD8AO concentrations reached 87 ppb at the peak of the event at the Fair Hill monitor in northeast Maryland, which is considered "Unhealthy" and was the highest MD8AO during the 2016 ozone season for that site. Between the two days of the event 55% of the Maryland ozone monitoring network observed MD8AO which were among the fourth-highest MD8AO observations of the 2016 season (Table 1).

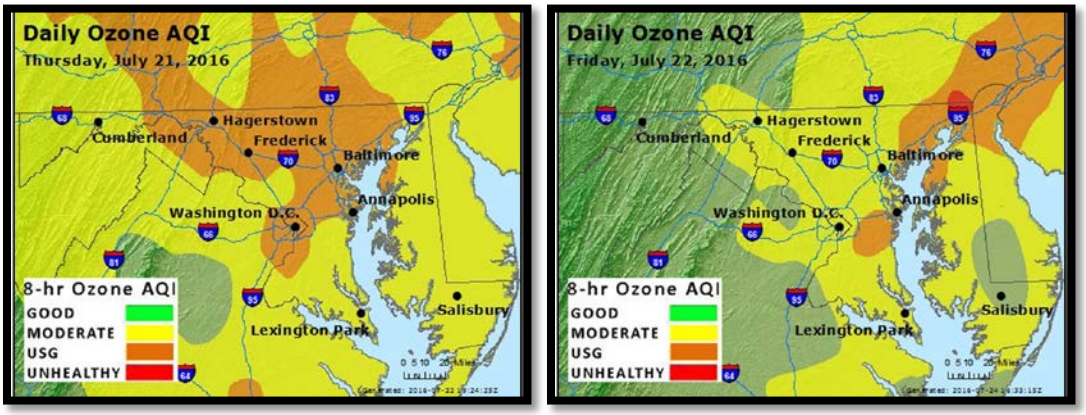

Figure 1. Ozone Air Quality Index (AQI) maps from July 21 and 22, 2016.

Following the U.S. Environmental Protection Agency's (EPA) Exceptional Events Rule (Title 40 of the Code of Federal Regulations Part 50.14), the Maryland Department of the Environment (MDE, "The Department") flagged the data as being influenced by a Canadian wildfire and communicated to EPA our intention of submitting an exceptional event package for July 21 and 22, 2016. This analysis is to demonstrate that Maryland's 8-hour ozone concentrations that exceeded the 2015 standard meet the requirements for having been influenced by an exceptional event and should therefore be excluded from design value (DV) calculations used to determine Maryland's ozone attainment status.

1.2. July 2016 Exceptional Event Summary of Approach

The Exceptional Events Rule as defined in 40CFR 50.14 states that an event may be excluded from regulatory use if it had the following characteristics:

[1]Smoke from biomass burning contains volatile organic compounds (VOCs) and nitrogen oxides (NOx), which react to form ozone.

1) There is a clear, causal relationship between the event and the monitored exceedance that affects air quality;

2) The event was of human origins not likely to recur or was natural in origins;

3) The occurrence was not reasonably controllable or preventable.

Table 1. Maximum 8-hour ozone concentrations and ranks on July 21 and 22, 2016 for all Maryland sites. Maryland sites are listed using the common site name and Air Quality System (AQS) identification number (AQSID). Also given are the maximum daily 8-hour average ozone (MD8AO) concentrations in ppb along with that day's rank in the 2016 ozone season in parentheses. A rank of (1) indicates the MD8AO was the highest recorded at that site in the 2016 season. The final columns indicate the current fourth high and design value with no exclusion of any data. Sites with an asterisk indicate the site does not have a valid design value in 2016. Monitors exceeding 70ppb during the event are highlighted in orange (for USG Air Quality Index) or red (for Unhealthy Air Quality Index).

SiteName	AQSID	MD8AO[ppb] (rank)		2016	
		July 21	July 22	Fourth High [ppm]	Design Value [ppm]
Aldino	240259001	77 (3)	72 (9)	0.077	0.073
Beltsville CASTNET	240339991	78 (1)	70 (4)	0.070	0.068
Blackwater NWR CASTNET	240199991	54 (39)	56 (29)	0.068	0.066
Calvert	240090011	61 (17)	59 (28)	0.070	0.069
Edgewood	240251001	72 (9)	82 (1)	0.079	0.073
Essex	240053001	75 (7)	72 (13)	0.078	0.072
Fair Hill	240150003	65 (15)	87 (1)	0.080	0.076
Frederick	240210037	75 (2)	62 (8)	0.070	0.067
Furley	245100054	74 (5)	65 (15)	0.075	0.069
Glen Burnie	240031003	76 (4)	69 (11)	0.076	0.076*
Hagerstown	240430009	74 (1)	56 (38)	0.070	0.066
Horn Point	240190004	59 (18)	56 (27)	0.067	0.064
HU-Beltsville	240330030	78 (1)	65 (9)	0.070	0.069
Millington	240290002	62 (22)	66 (13)	0.072	0.070
Padonia	240051007	73 (4)	63 (24)	0.073	0.072
PG Eq Cntr	240338003	65 (18)	76 (4)	0.076	0.071
Piney Run	240230002	59 (17)	54 (28)	0.066	0.065
Rockville	240313001	68 (4)	59 (18)	0.068	0.068
South Carroll	240130001	70 (5)	61 (16)	0.072	0.068
S. Maryland	240170010	67 (10)	63 (18)	0.073	0.070

Finalized revisions to the Exceptional Events Rule were established by the EPA by October of 2016[2]. The revised rule describes the procedures for treating data which has been influenced by an exceptional event. These were further clarified in an Exceptional Events Guidance Document[3] promulgated about the same time. Accordingly, an exceptional events demonstration must include all the following elements:

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2 Federal Register / Vol. 81, No. 191 / Monday, October 3, 2016: Treatment of Data Influenced by Exceptional Events

[3]Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations, Final, EPA, September 2016: https://www.epa.gov/sites/production/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf

1) A narrative conceptual model that describes the event(s) causing the exceedance or violation and a discussion of how emissions from the event(s) led to the exceedance or violation at the affected monitor(s);
2) A demonstration that the event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation;
3) Analyses comparing the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times. The Administrator shall not require a State to prove a specific percentile point in the distribution of data;
4) A demonstration that the event was both not reasonably controllable and not reasonably preventable;
5) A demonstration that the event was caused by human activity that is unlikely to recur at a particular location or was a natural event; and
6) Documentation that the submitting air agency followed the public comment process.

Furthermore, 40CFR50.14(b)(4) states that the EPA " … Administrator shall exclude data from use in determinations of exceedances and violations where a State demonstrates to the Administrator's satisfaction that emissions from wildfires caused a specific air pollution concentration in excess of one or more national ambient air quality standard at a particular air quality monitoring location and otherwise satisfies the requirements of this section. Provided the Administrator determines that there is no compelling evidence to the contrary in the record, the Administrator will determine every wildfire occurring predominantly on wildland to have met the requirements identified in paragraph (c)(3)(iv)(D) [item (4) above] of this section regarding the not reasonably controllable or preventable criterion."

The guidance document also recommends following a tiered based approach to the analysis, providing evidence of "Key Factors" in each tier. Following the elements suggested in the Exceptional Events Guidance Document[3] as outlined above, MDE contends and demonstrates here-in that the transported wildfire smoke had a direct role in amplifying ozone concentrations on July 21 and 22, 2016 to a level which would not have been possible in the absence of smoke constituents and satisfies the three core exceptional event criterion. Based on recommendations from the EPA, Maryland used a Tier 3, weight of evidence approach for this analysis. MDE addresses each of the necessary elements cited previously in the subsequent sections of this document. EPA guidance offers suggestions for appropriate analyses to demonstrate the clear causal relationship between the wildfire and excessive ozone levels and recognizes that appropriate levels of analysis will vary for particular locations and conditions. EPA does not intend for the guidance to constrain the analysis. MDE therefore includes some of the suggested analytics and variations on those methods to support our conclusion that the high ozone concentrations in Maryland on July 21 and 22, 2016 were caused and/or worsened by the wildfire smoke plume from the fires across northwestern Canada in July of 2016.

1.3. Regulatory Significance of the Exclusion

1.3.1. July 2016 Exclusion Request

There are 20 ozone monitors in the state of Maryland (Figure 2) covering three different Metropolitan Statistical Areas (MSAs). MDE operates 18 of these regulatory ozone monitors while the EPA Clean Air Status and Trends Network (CASTNET) program operates the additional two monitors. On July 21 and 22, 2016, ten and five monitors, respectfully, (12 separate monitors) exceeded the 70ppb ozone NAAQS across the state of Maryland and meet the criteria for further analysis and potential exclusion if given concurrence that an exceptional event occurred by the EPA, according to criteria listed in 40 CFR 50.14(a)(1)(i). MDE asks for exclusion of all the MD8AO observations on July 21 and 22, 2016 which exceeded the 70ppb ozone NAAQS (Table 2). While MDE does not operate the CASTNET monitors, MDE requested the CASTNET monitor data be flagged by the Clean Air Markets Division (CAMD) of EPA (Appendix A), who responded by flagging the data for exclusion in this demonstration. Therefore Maryland asks for exceptional event concurrence of 15 MD8AO observations between July 21 and 22, 2016 which exceeded 70 ppb at the following 12 monitors: Aldino (240259001), Beltsville-CASTNET (240339991), Edgewood (240251001), Essex (240053001), Fair Hill (240150003), Furley (245100054), Glen Burnie (240031003), Hagerstown (240430009, HU-Beltsville (240330030), Padonia (240051007), and PG Eq Cntr (240338003). MDE requests that these observed ozone data on July 21 and 22, 2016 at these monitors as listed in Table 2 be flagged as impacted by an exceptional event and be excluded from regulatory use.

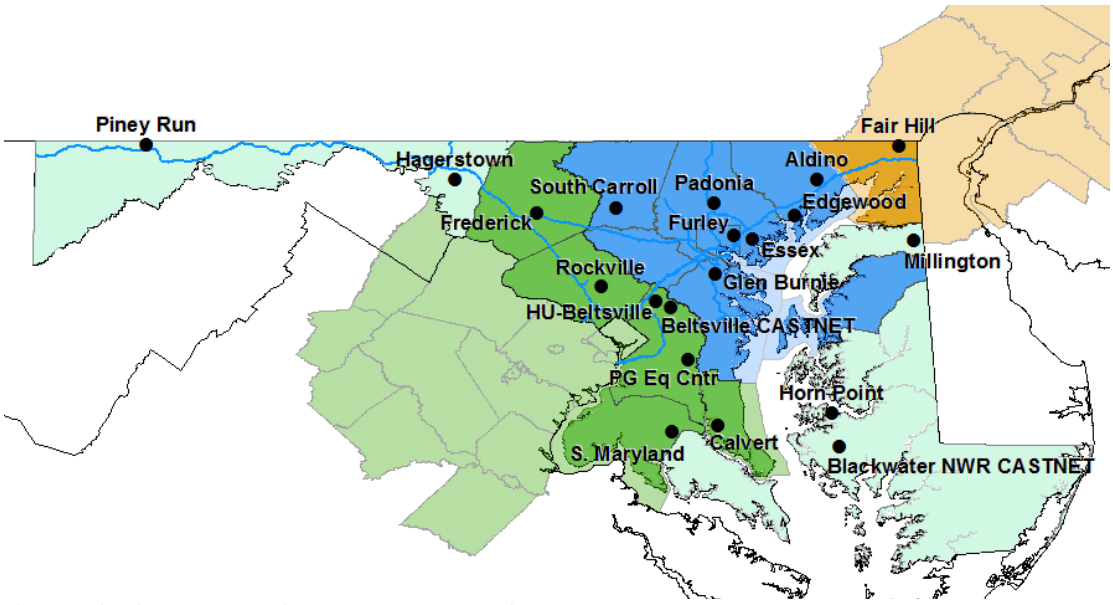


Figure 2. The Maryland ozone air quality monitoring network as of July 21, 2016. Black dots indicate the location of ozone monitors. Metropolitan Statistical Areas (MSAs) for Baltimore-Towson (Blue), Washington-Arlington-Alexandria (Green) and Philadelphia (Orange – Non-Attainment Area) show that Maryland monitors include three policy relevant areas and several states; all areas of which are above the new 70ppb standard. The Philadelphia MSA is in non-attainment of the old 2008 75ppb standard. The rest of Maryland is colored in light cyan. The blue lines show major interstates. Gray lines are county political boundaries. Other lines are state borders.

1.3.2. Design Value and Fourth High Impacts

Exclusion of the MD8AO concentrations on July 21 and 22, 2016 lowers the DV at several monitors in Maryland. The EPA designates an area's attainment status of the NAAQS via the DV metric. For 8-hour ozone, each monitor's annual fourth-highest daily 8-hour maximum concentration averaged over the past three years designates the attainment status for that particular area. Ozone concentrations on July 21 and 22 were within the fourth-highest 8-hour average observations of 2016 at 11 monitors (Table 1), though only 10 of those monitors exceeded the 70 ppb NAAQS to be included in this analysis. Excluding the July 21 and 22 MD8AO at the 10 requested monitors (Table 2) would reduce five monitors' DV, including the Fair Hill monitor (240150003), which would drop below the 2008 75 ppb level (from 76 to 74 ppb) and also bring the PG Eq Cntr monitor (240338003) into attainment of the 70ppb 2015 standard (71ppb to 70ppb). Details of specific site DVs with and without exceptional event concurrence along with changes in the fourth highest MD8AO concentrations for the 2016 season are provided in Table 2 for all 12 Maryland monitors that MDE is requesting exceptional event status. Reduction of these sites' DV would potentially be used to demonstrate compliance through 2018. Additionally, while MDE acknowledges the EPA's interpretation of 40 CFR 50.14(a)(1)(i), MDE also recognizes the importance of the fourth highest value in a given year potentially determining future year DVs. While not currently requesting sites based solely on their fourth high values, those monitors which observed one of their fourth highest ozone concentrations during the two day event but did not exceed an MD8AO of 70 ppb are listed in Appendix B.

Table 2. Ozone monitors at which MDE is seeking EPA concurrence to exclude data.
Local names and Air Quality System (AQS) identification numbers (AQSID) identify monitors in the text. Also given are the maximum daily 8-hour average ozone (MD8AO) concentrations in ppb along with that day's rank in the 2016 season in parentheses. A rank of (1) indicates the MD8AO was the highest recorded at that site in the season. The final columns indicate the 2016 fourth high and design value with no exclusion of data (Including) and if the requested data from July 21 and 22 are excluded from fourth high and design value calculations (Excluding). Sites with an asterisk indicate the site does not have a valid design value in 2016. Cells showing "-" are MD8AO at sites which did not exceed 70ppb and therefore cannot seek exclusion.

		2016							
		MD8AO[ppb] (rank)		Fourth High [ppm]			Design Value [ppm]		
SiteName	AQSID	July 21	July 22	Including	Excluding	Excluding May & July	Including	Excluding	Excluding May & July
Aldino	240259001	77 (3)	72 (9)	0.077	0.077	0.074	0.073	0.073	0.072
Beltsville CASTNET	240339991	78 (1)	-	0.070	0.070	0.069	0.068	0.068	0.068
Edgewood	240251001	72 (9)	82 (1)	0.079	0.079	0.077	0.073	0.073	0.072
Essex	240053001	75 (7)	72 (13)	0.078	0.078	0.077	0.072	0.072	0.072
Fair Hill	240150003	-	87 (1)	0.080	0.076	0.075	0.076	0.074	0.074
Frederick	240210037	75 (2)	-	0.070	0.067	0.067	0.067	0.066	0.066
Furley	245100054	74 (5)	-	0.075	0.075	0.067	0.069	0.069	0.066
Glen Burnie*	240031003	76 (4)	-	0.076	0.076	0.074	0.076	0.076	0.074
Hagerstown	240430009	74 (1)	-	0.070	0.068	0.068	0.066	0.065	0.065
HU-Beltsville	240330030	78 (1)	-	0.070	0.069	0.069	0.069	0.068	0.068
Padonia	240051007	73 (4)	-	0.073	0.073	0.073	0.072	0.072	0.072
PG Eq Cntr	240338003	-	76 (4)	0.076	0.074	0.073	0.071	0.070	0.070

Excluding the ozone concentrations associated with the July event will impact not only DVs in 2016, but also in 2017 and 2018, particularly in light of another wildfire smoke plume impacting Maryland in May (MDE will be submitting another exceptional event demonstration for that event separately). Excluding all the requested data associated with the July ozone event will decrease five monitors' DV and fourth-highest observations in 2016. However, if the May event was also concurred, three additional monitors' DV and seven monitors' fourth-high would decrease further than if July or May were excluded alone. Given the fourth high value will impact the DV calculation through 2018, the exclusions have large ramifications for regional attainment. For example, an EPA concurrence of only the May exceptional event at Aldino (240259001) changes that monitor's fourth high from 0.077 to 0.076ppm, but does not reduce Aldino's 2016 DV. However, if the July exceptional event demonstration receives EPA concurrence at Aldino, the fourth high is reduced an additional 0.02 ppm (bringing it to 0.074 ppm) and the 2016 DV drop 0.01 ppm to 0.075 ppm. If July does not receive EPA concurrence, there is no change to the DV at the Aldino site if only May receives EPA concurrence.

1.3.3. NAAQS Attainment Considerations

As discussed above, the fourth-highest observations have ramifications for a monitor's design value for the next three years. At Fair Hill (240150003), an EPA concurrence of both the May and July events drops the 2016 fourth high from 0.080 ppm to 0.075 ppm, which would keep the monitor in attainment of the 75ppb NAAQS level, given similar years in 2017 and 2018. Regardless of the future year considerations concerning the fourth-highest values, exclusion of the requested MD8AO observations on July 21 and 22, 2016 in Maryland will bring the Fair Hill monitor (240150003, Philadelphia Non-Attainment Area (NAA)) into attainment of the 2008 ozone standard already in 2016.

At this time only the Fair Hill monitor would be re-classified as attainment of the 2008 NAAQS should EPA concur with Maryland's exceptional event demonstration. However, the Fair Hill monitor is part of the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE NAA and EPA would need to concur with the Exceptional Event demonstration submitted by Pennsylvania Department of Environmental Protection (PA DEP) for the NAA to be found attaining the 2008 ozone NAAQS. It is therefore uncertain if the Philadelphia NAA will achieve attainment of the 75 ppb standard even if EPA concurs with MDE's demonstration. The EPA evaluation of the May exceptional event in the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE NAA would potentially affect its designation status, which is due later in 2017. In any case the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE area would still be classified as non-attainment of the 2015 ozone NAAQS. All other Maryland monitors are attaining the 2008 standard currently. EPA concurrence with the July exceptional event will also bring the PG Eq Cntr monitor (240338003) into attainment of the 70ppb 2015 standard (71ppb to 70ppb), helping to keep the DC area near the 70 ppb NAAQS threshold. Therefore, depending on future year ozone concentrations, this demonstration may significantly impact Maryland's attainment status in regards to the 2008 and 2015 ozone NAAQS. The Baltimore, Maryland area needs to demonstrate continued attainment of the 2008 ozone standard by 2018. This continued attainment of the 2008 ozone standard might only occur if EPA concurs with this exceptional event demonstration for July 21 and 22, 2016. If EPA does not concur with this exceptional event demonstration the Baltimore area

designation might change as a result. Thus, concurrence of this demonstration may significantly impact Maryland's attainment status in regards to the 2008 and 2015 ozone NAAQS.

1.4. Summary of Findings

This report demonstrates that:

- There was a clear causal relationship between the smoke and the MD8AO exceedances;
- The wildfire causing smoke was considered a natural event;
- The smoke events in question were not reasonably preventable and are unlikely to recur;

Key findings and evidence supporting these assertions include the following:

- Ozone concentrations above the 70ppb NAAQS were associated with a plume of wildfire smoke which subsided over Maryland late on July 20, 2016.
- Temperatures remained elevated (near or above 90°F) before, during, and after the ozone exceedance days. Ozone concentrations changed significantly only in the presence of the smoke.
- Ozone concentrations decreased on July 23, in the middle of a sunny day after the smoke departed.
- Ozone concentrations were higher than historical norms, beating the 99th percentile at most monitors, even within an environment of historically low anthropogenic precursors.
- Q/d analysis and conclusions were consistent with other previous long range smoke and ozone transport events from Canada to Maryland.
- Fine Particle ($PM_{2.5}$), Carbon Monoxide (CO) and Nitrogen Oxides (NOx) were elevated during the event, which are consistent with a wildfire smoke plume.
- $PM_{2.5}$ speciated data showed elevated wildfire attributable concentrations.
- VOC concentrations were the highest over entire month of July during the event, increasing with the onset of the smoke plume's arrival.
- Satellites captured a smoke plume transported to the northeastern US which was also associated with satellite retrieved CO, both which tracked from northwestern Canada.
- Similar day analysis showed similar days in previous years did not yield as much ozone.
- Photochemical modeling during the event showed under prediction due to the absence of gaseous wildfire emissions within the ozone chemistry of the model.

Several analysis methods were used to develop a weight of evidence demonstration that the 8-hour ozone concentrations above 70 ppb in the July 2016 event meet the rules for data exclusion as an Exceptional Event. In summary, satellite, meteorological data, trajectory analysis, emissions data, speciated $PM_{2.5}$ data, and numerical air quality model comparisons were used to assess whether conditions were favorable for transport of smoke from the Northwestern Canada wildfires to monitors that showed 8-hour ozone concentrations above 70 ppb. The data also show that the transported smoke subsided over the Maryland region, creating a spatially and temporally focused enhanced ozone period (July 20-22) over the northern Mid-Atlantic.

Substantial changes in chemistry in the eastern United States due to regional NOx emissions reductions have occurred over the last decade. The following analysis puts the 8-hour ozone concentrations in Maryland during this ozone event in the context of these. Comparison of emissions during July of 2016 to previous

years showed Electric Generating Unit (EGU) NOx emissions were lower than any other year on record during the smoke event. Yet, ozone concentrations in July of 2016 exceeded ozone concentrations in earlier years during similar meteorology and under heavier anthropogenic precursor emissions. Analysis of the airmass associated with the Maryland ozone exceedances on July 21 and 22, 2016 revealed a composition characteristic of wildfires with an abundance of ozone precursors not typically or largely attributable to anthropogenic sources.

MDE's analysis strongly supports that MDE monitors were impacted by smoke, that all of the MD8AO concentrations above 70ppb in Maryland on July 21 and 22, 2016 meet the rules of an Exceptional Event, and that the 12 monitors and 15 MD8AO observations in Table 2 should be excluded from DV calculations. The following analysis justifies these claims and is outlined as follows: Section 2 contains a conceptual model overview of the event including a synopsis of the meteorological and air quality conditions, emissions, transport and characteristics defining the event. Section 3 demonstrates a clear causal relationship between the exceedance via a tiered, weight of evidence approach. Section 4 demonstrates that this event fulfills the definition of the natural event unlikely to recur while Section 5 fulfills the requirements that demonstrate the event was not reasonably controllable or preventable. Section 6 documents the public comment process while section 7 summarizes and concludes the analysis.

2. Conceptual Model and Overview of the July 20-22, 2016 Smoke and Ozone Event

2.1. Maryland Area Description

As part of the Clean Air Act (CAA), both local and state air quality agencies are required to maintain and operate ambient air quality monitoring networks. MDE complies with all EPA regulations defined in 40 CFR Part 58 and maintains a dense network of in situ and remote sensing pollution sampling platforms in Maryland. Surface monitors used for regulatory purposes include 20 ozone monitors as of July 21, 2016 (Figure 2) (including two EPA CASTNET sites, (EPA, 1997)), nine hourly fine particle ($PM_{2.5}$) Beta Attenuation Monitors (BAMs) with additional $PM_{2.5}$ hourly observations from six locations in Washington D.C. (DC) and northern Virginia, various $PM_{2.5}$ Federal Reference Method (FRM) filter speciations, VOC canisters and three 915 MHz radar wind profilers (RWP; Ryan, 2004; MDE, 2015). A full description of the various instrumentation used by MDE is available in the MDE Network Plan (MDE Ambient Air Monitoring Plan, 2017).

The dense MDE network exists to account for a densely populated area of the United States between DC and Baltimore. The distribution of ozone monitors across the state favors the I-95 corridor (blue line running southwest to northeast from DC to just south of the Fair Hill ozone monitor on Figure 2), which stretches across the central part of the state from DC to along the northern portion of the Chesapeake Bay. Approximately 9,000,000 people reside along the I-95 corridor (including DC and northern Virginia) as of 2012. Statewide, Maryland's population was estimated to be 6,000,000 as of 2016 by the US Census

Bureau. The state of Maryland also has diverse geography, with mountains greater than 2,000 ft to the west and coastal plains near sea level to the east that border the Chesapeake Bay and Atlantic Ocean. Outside of urban areas, Maryland is characterized by a mix of farmland to the east and mainly deciduous forests in the mountains to the west. The dynamic interplay between the dense population and diverse geography, particularly biogenic emissions, lee side subsidence by the mountains, and land/water interaction gives Maryland distinct and variable air quality issues, which previously gave the Baltimore, Maryland area the distinction of having the highest reading ozone monitor (Edgewood; 240251001) along the US East Coast.

2.2. Characteristics of Typical, Non-Event Ozone Formation

Over the past two decades MDE has contracted with universities in and around Maryland to conduct thorough research of air quality in Maryland. In particular this collaboration has focused on the origin of ozone in Maryland. This research was done utilizing balloon-borne ozonesondes and airplane flights to capture vertical profiles of atmospheric composition. Computer modeling based on these observations further enhanced our understanding of the origin of ozone in Maryland. The understanding garnered from years of vertical and surface ozone measurements indicated a significant fraction of ozone and ozone precursors observed in Maryland were due to transport by winds from upstream states into Maryland which mixed with and compounded local emission issues. Major legislation resulting from conclusions of this research resulted in robust changes in the air composition in the eastern United States over the past 10 years. Full details of this ongoing collaboration may be found on the RAMMPP[4] webpage. The following describes the current understanding of ozone formation in Maryland.

In the absence of a-typical airmass composition (e.g. exceptional events, smoke plumes), ozone formation in Maryland occurs primarily due to the photolization of volatile organic compounds (VOCs) and a combination of regional and locally sourced anthropogenic NOx in the presence of sunlight. The combination of high density population (pollution sources) and topography often focuses these reactions in well-defined areas that have historically created ozone issues east and northeast of DC and Baltimore. The main sources of anthropogenic emissions contributing to these issues are stationary point sources such as EGUs, mobile sources (cars, trucks, boats, locomotives and non-road equipment), and area sources that include industrial processes and consumer products. The urban pollution plumes that develop along the I-95 corridor between DC and Baltimore (mobile, industrial, area) and surrounding point sources (EGUs) constitute the overwhelming percentage of locally sourced NOx which contributes to Maryland ozone formation. However, these emissions alone regularly fall short of producing ozone capable of MD8AO concentrations above 70 ppb in Maryland. Photochemical modeling supports the assertion that exclusive of light winds and recirculation which build up the local emissions, Maryland EGU and mobile emissions alone are not great enough to support ozone exceedances. However, Maryland is also at the “tail pipe” end of the EGU rich Ohio River Valley (ORV) where a high density of large EGU point sources create a regional NOx plume upstream that transports NOx and/or ozone in to Maryland. The majority of Maryland exceedances historically have been associated with such transport. Thus the amount of ozone and ozone precursors (typically NOx) within the residual layer (layer of air immediately above the surface, typically around 500-2000m above ground level) transported into Maryland adds to and raises local Maryland ozone

[4] Regional Atmospheric Measurement Modeling and Prediction Program (RAMMPP): http://www.atmos.umd.edu/~rammpp/

concentrations to and above NAAQS thresholds. Without significant transport, Maryland no longer observes wide spread or frequent ozone exceedances of the NAAQS.

In the past four years, Maryland has had few cases of pollutant transport comparable to historical (pre-2013) norms. In these recent years (2013-2016), the amount of ozone/precursors within the residual layer has declined to the lowest levels ever recorded, leading to a reduction of maximum ozone concentration on any one day in Maryland and thus a decrease in the number of ozone exceedance days. This has caused local effects (meteorology, emissions) which previously were overwhelmed by regional signals to become more prominent, but overall has made exceedances isolated spatially and infrequent in occurrence at all NAAQS levels (Figure 3). Point source NOx emissions from states upstream of and including Maryland (Maryland, DC, Virginia, West Virginia, Pennsylvania, Ohio, Indiana – "Total NOx" in Figure 3) have dropped to record low levels each of the last three consecutive years. Said simply, EGU NOx emissions as a whole in 2016 were the lowest ever in states upstream of and including Maryland for the ozone season as a whole and for each month through the season, representing a total regional anthropogenic NOx decrease of nearly 50% in the past six years (Figure 4). Despite increasing vehicular traffic and vehicle miles traveled, NOx from mobile sources also has decreased over the same period, though the magnitude decrease is dwarfed by the EGU NOx decrease. However, even while mobile NOx has decreased less than EGU NOx, current Maryland mobile emissions, even with added local EGU emissions, are incapable of all but isolated, infrequent ozone exceedance days in Maryland on their own. Maryland therefore continues to require additional transported NOx precursors for ozone exceedance days, which is still sourced predominately from upstream EGUs.

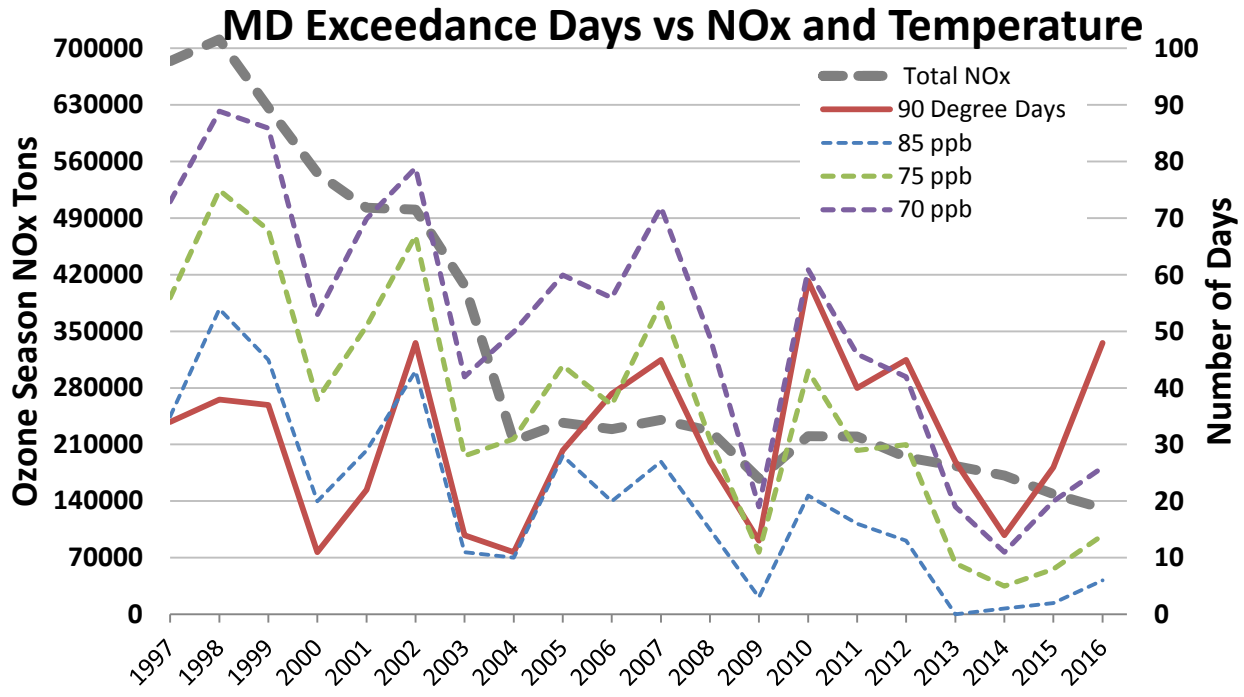


Figure 3. Total Ozone Season EGU NOx from Maryland and upwind states, number of days at or above 90°F at Baltimore-Washington Airport (90 DD) and exceedance days at various standards.

2.2.1. Emissions Trends

The Clean Air Markets Database (CAMD) records NOx output from EGU point sources across the country. In the typical, non-exceptional event model of a Maryland ozone exceedance day described above, transport of NOx into the state was primarily from upwind EGU point sources which vertically mixed ozone or ozone precursors (i.e. NOx) downward the next day to produce high concentrations of ozone which added to local emissions. Significant and sustained reductions in NOx across the eastern US have occurred in the past 10-15 years (Figure 3). Aggregate NOx emissions from upstream areas are only 25% of their pre-2003 amounts in 2016, a reduction of approximately 75%. Aggregate monthly total NOx emissions in the 2016 ozone season (May - September) were the lowest ever observed from upwind states, which included Indiana, Ohio, West Virginia, Virginia, Pennsylvania, and the District of Columbia (also including Maryland), as shown in Figure 4. These states represent an area which contributes to the amount of ozone or ozone precursors transported into Maryland under typical summer conditions where the Bermuda High moves over the southeastern US. The month of July, 2016 observed roughly half the NOx emissions from these areas compared to 2010 and 2011.

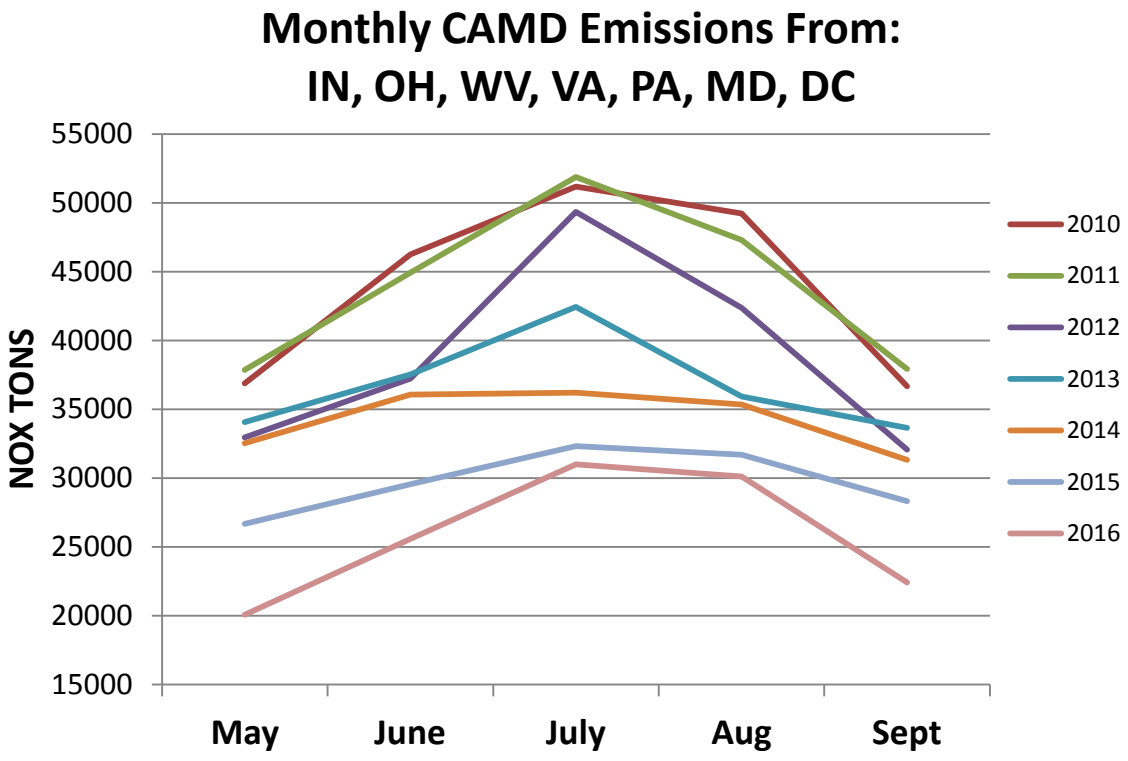


Figure 4. Monthly NOx emissions aggregated from the group of upwind states, including Maryland, by month of ozone season.

Daily emissions for the same states reflect the same reductions. Daily aggregate NOx emissions of Indiana, Ohio, West Virginia, Virginia, Pennsylvania Maryland and the District of Columbia for only the month of July from 2010 – 2016 pulled from CAMD showed emissions during late July 2016 were some of the lowest daily emissions ever (blue line, Figure 5). There is also an obvious downward trend, most notable in2014 - 2016.

For the month as a whole, July of 2016 had the lowest emission ever (Figures 4 and 5). Even with these record low emissions in July of 2016, Maryland recorded two consecutive days of near-record high ozone concentrations in the state for the month of July (red outlined bars, Figure 5) and had two consecutive days of the greatest number of monitors exceeding 70 pbb since 2012 (black bars, Figure 5) on July 21 and 22, 2016.

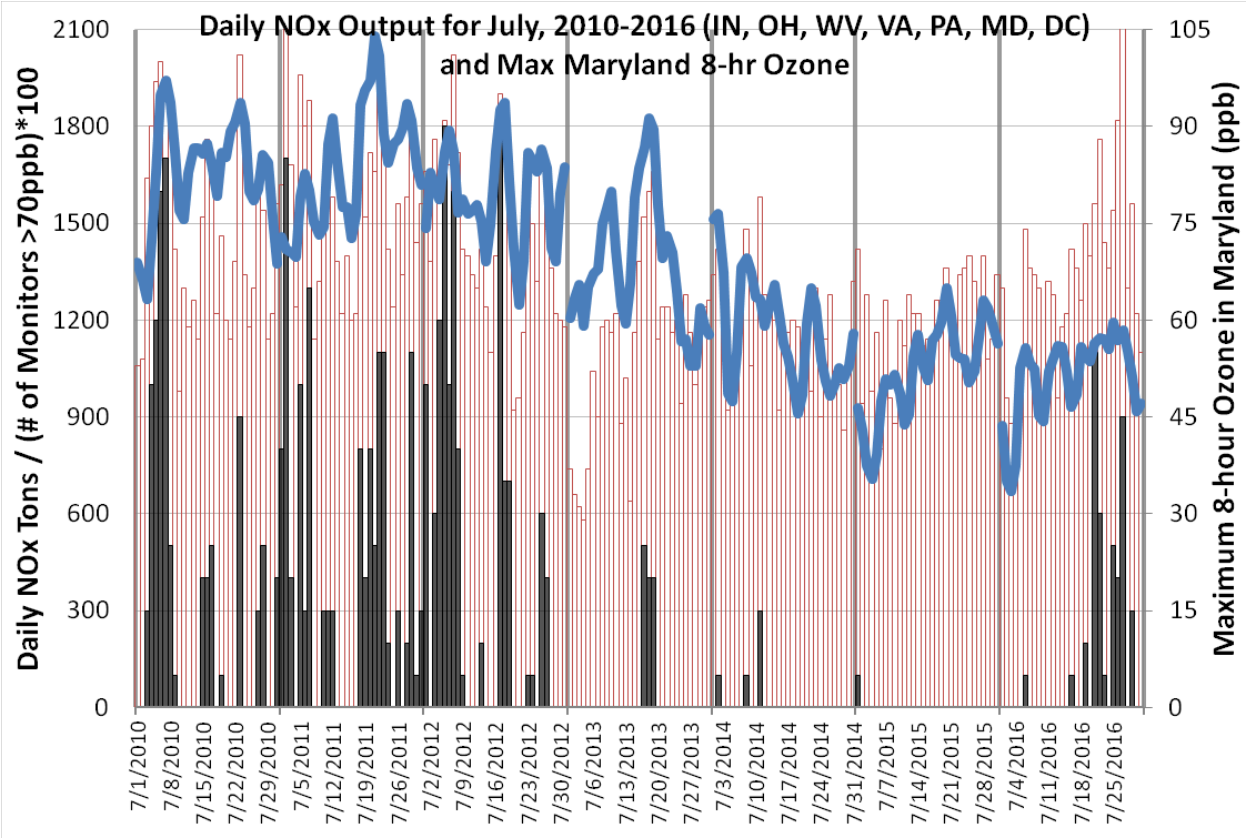


Figure 5. Daily aggregate NOx, maximum Maryland ozone, and monitors exceeding 70ppb in July, 2010-2016. Aggregate NOx emissions from EGU point sources for states upwind of Maryland (Indiana, Ohio, Pennsylvania, West Virginia, Virginia, DC and Maryland) from the CAMD database for 2010 – 2016 are shown with a thick blue line. The maximum 8-hour average ozone at any monitors in Maryland for each day in July 2010-2016 (red hollow bars) and the number of monitors exceeding 70ppb in Maryland (black bars x 100) is also shown. Number of exceeding monitors is multiplied by 100 for scale purposes. A downward trend in emissions is noticeable from 2013-2016. Each year/month is divided by a solid vertical line.

2.2.2. Ozone Production in Maryland

Research has found ozone production in Maryland to be a complicated mix of VOCs and NOx and that the atmospheric stoichiometry (the balance of compounds needed to make a third, such as ozone) can change on a daily basis. Previously the balance of either precursor group was insignificant to their absolute measure in the atmosphere; both precursors were always in abundant supply for ozone exceedances and were simply dependent on weather. For example, the variability in exceedances in Figure 3 at 70ppb is strongly correlated (R^2 = 0.51) to the number of 90°F days from 1997 to 2015. However, adding just 2016,

one of the hottest years of the past three decades, decreases this correlation (1997-2016: $R^2 = 0.40$). Notice also that in Figure 5, the number of exceedances and the spatial magnitude (number of monitors exceeding) dropped in 2013-2016 as the aggregate NOx emitted declined by around 30-40%. Maryland now exists primarily in the NOx limited regime due to regional NOx reductions. The stoichiometry of the ozone production is no longer balanced and daily ozone production is instead based on the daily availability of precursors and/or the amount of ozone transported into the state. As a secondary consequence therefore, hot temperatures are no longer a reliable predictor of daily ozone exceedances of the NAAQS.

Ozone production is controlled by the relative availability of NOx and VOCs, with ample heat and sunlight. VOCs relevant to ozone production in Maryland are both naturally occurring and anthropogenic. A significant but lesser decrease in anthropogenic VOCs was observed concurrent with NOx reductions. However, daily ozone production due to biogenic (naturally occurring) VOCs cannot be regulated and remain important to ozone production chemistry in Maryland. Isoprene, for example, a naturally occurring VOC, has the highest maximum incremental reactivity (i.e., easily makes more ozone) of VOCs tested in Maryland and is the highest VOC contributor on high ozone days. Isoprene is released by the biosphere (i.e., trees) due to environmental stresses such as heat. NOx output also increases from stationary sources on warm summer days in response to increased energy demand. Mobile emissions are not dependent on temperature and are relatively constant between workdays; Mobile emissions' impact on ozone generally decreases on the weekend. At the same time that relative NOx output increases, biogenic VOCs are released into the local environment, and, in the presence of sunlight and heat, create local ozone. When ozone and ozone precursors transported into the state combine with these local emissions, Maryland observes MD8AO above 70ppb and exhibits its fundamental non-event ozone exceedance. In this NOx limited regime, without additional transported ozone or ozone precursors, Maryland's local NOx emissions are insufficient to produce ozone exceedance days.

2.2.3. Weather Patterns Leading to Ozone Formation

Summertime meteorology is variable in Maryland. Occasional April ozone exceedance days are possible, but most of the ozone exceedance days occur primarily from May through September. The intra-seasonal variations of weather that occur through the ozone season therefore result in various meteorological patterns conducive to ozone formation. In no specific order, the generic patterns are lee-side troughing (where downward air motions in the lee of the Appalachian Mountains induces an area of pollutant convergence along I-95 [parallel to the mountains]), airmass/ozone/pre-cursor transport, and local recirculation and stagnation (to include reverse[from the northeast] I-95 corridor flow). Ozone production in each pattern depends on ozone conducive local weather conditions (i.e., warm, sunny conditions with light to moderate surface winds). The location of the Bermuda high ultimately determines which, if any, of these scenarios develops. Average summer conditions place the Bermuda High off the southeast Atlantic coast of the US, which gives Maryland westerly (south-southwest to north-northwest depending on height) transport of upstream air. Lee-troughing is dependent on weak (<15 kts) cross-mountain flow around 850mb creating compressional heating/column stretching in the lee of the mountains. This induces a "trough" of lower pressure which often aligns with the I-95 corridor. Convergence along the trough

increases ozone concentrations there. Both transport and lee troughing patterns may occur simultaneously or independently of each other. Assuming at least some downward mixing of transported ozone lee-troughing may lead to an ozone exceedance day. Recirculation and stagnation over several days can cause local pollution concentrations to increase to levels exceeding the NAAQS. All three of these patterns are most probable during the summer months of June through August which, historically, were the climatological maximum for ozone production in Maryland. Shoulder seasons (Spring and Fall) typically are not warm enough and have active weather patterns preventing local or regional emissions from building. Winter is too cold for ozone exceedances and Maryland's Appalachian peaks are too low for Stratospheric ozone intrusion that could lead to an ozone exceedance day.

Differential heating at the land and water interface recirculates local and transported pollution near coastal areas via a thermally driven solenoidal circulation. Such circulations are believed to be the cause of high ozone DVs northeast of Baltimore. With increasing temperatures, super-regional NOx output increases from upstream EGUs in locations such as the ORV and western Pennsylvania, increasing residual layer concentrations of ozone and ozone precursors. After being transported these mix downwards at later times, combining with local sources, contributing to Maryland's ozone exceedances. This downward mixing is enhanced by the solenoidal circulation of the Chesapeake Bay Breeze (BB). Then lower mixing heights over the water "overcook" the precursors, creating greater concentrations over the Bay than nearby land sites. As a result, coastal sites achieve greater ozone concentrations as both regional and local emissions are concentrated by the land/water meteorology. It is no coincidence that the area of peak ozone in Maryland during a typical non-event ozone exceedance is northeast of Baltimore where local I-95 corridor emissions (the urban plume) are enhanced by transported regional pollution concentrated by land-water meteorology dynamics.

2.3. Exceptional Event Description: July 2016 Northwest Canada Wildfires

Abnormally warm and dry conditions across central Canada in late Spring of 2016 promoted wildfire conditions in the provinces of Alberta and Saskatchewan. In May, fire concern was most concentrated around or near the town of Fort McMurrary when a large fire consumed over a million acres of woodland through early July. Fire prone conditions persisted even as this fire was extinguished, and the area prone to wildfires expanded into northeastern British Columbia and the Northwest Territories of Canada. Between July 13 and July 20, 2016 the NOAA Daily Hazard Mapping System (HMS) smoke and fire analyses (McNamara, et al., 2004) detected a large increase in the number of fires across British Columbia and the Northwest Territories, in addition to a number of fires across the Alberta and Saskatchewan (Figure 6). Fires and associated smoke plumes analyzed by HMS were derived from the GOES Imager, the POES AVHRR, MODIS satellites and expert subjective analysis. In fact a total of 205 new fires started across northwestern Canada burning 109,724 ha (271,134 acres) over that week period. The majority of these fires (65%) occurred in British Columbia, Alberta and the Northwest Territories. The majority of the area burned (60%) was in the Northwest Territories.[5] Lightning was suspected as starting the majority of the fires reported across the area.

[5]Burn information is provided by the Canadian Wildland Fire Information System (CWFIS): http://cwfis.cfs.nrcan.gc.ca/home

HMS analysis of smoke across North America indicated that a large fraction of the smoke which impacted Maryland on July 20-22 came from northern Alberta and Saskatchewan, and the southern Northwest Territories (Figure 6). There were additional fires located across southern Saskatchewan and Alberta which produced smoke plumes of their own though less expansive or intensive than the combined northern plume. Thus, no single fire was responsible for the large aggregate smoke plume which existed across central and southern Canada between July 13 and July 20. Together the large number of fires and associated aggregate smoke plume affected the air quality in Maryland as smoke was transported into and subsided over the northern Mid-Atlantic region.

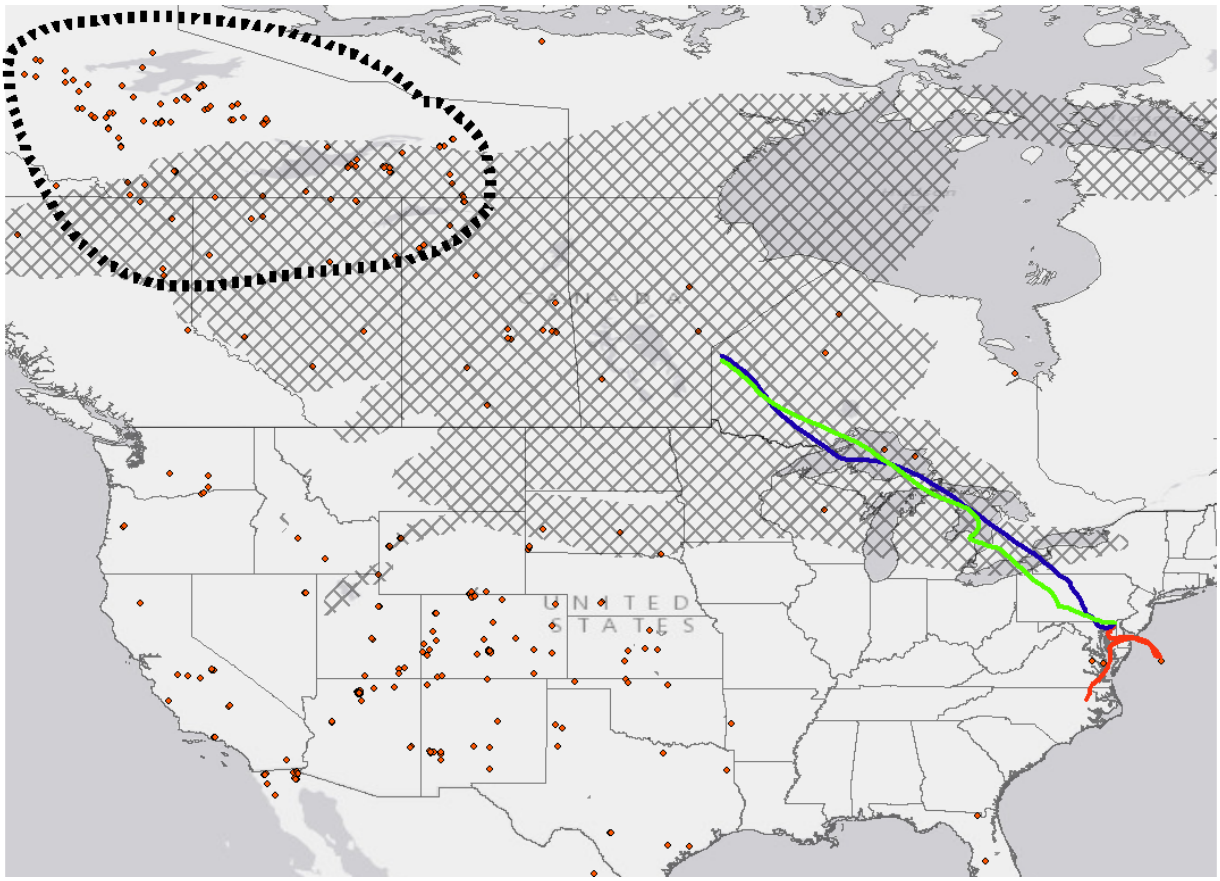


Figure 6. Location of fires and smoke on July 18, 2016.
Fires (orange dots) analyzed by the Hazard Mapping System (HMS) derived from the GOES Imager, the POES AVHRR, MODIS satellites and expert subjective analysis are shown for the period from July 13-17, 2016. The relevant fires discussed in the text are circled by the dashed line. HMS analyzed smoke (hatching) on July 18, 2016 is overlain to display the expansive nature of the plume created by these fires prior to moving into Maryland. Backwards trajectories originating at Fair Hill, Maryland on July 21, 2016 at 4pm for 96-hours (4 days) in time showed that transport at 3000m (green) and 1500m (blue) came from within the HMS analyzed smoke plume. Surface trajectories (50m, red) remain mainly local to Maryland during this time.

2.4. Conceptual Model of Ozone Formation from May 2016 Fort McMurray Fire

2.4.1. Overview and Literature Review

Wildfires are known sources of emissions responsible for both primary and secondary pollutants including CO, $PM_{2.5}$, NOx, VOCs, as well as ozone (Andreae and Merlet, 2001; McKeen et al., 2002; Bytnerowicz, et al., 2010). Similar to the study presented here, Canadian wildfires have increased ozone concentrations in Houston, TX (Morris et al., 2006) and as far away as Europe (Spichtinger et al., 2001). Evidence of Canadian wildfire smoke and biomass burning affecting the Mid-Atlantic's particulate matter (PM) air quality was also previously reported (Adam et al., 2004; Colarco et al., 2004; Sapkota et al., 2005) but wildfire smoke has also been recognized in high-ozone events on the east coast (Fiore et al., 2014). DeBell et al., (2004) presented a chemical characterization of the July 2002 Quebec wildfire smoke plume and its impact on atmospheric chemistry in the northeastern US. Most recently, Dreessen et. al., (2016) presented a case where a Saskatchewan, Canada wildfire smoke plume amplified ozone in Maryland in June of 2015, similar to the May 2016 case presented here. While relatively infrequent in the Mid-Atlantic, wildfire smoke has been an increasing fractional contribution to high-ozone exceedance days, particularly in light of increased fire frequency in a warming climate (Flannigan and Wagner, 1991; Marlon et al., 2009; Westerling et al., 2006; Spracklen et al., 2009; Pechony and Shindell, 2010), decreasing regional emissions (Gégo, et al., 2007) and tighter ozone NAAQS (http://www3.epa.gov/ozonepollution/actions.html).

2.4.2. Ozone Generation from the Fire

Dreessen et. al. (2016) previously showed that smoke plumes from Alberta and Saskatchewan are capable of transporting ozone precursors to the Mid-Atlantic and causing ozone NAAQS exceedances, even in the contemporaneously low NOx emission environment. In the present July 2016 exceptional event case, sufficient amounts of NOx and/or VOCs were generated by fires across northwest Canada in mid-July of 2016, were lofted and transported long distances, and then contributed to ozone production in Maryland where the smoke plume subsided to the surface.

In the 2015 case study examined by Dreessen et al. (2016), it was hypothesized the VOC-rich smoke plume was the key to ozone development. In that study, once the smoke-sourced VOC-rich plume interacted with anthropogenic NOx sources profuse ozone production began, which was capable of being transported long distances as either ozone or within ozone reservoir species. Dreessen et al. (2016) also acknowledged NOx contribution from the fire itself, though focused on the plume's interaction with anthropogenic sources. In that 2015 study, smoke subsided across the eastern Midwest and northern Mid-Atlantic and took over 24 hours of aging before ozone above 70ppb was widespread across the region. This delay in ozone production while the airmass aged is consistent with previous studies such as Putero et al. (2014) which observed the largest increases in ozone from fires five days (120 hours) after the initial pollutants were emitted from the fire (Figure 7). This observation was also consistent with the behavior of the smoke plume in the July 2016 case, where smoke was already well-aged, was entrained to the surface on July 20 but did not produce ozone in excess of the NAAQS until July 21, suggesting aging in the presence of diminutive anthropogenic emissions was necessary, similar to the June 2015 and May 2016 Maryland smoke cases. Thus while

sufficient precursors were generated by the fires in July of 2016 for ozone production, it was as the plume aged and mixed with anthropogenic NOx (albeit the lowest NOx on record) that ozone concentrations were augmented to and above levels exceeding the NAAQS not possible without the smoke.

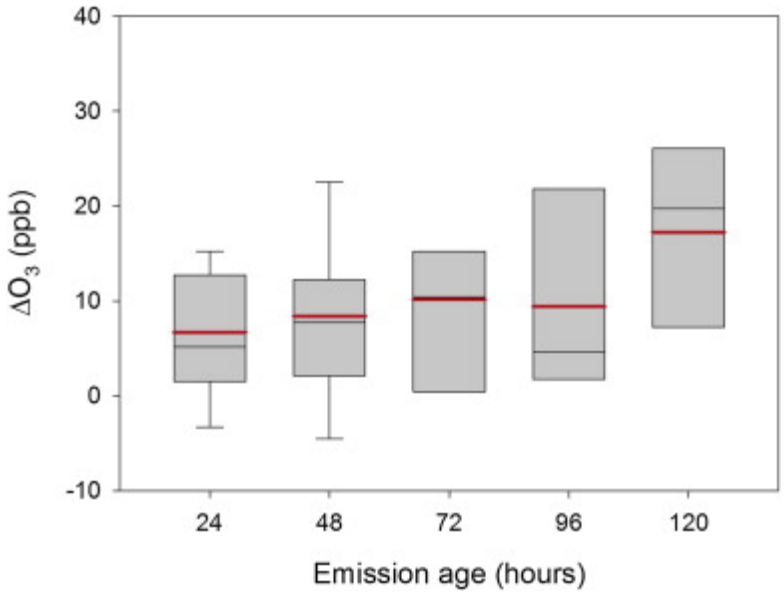


Figure 7. Ozone enhancement with smoke plume age.
(from Putero et al. (2014), their Figure 7)

The ozone precursor-rich smoke plume subsided to the surface behind a cold front which passed through Maryland on July 20. Smoke was undoubtedly present in the PBL on July 21 and 22. Precursor observations within Maryland showed the smoke and/or the ozone precursors it carried persisted in concentrations above normal to contribute to ozone formation on July 21 and 22. After a day without an exceedance (July 20) during a prolonged hot period in Maryland, 10 monitors exceed the 70ppb standard on July 21. Five monitors also exceeded on July 22 as smoke bi-products (ozone and ozone precursors) persisted. With the additional ozone precursors delivered to the surface on July 20, ozone concentrations on July 21 were 7ppb higher than July 20, and increased to 87ppb on July 22, 16ppb higher than July 20, as the smoke filled air photochemically aged and combined with local emissions. Then, all ozone concentrations decreased again on July 23 despite even warmer temperatures as winds turned to the southwest and removed the smoke filled airmass off the coast. This removal process decreased hourly ozone concentrations in Maryland in the middle of the day on July 23, despite temperatures climbing to 98°F at BWI airport!

MDE contends that the chemical composition of the air changed due to smoke. An over-abundance of VOCs observed at Essex showed there were never more VOCs available in a 24-hour period during the month of July than during the evening of July 20 into the morning of July 21. While Maryland and Pennsylvania EGUs were running, the NOx emissions they delivered were still lower than the previous four years of emissions during the same time period. Thus, ozone concentrations would not have been as high in the absence of the smoke. Once the smoke-influenced airmass was removed from the region, the constituents associated with

ozone production were also removed on the regional scale. Without the support of the smoke, local emissions were mixed out and ozone concentrations dropped despite the warm temperatures on July 23.

While ozone exceedance days in Maryland are historically common place during the month of July, the magnitude, and spatial scale of these exceedance days was beyond contemporary norms. As one of the hottest months of the year, July is typically the climatological maximum for ozone exceedance days in Maryland. However, in recent years July has had very few exceedance days (Figure 5) and even fewer covering such a wide area or large number of Maryland monitors since at least 2012. Thus, it was unlikely such a widespread area of ozone exceedance could have occurred in the contemporaneously low emissions without additional supportive atmospheric chemistry (ozone precursors) provided by the wildfire smoke.

2.4.3. Meteorological Conditions Driving Smoke and Ozone Transport

2.4.3.1. Conceptual Model Overview

A significant increase in the intensity and spatial coverage of the conglomerate smoke plume across northwest Canada took place between July 16 and July 18 (Figure 8, #1). Impacting the plume was an area of low pressure moving across southern Canada from July 17-19, 2016 (Figure 8, #2). The back side (west side) of this low pressure area provided northerly transport winds which pushed the smoke plume southeastward towards the northern CONUS and into southern Ontario by July 19. A cold front trailing the low pressure moving across Canada (Figure 8, #3) led the transported smoke plume into the CONUS and was located across the northern Mid-Atlantic by that same time. The continued northwest transport of the smoke combined with the subsidence under high pressure behind the cold front brought the smoke to the surface in Maryland (Figure 8, #4). Continued southward transport of the smoke was stifled however, and smoke was only analyzed as far south as Maryland. Temperatures behind the cold front were not significantly cooler than temperatures ahead of it and as the cold front moved southward it lost its defining characteristics (wind shift and/or temperature change) and dissolved. Then, as low pressure over Canada and High pressure over the US both moved eastward, surface winds over Maryland turned back towards the southwest and persisted that way from July 21-23, through the duration of the high ozone event (Figure 8, #5).

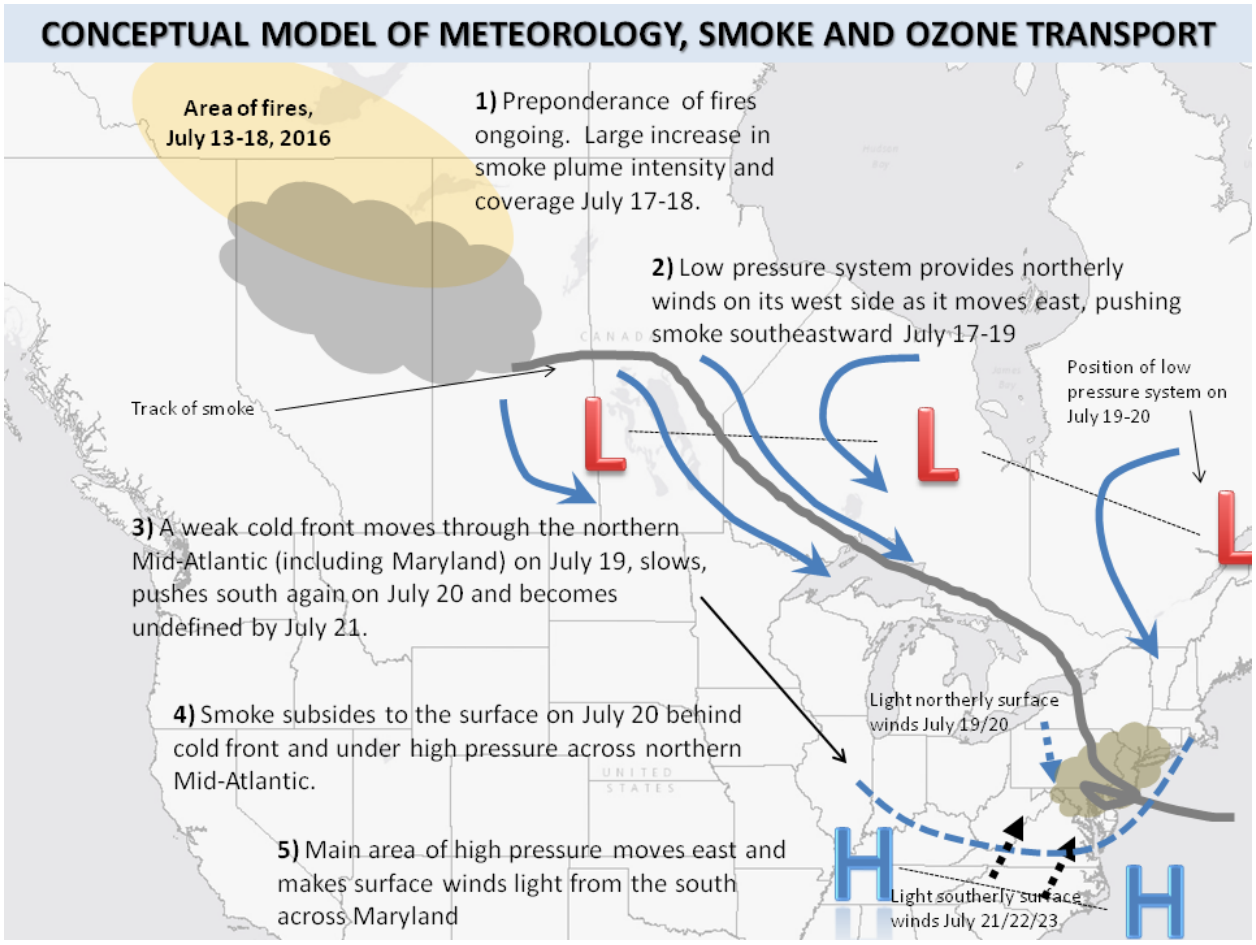


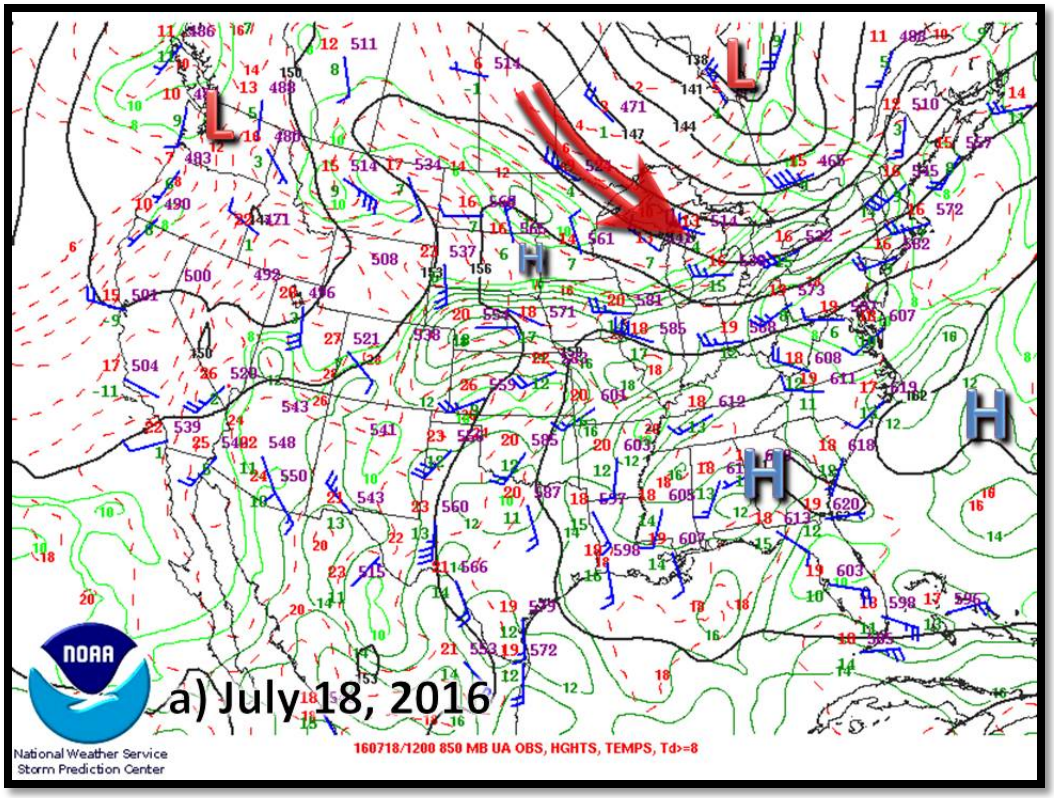
Figure 8. A simplified illustrated conceptual model of the July 21 and 22, 2016 wildfire influenced ozone event.

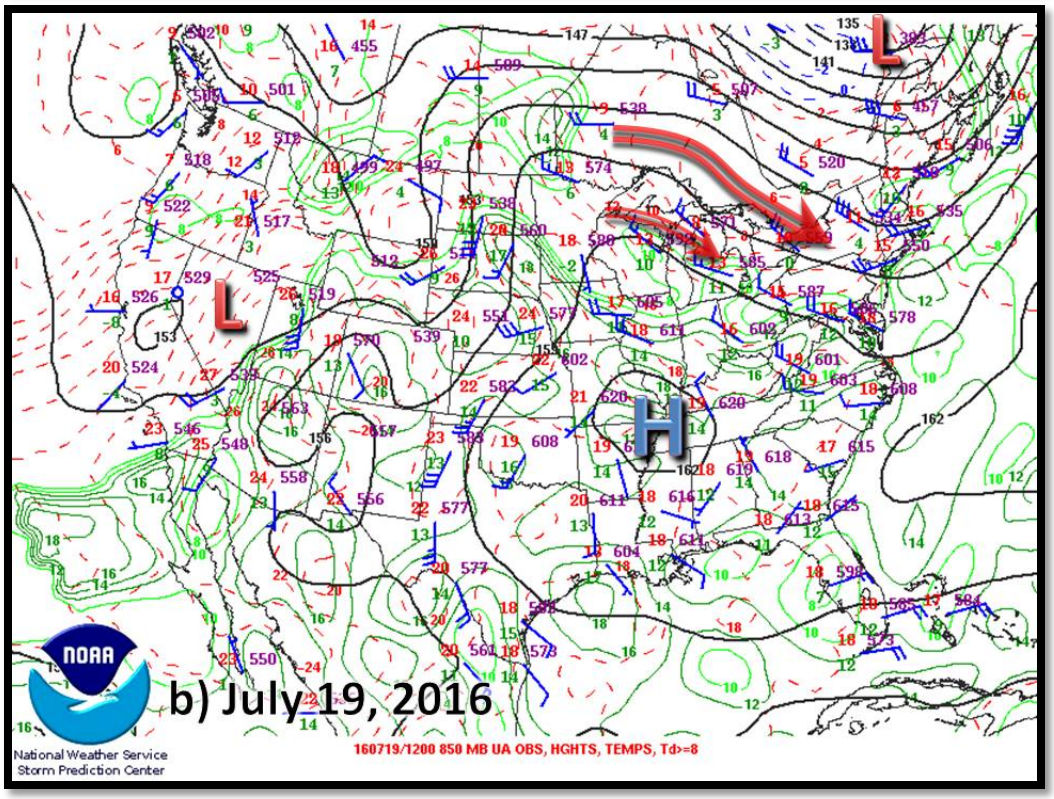
2.4.3.2. Upper Level Pattern Overview

The 850mb level (approximately 1500m above sea level) sits near the top of the planetary boundary layer, the atmospheric layer in which ozone pertinent to surface observations and human health develops. The 850mb height level can serve as a guide for the transport of pollutants. The morphology of this atmospheric level is given for July 18-23 in Figure 9. The upper level transport across Maryland remained from the northwest through nearly the entire period. A continental ridge persisted across the central CONUS in mid July of 2016. As the area of low pressure at 850mb progressed eastward across Canada the continental ridge over the central CONUS was strengthening in the Mississippi and Ohio River Valley areas on July 18 and 19, 2016 (Figure 9a and b). These two features kept northwest winds over the Great Lakes area at 850mb, which kept the smoke plume moving southeastward towards the Mid-Atlantic.

Continued eastward movement of the low pressure system in Canada weakened the pressure gradient between it and the ridge of high pressure across the east-central US. A weakening pressure gradient weakened the wind speed at 850mb, however, the transport direction remained persistent from the northwest on July 20 (Figure 9c). While the amplitude of the east central CONUS ridge of high pressure weakened on July 21 (Figure 9d), the 850mb winds remained from the northwest, albeit rather light at

around 10 knots on the first day of the exceedance. Flow at 850mb turned more west-northwesterly on July 22 (Figure 9e) as an area of low pressure across eastern Canada flattened the ridge of high pressure, which had now moved southeastward. Thus, pollutant transport on the second day of the exceedance was slightly more from the west-northwest than directly northwest. However, by July 23, transient low pressure across southern Canada had moved the trough farther east, again turning the transport relevant (850mb) flow back to the northwest (Figure 9f).


L
L
H
H
H
NOAA
a) July 18, 2016
National Weather Service
Storm Prediction Center
160718/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8


L
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NOAA
b) July 19, 2016
National Weather Service
Storm Prediction Center
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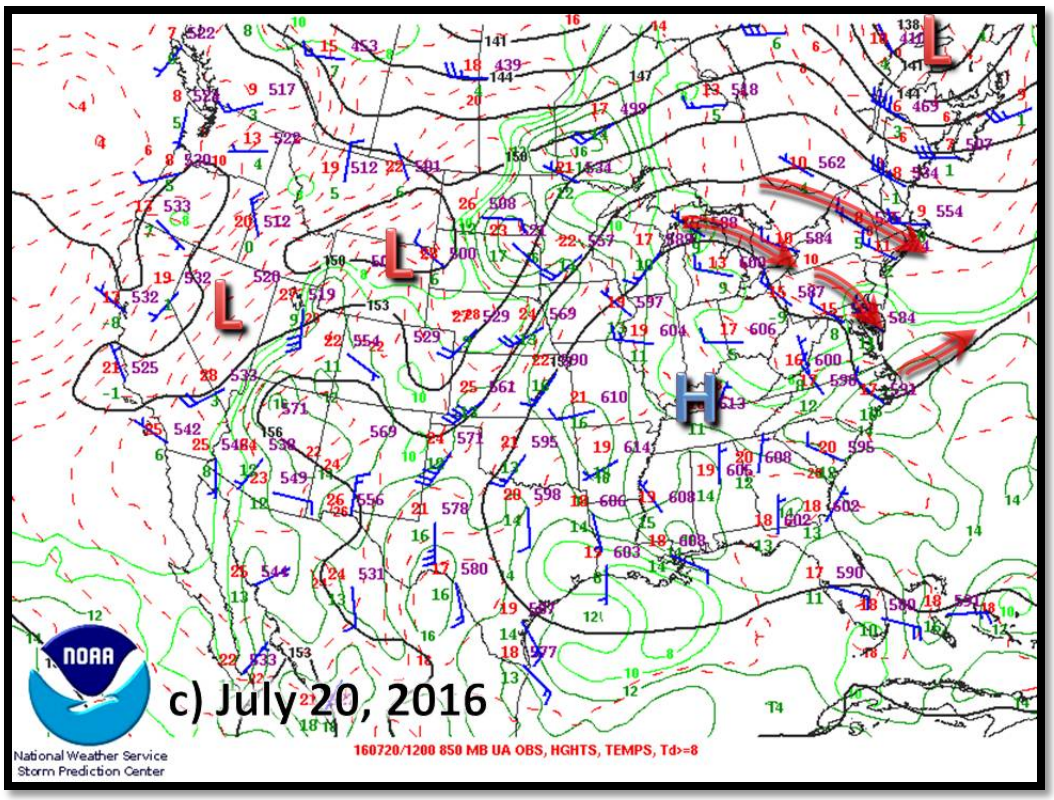
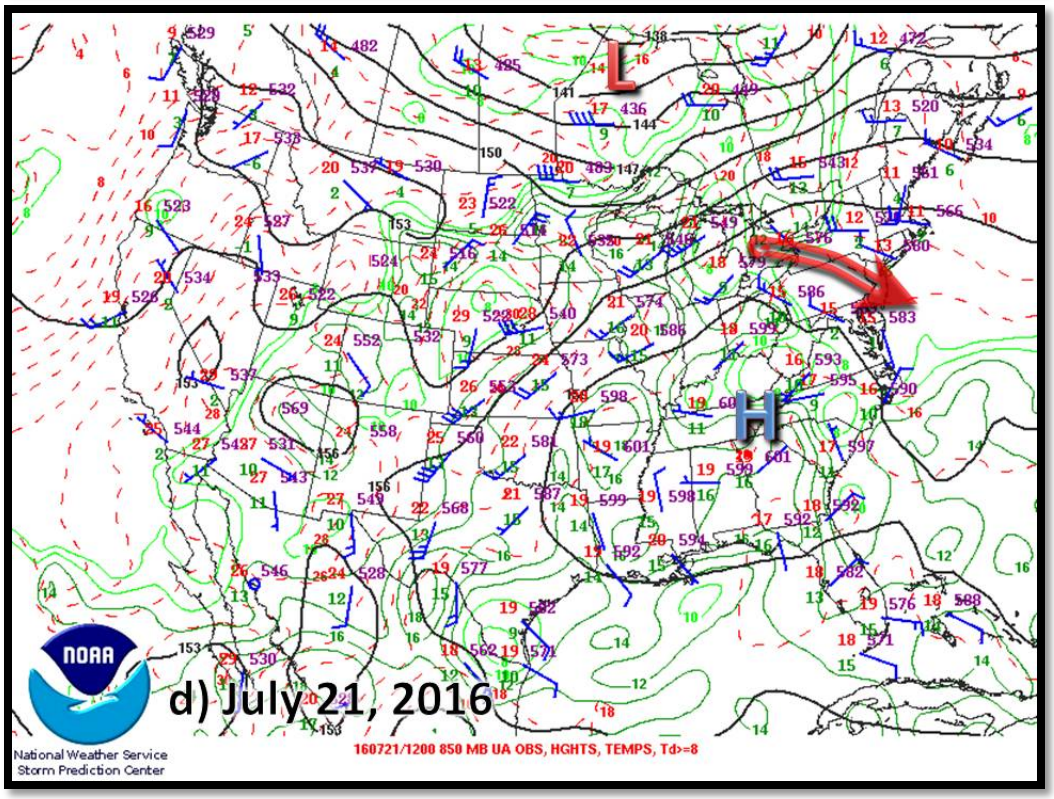

c) July 20, 2016
National Weather Service
Storm Prediction Center
160720/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8


d) July 21, 2016
National Weather Service
Storm Prediction Center
160721/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8

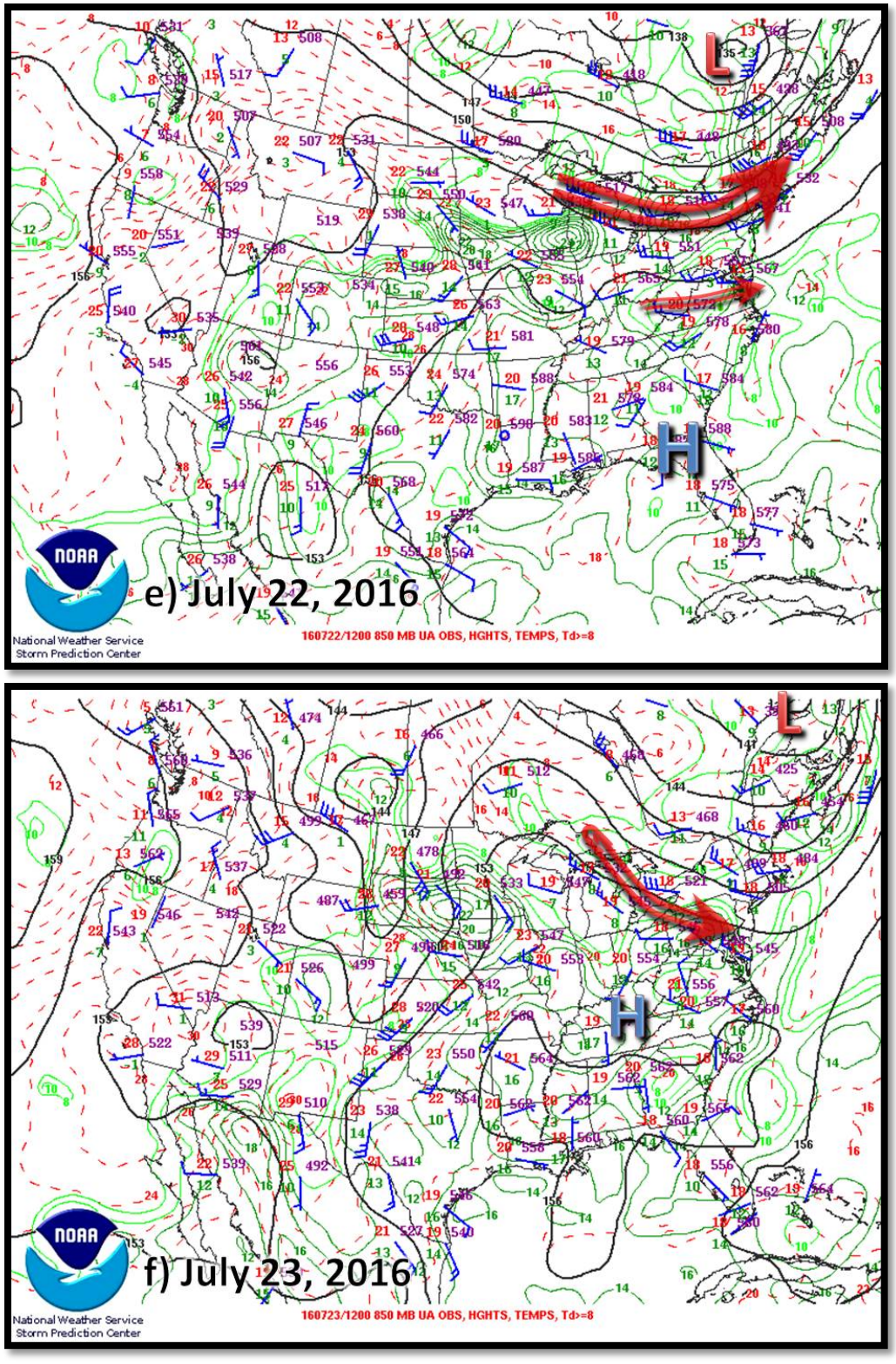
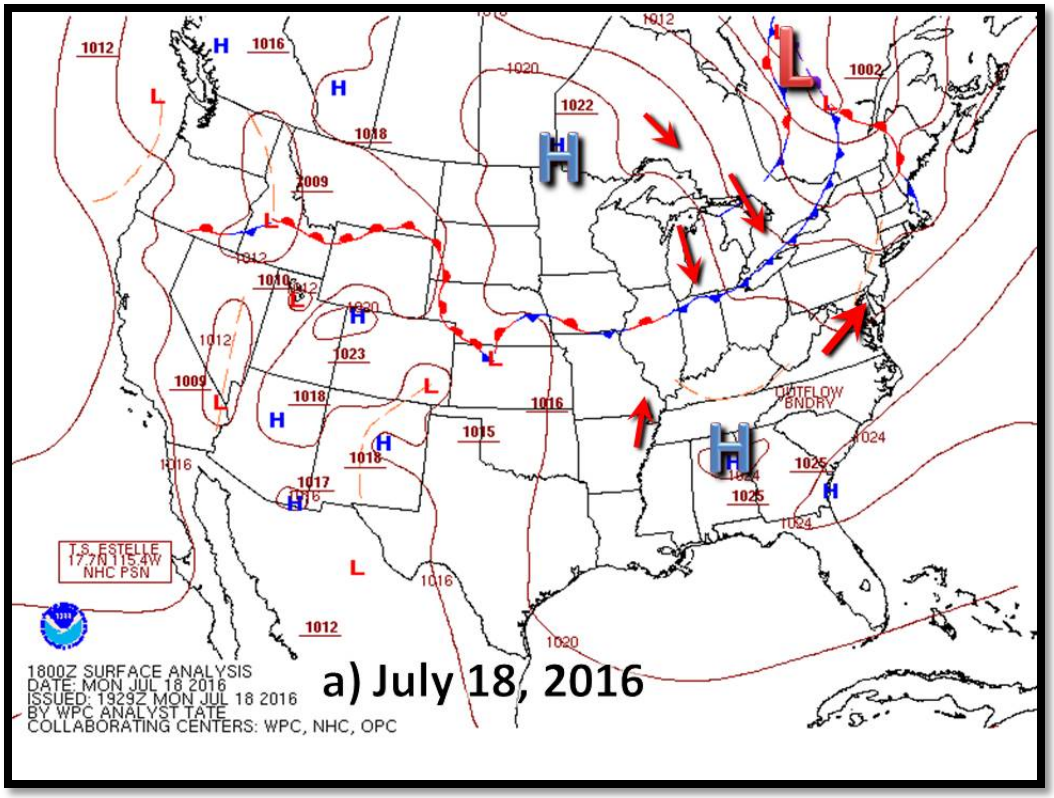
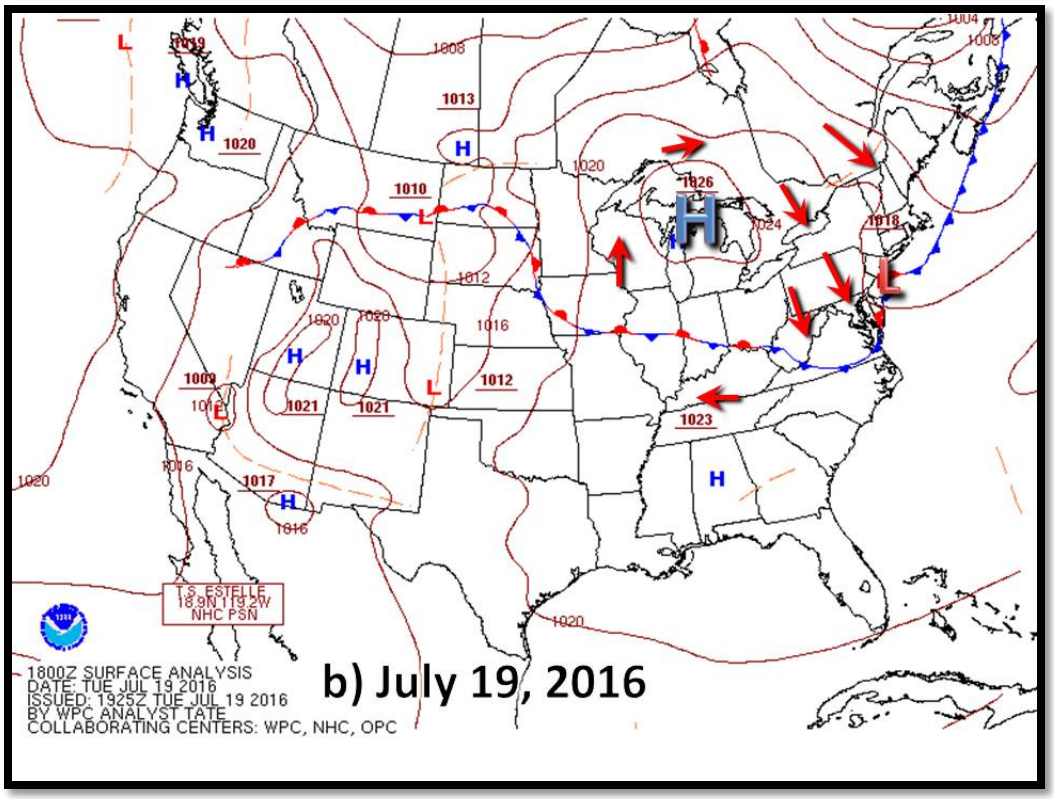


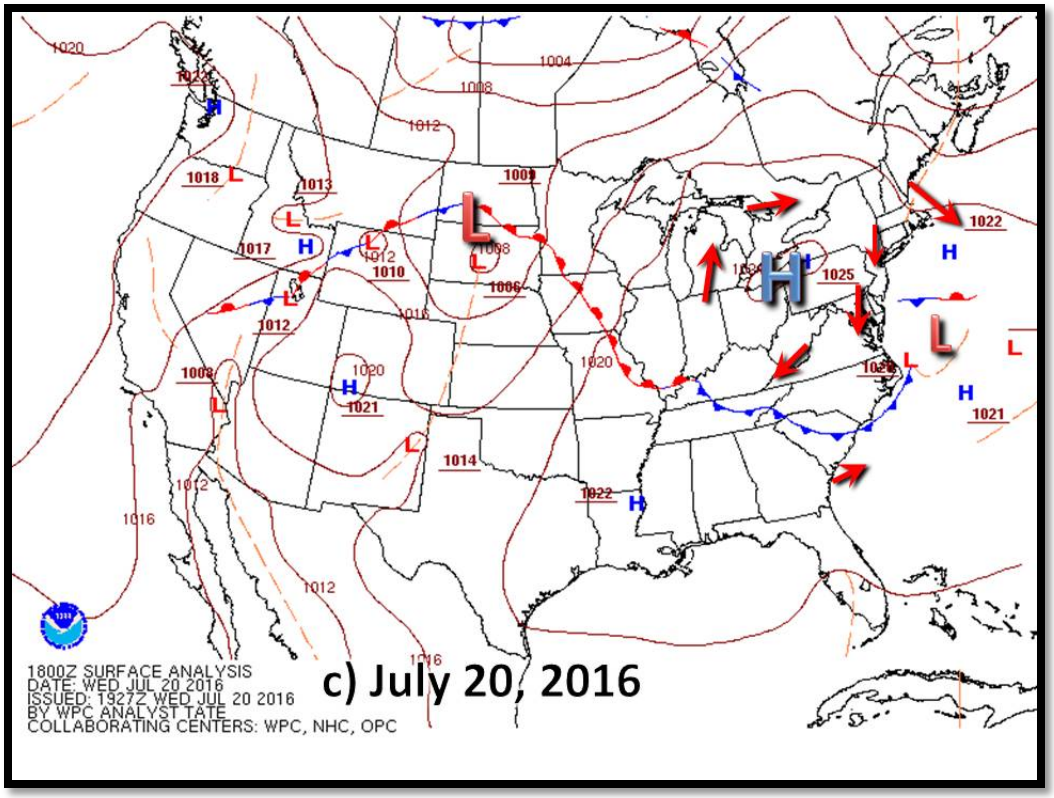
Figure 9. The 1200UTC 850mb pattern for the CONUS on July 18-23.
Upper level charts at 850mb are for a) July 18, b) July 19, c) July 20, d) July 21, e) July 22, f) July 23. Red arrows show the general transport pattern. Big letter "H" is high pressure, letter "L" is low pressure. Heights (black lines), temperatures (red dashed lines), dewpoint (green lines), and winds (blue barbs) are also analyzed.

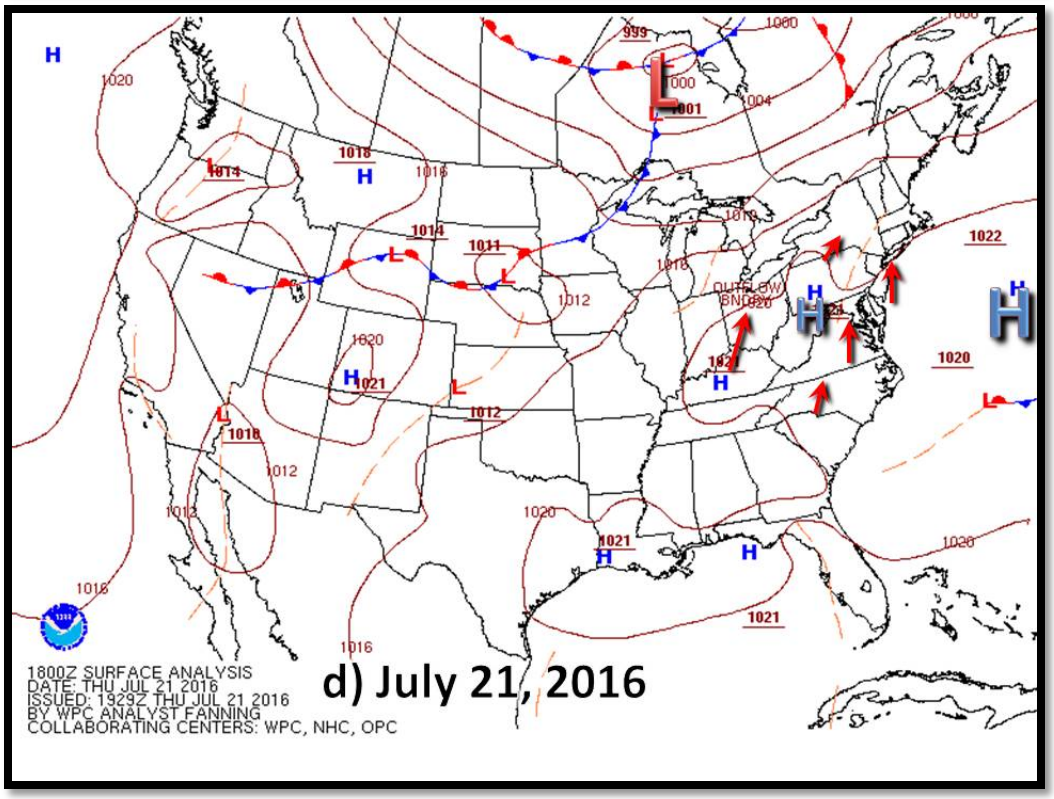
2.4.3.3. Surface Pattern Overview

While transport winds provide information on the transport of airmasses and weather systems, surface conditions and features dictate whether an airmass may be capable of ozone production. As an area of low pressure moved across southern Canada a cold front dropped southward across the Great Lakes region of the CONUS and provided northerly and northwesterly flow in its wake (Figure 10a). Ahead of the front southwesterly winds existed across Maryland within warm and moist air. Thunderstorms developed on July 18 in a surface trough ahead of the front. By midday on July 19, northerly flow behind the front existed in Maryland (Figure 10b). Despite the passage of the front and northerly winds, temperatures were not significantly cooler behind the front. With sunny skies and relatively light winds, Maryland did have one monitor near Baltimore exceed 70ppb for its MD8AO (Essex – 75ppb). However, this was only one monitor which exceeded due to local influences related to the land/water interface near the site. The front briefly retreated as weak low pressure developed off the coast (Figure 10b) before again pushing southward and further weakening on July 20 (Figure 10c). High pressure originally over northern Minnesota (Figure 10a) also worked its way southeastward over this time, settling over western Pennsylvania by July 20 (Figure 10c). Both the strength of this high pressure and the characteristics of the cold front dropping southward across the Mid-Atlantic faded on July 21 (Figure 10d). Because of the weakening high pressure over the West Virginia, Maryland, Pennsylvania tri-state area as compared to that of the Bermuda High, the surface pressure gradient changed from favoring northerly winds to southwesterly winds (Figure 10d). This continued on July 22 (Figure 10e) and through July 23 (Figure 10f). Consistent with lowering pressure ahead of another front dropping from the north as well as lee-subsidence with the northwest flow at 850mb, a surface pressure trough (lee trough) developed along the I-95 corridor on July 22 and July 23 (Figure 10e and f).


1800Z SURFACE ANALYSIS
DATE: MON JUL 18 2016
ISSUED: 1929Z MON JUL 18 2016
BY WPC ANALYST TATE
COLLABORATING CENTERS: WPC, NHC, OPC
T.S. ESTELLE
17.7N 115.4W
NHC PSN
OUTFLOW BNDRY
a) July 18, 2016


1800Z SURFACE ANALYSIS
DATE: TUE JUL 19 2016
ISSUED: 1925Z TUE JUL 19 2016
BY WPC ANALYST TATE
COLLABORATING CENTERS: WPC, NHC, OPC
T.S. ESTELLE
18.9N 119.2W
NHC PSN
b) July 19, 2016


1800Z SURFACE ANALYSIS
DATE: WED JUL 20 2016
ISSUED: 1927Z WED JUL 20 2016
BY WPC ANALYST TATE
COLLABORATING CENTERS: WPC, NHC, OPC
c) July 20, 2016


1800Z SURFACE ANALYSIS
DATE: THU JUL 21 2016
ISSUED: 1929Z THU JUL 21 2016
BY WPC ANALYST FANNING
COLLABORATING CENTERS: WPC, NHC, OPC
d) July 21, 2016

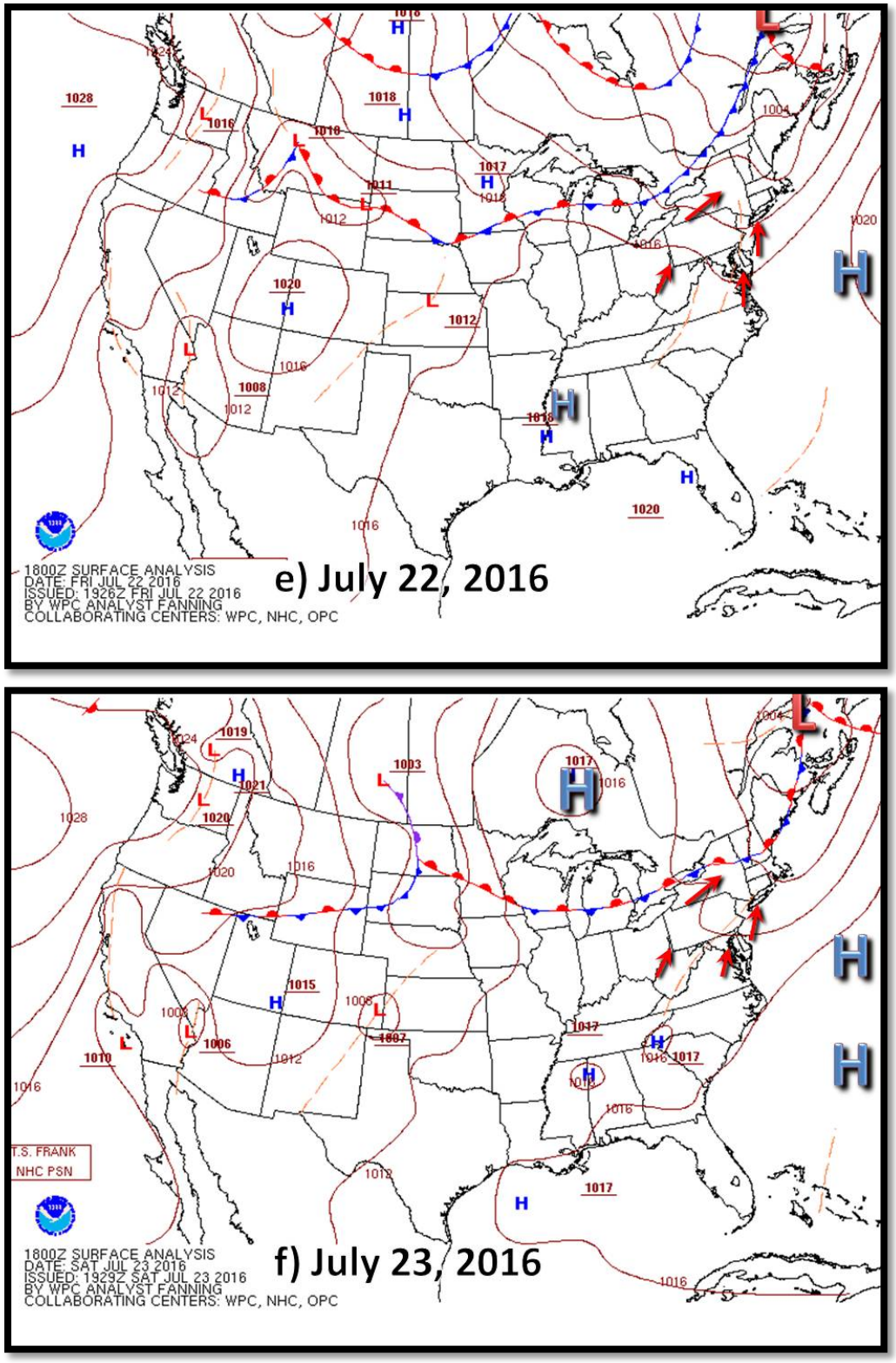


Figure 10. Surface analysis at 1800 UTC (2pm LDT in Maryland) for July 18-23, 2016.
Surface level charts are for a) July 18, b) July 19, c) July 20, d) July 21, e) July 22, f) July 23, 2016. Red arrows show the general surface wind pattern/direction. The letter "H" highlights high pressure, letter "L" is low pressure. Heights (brown lines) and fronts are also analyzed.

2.4.3.4. Temperature

Despite a period of prolonged warmth prior to the smoke event, ozone increased above the 70ppb standard over a wide area only in the presence of smoke. The hottest temperatures between July 15 and 23 occurred the day after the highest ozone concentrations occurred in Maryland (i.e., July 23), indicating that while warm temperatures supported ozone production, they did not drive it. Only one day between July 15 and July 23 was below 90°F and/or below normal (Table 3). As asserted earlier and exemplified over this period of warm weather, temperatures no longer necessarily predict ozone production. In fact, temperatures were warmer than normal through the 2016 ozone season, but recent data has shown that warm temperatures are no longer sufficient for ozone exceedances in Maryland. For example, the once steady ratio of "hot days" to ozone exceedances from 1980 – 2003 hit an all time high in 2016 with nearly twice as many hot days as ozone exceedances at the 70ppb standard (Figure 11). Previously, greater probability of ozone NAAQS exceedance in Maryland was shown with higher temperatures (Lin et al., 2001) and historically, MDE has tracked Maryland's ozone exceedance days with temperatures equal to or exceeding 90°F (MDE, 2012; Warren, 2013). However, Maryland also had near-record warmth throughout the 2016 ozone season but recorded a very low number of exceedance days. In fact, in a year with 48 days at or above 90°F, the greatest number of days in the last 17 years, there were only 26 exceedance days, which is the highest ratio of hot days to ozone exceedances at the 70 ppb level ever (Figure 11 and Figure 3). For example, in August of 2016, a string of several days in the mid 90s produced no ozone exceedances. The number of hot days to the number of ozone exceedances has been steadily increasing since 2003 indicating that temperature alone as a factor in ozone production is decreasing in importance in Maryland and emphasizes the important role of smoke and the additional ozone precursors it provided in this case.

All but one day was at or above the 90 °F threshold from July 14 – July 23 (Table 3). Except for the two and a half days with smoke influence, maximum one-minute ozone concentration measured in ppb was always lower than the maximum 10m temperature measured at the same sites (Figure 12). This is not to suggest that the absolute temperature is a proxy for ozone concentrations, rather, this is offered as a relative comparison for this period. For example, notice the similar diurnal temperature profiles on July 17 and July 21, 2016 but the drastic difference in ozone concentrations between the two days (Figure 12). This suggested substantial atmospheric composition differences between the two days. Additionally, on the day with the warmest temperature in the period (July 23), minute averaged ozone decreased after concentrations reached their peak around noon. This peak was also lower than ozone concentrations at the same time on the previous two days. Maryland did experience scattered evening thunderstorms on July 23, but the ozone concentrations peaked at 69ppb at HU-Beltsville at 11:56am while the temperature peaked several hours later at 92°F at 3:11pm. A fair weather cumulus field was present but insufficient for UV shielding and afternoon cloud cover due to thunderstorms did not impact Fair Hill (FH) or Hagerstown ("Hager" on figure) until approximately 4pm. Thus storm influences were an unlikely cause for the decrease in ozone concentrations after noon on July 23. Since the smoky airmass had been removed by July 23 by persisting transport of unaffected (non-smoky) air, the drop in ozone supported the assertion that the removal of smoke from the region is what improved air quality conditions and thereby the smoke was what

caused MD8AO in exceedance of the NAAQS at multiple monitors in Maryland on the previous two days, July 21 and 22, 2016.

Table 3. Temperatures at BWI & MD8AO for Maryland July 14-23, 2016.
Maximum and minimum daily temperature, average maximum daily temperature and departure from normal (observation minus normal/average) at BWI. All temperatures are in degrees Fahrenheit.

DATE	Tmax (°F)	Tmin (°F)	Normal Tmax(°F)	Departure (°F)	MD MD8AO (ppb)
7/14/2016	96	75	88	8	59
7/15/2016	90	73	88	2	61
7/16/2016	92	68	88	4	71
7/17/2016	90	65	88	2	65
7/18/2016	94	71	87	7	63
7/19/2016	90	70	87	3	75
7/20/2016	86	66	87	-1	70
7/21/2016	90	63	87	3	78
7/22/2016	94	69	87	7	87
7/23/2016	98	73	87	11	66

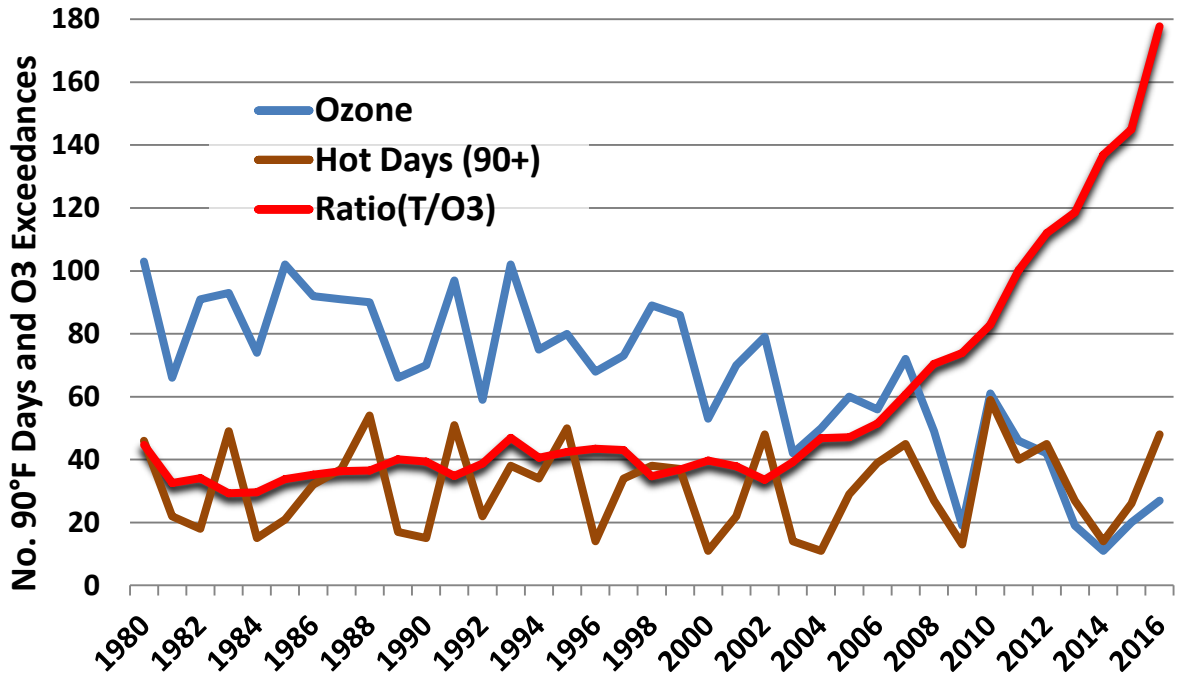


Figure 11. Ozone exceedance days to high temperature ratio.
A graph of the number of days with MD8AO in Maryland greater than 70ppb in a given ozone season (blue line), the number of days where the temperature at BWI airport reached at least 90°F in a given year (brown, thin line), and the five year moving average (multiplied by 100) of the ratio of "hot days" to ozone exceedances (thick red, shadowed line) from 1980-2016. The dramatic increase in the ratio of hot days to ozone exceedances indicates the decreasing significance temperature has on ozone exceedance days in Maryland.

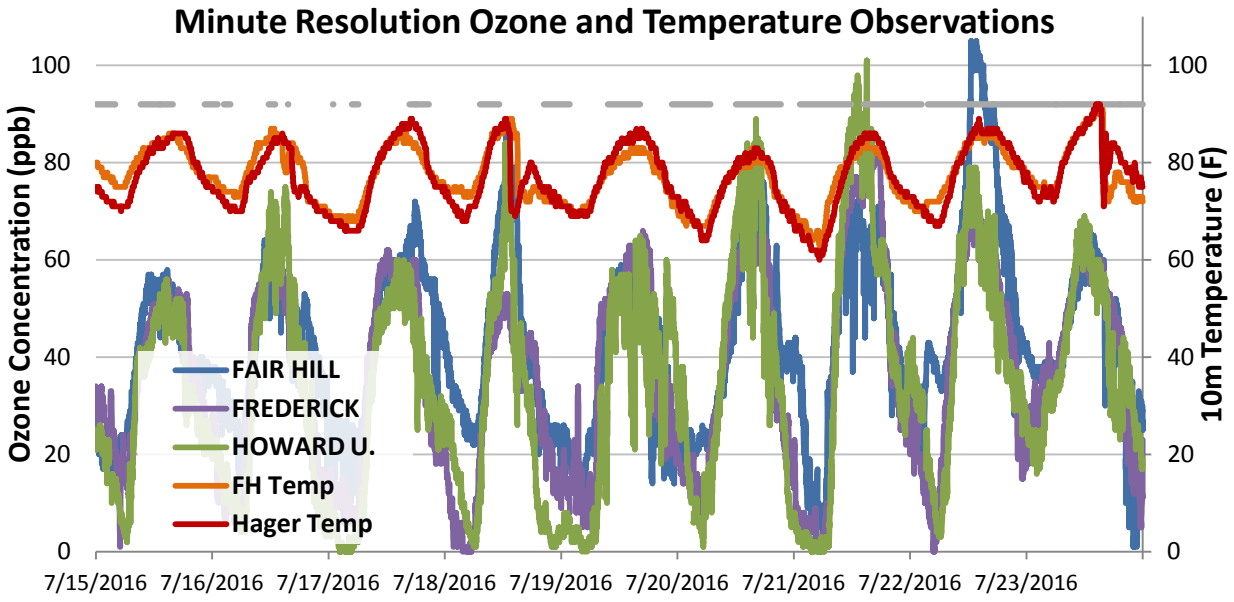


Figure 12. Minute resolution surface temperature (°F) and ozone (ppb).
Days with similar temperature to July 21 and 22 had ozone lower than the maximum achieved in the presence of a smoke-modified airmass. Ozone concentrations on July 23, 2016 at Fair Hill, Frederick and Howard U. (HU-Beltsville) all declined while temperatures continued to increases and prior to the sharp decline in temperatures at both Fair Hill (FH) and Hagerstown (Hager) dropped due to approaching storms.

2.4.4. Tracking Smoke and Wildfire Emissions Transport to Maryland

Unlike the May 25 and 26, 2016 Maryland smoke and ozone event in which smoke degraded air quality well upstream of Maryland, July's smoke plume appears to have remained mostly elevated until subsiding in Maryland on July 20. Lidar imagery acquired by the University of Maryland Baltimore County (UMBC) Elastic Lidar Facility (ELF) aerosol Lidar, located in Catonsville, MD (39.255°N, -76.711°W) or about 10 km west of the Baltimore Inner Harbor showed that a layer of aerosols (smoke) subsided over Maryland and was incorporated into the planetary boundary layer (PBL; near surface layer of air) on July 20 between 4:00 and 6:00pm (Figure 13). The sinking motion of the smoke is consistent with subsidence typical of post frontal airmasses and high pressure as was present across the northern Mid-Atlantic on July 20 (Figure 10c). While the cold front passed through Maryland on July 19, the smoke had not yet been transported into the subsiding air by the northwesterly flow at 850mb, which continued through the smoke transport period into Maryland between July 18 and July 20 (see below).

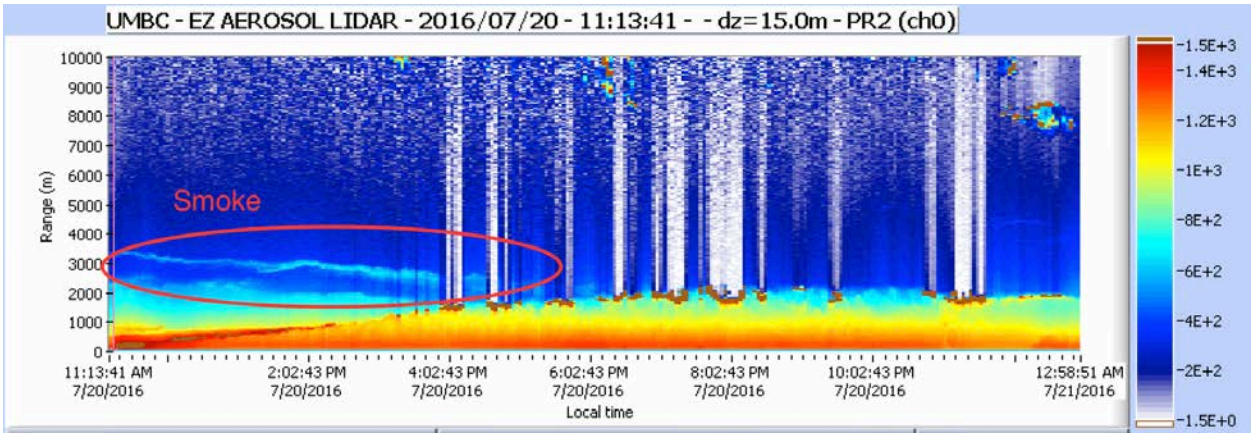
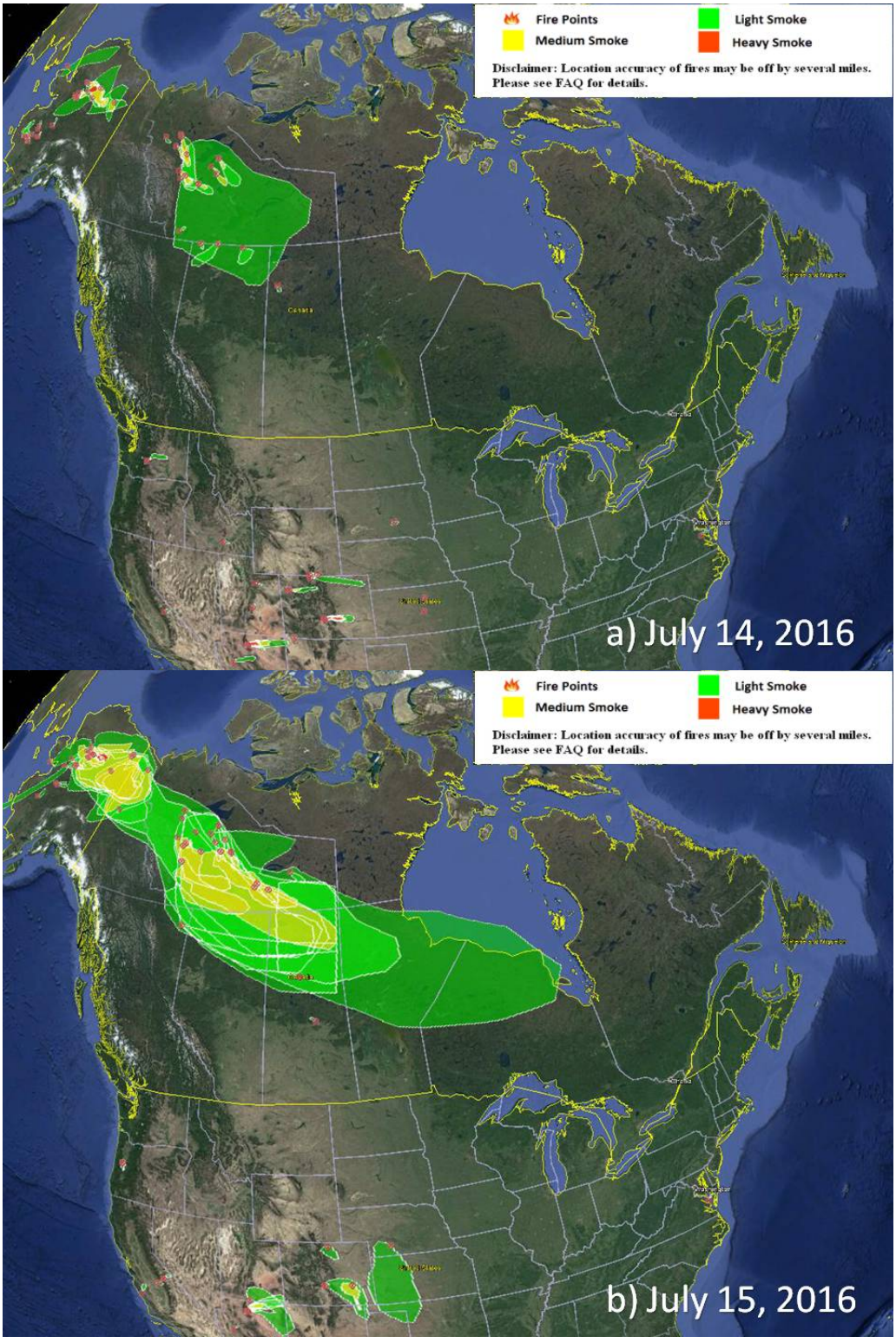


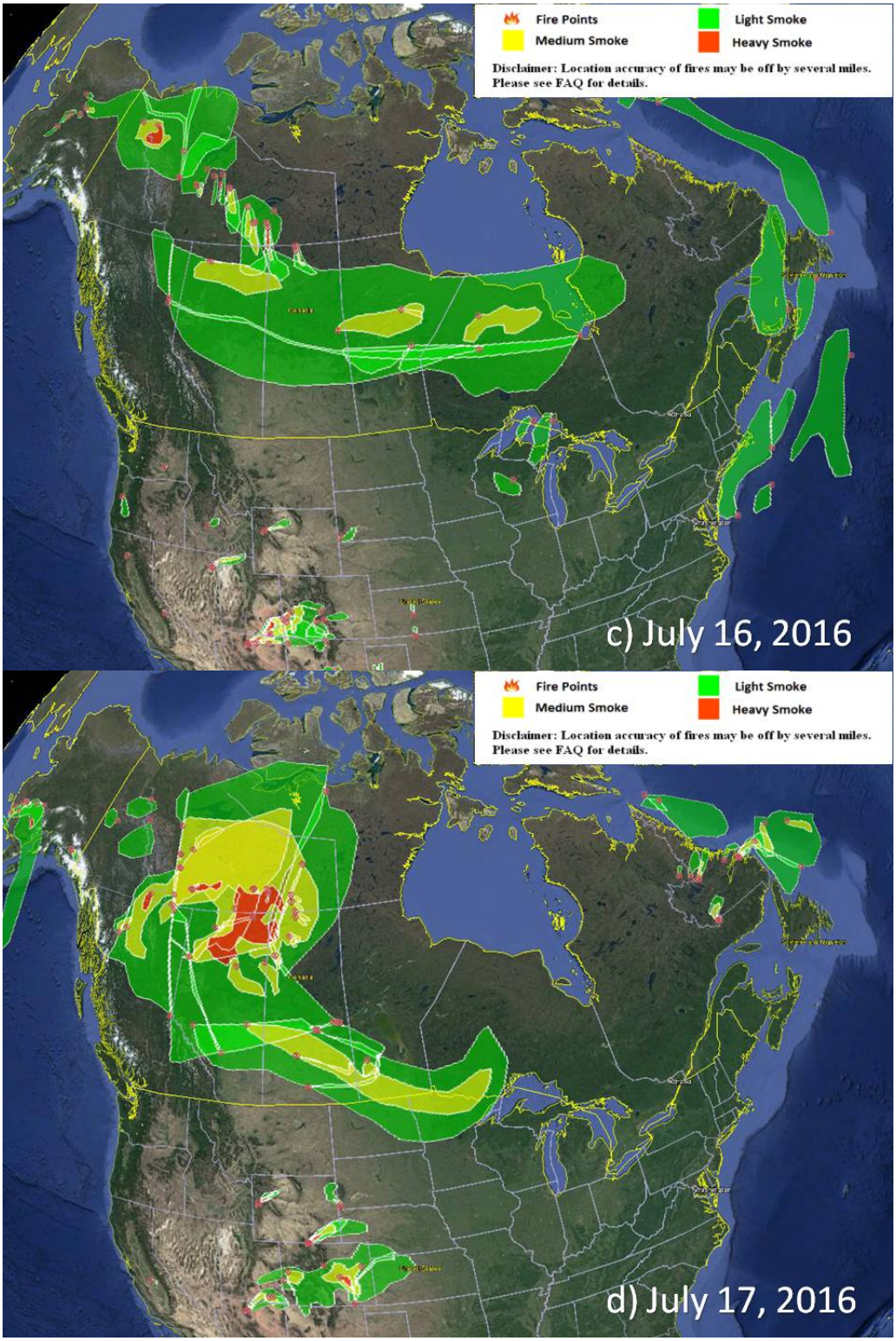
Figure 13. UMBC Aerosol Lidar from July 20 -21, 2016.
Increased back scatter is indicated by warmer colors. A layer of aerosols subsiding from above 3000m is circled and identified as smoke. The smoke is seen mixing with the planetary boundary layer (PBL) between 4:00 and 6:00pm on July 20, 2016, indicating smoke mixed into the local air in the greater Baltimore region the evening before the exceedances on July 21. White vertical banding is due to cloud interference.

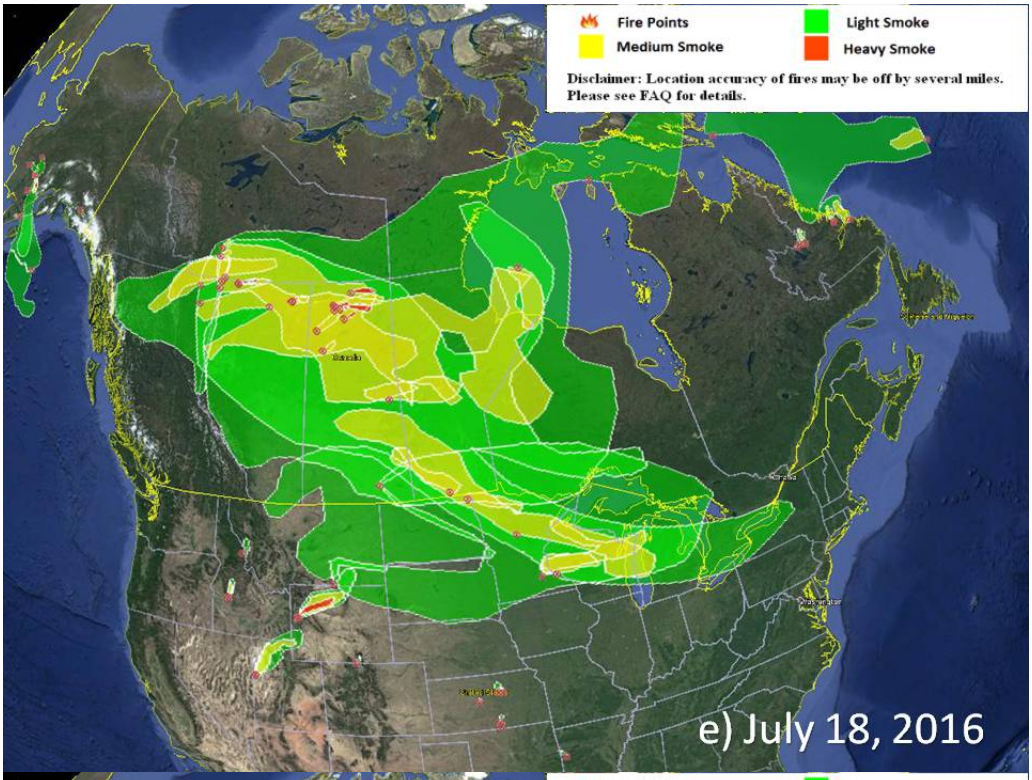
As a result of the evolution of the upper level and surface weather patterns, smoke from northwestern Canada was transported to Maryland. HMS smoke analysis prior to the ozone event clearly showed a smoke plume originating over northwestern Canada which progressed southeastward towards the northeastern US and northern Mid-Atlantic (Figure 14). Smoke was analyzed already on July 14 from fires over northwestern Canada across Alberta, British Columbia and the Northwest Territories (Figure 14a). This plume grew in size and worked southeastward across northern Alberta, Saskatchewan, Manitoba, and Ontario on July 15 (Figure 14b) where it persisted into July 16 (Figure 14c). The remnants of this first plume moved southward on July 17 to be across the US/Canada border as the number of fires across the fire region also grew according to fire information from the Canadian Wildland Fire Information System (CWFIS) for the week of July 13 -20, 2016. The new fires reinvigorated smoke across the Northwest Territories and northern Alberta (area in red, Figure 14d). As discussed previously, the upper level winds moved this new plume of smoke (and whatever remnant smoke there was across the US/Canada border) southeastward. By July 18 the smoke plume stretched from the fire source area across northwest Canada all the way to the Great Lakes as it was impacted by the passing low pressure system that moved across Canada (Figure 14e). The first mentioned remnant plume appeared to be across the great lakes while the new plume seemed to be still concentrated a bit farther northwest across central Canada where greater smoke concentrations existed over a wider area.

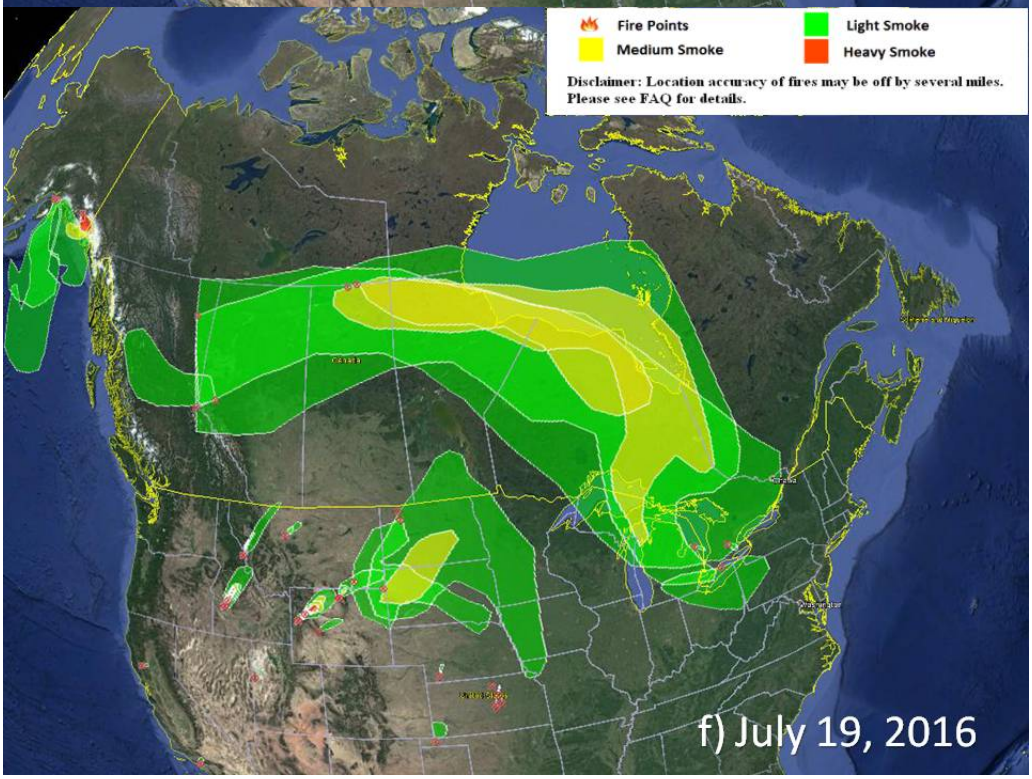
By July 19, the main, concentrated smoke plume which started out as an area of analyzed heavy smoke on July 17, stretched from the Hudson Bay to the northern Great Lakes (Figure 14f). The remnant plume emitted earlier in the period was no longer analyzed ahead of the thicker plume and/or was no longer distinguishable as separate from the plume generated at the later date. The smoke plume by July 19 had pushed southward, caught in the northwest flow around or above 850mb. Though at this time it was well behind the surface cold front and also just to the east of the center of high pressure located over the

western Great Lakes (compare Figures 14f and 9b and 10b). The smoke plume continued southeastward on July 20 (Figure 14g). However, by this time subsidence associated with the high pressure and post frontal air mass moving southward over the northern Mid-Atlantic had been acting on the smoke plume, forcing it downwards towards the surface. Lidar imagery showed the smoke subsided from heights greater than 3000m above the surface, suggesting the path of the smoke was consistent with the 3000m (green) trajectory seen in Figure 6 which showed transport of the smoke plume from southern Canada several days earlier. This path is also consistent with the HMS smoke analysis evolution over several days, presented in Figure 14, conclusively showing the smoke was transported not only to Maryland, but to the surface air in Maryland and made available for ozone production on July 21. Analyzed smoke was no longer present over Maryland on July 21 (Figure 14h), though further analysis presented below showed the impact from the smoke on the composition of the atmosphere in Maryland persisted on July 21 and 22, 2016.


Fire Points
Light Smoke
Medium Smoke
Heavy Smoke
Disclaimer: Location accuracy of fires may be off by several miles.
Please see FAQ for details.
a) July 14, 2016
Fire Points
Light Smoke
Medium Smoke
Heavy Smoke
Disclaimer: Location accuracy of fires may be off by several miles.
Please see FAQ for details.
b) July 15, 2016


Fire Points
Light Smoke
Medium Smoke
Heavy Smoke
Disclaimer: Location accuracy of fires may be off by several miles.
Please see FAQ for details.
c) July 16, 2016
Fire Points
Light Smoke
Medium Smoke
Heavy Smoke
Disclaimer: Location accuracy of fires may be off by several miles.
Please see FAQ for details.
d) July 17, 2016


Fire Points
Light Smoke
Medium Smoke
Heavy Smoke
Disclaimer: Location accuracy of fires may be off by several miles.
Please see FAQ for details.
e) July 18, 2016


Fire Points
Light Smoke
Medium Smoke
Heavy Smoke
Disclaimer: Location accuracy of fires may be off by several miles.
Please see FAQ for details.
f) July 19, 2016

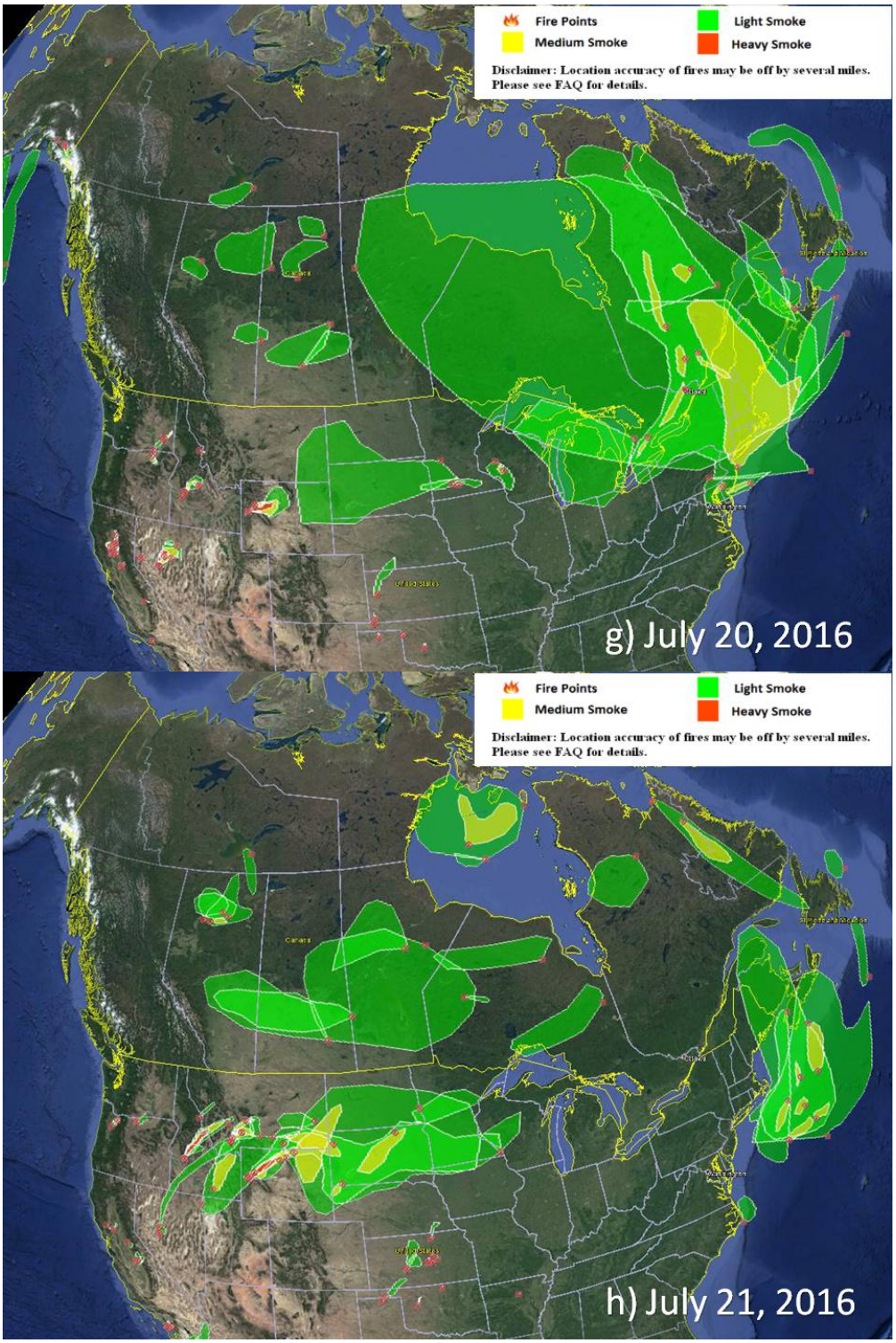


Figure 14. HMS analyzed smoke showing transport from the fire region to Maryland.
The North America view showed the transport of smoke from the fire source region to Maryland over the course of several days: (a) July 14, (b) July 15, (c) July 16, (d) July 17, (e) July 18, (f) July 19, (g) July 20, (h) July 21. Green shading shows light smoke, yellow medium/moderate smoke, and red heavy smoke coverage. Notice smoke from northwest Canada was present beginning July 14, drifting towards the CONUS, but a large increase in the smoke coverage occurred between July 17 and July 18. This plume moved into Maryland by July 20.

2.4.5. Smoke and Ozone Discussion and Analysis

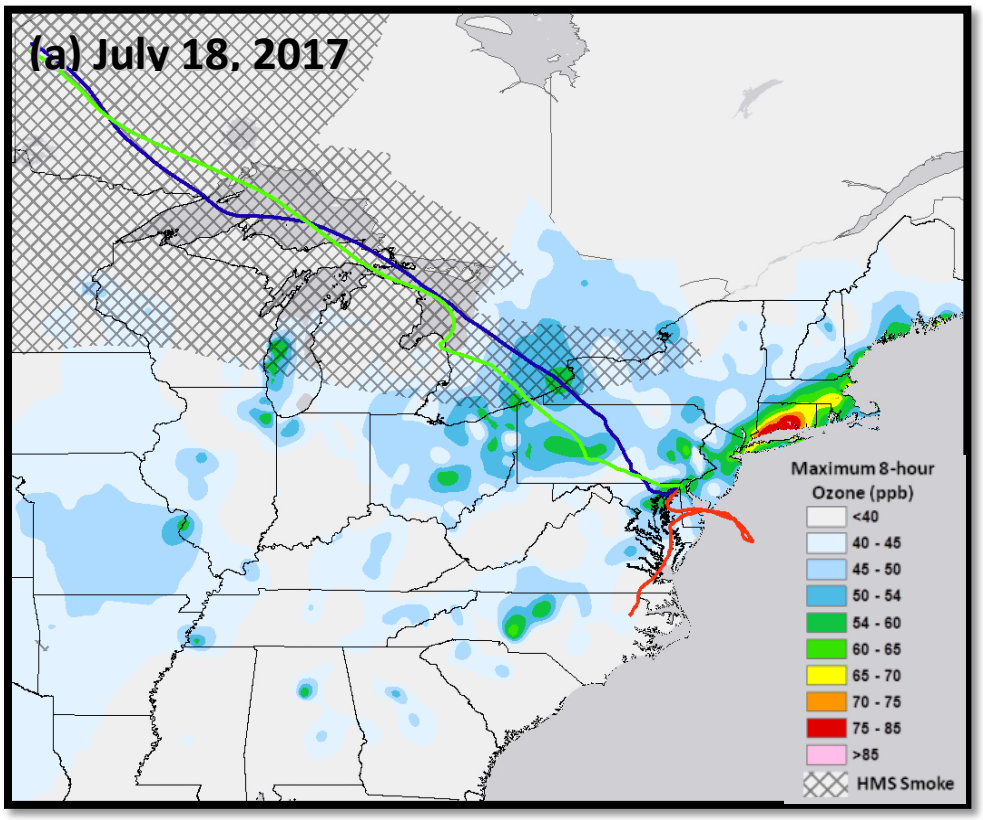
Spatial analysis of contoured MD8AO concentrations and HMS analyzed smoke were consistent with the transport of an elevated smoke plume across the upper Great Lakes into the northeast CONUS that subsided to the surface across the northern Mid Atlantic. The subsidence of the smoke to the surface in Maryland was clearly connected to the onset of an ozone exceedance event. The magnitude of ozone concentrations across the entire eastern US remained quite low on July 18 and 19 (Figures 15a and b). Outside of the single exceedances around Chicago and at Essex, Maryland on July 19, any MD8AO above 55 ppb was extremely isolated. In these early analysis days there appears to be little correlation of the location of the smoke plume to surface ozone. This is logical, since the plume was shown to be elevated during this time and was not yet impacting the surface air. Thus, the lack of correlation of ozone and the smoke plume on July 18 and 19 actually bolsters the argument that the smoke heightened the MD8AO concentrations once the smoke reached the surface. Slightly cooler temperatures and initially cleaner air in northern Pennsylvania behind the front kept ozone values low there on July 19 but also brought the elevated smoke farther south across areas such eastern Ohio and western Pennsylvania (Figure 15b). The cold front created a well defined ozone gradient across central Pennsylvania on July 19 that persisted on July 20 while temperatures recovered regionally (Figure 15c) and smoke began impacting the surface.

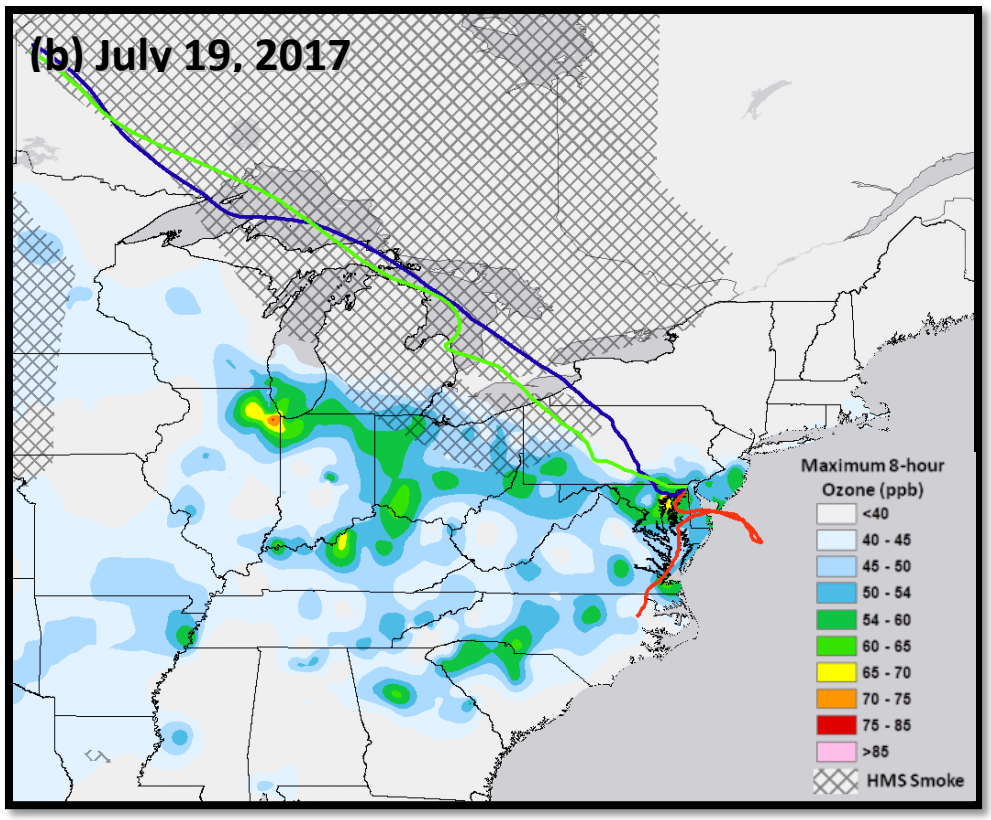
By July 20, the combination of high pressure northwest of Maryland and the weak low pressure associated with the cold front just off the east coast (see Figure 10b and c) caused near-surface winds to turn northeasterly in Maryland on July 20 (red and blue trajectories on Figure 15c) bringing smoke down to the surface across Maryland with a slight easterly component. MD8AO concentrations increased along the I-95 corridor to around 65ppb on July 20 (Figure 15c), but only along the I-95 corridor. Elsewhere, concentrations were at or below 60ppb. Particularly of note are the low (<55ppb) MD8A in locations across Pennsylvania, New Jersey, New York and Connecticut. These were important to note for comparison of these same locations on July 21, the first day of an ozone exceedance across the region. As the smoke subsided across the area, substantial ozone production began. MD8AO concentrations in excess of 70ppb were observed from western Pennsylvania southward through DC to Richmond and Hampton Roads, Virginia and northeastward all the way to Connecticut. Recall areas over Connecticut and New York on the previous day had MD8AO concentrations below 55ppb. Other areas exceeding 75ppb on July 21 (Figure 15d) had MD8AO concentrations on July 20 (Figure 15c) of only 60ppb or less. All locations saw about a 15ppb jump between days. The main difference between the days was the arrival of smoke across the region late on July 20, with influences persisting on July 21.

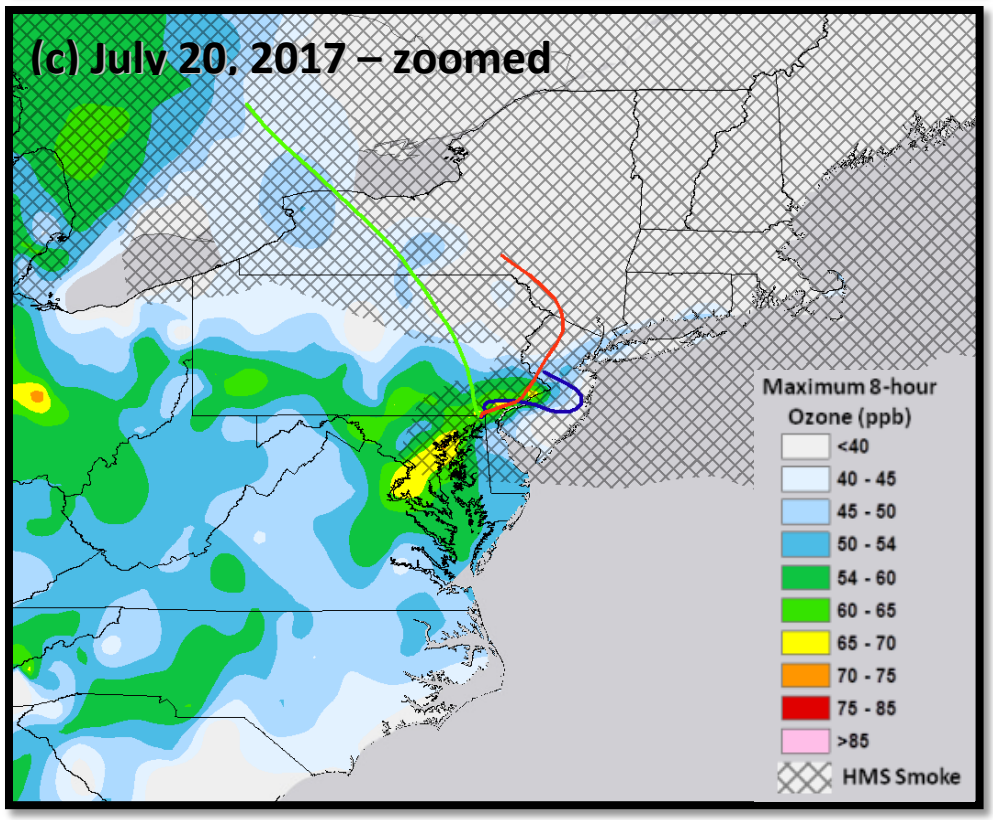
Although smoke was only analyzed by HMS over northeastern Maryland on July 20, the analysis can be off by several tens of miles. Additionally, HMS is a “one time” capture of the smoke by satellite, with further interpretation by subjective expert analysis. In other words, the smoke is only mapped once during the day and does not account for continued transport southwards towards areas such as Richmond. Nor does it account for residual smoke influences dispersing across the entire area exceeding 70ppb on July 21, regardless of HMS not analyzing smoke over these areas (Figure 15d). In fact, HMS DOES analyze a bit of smoke just east of the Richmond/Hampton Roads area of Virginia, showing that smoke did progress that far

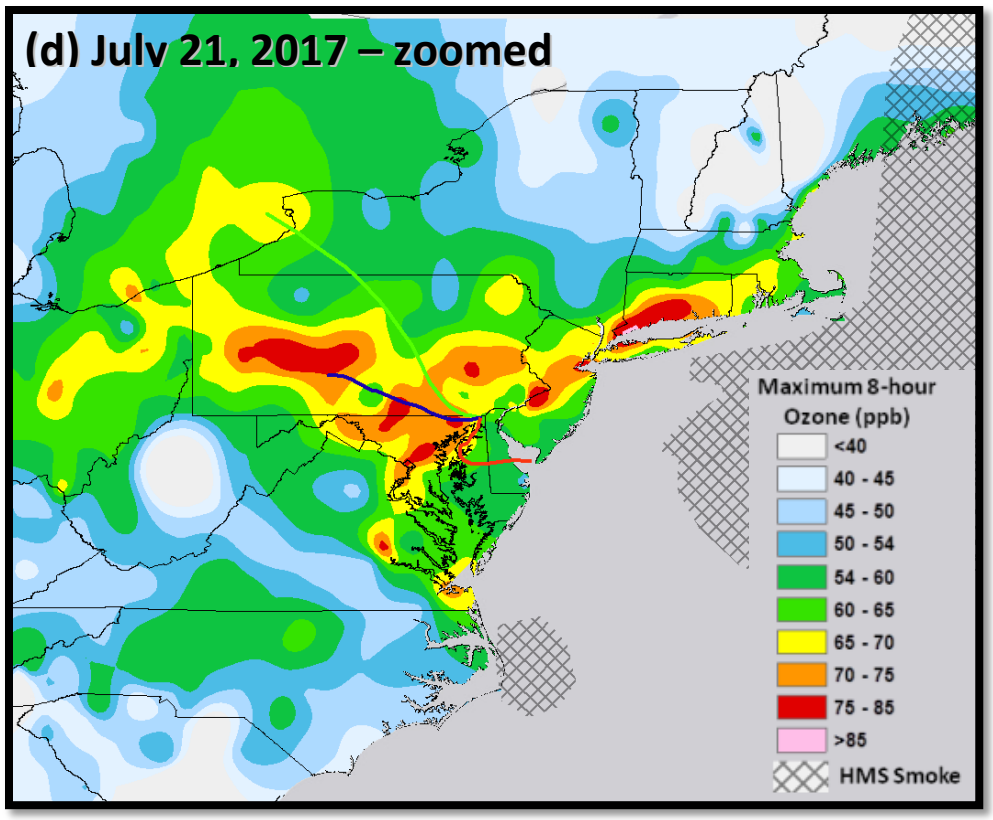
south, even if smoke was not analyzed directly over all the areas exceeding. In essence, smoke constituents had been introduced into the surface air and created conditions ripe for ozone production over a wide area, even as the surface smoke could no longer be picked up via satellite analysis. The impact of the smoke persisted on July 21 and 22 even as some analyzed smoke (that which was thick enough that it could be detected by satellite) moved offshore.

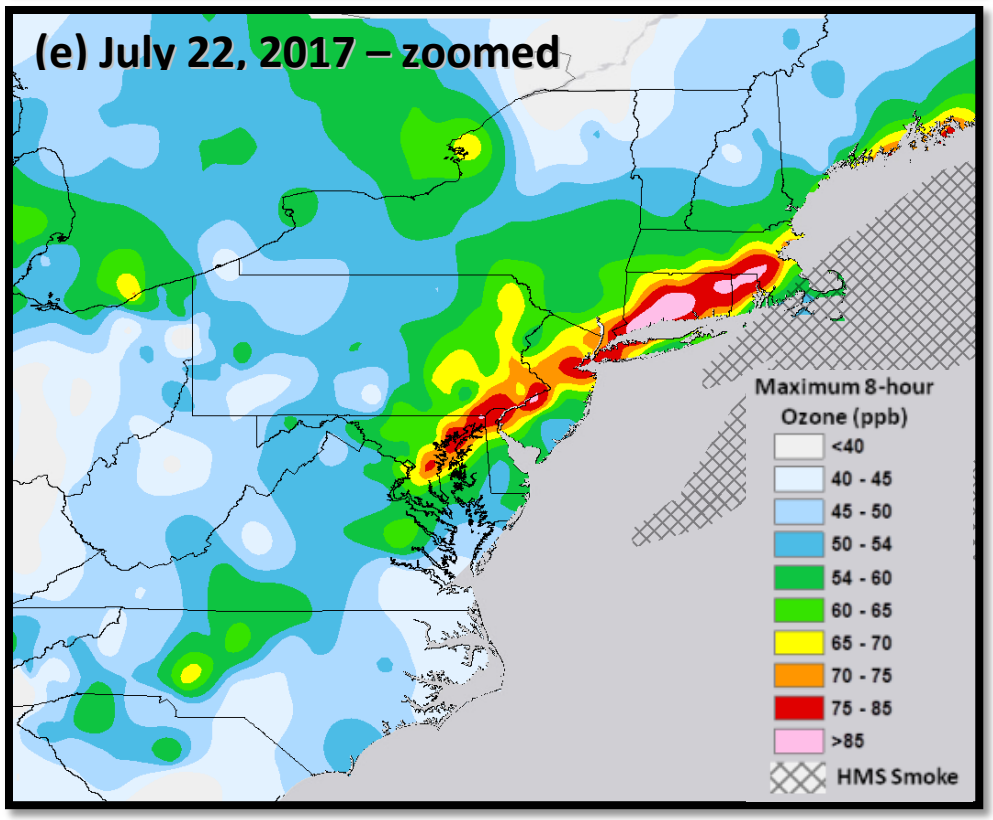
Transport winds at 850mb continued from the west and northwest on July 22 and 23 while surface winds persisted from the southwest. This favored the development of the lee trough (Figure 10e) which concentrated the remaining pollution into a tight corridor along I-95 from DC through Connecticut. As in earlier cases, as the smoky air aged, ozone concentrations also increased, and the Fair Hill monitor observed its highest MD8AO of the 2016 and similarly, areas like Connecticut had wide spread exceedances of the old 84ppb standard. Persistent conditions on July 23 across Maryland yielded decreasing ozone concentrations. Thus, as the smoke-affected air dissipated across the region, so too did the ozone concentrations. As Figure 15f showed, without the aid of additional smoke on these days, Maryland was unable to exceed the 70ppb ozone standard with its own "home grown" emissions.




(b) July 19, 2017
Maximum 8-hour Ozone (ppb)
<40
40 - 45
45 - 50
50 - 54
54 - 60
60 - 65
65 - 70
70 - 75
75 - 85
>85
HMS Smoke


(c) July 20, 2017 – zoomed
Maximum 8-hour Ozone (ppb)
<40
40 - 45
45 - 50
50 - 54
54 - 60
60 - 65
65 - 70
70 - 75
75 - 85
>85
HMS Smoke


(d) July 21, 2017 – zoomed
Maximum 8-hour
Ozone (ppb)
<40
40 - 45
45 - 50
50 - 54
54 - 60
60 - 65
65 - 70
70 - 75
75 - 85
>85
HMS Smoke


(e) July 22, 2017 – zoomed
Maximum 8-hour
Ozone (ppb)
<40
40 - 45
45 - 50
50 - 54
54 - 60
60 - 65
65 - 70
70 - 75
75 - 85
>85
HMS Smoke

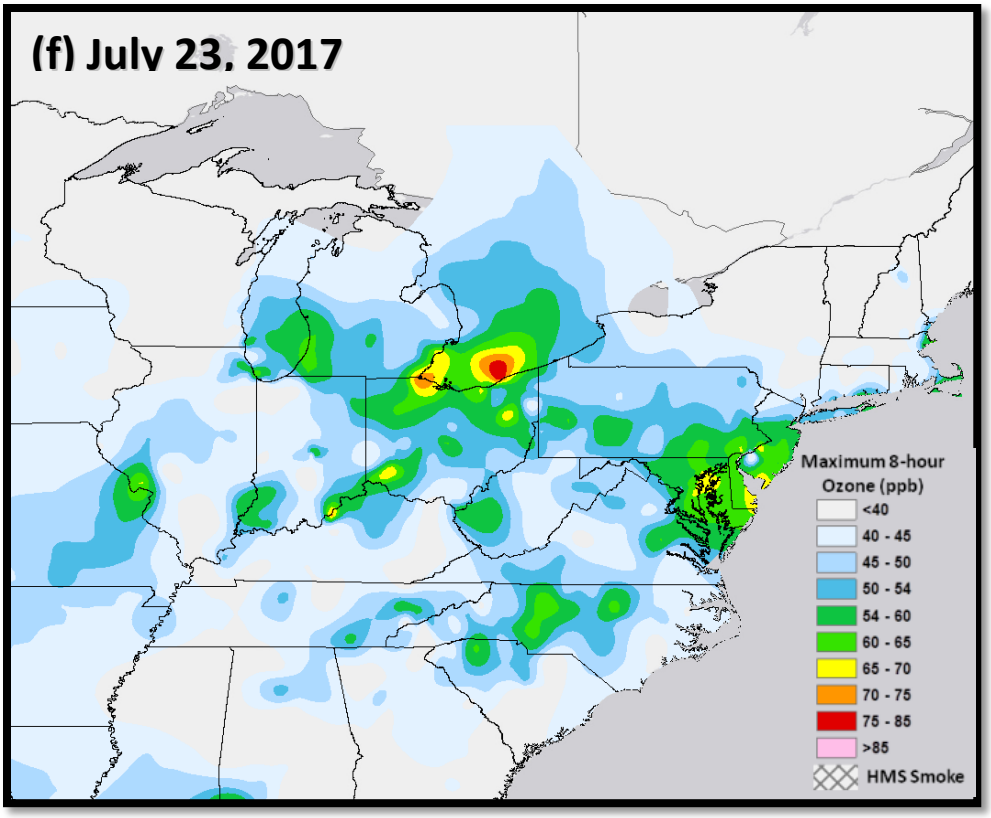


Figure 15. Smoke and maximum daily 8-hour average ozone concentrations for the eastern CONUS.
July 18-23 maximum 8-hour average ozone concentrations and Hazard Mapping System (HMS) analyzed smoke (hatching). Figures a, b, and f show most of the eastern CONUS while c, d, and e show a regional, zoomed-in view of the Mid-Atlantic area for greater detail. Backwards trajectories starting at 2100UTC running for 24 hours at 3000m (green), 1500m (blue), and 50m (red) are drawn in c, and d (July 20 and 21) while a 96 hour (4-day) backward trajectory at the same heights is shown in a and b, similar to Figure 6. No trajectories are shown in e or f. Transported smoke was closely associated with ozone in Maryland beginning on July 20.

3. Clear Causal Relationship Between The Event and Monitored Ozone Concentrations

The event presented in this analysis illustrates an example of the impact of subsidence of a smoke plume to the surface on ozone concentrations in Maryland. MDE here presents necessary evidence to show the smoke event affected air quality in Maryland and clearly was associated with ozone concentrations beyond what otherwise is expected in the absence of smoke and that smoke caused the exceedance days. Comparisons to historical concentrations and a Q/d analysis (Tier 1 and 2 steps) are provided. While MDE believes these analyses alone show a causal relationship between the ozone and smoke, the complicated nature of the event and the historically similar concentrations (though under greater anthropogenic emissions) may not clearly demonstrate a clear causal relationship. After conversations with EPA, it was deemed further analysis was necessary to establish and demonstrate a clear causal relationship. Therefore,

a weight of evidence (Tier 3) approach is used to build an irrefutable case that smoke transport was responsible for the ozone concentrations and the ozone exceedance days in Maryland.

3.1. Historical concentrations

Scatter plots of MD8AO at the 12 Maryland monitors exceeding the 70ppb NAAQS showed that the July 21 and 22, 2016 concentrations were elevated compared to seasonal observations from the last five years and were "exceptional", being above the 99th percentile of observations at most sites (Figures 16-27). All ozone data during the 2012-2016 ozone seasons (April 1 to September 30) were plotted for each monitor against that monitor's multi-season 99th percentile. However, recall significant and sustained reductions in ozone precursors across the eastern US have occurred in the past 10 years. These reductions have been particularly evident in NOx. Consequently, this has lead to a noticeable decrease in ozone concentrations and exceedance days in the past three to four years. Five of lowest seasonal number of exceedance days occurred in the past 8 years, with four in the past four years, due to these NOx reductions.

The July 21-22, 2016 period had one of lowest mid-July NOx emissions, ever, from 2010-2016 and July of 2016 as a whole had the lowest emissions ever (Figures 4 and 5). Therefore, amplified MD8AO concentrations on July 21 and 22, 2016 represented substantially more ozone generated from available NOx than in 2012, when emissions were substantially higher. Since 2012 is within the previous five years of data that EPA requests for historical comparisons, MDE feels the data from 2012 raises the 99th percentile higher than what is otherwise now representative of Maryland's ozone. Even 2013 appeared to be a transition year as the NOx downward trend continued. To address the outlier-like status of ozone and emissions in 2012 MDE also offered two additional 99th percentiles to compare each monitor's MD8AO on July 21 and 22. These additional 99th percentiles are calculated using data which excludes 2012 (2013-2016) for the entire season, then another which compares only July from 2013-2016. MDE believes this increases the robustness of the historical comparison.

The results at many of the monitors show that at least one of the two days (July 21 or 22) was close to or exceeded the 99th percentile at that monitor for the dataset using 2013-16. A few monitors still beat the full multi-seasonal (2012-2016) 99th percentile level (Hagerstown and Fair Hill for example) despite the inclusion of 2012 data.

Of the 12 monitors that MDE is pursuing as being influenced by an exceptional event, on July 21, 2016:

- Three (3) monitors met or exceeded the 99th percentile using all data from April 1 – September 30, 2012-2016 [Frederick (240210037), Hagerstown (240430009), HU-Beltsville (240330030)].

- Seven (7) monitors met or exceeded the 99th percentile of the data when comparing only July ozone from 2013-2016 [Aldino (240259001), Beltsville CASTNET (240339991), Frederick (240210037), Furley (245100054), Hagerstown (240430009), HU-Beltsville (240330030), Padonia (240051007)].

- Seven (7) monitors met or exceeded the 99th percentile of the data set when the entire 2012 ozone season was excluded. [Aldino(240259001), Beltsville CASTNET (240339991), Essex (240053001), Frederick (240210037), Furley (245100054), Hagerstown (240430009), HU-Beltsville (240330030)].

Of the 12 monitors that MDE is pursuing as being influenced by an exceptional event, on July 22, 2016:

- Two (2) monitors met or exceeded the 99th percentile using all data from April 1 – September 30, 2012-2016 [Edgewood (240251001), Fair Hill (240150003)].

- Three (3) monitors met or exceeded the 99th percentile of the data when comparing only July ozone from 2013-2016 [Edgewood (240251001), Fair Hill (240150003), PG Eq Cntr (240338003)].

- Three (3) monitors met or exceeded the 99th percentile of the data set when the 2012 ozone season was excluded [Edgewood (240251001), Fair Hill (240150003), PG Eq Cntr (240338003)].

All 12 monitors that MDE seeks concurrence for the influence of the wildfire smoke on ozone equaled or exceeded a 99th percentile. Additionally, 10 of the 12 monitors had one of the fourth highest observations of the 2016 season at the monitor. The Beltsville CASTNET (240339991), Hagerstown (240430009), and HU-Beltsville (240330030) had their highest observation of the 2016 season on July 21 while Edgewood (240251001) and Fair Hill (240150003) had their highest of the 2016 season on July 22. It is safe to say the event caused one of the highest ozone concentraitons at all monitors which exceeded the standard (and even at those that did not – see Appendix B). Scatterplots from all 12 monitors using all data from April 1 – September 30 (the typical months which historically have experienced ozone exceedance days) from 2012-2016 are given in Figures 16-27. Along with the 70ppb NAAQS threshold, three additional threshold lines show the 99th percentile for all ozone season data 2012-2016, ozone season data from 2013-2016, and only ozone in July, 2013-2016.

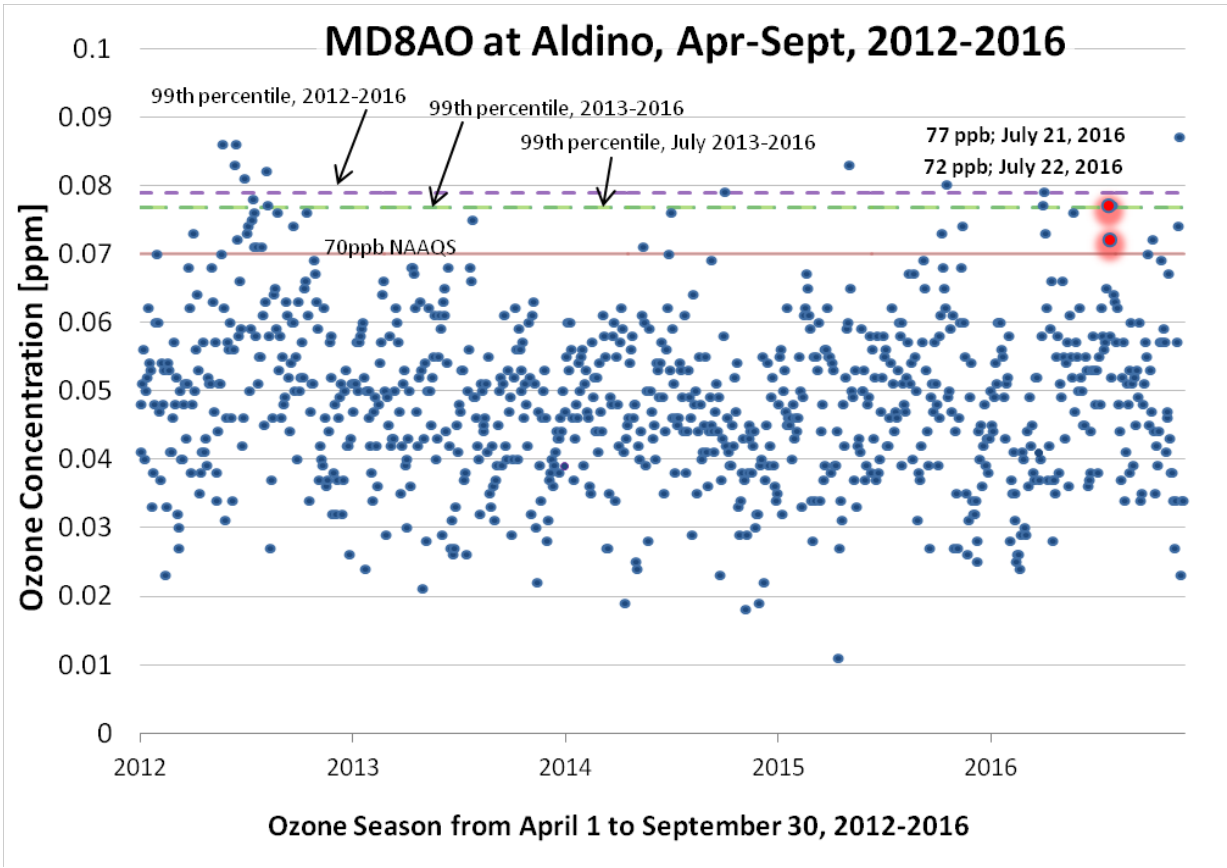


Figure 16. Scatterplot of Maximum Daily 8-hour Average Ozone (MD8AO) concentrations at Aldino (blue dots), April 1 – September 30, 2012-2016.
The days that exceeded the NAAQS on July 21 and/or 22 and for which MDE is seeking exclusion of the data are colored red. Textual annotations give the MD8AO for the red colored data point. Along with the NAAQS level (70ppb – red line), three 99th percentile lines are given to account for the changing NOx emissions and ozone levels in Maryland over the past 5-years. The 99th percentile for all ozone season data (April – September), 2012-2016, is given in dashed purple. All season data 2013-2016 is given in blue (dash-dot) while data only from July 2013-2016 is given in long-dashed green.

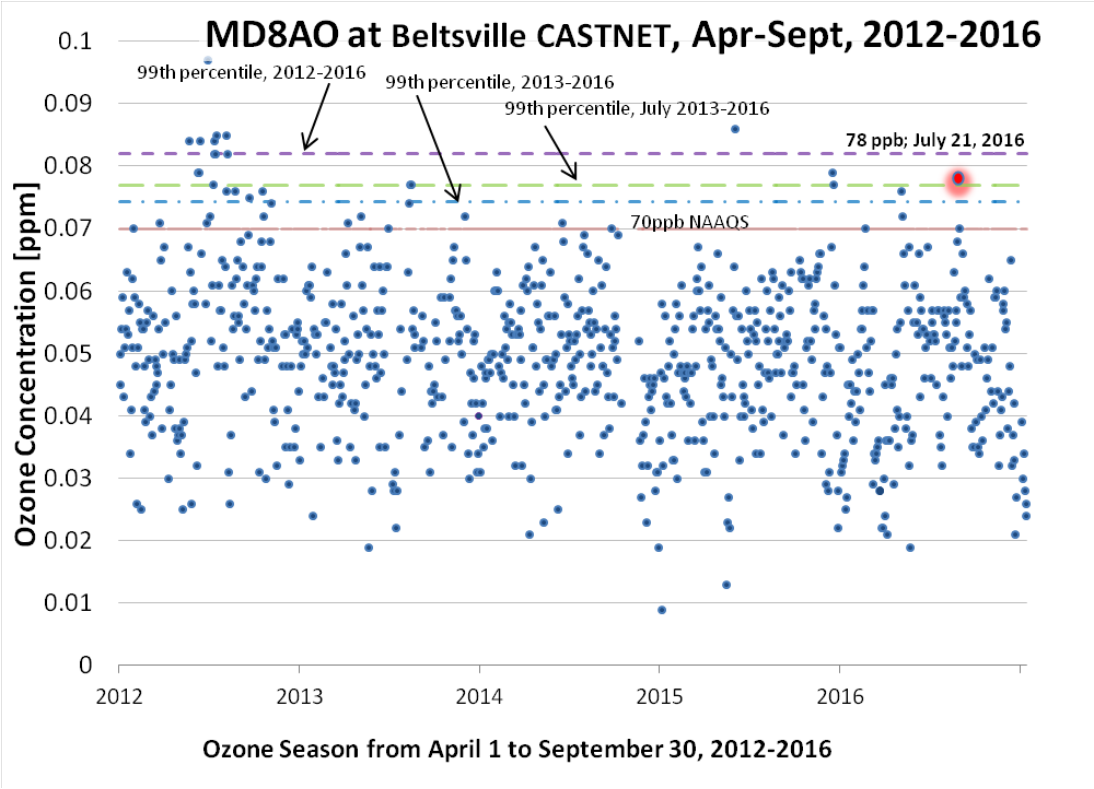


Figure 17. Same as Figure 16, except for the Beltsville CASTNET site.

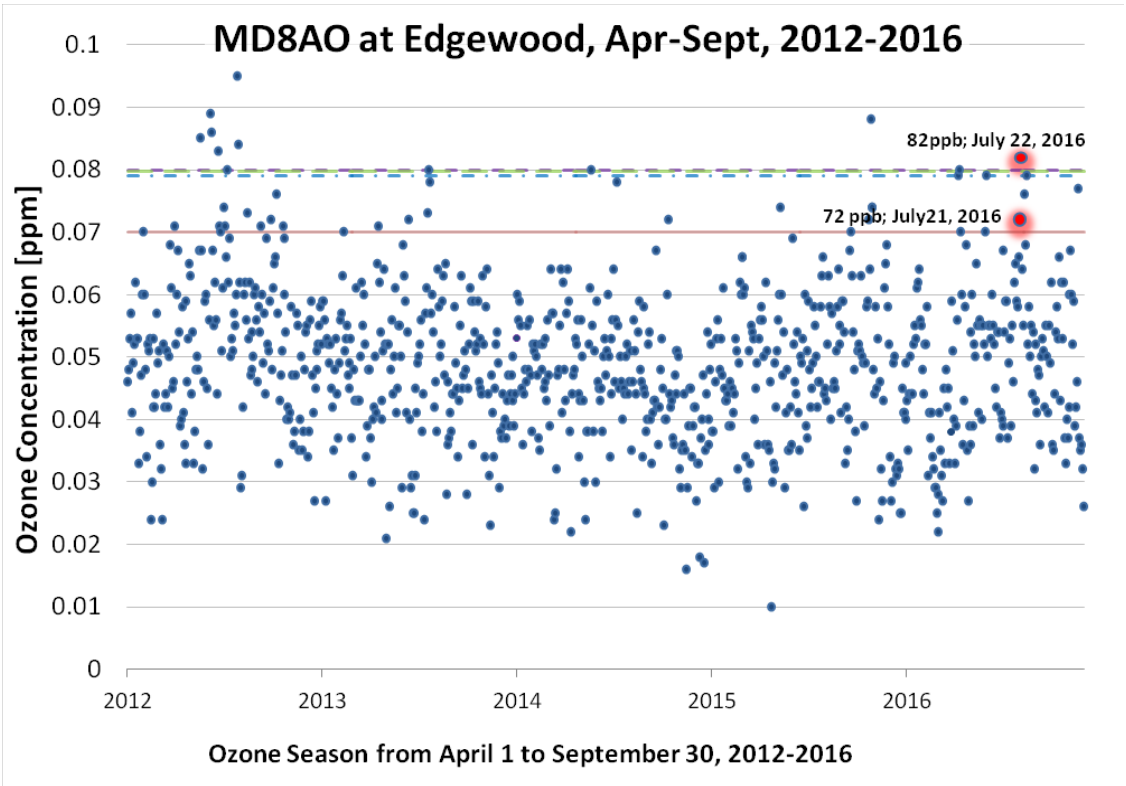


Figure 18. Same as Figure 16, except for the Edgewood site.

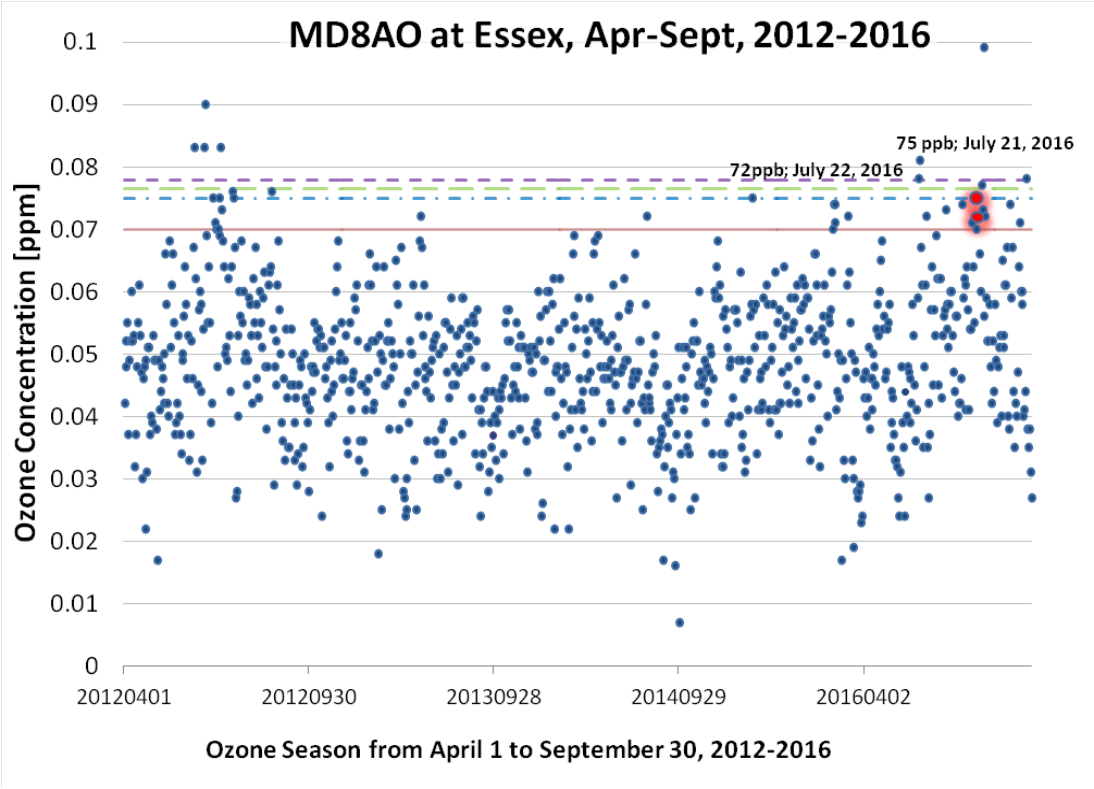


Figure 19. Same as Figure 16, except for the Essex site.

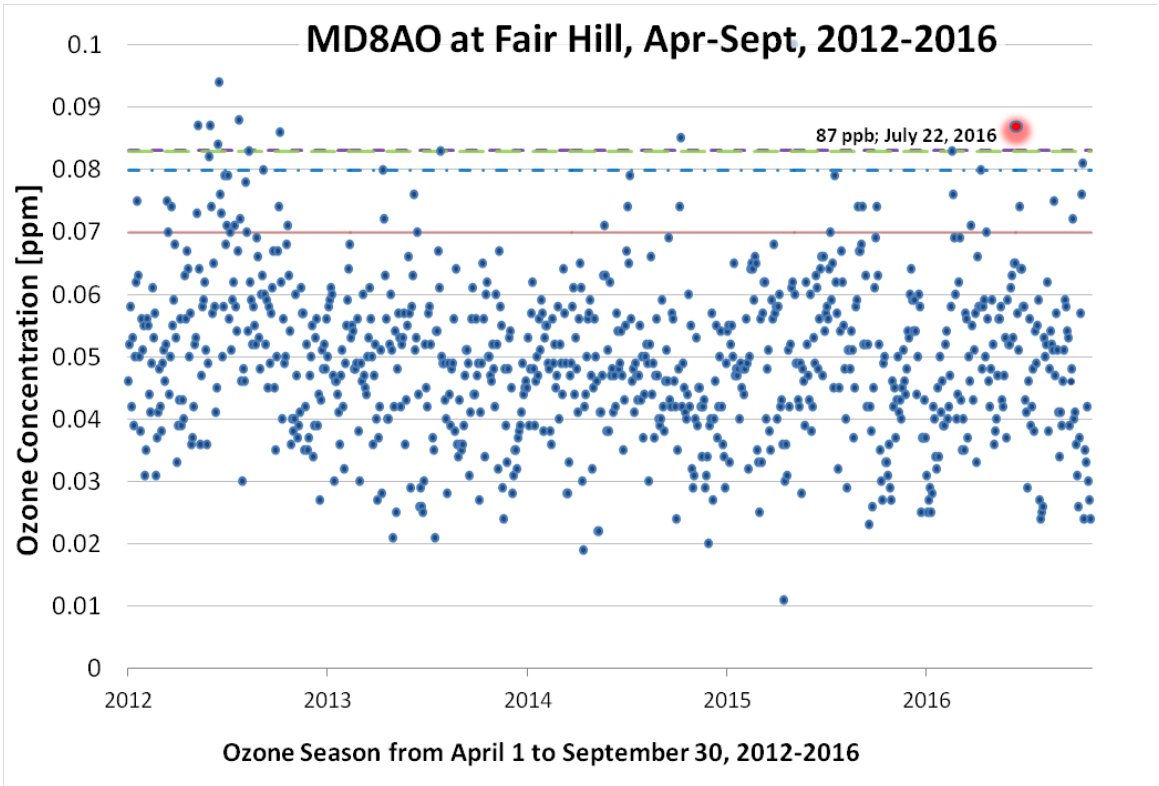


Figure 20. Same as Figure 16, except for the Fair Hill site.

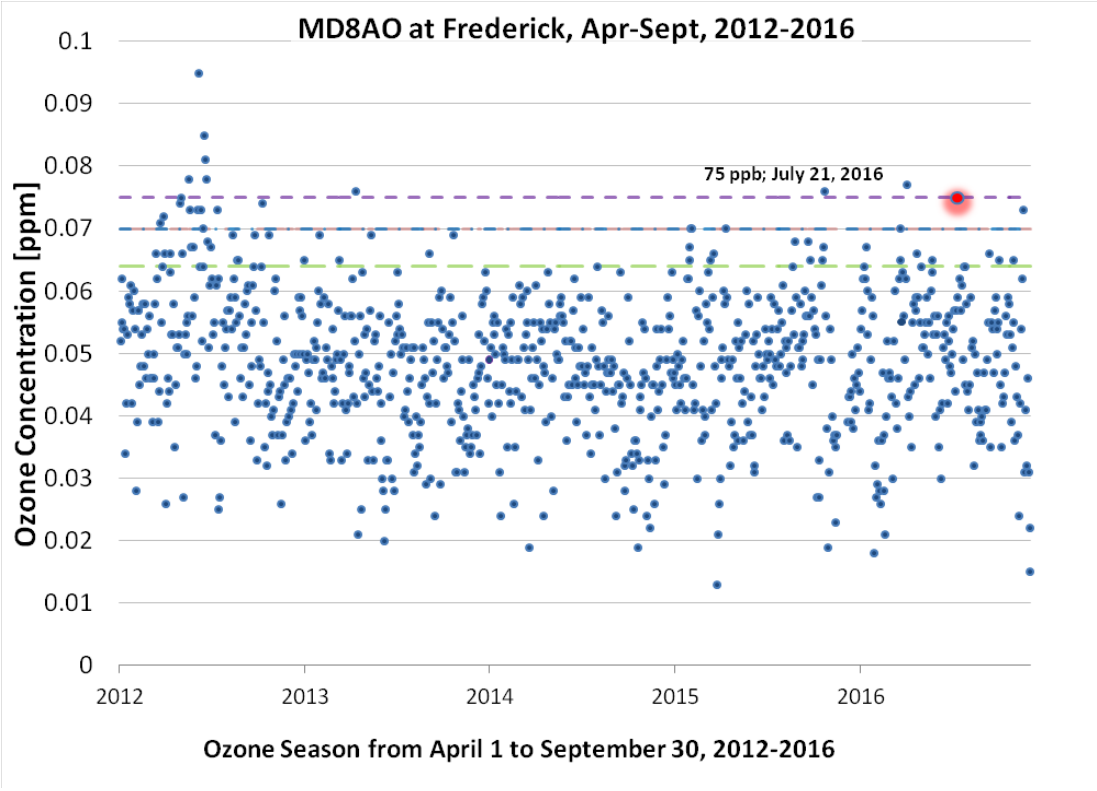


Figure 21. Same as Figure 16, except for the Frederick site.

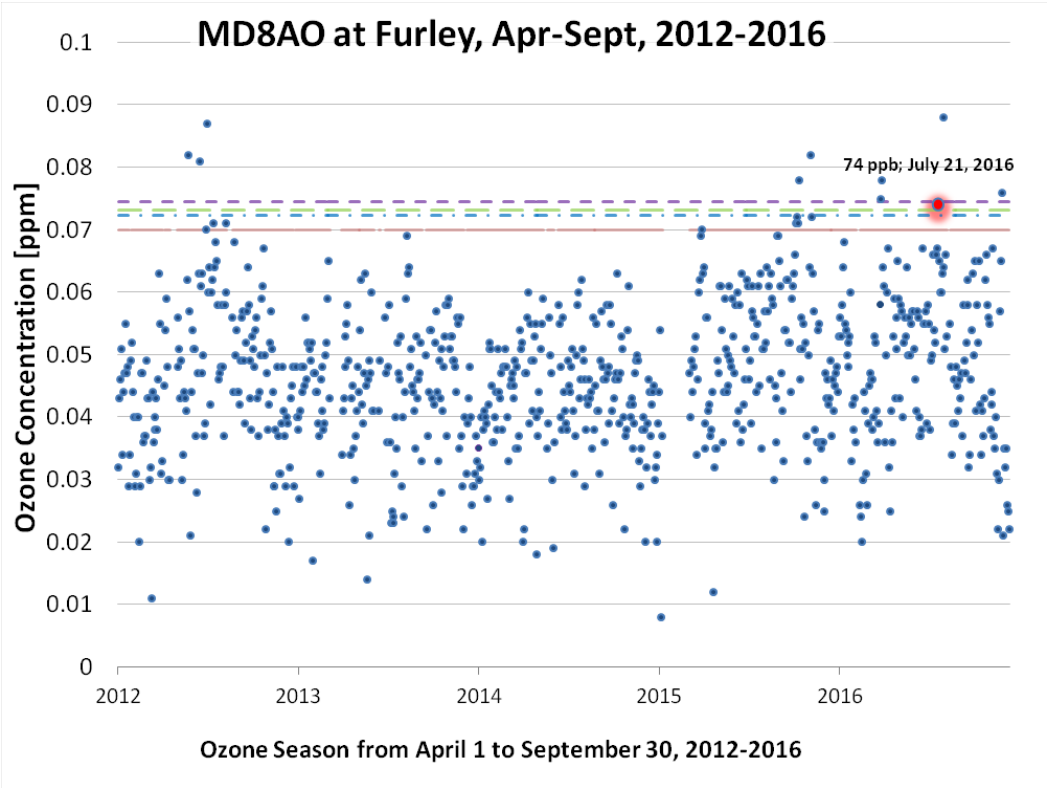


Figure 22. Same as Figure 16, except for the Furley site.

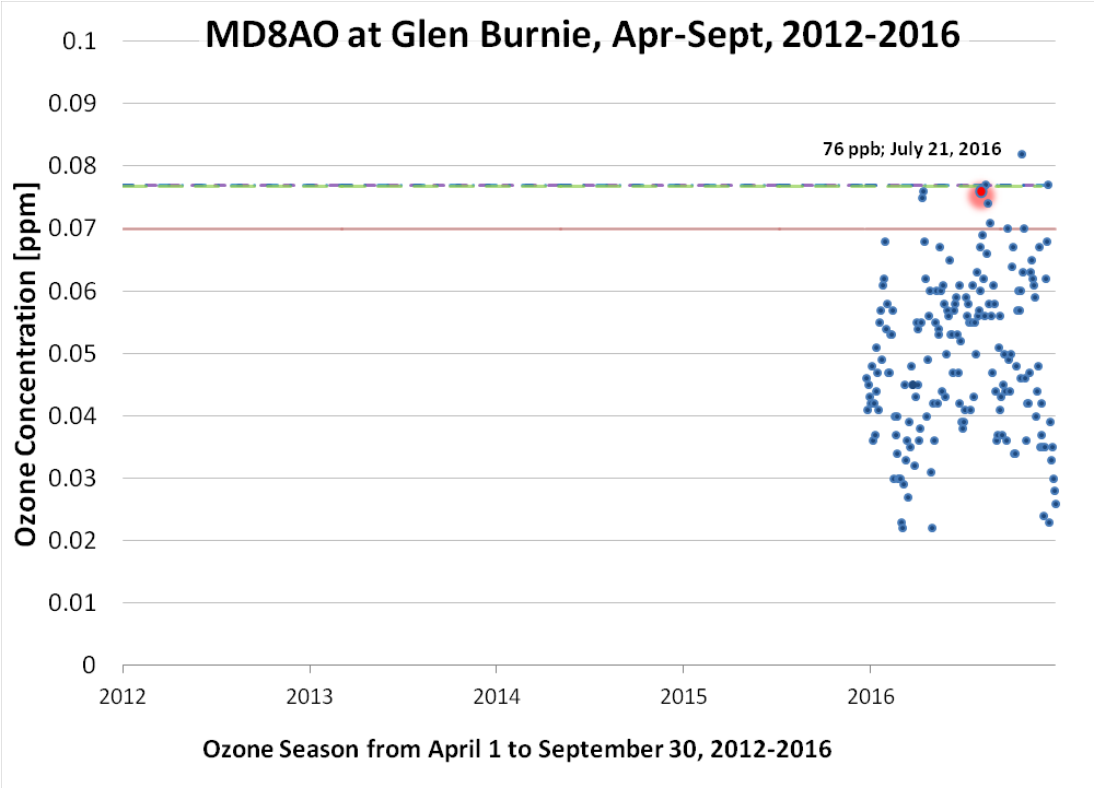


Figure 23. Same as Figure 16, except for the Glen Burnie site. Glen Burnie became operational in 2016.

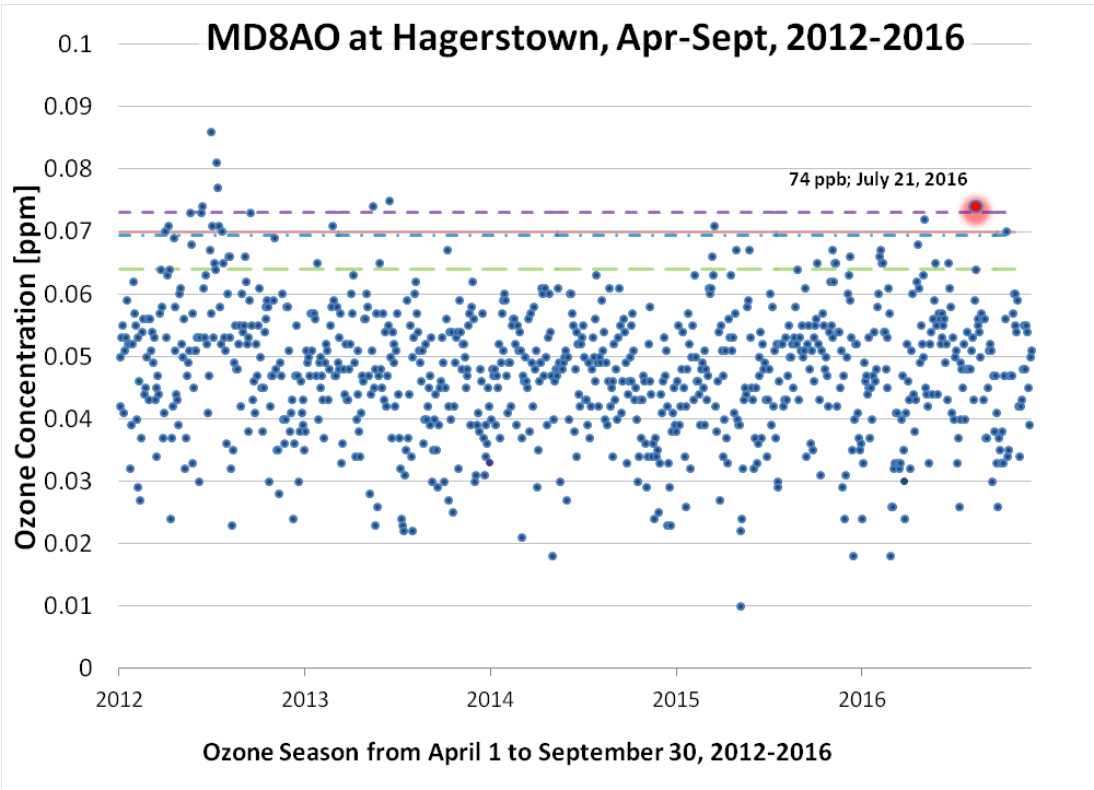


Figure 24. Same as Figure 16, except for the Hagerstown site.

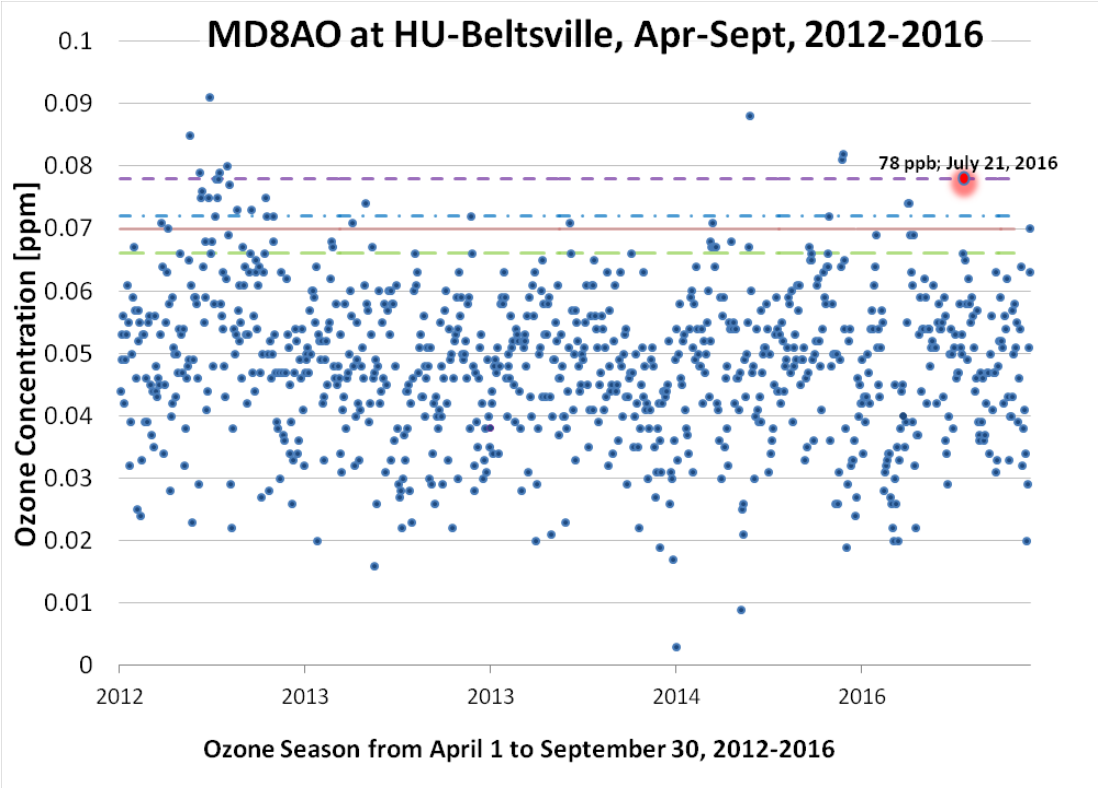


Figure 25. Same as Figure 16, except for the HU-Beltsville site.

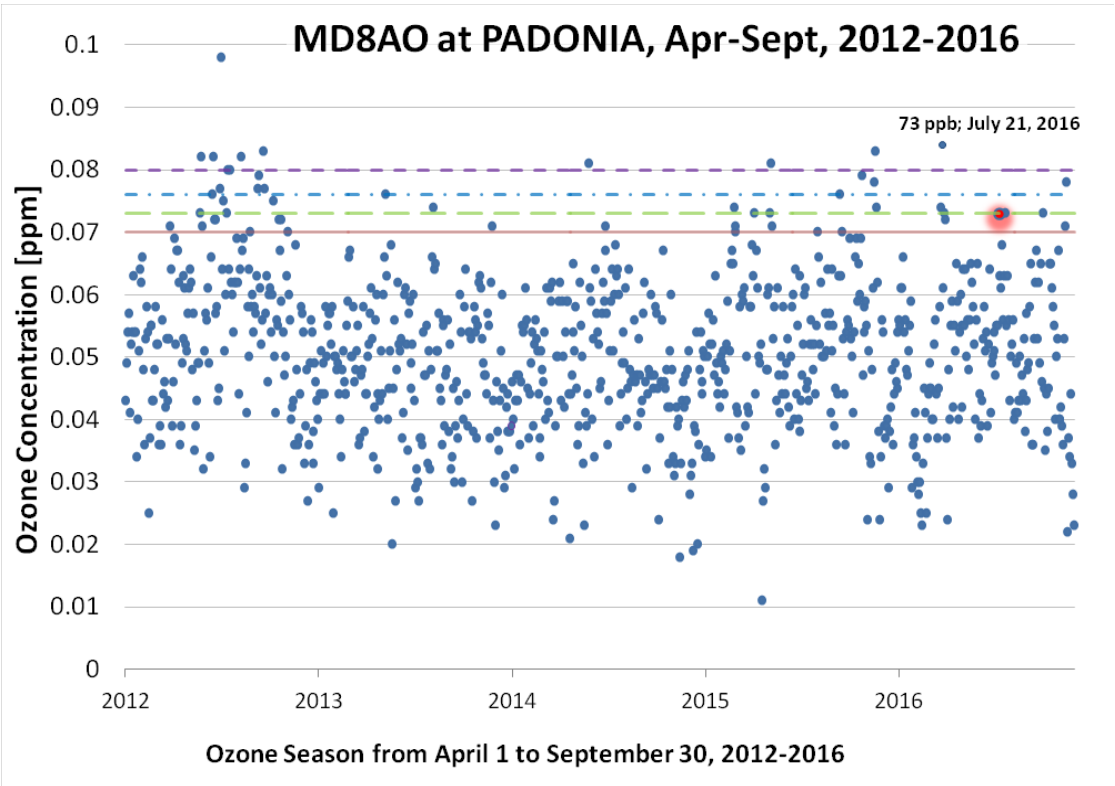


Figure 26. Same as Figure 16, except for the Padonia site.

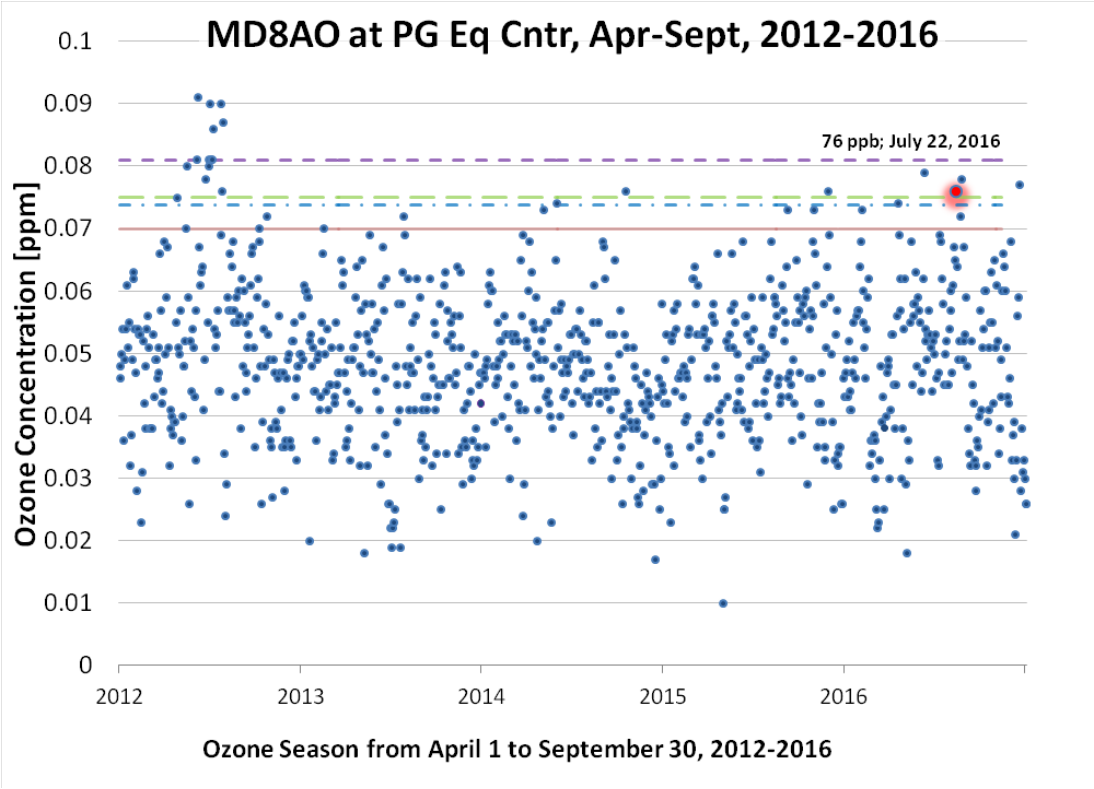


Figure 27. Same as Figure 16, except for the PG Eq Cntr site.

The preponderance of the monitors for which MDE is seeking as being influenced by an exceptional event show a "distinctive level" of monitored ozone concentration. Eleven of the 15 observations for which exclusion is requested were at or above a 99th percentile level with a majority of monitors observing one of the top four highest MD8AO concentrations of the 2016 season. Concentrations during the smoke-influenced event exceeded the 99th percentile of not just July data but also the entire seasonal dataset at some monitors. Therefore, the July event should be considered exceptional in nature. MDE has observed concentrations like those observed in July 2016 previously, but with greater anthropogenic NOx emissions, such as in 2012. The uncharacteristically high ozone concentrations, particularly in light of the huge precursor reductions over the past five years, and the exceptional spatial coverage of the event over a wide area compared to previous exceedances (see Figure 5), all which occurred with a big change in MD8AO concentration regionally (around 15ppb change between days before and after the smoke) all suggest the monitors were influenced by wildfire smoke. MDE believes the evidence presented thus far indicates a clear causal relationship. Additional supportive analysis is presented below.

3.2. Evidence that Fire Emissions were Transported to Maryland

To further demonstrate that the northwest Canada wildfire emissions were transported to the Maryland ozone network, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT; Rolph, 2015; Stein et al., 2015) model was used to calculate forward trajectories originating from within the smoke plume at the

fire sites and backward trajectories from Maryland. Meteorological data driving these trajectories was from the North American Regional Reanalysis (NARR) and North American Mesoscale (NAM) model datasets. For the forward trajectories, the reanalysis dataset was used; the origin of the trajectories was near the northern edge of the NAM domain, so it was thought prudent the reanalysis dataset would decrease error, even while sacrificing spatial resolution. These forward trajectories showed transport from the fire and smoke locations towards Maryland which mimicked the path of the HMS analysis presented in Figure 14. A matrix of forward trajectories (Figure 28a) centered across the location of the smoke plume as of July 17 showed a transport pattern to the east and east-southeast. A group of trajectories moved more southeastward compared to the rest of the group (blue shading in Figure 28a) and it appeared these were responsible for transport of smoke towards Maryland. Running a matrix of trajectories (several trajectories which start from a gridded pattern over the source area) instead of a single trajectory allows the trajectories to show a spread of possible dispersion of the plume while increasing the confidence in the general transport pattern/direction of the smoke plume. Due to increasing model error with time (an intrinsic occurrence when modeling the atmosphere) no single trajectory should be considered representative of the exact path of the smoke plume, and the longer the trajectory is run, the greater the error of the modeled path is likely to be. Therefore, clusters of trajectories increase confidence of the path of the smoke. The trajectories in this case showed general agreement with the main smoke plume analyzed by HMS (Figure 14). The difference in end location (trajectories not quite in Maryland by July 20) was simply attributed to increasing error with model run time. Thus, the trajectories continue to support smoke transport to Maryland. These forward trajectories also support the assertion that smoke did not subside to the surface before the afternoon of July 20, as observed by the UMBC Lidar. The vertical distribution of the trajectories (bottom panel of Figure 28a) showed the forward trajectories subsiding downwards, but not yet impacting the near-surface layer: the lowest trajectories are around 1500m, which was the height of the boundary layer (near surface layer of air) as seen in the Lidar retrieval (transition from light blue to dark blue vertically, on Figure 13).

Backward trajectories took a path northwestward which more directly indicated transport to northeast Maryland from the upper Great Lakes and southern Canada (Figure 28b). Consistent with prior presented information, the smoke plume was transported southeast across southern Canada and the Great Lakes then pushed southward and downward behind a cold front sweeping across the northeast US. Eventually, this allowed the plume's southern fringe to reach Maryland. Similar to the forward trajectories, the back-trajectories illustrate the downward motion of the trajectory well, with subsidence clearly indicated in all three trajectory levels (line dropping downwards with time). The 50m (red) trajectory even indicated it reached near the surface between 18 and 00 UTC, which was between 2pm and 8pm LDT on July 20, 2016 and in very good agreement with the Lidar image from UMBC.

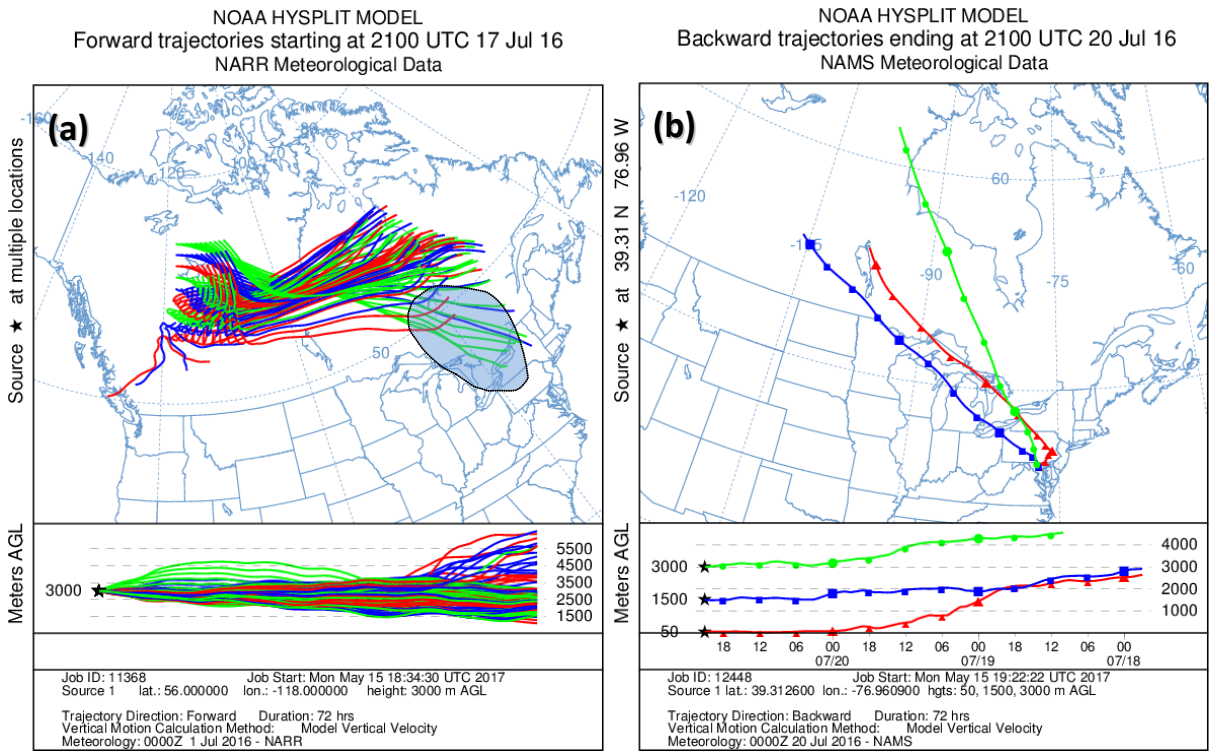


Figure 28. Forward and Backward Transport Trajectories.
(a) A Matrix of 72-hour (3 day) North American Regional Reanalysis (NARR) data forward trajectories with starting points centered around the location of the smoke plume on July 17, 2016 across northwestern Canada. The trajectory cluster shaded in blue show general transport towards the northeast US. (b) 72-hour North American Model (NAM) back trajectories from central Maryland beginning on July 20 showing transport from the area of the smoke into Maryland over the course of about 3 days.

3.2.1. Evidence of Residual Layer Ozone via Ozonesondes

MDE requested ozonesondes in time to capture the morning vertical profile of the exceptional event on July 22. These ozonesondes recorded substantial ozone concentrations within the nocturnal residual layer (i.e., pre-dawn, ozone above the surface). The ozone vertical profile observed by the ozonesonde had approximately 70ppb of ozone between 1.5 and 2km where winds were from the west northwest (Figure 29). This layer had been previously influenced by smoke (per backwards trajectories into Maryland – Figure 28b). This layer vertical layer of ozone is also from prior day's (July 21) concentrations across Pennsylvania (per trajectories – Figure 30) that were now preserved in the residual layer. At night ozone is removed from the layer of air a few tens of meters from the surface as it interacts with other molecules or objects. However, the layer of air immediately above the surface at night "preserves" ozone overnight making it the "transport relevant" layer or simply known as "the residual layer." The residual layer is usually found from around 500m to 1,500-2,000m above ground level at night. Therefore, surface ozone may be at or near zero at night while just a few hundred meters above the ground ozone may still be 50-80ppb. The ozonesonde on the morning of July 22 therefore verifies that the airmass over Maryland on July 22 had substantial ozone available within the residual layer to create an ozone exceedance day on July 22. The ozonesonde, along with trajectories, also showed this ozone-laden air came from areas of Pennsylvania and Maryland (such as around Hagerstown) on July 21. Since high ozone concentrations across these upstream areas were due to the impacts of smoke transported from Canada on July 21, by extension, the ozone exceedance days on

both July 21 and 22 were caused by the influence of the Canadian wildfire smoke transport. Said another way, smoke subsided late on July 20, caused substantial and widespread ozone formation on July 21 which lingered into July 22 via the residual layer.

The ozone concentrations exceeding the ozone standard on July 22 were chiefly in northeastern Maryland, which was consistent with the light westerly transport during the night and early morning on July 22 taking ozone from areas which had experienced heighted ozone on July 21 towards northeast Maryland. This eventually also led to high MD8AO in northeastern Maryland where Fair Hill reached an MD8AO of 87ppb, its highest of the entire 2016 season. Ozone was focused along the I-95 corridor around and northeast of Baltimore due to the development of a lee-trough, as discussed in the surface analysis above.

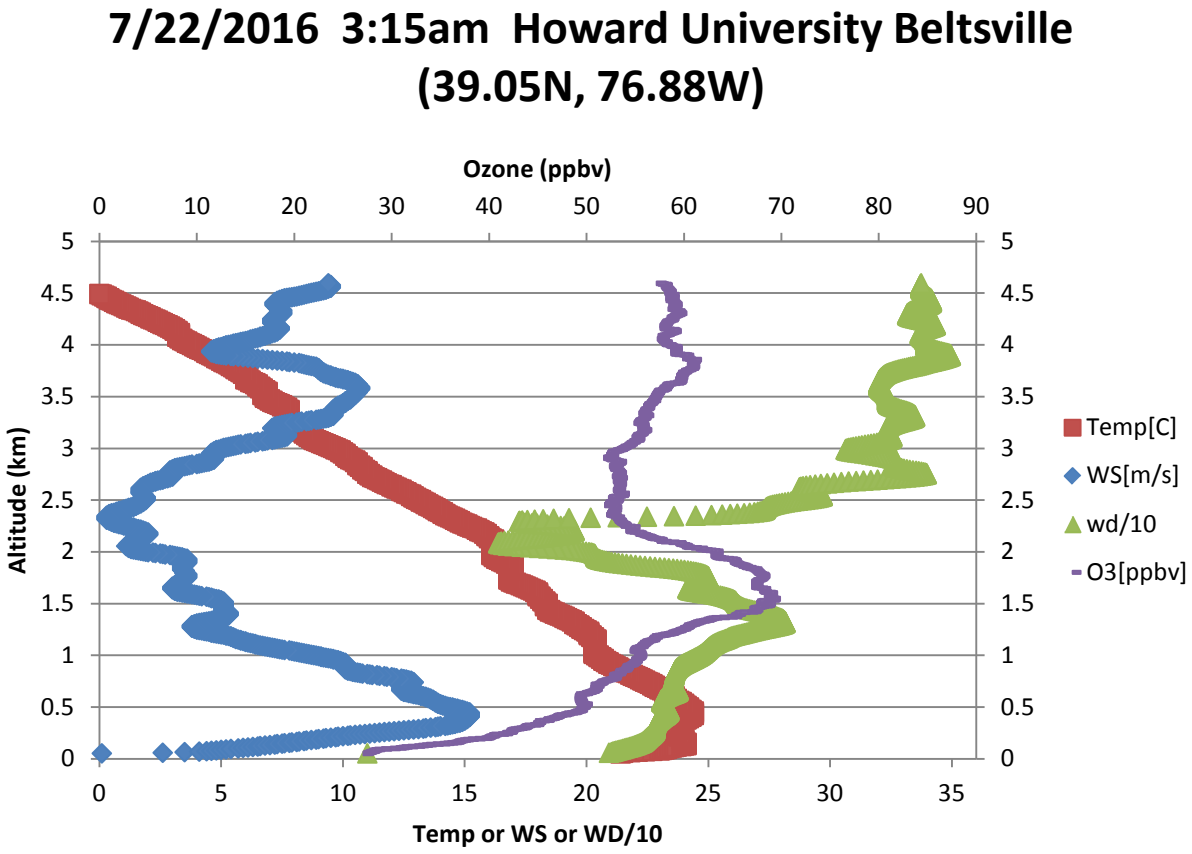


Figure 29. Ozonesonde launched from Howard University Beltsville (HU-Beltsville) on the morning of July 22, 2016. Temperature (°C, red squares), wind direction (degrees divided by 10 [180° is shown as 18 on graph], green triangles), wind speed in m/s, blue diamonds), and ozone (ppb, purple dashes) are shown from the surface through 5km AGL. Ozone is given on the top horizontal axis. Temperature and winds are given by the bottom horizontal axis. The profiles show a substantial amount of ozone between 0.5 and 2km was transported into and/or present above Maryland on the morning of July 22, 2016, the second day of the exceedance event.

As a verification of the transport of the residual layer towards northeastern Maryland, forward trajectories from the site of the ozonesondes launch and backwards trajectories from Fair Hill were constructed. Meteorology was driven by the High Resolution Rapid Refresh (HRRR) model, which is updated every 6

hours for trajectory construction at 1 hour time intervals at 3km resolution. The HRRR dataset was chosen in this case for its high resolution and the short time scale (12 hours) analyzed here. The forward trajectories run forward from HU-Beltsville at 3am (0700 UTC, Figure 30a) showed that air located at 500m (red, triangles), roughly the bottom of the residual layer, moved northeastward towards Fair Hill overnight. At the same time, shorter trajectories at 1500m (blue, squares) and 2000m (green, circles) within the residual layer indicated substantial subsidence over the next 12 hours, mixing ozone at these levels downwards towards the surface. While these trajectories stayed south of the 500m trajectory, the same vertical movement can be assumed true across Maryland (weather does not often change dramatically from one location to another in the absence of phenomenon such as thunderstorms), thus the downward mixing of ozone was significant for ozone considerations once the sun rose on July 22.

Backwards trajectories beginning from Fair Hill at 3pm on July 22 (at time when Fair Hill was observing hourly ozone concentrations above 90ppb) suggested that low-level flow around 500m came from areas such as Hagerstown during the night hours (Figure 30b). Recall that Hagerstown exceeded 70ppb the day before (July 21). The exceedance at Hagerstown on July 21 was the highest ozone that site observed in 2016. Upper level trajectories were northwesterly with subsidence clearly evident. In general, the two sets of 12-hour trajectories showed considerable wind shear (changing wind direction with height) within the residual layer, which was consistent with the ozonesonde. Westerly flow around 1500m coincident with a layer of ozone of almost 70ppb was observed by the ozonesonde. Trajectories both from the ozonesonde time and point of origin (Figure 30a) and backwards from the Fair Hill monitor (Figure 30b) were consistent with the westerly flow observed by the ozonesonde and also consistent with the slight turn towards westerly at 850mb discussed in the upper air analysis. Southwesterly winds below 1500m were also displayed on both sets of trajectories. As a whole then, the ozonesonde and trajectories showed that residual ozone from July 21, which had already been influenced by a smoke laden PBL, carried over to July 22. This was why on July 22 most of the ozone monitors exceeded the 70ppb ozone NAAQS were located in northeastern Maryland. In fact, high concentrations of ozone and ozone exceedances were located from northeast of DC northeastward through Connecticut. It was no coincidence that areas upwind of these same areas also exceeded on July 21. Even greater ozone was generated on July 22 as the smoke influenced air photochemically aged and the lee trough concentrated the pollutants along the I-95 corridor from Maryland through Connecticut.

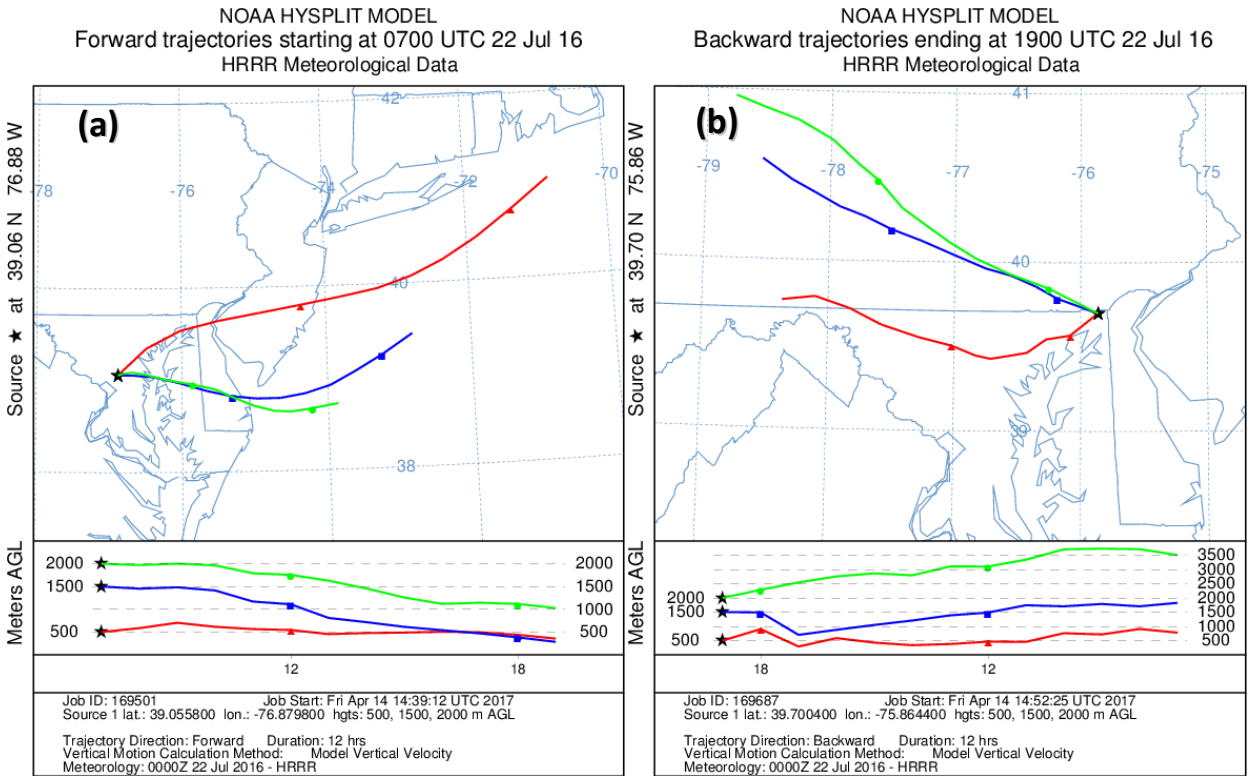
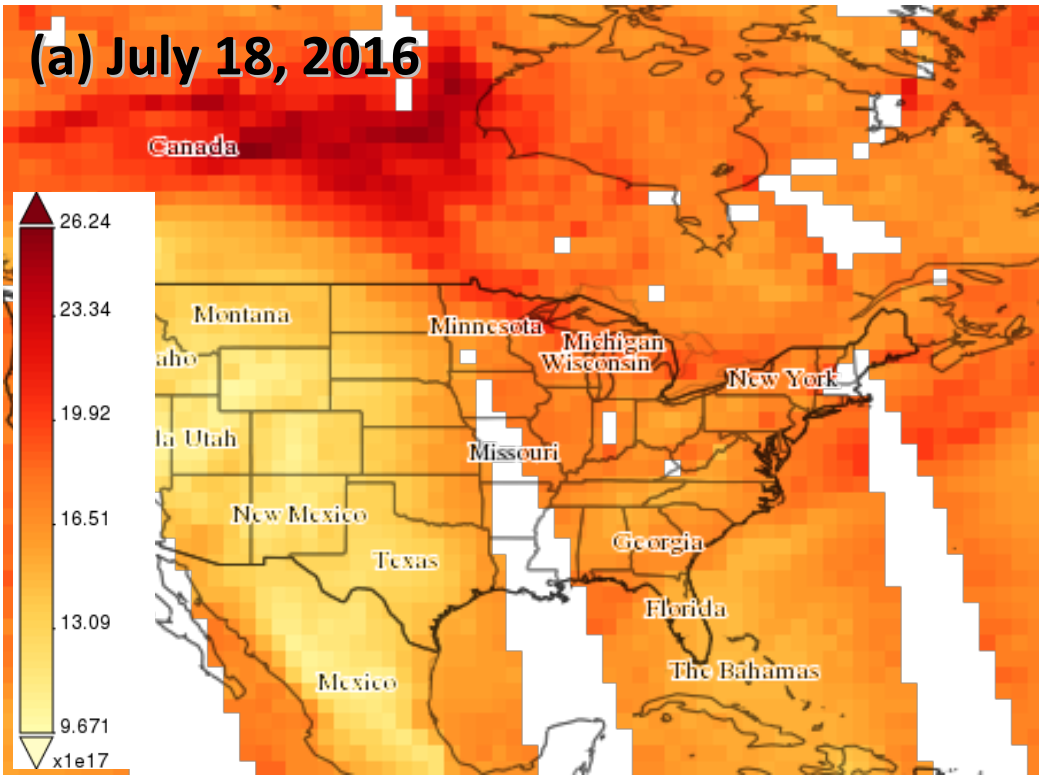


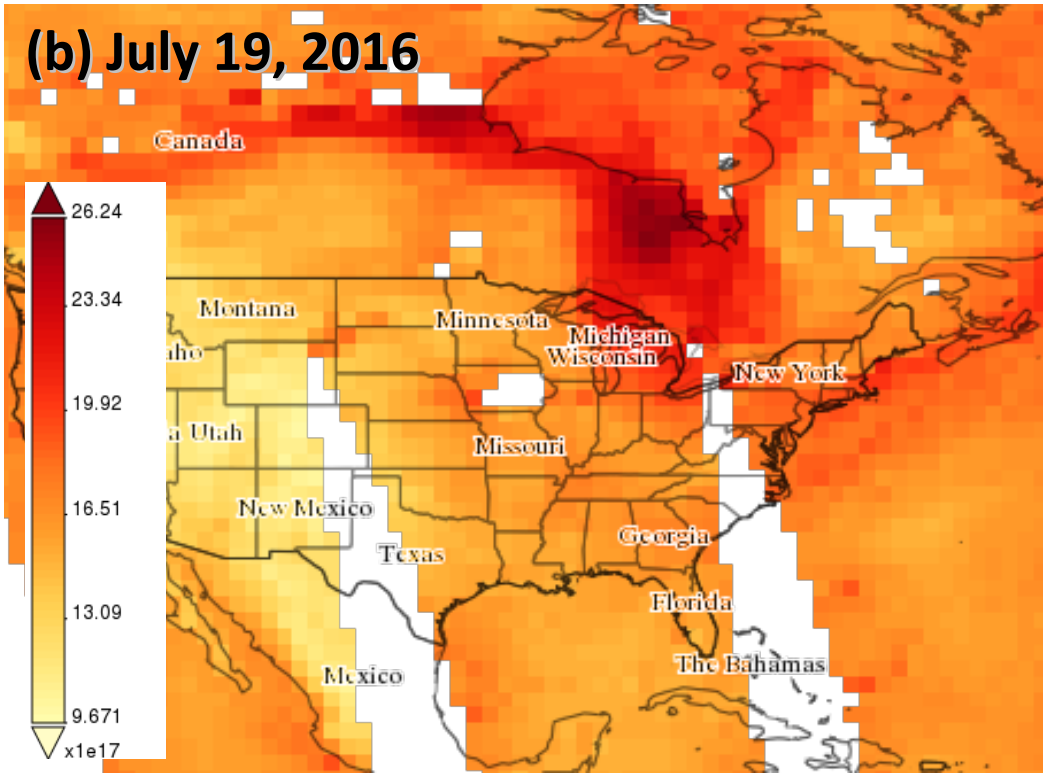
Figure 30. HYSPLIT trajectories related to the ozonesonde on July 22, 2016.
The trajectories shown are 12 hour forward trajectories (a) beginning at the time of the ozonesonde launched at the HU-Beltsville site in Maryland at 3:15am (~0700 UTC) on July 22, 2016 using the HRRR meteorological dataset. Backwards trajectories from Fair Hill at 3:00pm (1900UTC) were also shown (b). Fair Hill observed its highest ozone concentration for the 2016 season on July 22, 2016. Trajectory heights chosen are the same in both (2000m, green; 1500m, blue; 500m red) and are based on features within the July 22 ozonesonde.

3.2.2. Evidence of Wildfire Emissions via Satellite

Smoke analyses from the HMS already showed a plume of smoke being transported across the Great Lakes and Midwest towards Maryland and the northeastern CONUS. Satellites retrievals are capable of tracking wildfire species as well. When in combination with the expertly analyzed HMS smoke plume, they can together provide irrefutable evidence of the transport of wildfire ozone precursors. CO has been previously identified as a wildfire smoke indicator (Andreae and Merlet, 2001; McKeen et al., 2002, DeBell et al., 2004, Dreessen et al., 2016), can play a role in ozone production. Total column CO (that is the sum of the CO between the ground and the satellite, most of which is near the ground unless lofted as a consequence of a large combustion source) was observed to follow a pattern of transport similar to Maryland's ozone exceedance conceptual model (Figure 8). Animations of total column CO from satellite retrieval via Giovanni Data (https://giovanni.sci.gsfc.nasa.gov/giovanni/) indicated an area of enhanced CO starting over Canada meandering southeastward across the Great Lakes and southern Ontario, Canada, coincident with the analyzed smoke. Individual images were captured and shared here to illustrate the transport of CO to the area (Figure 31). The largest concentrations of CO through the atmospheric column (deeper reds) stayed north of the Mid-Atlantic, but show a south and southwestward turn between July 19 and July 21. For example, an area of high concentration of CO associated with the main smoke plume was observed west of

the Hudson Bay across central Canada on July 18 (Figure 31a). The smoke and CO plume then was located over the northern Great Lakes and south of the Hudson Bay on July 19 (Figure 31b). By July 20, however, areas of red (high CO) were located over New York, New Hampshire and Vermont, with orange (slightly lower concentrations of CO) from Pennsylvania southward to Virginia (Figure 31c). The CO then slowed its trek eastward and persisted off the coast of the central Mid-Atlantic on July 21 (Figure 31d). This motion is consistent with the smoke plume analysis shown previously indicating the smoke moved south and then slightly southwestward from locations across Pennsylvania and New York (See Figure 14) which was consistent with post-frontal subsidence into July 20. Though the satellite coverage missed a direct overpass of Maryland on July 21, the areal extent of the CO plume was still obtainable by interpolating between the deep red/orange areas east and northeast of Maryland over the ocean to orange areas still visible across southern Virginia. That interpolation puts a CO plume of lower concentration still over the central Mid-Atlantic into July 21, 2016. Therefore, the CO analysis presented here showed a plume of CO came from the northwestern Canada fires and remained over the Maryland area for at least the first day of the July 21-22 ozone exceedance.




(b) July 19, 2016
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26.24
23.34
19.92
16.51
13.09
9.671
x1e17
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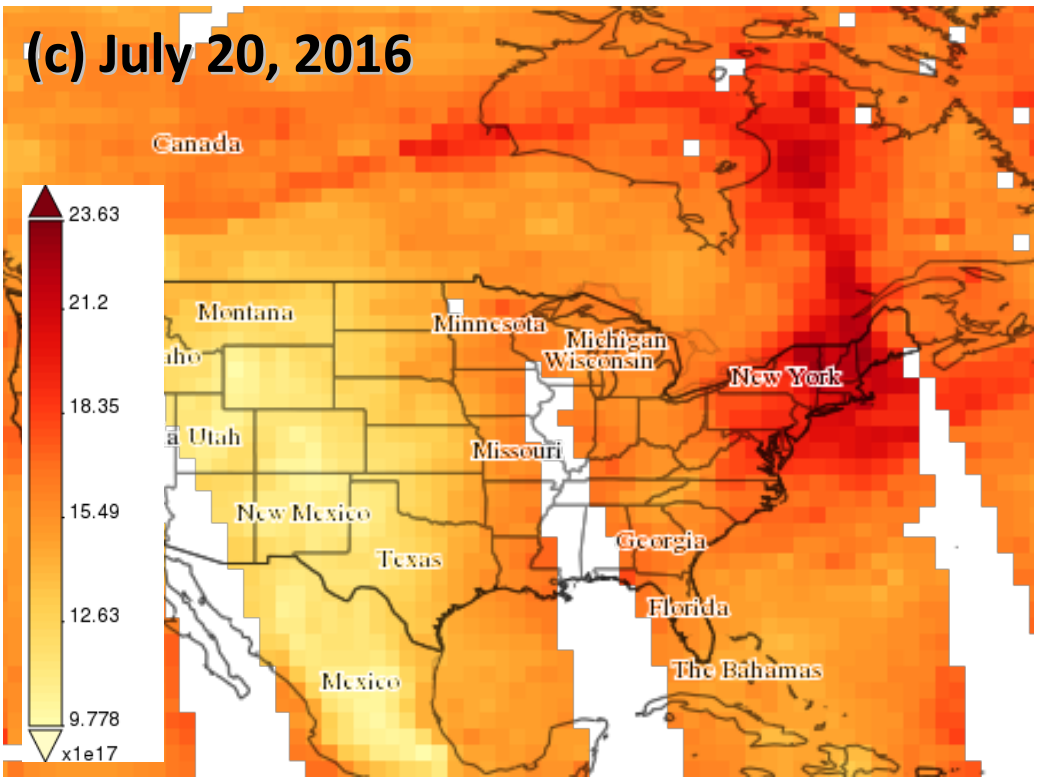
Minnesota
Michigan
Wisconsin
New York
Utah
Missouri
New Mexico
Texas
Georgia
Florida
The Bahamas
Mexico


(c) July 20, 2016
Canada
23.63
21.2
18.35
15.49
12.63
9.778
x1e17
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Minnesota
Michigan
Wisconsin
New York
Utah
Missouri
New Mexico
Texas
Georgia
Florida
The Bahamas
Mexico

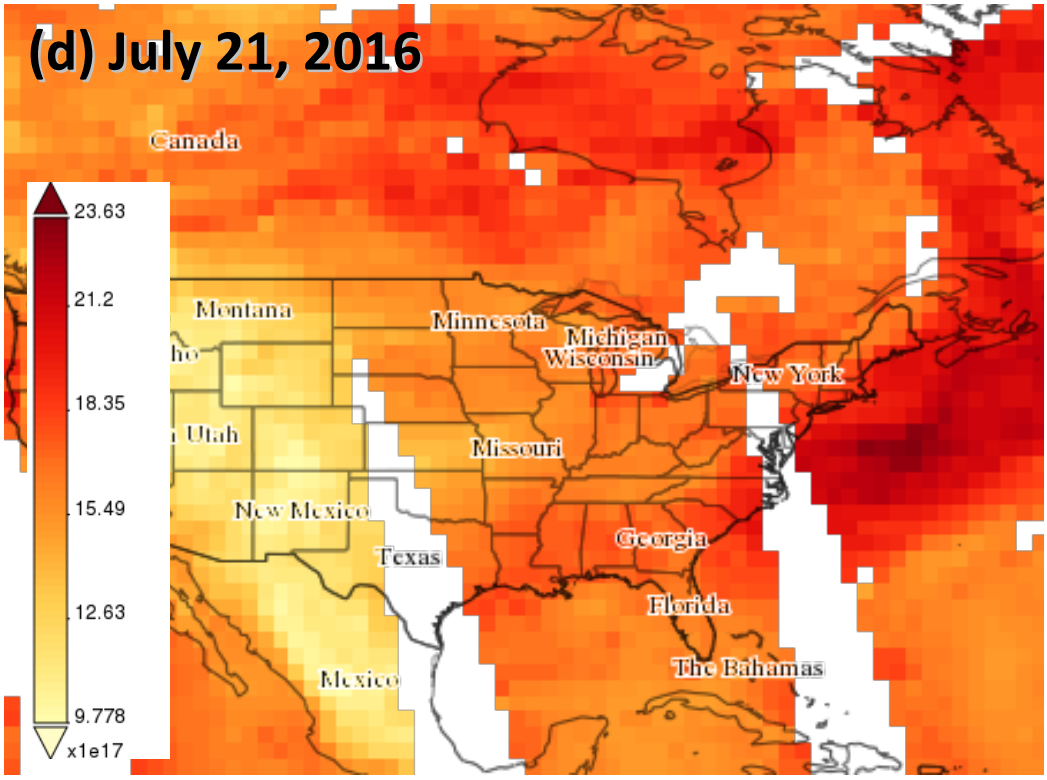


Figure 31. Carbon Monoxide from satellite.
Giovanni carbon monoxide images from July 18 (a), 19 (b), 20 (c), and 21 (d), 2016. Deeper reds indicate higher concentrations of carbon monoxide through the atmospheric column. Note that for detail, the color scale (mols/cm^2) for a and b is different than that used in c and d.

3.3. Q/d Analysis

EPA guidance [Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations, Final, EPA, September 2016] recommends conducting a Q/d analysis as a rough assessment of the ability of a wildfire to cause increased ozone concentrations. The Q/d analysis is simply a comparison of the ratio of Q, the daily tons of VOC and NOx emitted from the fire, to d, the distance in kilometers from the fire to the point of concern. If the Q/d value compares favorably to analytical data from other fires, then the fire can be presumed to have had a causal effect on ozone concentrations at the point of concern. The comparison to other fires is a key point that will be brought up again.

EPA guidance indicates that a fire should have a Q/d in excess of 100 tons per day per kilometer (tpd/km) in order to be considered to have a clear causal impact on ozone. EPA developed this value based on analyses of four fires which occurred in 2011. Due to the large distances which Canadian wildfire plumes must travel to Maryland, the Q/d analysis will regularly fail to achieve the 100 deemed acceptable by the EPA guidance. Therefore, MDE feels the 100 value is not representative for long-range east-coast smoke events. MDE instead presents several alternatives based on this analysis.

3.3.1. Estimate of Q

The emissions from the fire can be estimated using information from EPA's AP-42 Compilation of Air Emission Factors Section 13.1 Wildfires and Prescribed Burning. The equations given are as follows:

Fi = Pi * L (Equation 1)
Ei = Fi * A (Equation 2)

Fi = emission factor (mass of pollutant/unit area of forest consumed)
Pi = yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)
= 12 kg/Mg (24 lb/ton) for total hydrocarbon (as CH4)
= 2 kg/Mg (4 lb/ton) for nitrogen oxides (NOx)

L = fuel loading consumed (mass of forest fuel/unit land area burned)
A = land area burned
Ei = total emissions of pollutant "i" (mass pollutant)

Combining equations 1 and 2, we have:

Ei = Pi * L * A

Pi is given above for total hydrocarbons and for nitrogen oxides. The fuel loading is given in AP-42 for different regions of the United States and ranges from 9 to 60 tons per acre. Conservatively, we will estimate a low end emission rate using 10 tons per acre which is associated with North Central US conifer forests. Note that our results could increase by a factor of 6 were we to expect the high end of emissions.

Information provided by the Canadian Wildland Fire Information System (CWFIS) reported that between July 13 and July 20, 2016, fires across mostly northwestern Canada consumed 109,724 hectares (271,134 acres). For reference, the total land area of Rhode Island is approximately 270,000 hectares.[#] Daily acres burned was not available, however, satellite retrieval of the number of fires across the northwestern region of Canada shows a marked increase in the number of fires between July 13 and July 17 (jumping from 14 to 31 fires across this area) then a decrease in number thereafter. Assuming the number of fires retrieved can be a surrogate for percentage of acreage burned, the majority of the 271,134 acres burned in 4 days and the majority of the acreage was across northwestern Canada. Therefore, ignoring the smoldering of previously burned areas the total hydrocarbon emissions from the period can be estimated to be:
Ehc = 24 lbs of HC / ton of forest fuel consumed * 10 tons fuel / acre * 271,134 acres
Ehc = 65,072,160 pounds of HC
Ehc = 32,536 tons of HC emitted during the period from July 13 to July 17

[#]A contextual comparison to the State of Rhode Island makes the fires' size more comprehensible.

Similarly for NOx:
Enox = 4 lbs of NOx / ton of forest fuel consumed * 10 tons fuel / acre * 271,134 acres
Enox = 10,845,360 pounds of NOx
Enox = 5,423 tons of NOx emitted during the period from July 13 to July 17

Q is the total daily emission rate in tons per day of reactive hydrocarbons and nitrogen oxides. EPA recommends in the exceptional events guidance that only 60% of the hydrocarbons should be considered reactive. Therefore the reactive hydrocarbon emissions become rHC = 0.6 * Ehc or 0.6 * 32,536 = 19,522 tons of reactive HC emitted during the period of interest. No adjustments are suggested for the NOx emissions. Therefore the total rHC and NOx emissions over the period are 19,522 + 5,423, or 24,945 tons over the four days. On average this results in a daily emission rate, or Q, of 6,236 tons per day.

3.3.2. Estimate of d

Based on the large distance, there will not be individual analyses completed for each monitor in Maryland but an estimate of the distance from the fire centroid to Fair Hill, MD, the most distant smoke impacted monitor, will be calculated. The fire centroid was near the border between Alberta and the Northwest territories, approximately halfway between the east and west borders of Alberta (60°N, 115°W). Using this location supplies a conservative yet representative distance the smoke traveled to the Maryland ozone network. The flight distance between these two locations gives a value 3530 km for d.

3.3.3. Q/d Estimate

Using the values determined above, Q/d becomes 6,236 tpd divided by 3530 km or 1.8 tpd/km (Table 4). This value is well below the EPA recommended level of 100 tpd/km indicating clear causality. If instead we aggressively assumed the out of control fire consumed most of its fuel in 2 days time, Maryland's Q/d value climbs to 3.5; Still well below 100.

Table 4. Q/d analysis.

ACRES	Ehc (tons)	Enox (tons)	Q (tons)	No. days burning	d (km)	Q/d	DESCRIPTION
271,134	32,536	5,423	24,945	4.0	3530	1.8	Standard Q/d

EPA guidance states that *"If the Q/d value compares favorably to analytical data from other fires, then the fire can be presumed to have had a causal effect on ozone concentrations at the point of concern."* Since 2015, at least three major Canadian wildfire episodes have impacted Maryland: June 9-12, 2015 (as thoroughly described in Dreessen et al., 2016); May 25-26, 2016; and July 20-22, 2016. Thus, by EPA's Q/d definition, MDE now has a small subset to compare other wildfire impacts on ozone within the contemporary emissions environment. A Q/d analysis for July 2016 is done in that exceptional event analysis. For June of 2015, Q/d was calculated using values in Dreessen et al., 2016, which listed 77,000 acres burned in a two (2) day period and smoke transported 3100km from central Saskatchewan. Dreessen et al., 2016, goes on to show the impact of the smoke plume as it descended on the eastern Midwest and

Mid-Atlantic on June 9-11, 2015 and showed clear wildfire signatures and influences on ozone. Based on that research, Q/d for that ozone episode would have been 1.1 (Table 5). The May 2016 event had a Q/d four times as large (4.1). The July 2016 event had a Q/d of 1.8. Some research has noted the uncertainties in the influence of wildfire emissions in terms of strength and composition on ozone production (e.g., Hu et al., 2008). Thus it is quite plausible the value of 100 for Q/d is not relevant for long-range transport cases. It appears a more appropriate Q/d number for Canadian wildfire smoke transport cases to Maryland is closer to one (1), 100 times lower than the EPA suggested value. As the July 21-22 ozone event had a Q/d value which compared favorably with other fire events in Maryland, MDE believes this shows a clear causal relationship between the ozone and smoke.

Table 5. Q/d Analysis for three Canadian Wildfire events impacting Maryland.

ACRES	Ehc (tons)	Enox (tons)	Q (tons)	No. days burning	d (km)	Q/d	DESCRIPTION
368,187	44,182.00	7,364.00	33,873.20	2.5	3280	4.1	Fort McMurray - May 2016
271,134	32,536	5,423	24,945	4.0	3530	1.8	Northwest Territories - July 2016
77,000	5,544.00	1,540.00	7,084.00	2.0	3100	1.1	Lac La Ronge - June 2015

Noting the wide variability in emissions estimates from different approaches, and as the Q/d method does not generally satisfy the expectation of a clear causal impact per EPA guidance, MDE presents other evidence demonstrating that the plume from the northwestern Canada fires caused elevated ozone levels in Maryland.

3.3.3.1. 99th Percentiles (July)

As part of demonstrating a clear causal relationship between ozone concentrations and the fire event, monitored concentrations were put in the context of historical observations. Observations at monitors falling at or above the 99th percentile in the past five years establish statistical evidence that the event was likely influenced by an exceptional event and are a "Key Factor" used to determine whether a Tier 2 application is appropriate. Following the Exceptional Events Guidance documents, the 99th percentile was calculated for all Maryland monitors for all days of the ozone season (April – September) from 2012-2016. Additionally the 99th percentile was calculated for all days of the ozone season excluding 2012, and all days of the month of July 2013-2016 to account for the rapid emission changes ongoing across the eastern US. These percentiles have been presented previously in scatterplots in Figures 16-27 and summarized in section 3.1. However, for the reader's convenience a summary table with comparisons of all the 99th percentiles is given in Table 6.

Table 6. 99th percentile values and comparisons to observations on July 21 and 22, 2016 for all Maryland monitors. The 12 Maryland monitors for which MDE is seeking exclusion of event influenced ozone data have their 99th percentiles presented based on data from April 1 – September 30, 2012-2016, only 2013-2016, and only July 2013-2016. The final 6 columns highlight which monitors exceed their 99th percentile level ("YES") for a given data set and day (July 21 or 22). Blanks indicate the monitor did not meet the 99th percentile for that dataset.

		99th Percentile [ppm]			July 21, 2016			July 22, 2016		
Name	AQScode	All Data	No 2012	July '13 - '16 Only	All Data	No 2012	July '13 - '16 Only	All Data	No 2012	July '13 - '16 Only
Aldino	240259001	0.0790	0.0768	0.0768		YES	YES			
Beltsville CASTNET	240339991	0.0820	0.0743	0.0770		YES	YES			
Edgewood	240251001	0.0800	0.0790	0.0798				YES	YES	YES
Essex	240053001	0.0780	0.0750	0.0765		YES				
Fair Hill	240150003	0.0831	0.0799	0.0828				YES	YES	YES
Frederick	240210037	0.0750	0.0700	0.0640	YES	YES	YES			
Furley	245100054	0.0744	0.0724	0.0729		YES	YES			
Glen Burnie	240031003	0.0770	0.0770	0.0767						
Hagerstown	240430009	0.0730	0.0695	0.0640	YES	YES	YES			
HU-Beltsville	240330030	0.0780	0.0720	0.0660	YES	YES	YES			
Padonia	240051007	0.0800	0.0760	0.0730			YES			
PG Eq Cntr	240338003	0.0809	0.0737	0.0751					YES	YES

3.4. Evidence that the Fire Emissions Affected the Monitors

3.4.1. Evidence of Fire Emissions in Maryland

Wildfires produce both primary and secondary pollutants which may be utilized to track the impact of smoke downstream from the fire source. While satellites may be able to track smoke plumes over wide areas and track their transport, they do not necessarily confirm the existence of smoke at the surface by themselves. The Lidar at UMBC showed that the smoke plume subsided to the surface on the afternoon of July 20, thus, if the smoke impacted surface air chemistry by providing ozone precursors within the smoke, these would be observable about that time in the surface monitor network. The MDE monitoring network observes both total $PM_{2.5}$ mass and speciated compounds such as ionic potassium (K+) and organic carbon (OC), as well as other pollutants such as CO and NOx and VOCs, which can act as tracers of wildfire emissions. Analyses of the various species which can be attributed to wildfires are presented. The analyses show the ozone episode in Maryland was characterized by enhanced precursors attributable to wildfire species. Unfortunately, the specific days of interest in Maryland (July 21 and 22) did not fall on 1 in 3 run PM speciation days. Additionally, MDE did not receive speciation data from days bracketing the event by the time of the submittal of this analysis. The data presented below were available as preliminary data.

3.4.2. Particles

$PM_{2.5}$ can be both a primary pollutant and as a resultant secondary pollutant of wildfire emissions downstream as photochemistry within the plume converts certain species to aerosol. The entire MDE

network of hourly $PM_{2.5}$ data at the BAM sites showed an increase in $PM_{2.5}$ 6-hour averages from July 20-22 which aligned with the onset of the smoke plume in Maryland on July 20 (Figure 32a). No other period of the month exhibited such as consistent increase across the entire Maryland network. The absence of very low observations (< 5 $\mu g/m^3$) at any monitor during the three day smoke period was also distinctly different than other periods of the month. Though the July period did not possess the highest hourly particle observations of the month, it did have the highest network 6-hour average which persisted through the period of smoke impact on the Maryland network (yellow box in figure).

Daily average fine particle concentrations showed a similar pattern to the hourly concentrations (Figure 32b). Beginning on July 20, daily average concentrations across the entire network increased, primarily into the Moderate AQI range (> 12 $\mu g/m^3$). Daily average concentrations did increase earlier than July 20. For instance, there appears to be an upward trend in daily average fine particles on July 18, 2016. However, the entire network also saw a noticeable increase in daily average particle concentrations between July 20 and July 21 distinct from the increase beginning on July 18. Thus, the earlier increase in particle concentrations should not be incorrectly concluded as the cause of the increase on July 20-21, rather, the increase on July 20-21 was independent of the increase seen a couple of days earlier.

Similar to observations in Dreessen et al. (2016), particle concentrations increased over the three day period instead of a rapid increase coincident with the first onset of the smoke. While fires are primary sources of $PM_{2.5}$ the reaction of wildfire emissions with other biogenic and anthropogenic sources creates secondary $PM_{2.5}$ creation. As the airmass photochemically aged, the smoky airmass became more $PM_{2.5}$ laden. Hourly fine particle observations (Figure 32a) showed the network 6-hour average to be increasing during the duration of the event. For example, the 6-hour running average peaked on July 22, then fell about 5 $\mu g/m^3$ on July 23 as the smoke (and created particles) was removed from the region. The fine particle observations therefore provide additional evidence that wildfire affected air reached the surface at timing consistent with that observed by the UMBC Lidar.

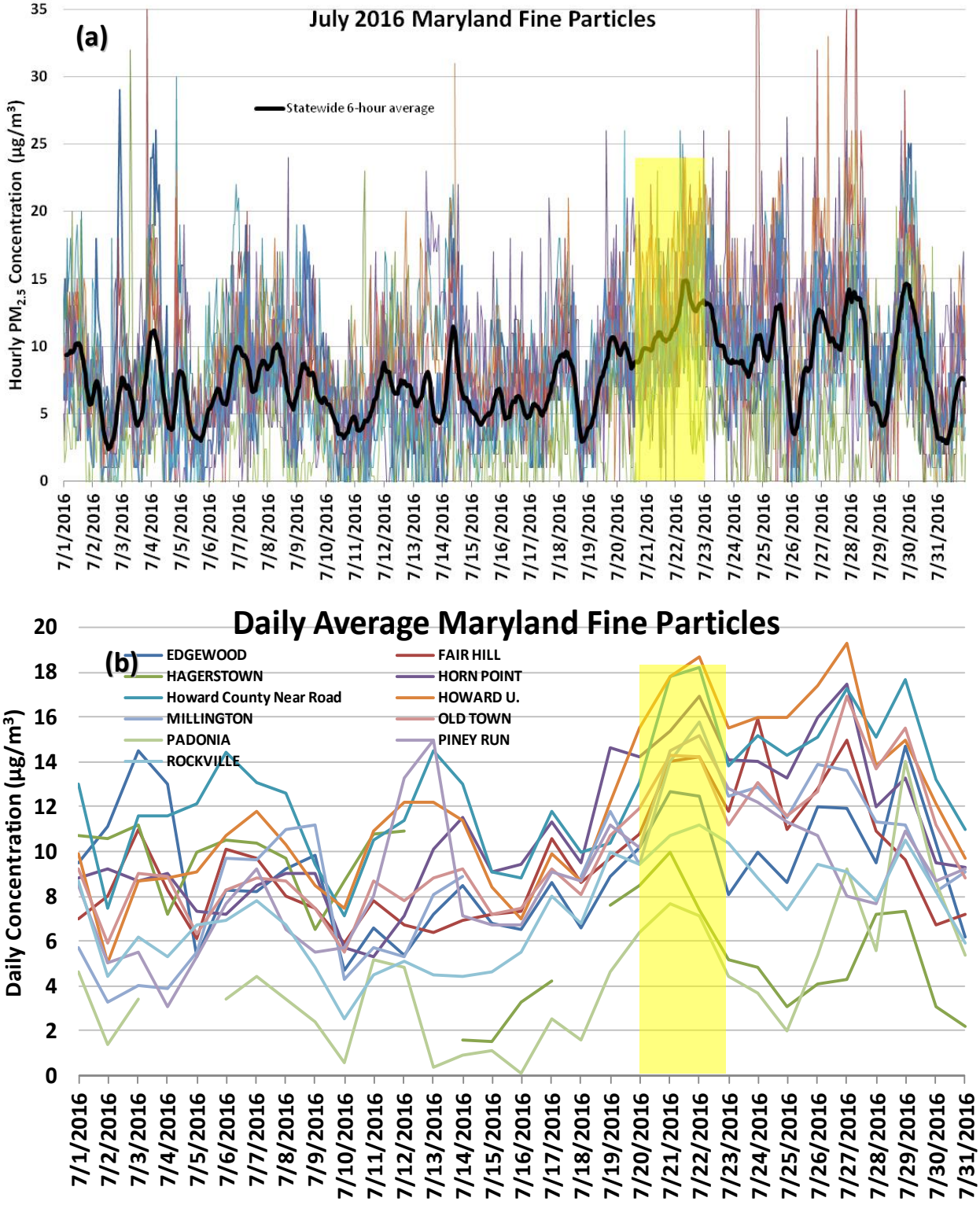


Figure 32. Hourly averaged (a) and daily averaged (b) fine particle ($PM_{2.5}$) concentrations for all Maryland sites in July 2016. The smoke influence as defined by the HMS analysis and described in the conceptual model of this document is highlighted by the yellow shading from July 20-22.

3.4.2.1. Potassium Ions and Organic Carbon

Particle pollution generated from biomass burning is typically dominated by organic carbon (OC) and black carbon (BC; Martins et al., 1998), and possesses ions such as potassium (Lee et al., 2010). Ionic potassium (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. Unfortunately, speciation data (such as OC and K+) was not provided to MDE in time to be included in this analysis. However, based on other evidence provided below, MDE believes the speciated PM data will continue to support that wildfire emissions, to include ozone precursors, impacted Maryland on July 21 and 22.

3.4.2.2. Black Carbon

An aethalometer located at the HU-Beltsville site indicated heightened black carbon (BC) from July 20-22 (Figure 33). While BC can also be sourced from mobile emissions, globally one-third of BC is sourced from biomass burning, such as forest fires (Lamarque et al., 2010; U.S. EPA, 2010). The optical absorptions of UV (370 nm) and near-infrared (880 nm) wavelengths of the aethalometer are generally very similar when observing anthropogenic-sourced particles such as diesel exhaust, but increased absorption at shorter wavelengths causes a separation of the signals(deemed "Delta-C") while observing naturally sourced BC due to the presence of VOCs (Hansen, 2005; Allen et al., 2004). The actual magnitude of BC was measured by the 880-nm, near-infrared wavelengths in the sampled air. Beginning in the evening of July 20 and coincident with the first smoke entrainment to the surface layer as observed by the UMBC aerosol Lidar (Figure 13), the aethalometer observed a distinct increase in BC concentration (Figure 33). BC concentrations near 1 $\mu g/m^3$ were sustained for multiple days (July 21-22), twice the seasonal average concentration between June and September in 2016 (0.5 $\mu g/m^3$).

With more power from the UV wavelengths the added VOCs in the environment implied the increased Delta-C was due to wildfire BC particles (Hansen, 2005). [VOCs impact UV wavelengths more than near-infrared wavelengths. The stronger UV signal implies VOCs are present in the ambient air and caused more impact on the UV Aethalometer signal. VOCs are present in wildfire smoke.] Given the preponderance of evidence of smoke and the coincidental timing of the Delta-C increase, Delta-C and BC can also be considered tracers of wildfire smoke near the surface. Under this assumption, July 21-22 exhibited concentrations of BC twice the seasonal average which was indicative of surface wildfire smoke. This was coincident with an ozone exceedance event in which some monitors observed the greatest ozone concentration during the whole of the 2016 season.

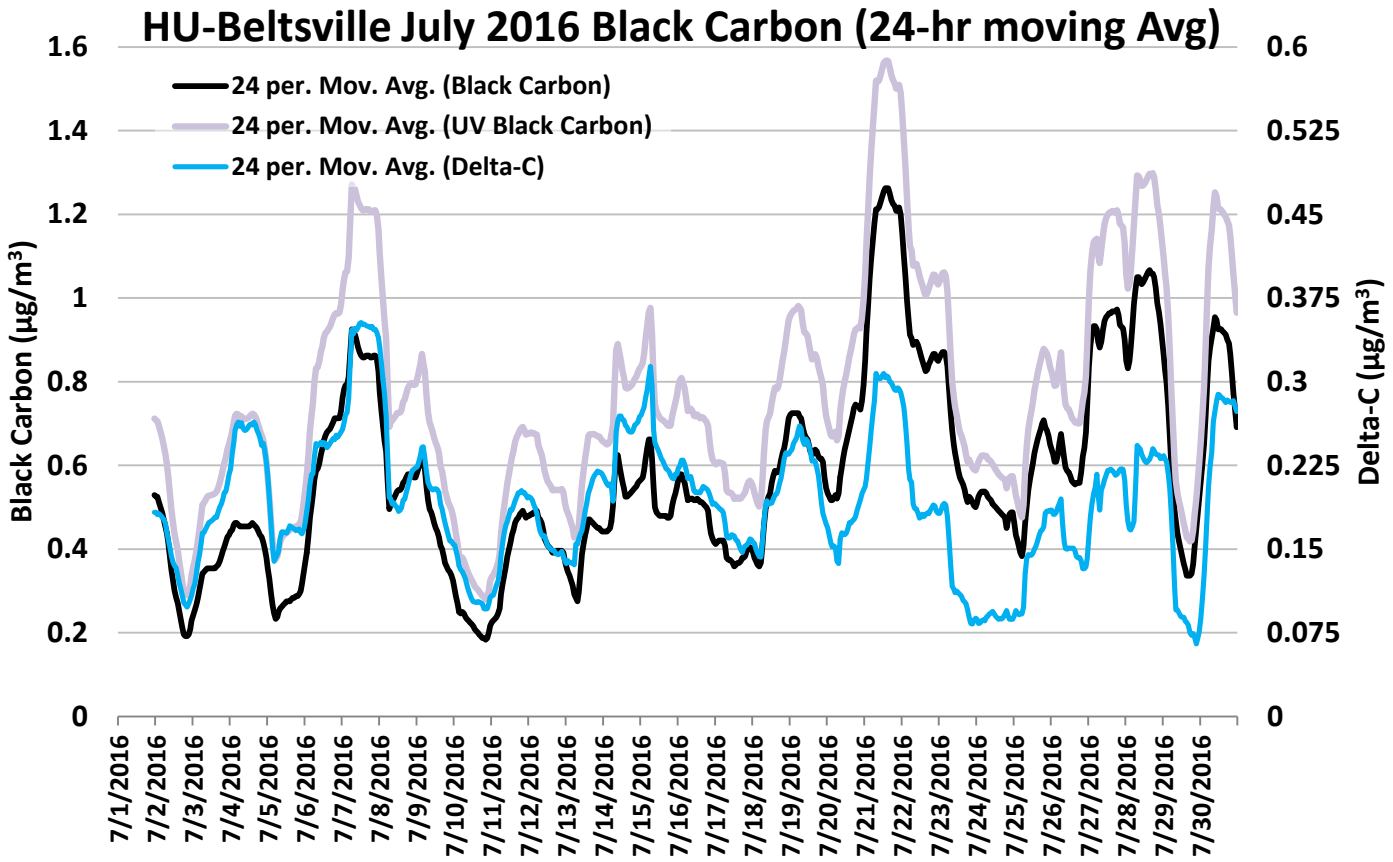


Figure 33. HU-Beltsville Aethalometer for July, 2016.
The Aethalometer observed an increase in Black Carbon concentrations (Black line) which ended up being the highest concentration observed all month. At the same time a sustained increase in Delta-C was observed (blue line), indicative of an increase in VOCs within the sampled air. Typically this may be interpreted as a signature indicating the Black Carbon was sourced from natural combustion, such as wildfires.

3.4.3. Carbon Monoxide (CO)

CO has been previously identified as a wildfire smoke indicator (Andreae and Merlet, 2001; McKeen et al., 2002, DeBell et al., 2004, Dreessen et al., 2016), can play a role in ozone production, and followed similar patterns to other pollutants over the lifetime of the event, though with a relatively subtle signal in surface data (Figure 34). Piney Run, Essex, and Horn Point showed varying degrees of CO influence from July 20-22 and were the three monitors observing CO during the event. The timing of the CO increase at Essex (thin blue line) occurred late in the day on July 20, the same timing of the smoke subsidence to the surface, shown earlier in the Lidar data (Figure 13). Horn Point (thin red line in Figure 15) was far from major sources, yet showed a spike in CO around midday on July 20. Such timing would also be consistent with smoke mixing to the surface as seen at UMBC with the different location resulting in different timing. At no other time in the month did Horn Point observe such high concentrations of CO. Piney Run also showed an increase in CO late on July 20, fairly consistent with the Essex monitor.

The state-wide peak in CO late on July 20 (black line, Figure 34) was consistent with the onset of smoke and the arrival of the CO plume on satellite to the region (Figure 31). However, the CO concentrations did not remain consistently high through the period. There may be several reasonable explanations for this. The primary and most likely explanation is that CO can itself be an ozone precursor. As such, CO can react with other atmospheric constituents, reducing its concentration in the atmosphere. Regardless of its quantitative contribution to ozone specifically, CO was likely removed from the atmosphere via photochemical reactions beginning on July 21 (the big drop in concentrations). Thus the onset of the smoke with an increase in CO is more indicative of smoke emissions impacting the surface network than sustained elevated CO concentrations would be.

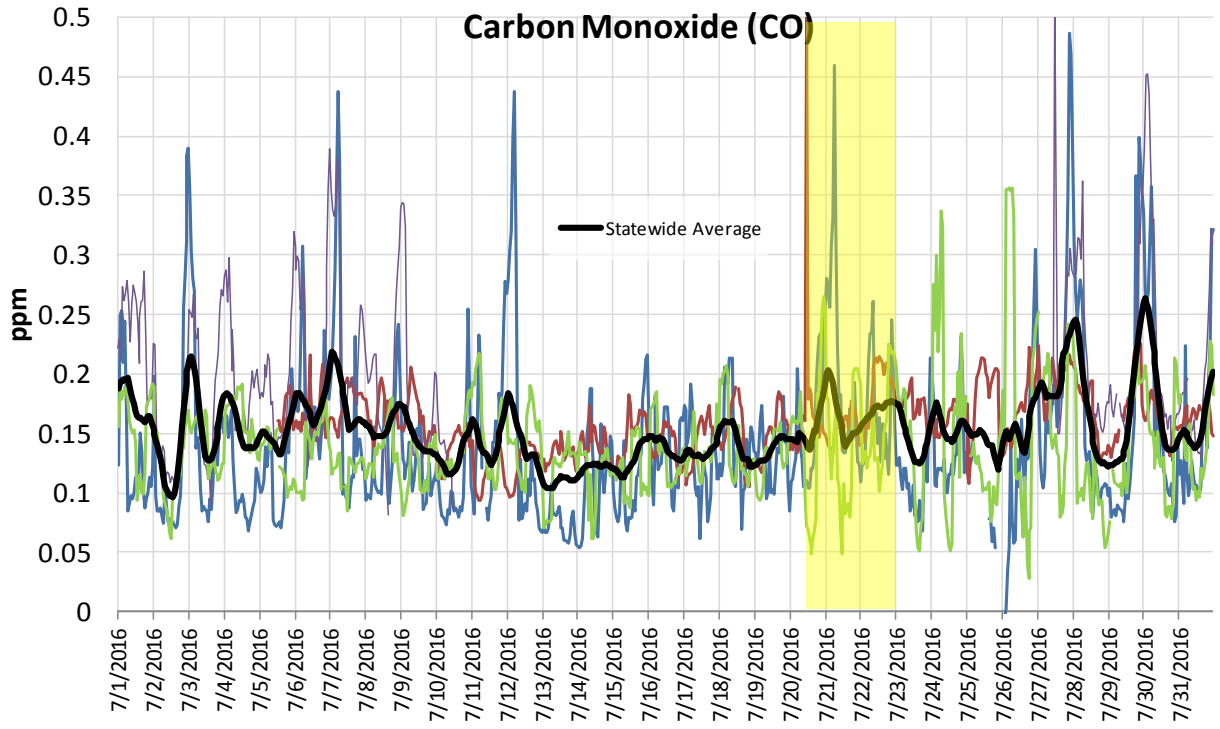


Figure 34. Hourly Carbon Monoxide (CO) overlaid with a running 24-hour average.
Hourly data at five sites in Maryland are displayed, though only Essex (thin blue), Piney Run (thin green), and Horn Point (thin red) operated from July 20-22. The smoke event is highlight in yellow. The "statewide average" is a running 12-hour hour boxcar average of the underlying hourly data, given as a bold black line. The average is taken of all available data points in that time period.

3.4.4. Nitrogen Oxides

Singh et al. (2012) showed that ozone production rates from wildfires in California were dependent upon available nitrogen oxides (NOx = sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2)) and that NOx from the fires themselves was relatively low. However, NOx emissions from fires can vary greatly and the Fort McMurray Fire in May of 2016 was associated with large amounts of NOx from the fire itself, detected as far away as Maryland. Since the smoke plume in the July case subsided from a height of over 3km on July 20 to reach the surface layer, any change in atmospheric composition at the onset of the smoke was highly likely

due to fire emissions due to lower reactivity (due to lower anthropogenic inputs) at higher elevations above the ground. For example, increases in NOx coincident with the timing of the smoke plume's subsidence are most likely a consequence of transport within the smoke plume, which was devoid of most anthropogenic sources as the plume remained aloft during transport. On July 20 a NOx increase was observed which persisted through the days of the event, suggesting some NOx enhancement within the smoke (Figure 35). However, the degree of NOx observed was not particularly high in relation to other days through the 2016 season, but all sites, saw an increase in NOx concentrations at hourly averages. Additionally, the concentration of NOx was the highest observed during the month of July in 2016. The timing of the NOx increase and the amount of NOx observed coincident with the smoke arrival all suggest the smoke played a large role in ozone production via added NOx during the high ozone period of July 21-22, 2016.

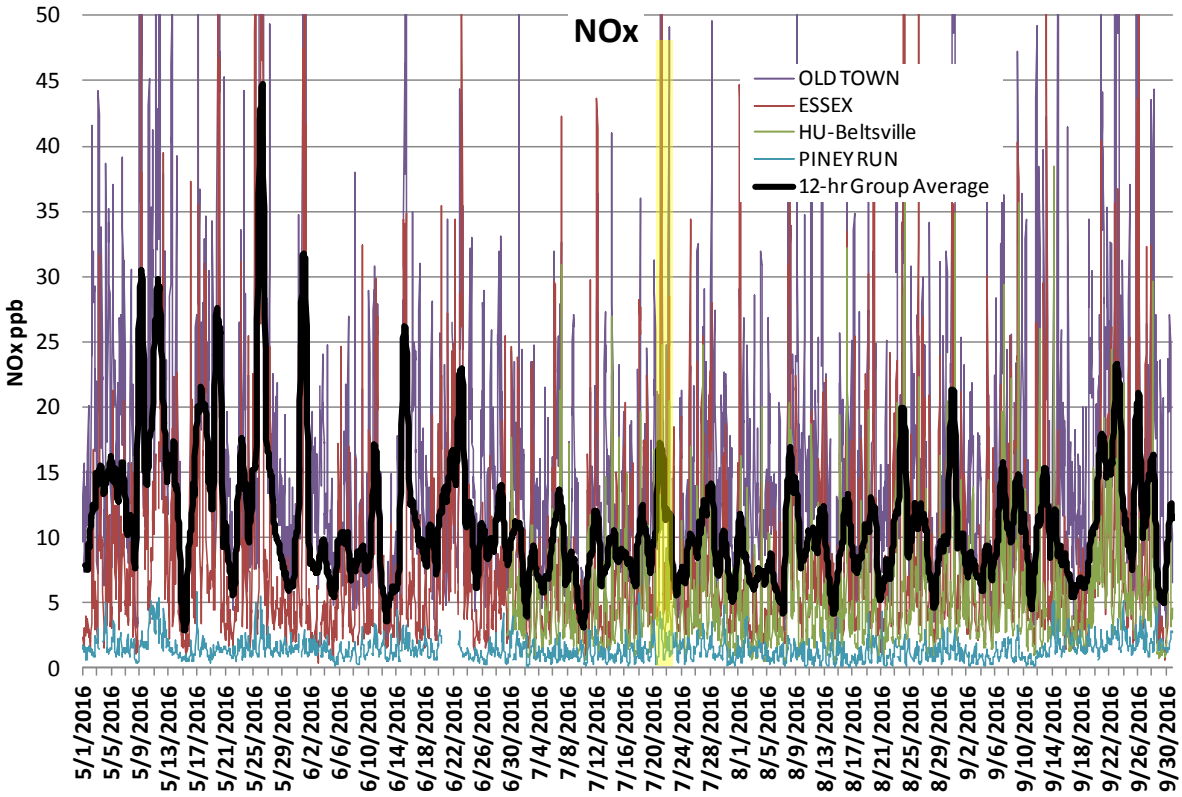


Figure 35. Nitrogen oxides (NOx) from available Maryland monitors for May-September of the 2016 ozone season. The thin yellow box highlights the July smoke event. The dark black line was a 12-hour box-car running average concentration of NOx using Oldtown, Essex and HU-Beltsville. Piney Run was not included in the average because spatial evidence suggests it was not greatly influenced by smoke during the event. Hourly concentrations of NOx at each site were given with fine lines.

3.4.4.1. Total Reactive Nitrogen, and Reservoir/Aged Nitrogen

The several day travel time of the smoke plume provided plenty of time for nitrogen to age within the smoke plume. Thus, in similar fashion to Dreessen et. al, (2016), NOy and NOz should be much higher than other times of the season if an aged plume of NOx traveled with the smoke plume. In essence, in the

presence of sunlight, the NOx and VOCs present within the plume should react and "age". The HU-Beltsville site had observed both NOy and NOx at the time of the smoke even in July. Together, these observations can also give NOz, which is a category of nitrogen compounds encompassing "reservoir species" which can be transported long distances, indicate aged pollution, and which can dissociate (break apart) in sunlight to enhance ozone production by providing additional NOx for chemical reactions. Observations of these chemical species showed an increase in total active nitrogen (NOy) coincident with the second highest observed daily running average of NOz of the entire 2016 season during the smoke event on July 20-22 (Figure 36). As mentioned, NOz concentration is often an indicator of not only the age of an airmass, but also a measure of available "transported" NOx, locked up in molecular bonds created by reactive VOCs within the smoke. The measure of NOz then, when available, is a pseudo-measure of total available ozone precursors, since it encompasses reactive VOCs and actually measures available nitrogen. The timing of NOz increase coincident with the arrival of the smoke is irrefutable evidence that the smoke supplied necessary atmospheric constituents to foster exceptional ozone production in Maryland which led to exceedances of the 70ppb NAAQS on July 21 and 22, 2016.

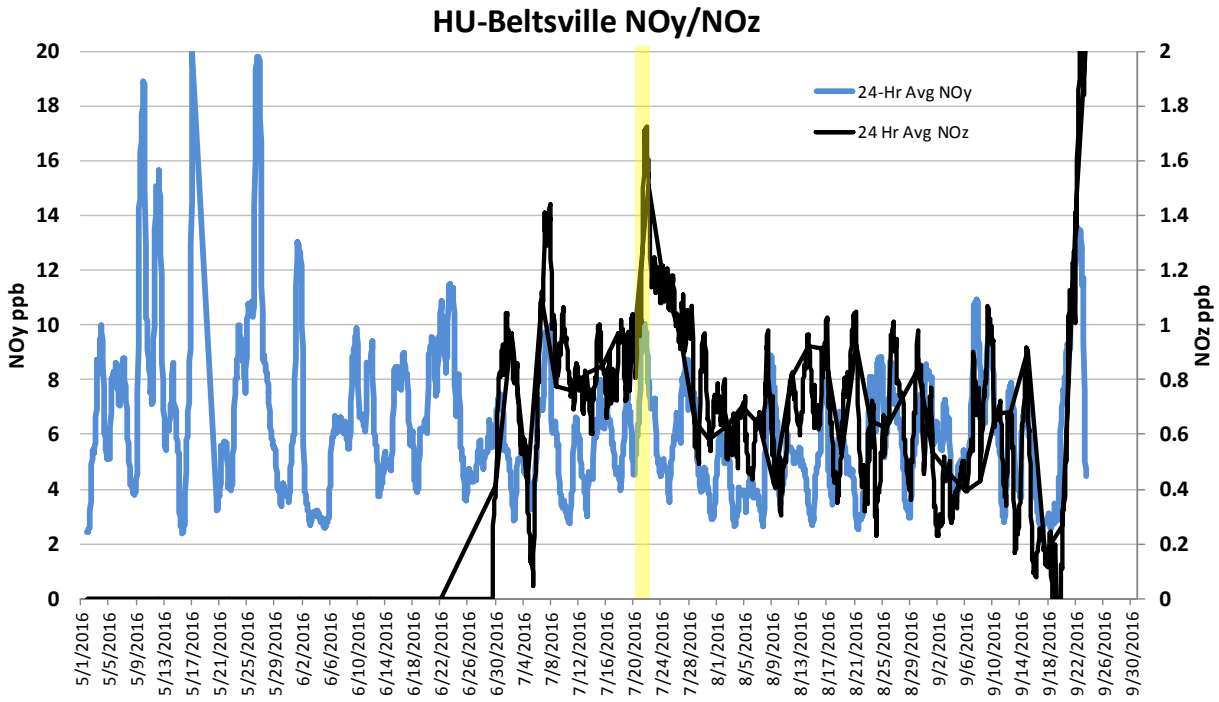


Figure 36. Total reactive nitrogen (NOy, blue) and other non-NOx species (NOz, black) at HU-Beltsville for the 2016 season. NOy was observed during the entire 2016 season, however NOx was only available beginning in late June (necessary for NOz calculations). NOz showed a pronounced spike at the onset of the smoke event.

3.4.5. Volatile Organic Compounds

Wildfires are known emission sources of Volatile Organic Compounds (VOCs) and the importance of VOCs emitted from wildfires on ozone production has been well documented (i.e, Dreessen et al (2016), Hu et al. (2008)). An airmass characterized by abundant VOCs will be more able to not only form ozone but also transport it or ozone precursors long distances due to the reactivity of the VOCs (which can also store the NOx). Thus, a significant increase in VOC concentrations coincident with the arrival of smoke and rising ozone concentrations are therefore likely interconnected. While VOCs are reactive and thus would "react away," decreasing VOC concentrations, not all VOCs are equally reactive nor would all VOCs be expected to be removed from the plume, particularly when the smoke is transported while apart from the surface layer (above and separate from other anthropogenic sources which may react with the plume).

Hourly VOC concentrations were captured by the hourly Automatic Gas Calibrator (AutoGC) located at Essex. While MDE also conducts VOC canister collection through the ozone season, the two ozone days fell between canister collection days, leaving only the hourly AutoGC chromatograph data during the height of the ozone event. The AutoGC VOC data showed a large and sustained increase in hourly total non-methane organic compound (TNMOC; VOCs) concentrations beginning in the early evening of July 20, 2016 (Figure 39). This was coincidental with the arrival of the smoke plume seen on the Lidar in Figure 13. Using a 24-hour running average the period starting late on July 20 through July 21 had the highest TNMOC concentration for the entire month of July. Hourly concentrations of VOCs (thin blue lines in Figure 39) also showed the dramatic increase in VOCs occurred beginning at 6:00pm local time, which was far too coincidental with the arrival of the smoke on the Lidar imagery being entrained towards to surface to be circumstantial.

Hourly concentrations of VOCs do decrease quickly on July 21 and into July 22. This can either be attributed to smoke being transported from the area or the remaining VOCs reacting within the airmass to augment ozone concentrations to exceed the NAAQS. In either case, the decrease in VOC concentrations does not deduct from the influence of smoke on ozone for July 22. Instead, as stated earlier, the "damage had been done" on July 21. The ozonesonde on the morning of July 22 (Figure 29) showed substantial ozone left over from July 21, which had been created by the influx of smoke and caused the additional exceedance on July 22. That ozone generation on July 21 would have only have been possible to the degree that occurred with the additional VOCs and NOx within the smoke plume. So regardless of VOC content on July 22, their impact on air quality was already exemplified. Therefore, the VOCs have provided additional, irrefutable evidence that wildfire ozone precursors were delivered to the surface air in Maryland to augment ozone production to levels exceeding the NAAQS.

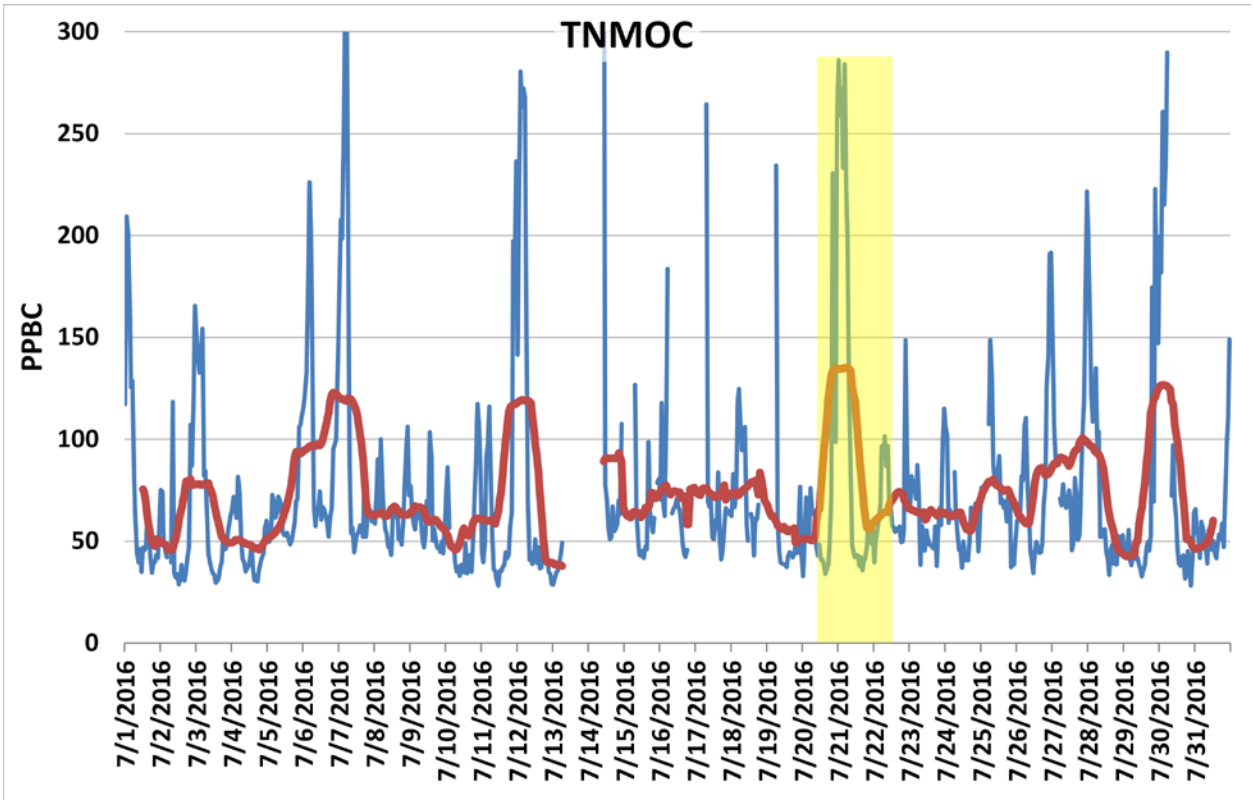


Figure 37. Total non-methane organic compounds(TNMOC)
Hourly TNMOC (blue thin line) and 24-hour box-car moving average (red thick line) in parts per billion carbon (PPBC) were observed by the AutoGC located at Essex Maryland. The yellow box highlights the smoke and ozone period.

3.5. Analysis Methods to assess impact of the SMOKE

3.5.1. Ozone to NOx ratio

MDE has asserted the excess NOx and NOy observed in the Maryland monitoring network was either from the fire itself or due to excessive storage of NOx within the smoke plume due to excess reactive VOCs supplied by the smoke as suggested in Dreessen et al., (2016). To further evaluate whether the increased NOx observed was carried within the smoke plume and was not simply from upstream EGUs (a typical "non-event" exceedance characteristic), MDE generated an ozone to NOx ratio for the past seven years. In a NOx limited environment, less NOx means less ozone. Thus, an airmass characterized by an abundance of ozone but also impacted by copious EGU NOx emissions will maintain a low or constant ozone to NOx ratio. A reduction in emissions leading to reductions in ozone and again the ratio would remain relatively constant. However, an airmass producing abundant ozone without substantial increases in anthropogenic NOx emissions produces a high ratio and indicates a highly efficient, ozone-productive airmass composition. Such a scenario indicates additional influences on the airmass composition.

The ozone values on July 21 and 22, 2016 reached MD8AO concentrations not often seen over the previous five years except with more EGU NOx emitted within the Maryland upstream airshed (Maryland,

Pennsylvania, West Virginia, Northern Virginia and Ohio, the states from which emissions would often affect Maryland ozone concentrations) such as in 2012. To further illustrate that the amount of ozone which was generated in Maryland was beyond normal in the context of decreasing regional NOx concentrations, the ratio of ozone produced against the NOx emissions from Maryland and Pennsylvania (the two main upstream states impacting the air on July 21/22, based on trajectories [Figure 15a, b and Figure 28]) was analyzed. The MD8AO on July 21 and 22 reached concentrations which were not uncommon in Maryland on exceedance days. But in previous years these ozone concentrations were achieved with abundant EGU NOx emissions. As a result, the ozone to NOx ratio (maximum statewide 8-hour average concentration divided by total NOx output from Pennsylvania and Maryland) reached the 24th and 13th highest ratio on July 21 and July 22, respectfully, using data since 2010 (217 days). The higher than typical ratio suggested ozone production was beyond classic event production and was likely aided by other constituents (Figure 38).

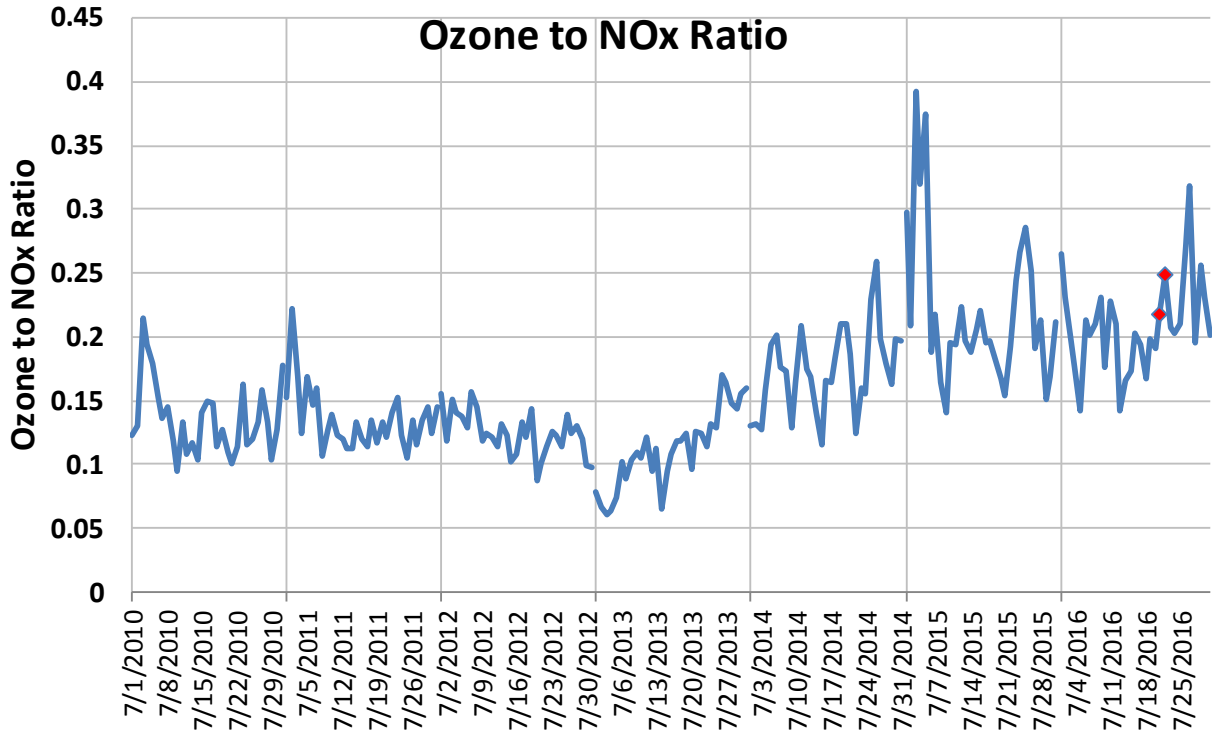


Figure 38. Ozone to NOx ratios for Maryland.
The higher the ratio, the more ozone is created for a given amount of NOx output from EGUs. NOx output used in each case is described in the text but is based on statewide EGU emissions from Pennsylvania and Maryland. States used were selected based on backward trajectories as described in the text. The red diamonds highlight the event on July 21 and 22, 2016, which were the 24 and 13 ranked ozone to NOx ratio in July, respectfully, since 2010, a period of 217 days.

3.5.2. Model Data: CMAQ Underestimation of Ozone

The presence of smoke during the July 21 and 22 ozone exceedance days and its associated tracers (such as VOCs and $PM_{2.5}$) provided clear evidence that significant portions of ozone production were attributable to smoke. Given the presence of increased smoke tracers at the surface and ozone values climbing to and above the 99th percentile levels of the past 5 years of data, the impact of smoke constituents on ozone was incontestable. To quantify the attribution, however, MD8AO concentrations forecast with the operational NOAA CMAQ ozone model were compared to observed concentrations. Source information from the Canadian fires as well as gas phase chemical interactions from wildfire smoke and their interactions with ozone were not included in the NOAA operational CMAQ model during 2016. Therefore, the NOAA operational CMAQ model represented a prediction of ozone in the absence of smoke. The NOAA CMAQ ozone model reported ~7ppbv high bias and 15.1ppbv RMSE for June ozone predictions in 2010 (Chai et al., 2013) (i.e., it tends to over-forecast ozone concentrations). The over prediction error has improved since 2010, but the model maintained a high bias in the Maryland area through 2016 (Figure 39). With this information in mind, the difference in the model forecast ozone to actual observations in July of 2016 provided an estimate of the increase in ozone due to smoke and the spatial extent of the influence.

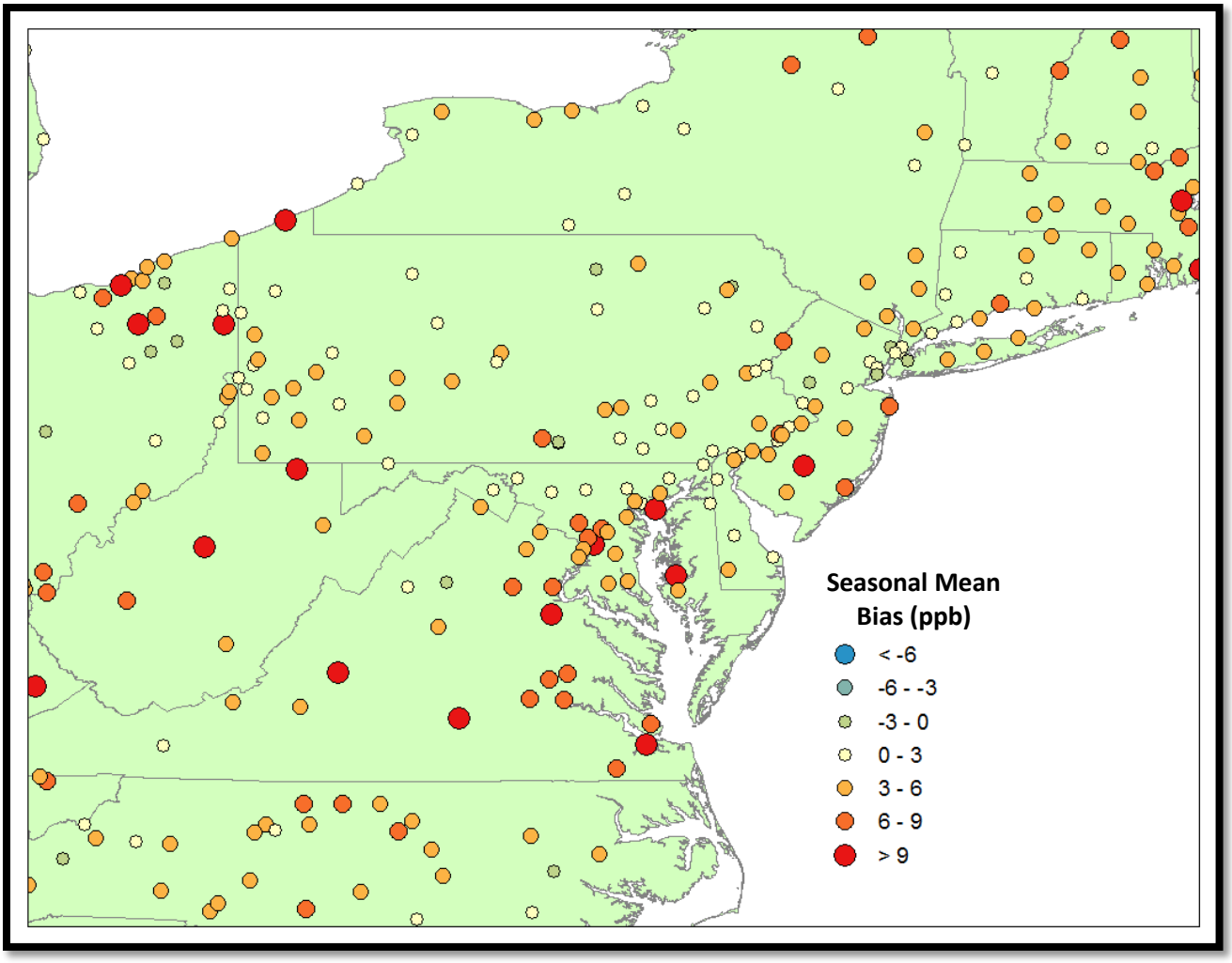
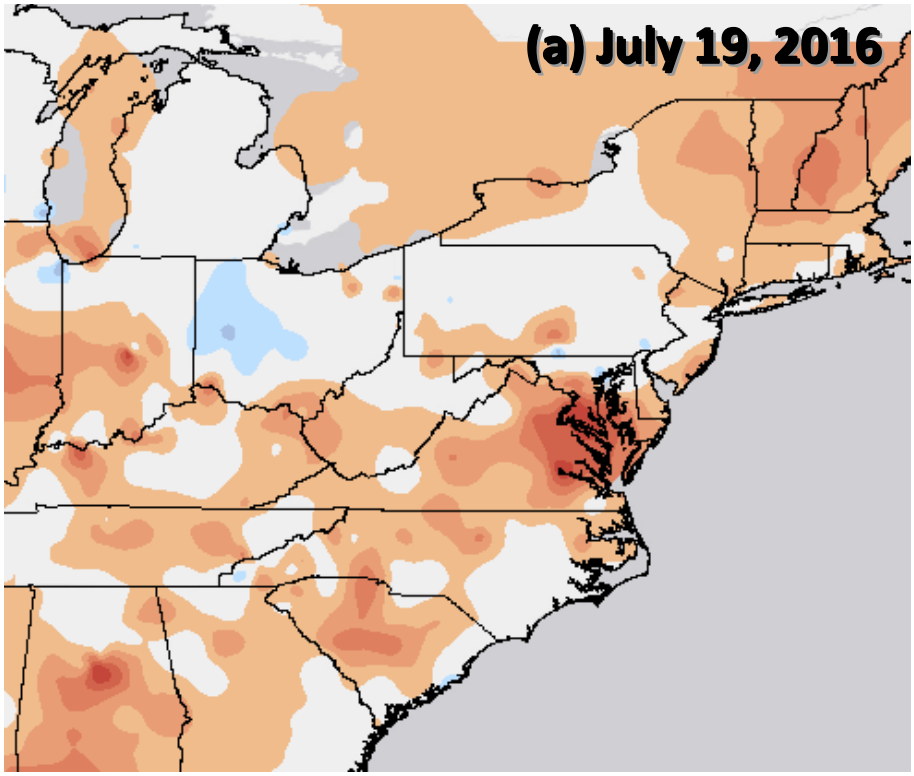
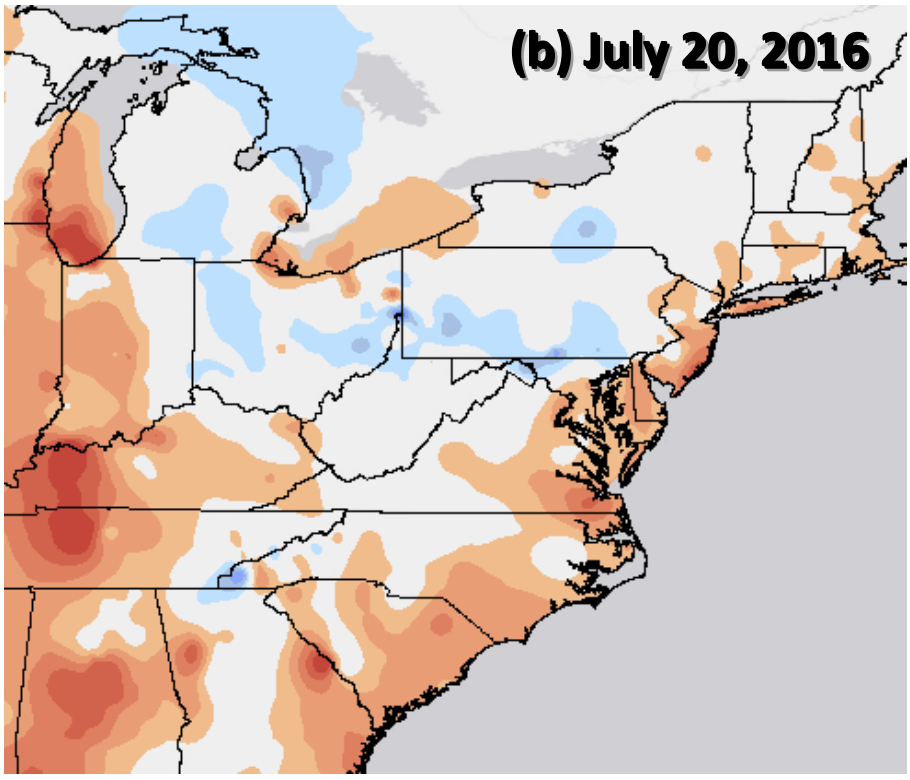


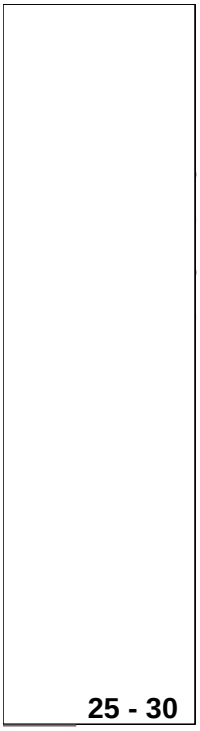
Figure 39. NOAA 2016 operational CMAQ ozone prediction errors at monitors across the northeast US.

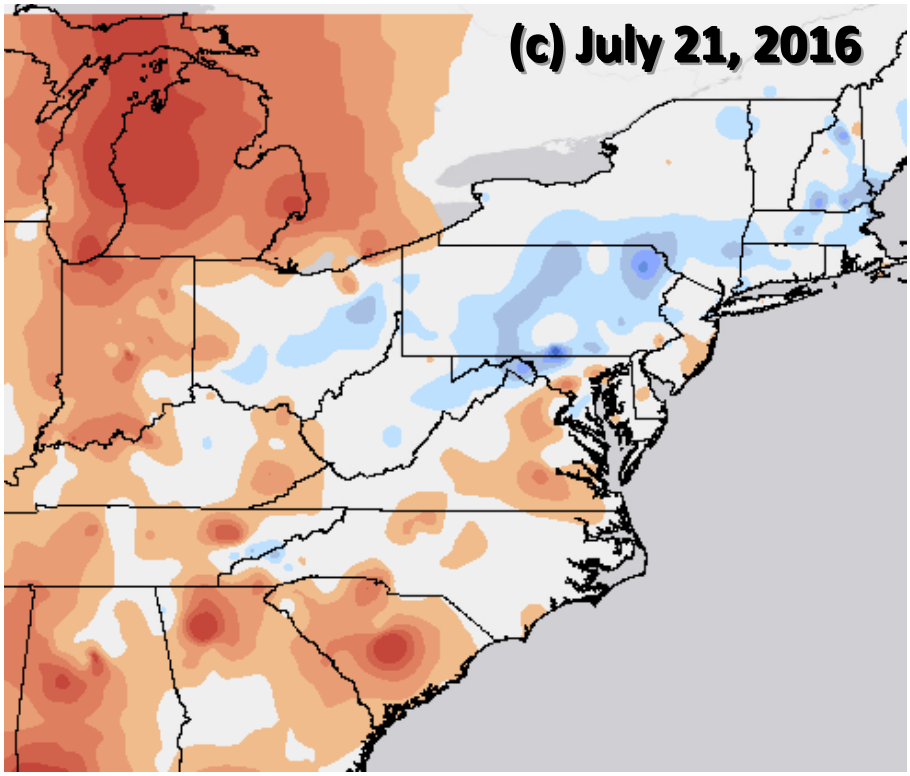
Gridded model data was extracted at observation points throughout the eastern CONUS for July 19-23, 2016. The difference between the predicted and observed 8-hour maximums were interpolated across the region on a daily basis and showed an area of modeled under prediction of MD8AO across Pennsylvania and Maryland on July 20 and 21, moving eastward to the US northeast by July 23 (Figure 40). Cross referencing Figures 14 and 15 with Figure 40 showed similar patterns of smoke, ozone, and under-prediction by the NOAA CMAQ model. Additionally, the NOAA CMAQ model traditionally over-predicts ozone by mid-season in the Mid-Atlantic. Since the NOAA CMAQ did not include smoke emissions in 2016, under predictions by the model were the result of fire emissions and ozone precursors which were not accounted for in the model input, leading to higher than predicted MD8AO. The underlying assumption then was that extreme under prediction of 8-hour maximums coincident with smoke to be due to the smoke itself. It would be very coincidental for the model to under predict both quantitatively and spatially in line with the smoke plume, particularly in the time of the season with documented model high bias.

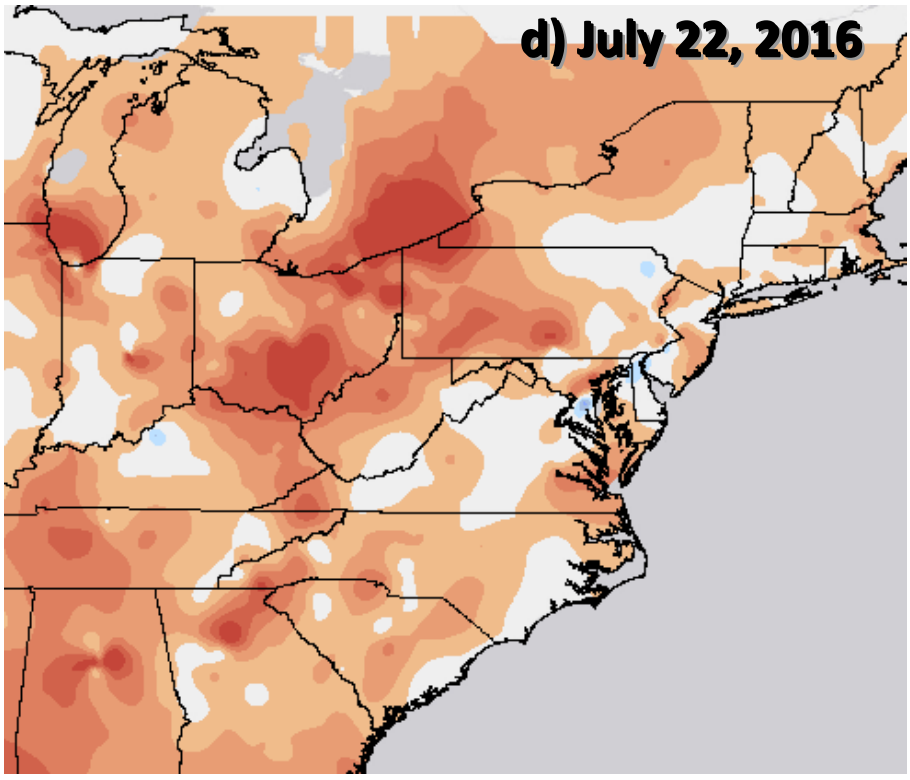
Sequential examination of the images reveals an area of modeled under prediction that developed across Pennsylvania and northern Maryland between July 19 (Figure 40a) and July 20 (Figure 40b), increased in magnitude on July 21 (Figure 40c) across these same areas and also farther northeastward into New York, then began to weaken and/or move northeastward out of the domain on July 22 and July 23 (Figure 38d,e). By July 22, warm temperatures and a high model bias nearly eliminated the area of under prediction (i.e., the model predictions were closer to correct but for the wrong reason – hot temperatures and over-aggressive anthropogenic emissions along I-95 causing a high model bias which incorrectly forecast the higher smoke concentrations) but the near zero bias across much of Maryland when the model was known for over predicting still suggests smoke influence and carry-over from the previous days into July 22, 2016. Then an area of near zero bias was located farther northeastward on July 23 to reside across New England; evidence of the transport of the airmass northeastward and away from Maryland. The area of under prediction in the model closely correlates to the movement of ozone and HMS analyzed smoke (compare Figures 14 and 15). Together, with the data presented previously, helps to quantify the ozone impact from the smoke and shows a wide area from at least Maryland through the northeast with ozone under predictions of at least 5ppb and as much as 10-15ppb over wide spread areas on July 21. This extra ozone carried over into July 22, where the model predicted values were closer to accurate, but for incorrect reasons.

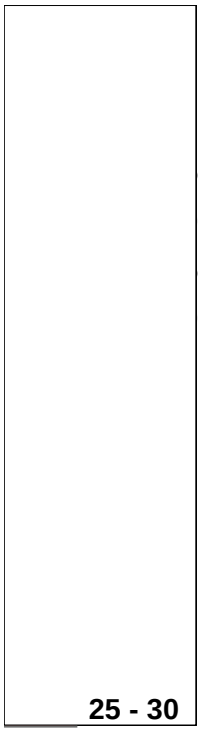

(a) July 19, 2016


(b) July 20, 2016


25 - 30


(c) July 21, 2016


d) July 22, 2016


25 - 30

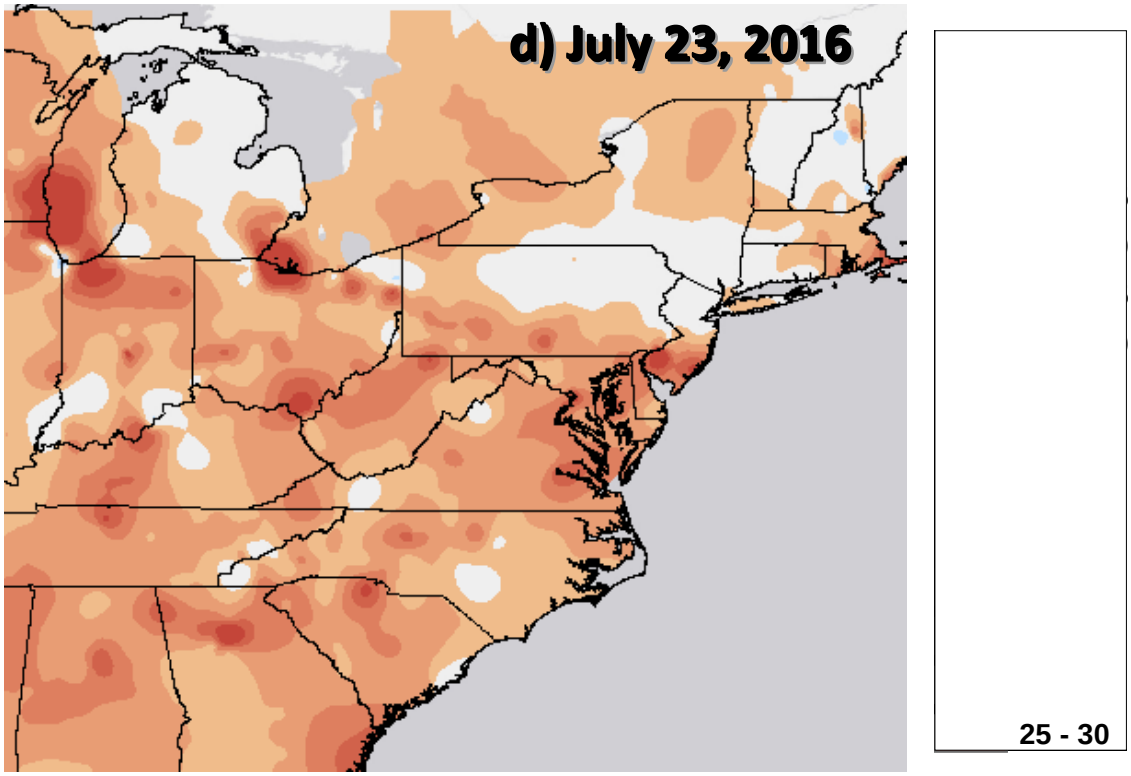


Figure 40. The NOAA CMAQ model MD8AO predictions for July 19-23, 2016 compared to AQS observations. Operational NOAA CMAQ model predicted MD8AO minus observations are contoured from July 18-28, 2016. Darker areas of blue show more significant model under prediction, while areas of red show areas of model over-prediction. Colors begin at +/- 5ppb error magnitude. Days shown are (a) July 19, (b) July 20, (c) July 21, (d) July 22, (e) July 23, 2016.

3.6. Similar Day Analysis

Similar meteorology in the absence of smoke should not produce ozone exceedances as was observed in Maryland on July 21 and 22, 2016. A similar day analysis attempts to identify days which are similar in pattern and characteristics (temperatures, winds, transport regime) but without the burden of smoke on ozone production. In an analog comparison of such days, affected monitors should show substantially less ozone when not impacted by smoke. To isolate such days within the past five years, days in July reaching at least 90°F at BWI airport were identified. From that list, days with morning winds at 925mb (approximately 1000m) from the northeast (>25° and <60°) based on the MDE wind profiler network on the morning of July 21 narrowed the group further. MDE's radar wind profiler (RWP) at Horn Point observed northeasterly winds on the morning of July 21 (Figure 41), consistent with Figure 15c which showed trajectories from the northeast on July 20, before turning northwesterly over northern areas of the state later on July 21. At 12Z the wind direction on the profiler around 1000m above ground level was from the northeast, or approximately between 25° and 60°. This wind direction and time was ultimately chosen for the similar day analysis since the smoke was first seen to subside to the surface late on July 20 and the first exceedance was on the afternoon of July 21; the morning (12Z) on July 21 falls in the middle of these two times and was therefore representative of the conditions leading up to the exceedance on July 21. Finally, those days subjectively similar to the pattern on July 21, 2016 over the eastern US determined the final group of days used for similar day comparisons.

Thirty-seven days in July of 2012-2016 were identified as meeting the temperature criteria which were not already connected or adjacent to the smoke event of 2016 (i.e., July 23, 2016 was not used). Of these 37 days, only 13 were found with northeast flow at 925mb and of these 13, none had weather patterns which closely matched the pattern on the exceedance day. Loose pattern similarity (post front, clear skies, with ridging over the eastern US) with some comparability to the July event was seen on three days and were used for comparison analysis (Table 6).

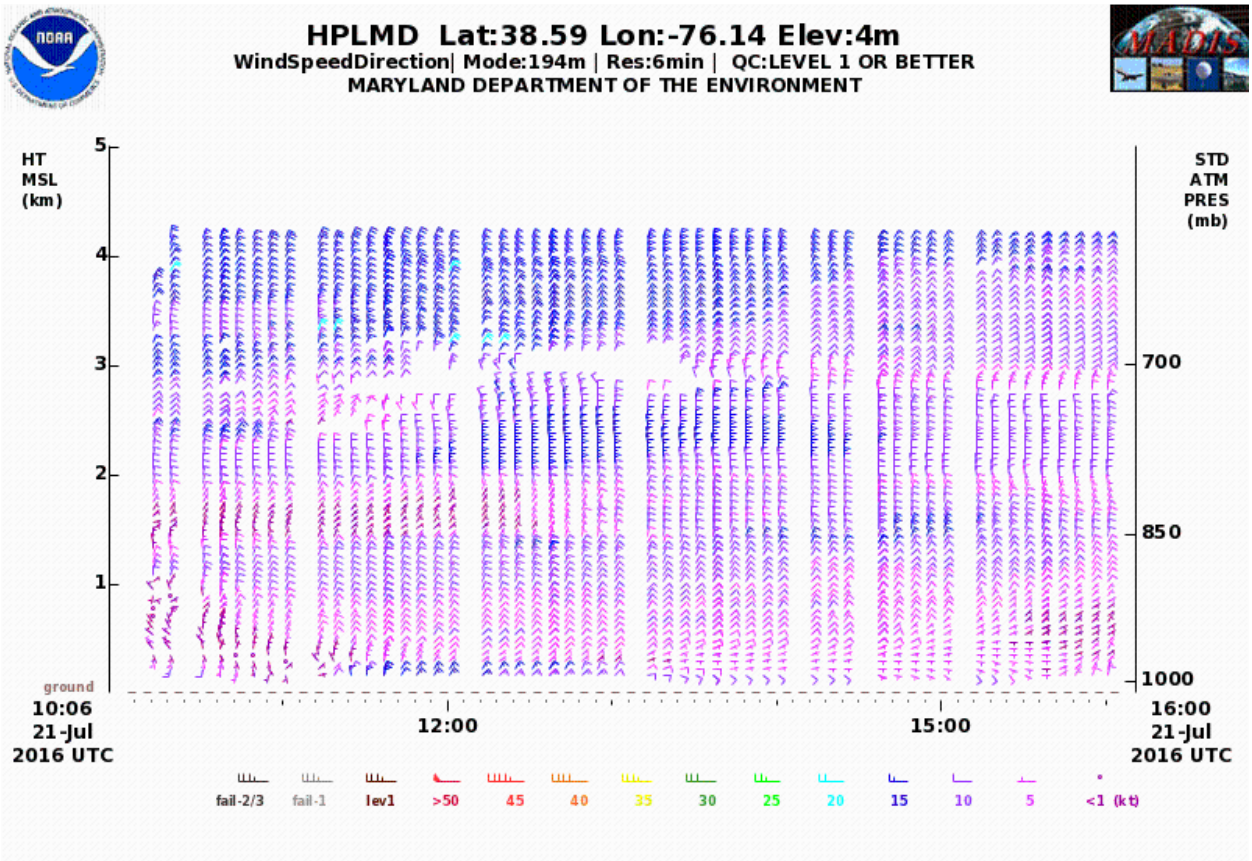


Figure 41. Radar Wind Profiler (RWP) output at Horn Point Maryland from 1006 UTC (6:06am LDT) on July 21 through 1600 UTC (12pm LDT) July 21, 2016.

Based on the similar day analysis, no other day in July from 2012 - 2016 which had similar meteorological characteristics produced similar levels of ozone. The highest ozone on July 21, 2016 was 78pb. On July 22, the highest MD8AO was 87ppb which qualified as an "unhealthy" AQI day based on the 2015 NAAQS. The next highest MD8AO concentration on a similar day was July 2, 2012 when temperatures 4°F warmer than in 2016 produced ozone which was 9ppb lower. Spatial coverage of ozone on the similar days was not comparable to the 2016 event either. More than half of the state was under code orange conditions in July

of 2016 when in the other events no monitors were above 70ppb. This analysis reveals that similar meteorological conditions in previous years did not produce as much ozone as on July 21 and 22 of 2016. This was true despite decreased emissions over the entire 5-year period, with the lowest anthropogenic precursor emissions occurring in 2016. Thus, analog evidence suggested the July 2016 exceedance event was influenced by factors not explained by a similarity analysis. The only conclusion was that the influence of wildfire smoke created the ozone exceedances July 21 and 22, 2016.

Table 7. Similar Day Analysis for July 21, 2016.
Three dates compared to the July 2016 ozone event were chosen by a similar maximum temperature (Tmax >=90°F) at BWI airport, 925mb winds from the northeast (>25° and <60°) on the 12 UTC (8am LDT) Sterling, VA sounding and comparable synoptic pattern characterized by high pressure over the southeastern US. **Due to the change in the ozone standard, the AQI color scale on the 2016 map is based on orange being greater than 70ppb for MD8AO. Earlier years use 75ppb for orange.

DATE	Ozone (ppb)	T_{max} (°F)	Mapped AQI
July 21, 2016	78	90	 *
July 2, 2012	69	94	
July 31, 2015	67	90	
July 16, 2013	69	95	

4. The Occurrence was a Natural Event

According to the Clean Air Act (CAA) and the Exceptional Events Rule (40 CFR 50), an exceptional event must be "an event caused by human activity that is unlikely to recur at a particular location or a natural event." The EPA also believes that treating all wildfires on wildland as natural events is consistent with the CAA and Exceptional Events Rule. Based on the documentation provided in section 2 of this submittal which discusses the origin and evolution of the wildfire events, the fires across the Northwest Territories and west-central areas of Canada qualify as a natural event because lightning activity was suspected as the cause of the unplanned fire event. Wildfire emissions affecting ozone concentrations in Maryland were generated predominantly from sparely populated forested areas, meeting the definition of wildland. The EPA generally considers the emissions of ozone precursors from wildfires on wildland to meet the regulatory definition of a natural event at 40 CFR 50.1(k). Accordingly, the Maryland Department of the Environment has shown that the event is a natural event and under this criteria may be considered for treatment as an exceptional event.

5. The Occurrence was Not Reasonably Controllable or Preventable

Based on the documentation provided in section 2, the majority of the fires relevant in this petition were likely due to lightning. These fires were considered natural wildfire events by the EPA as outlined in section 4, were outside of the United States, and were therefore neither reasonably controllable or preventable by the state of Maryland. No policy that Maryland enacted could have prevented the fire or the smoke which it caused, to enter the United States or Maryland. MDE was not aware of any evidence clearly demonstrating that prevention or control efforts beyond those actually made would have been reasonable. Therefore, emissions from these wildfires were not reasonably controllable or preventable and meet the criterion for treatment as an exceptional event.

6. Public Comment

MDE posted notice of this exceptional event demonstration on May 26, 2017 on the MDE website for a comment period of 30 days**.** MDE received comments from the Sierra Club, Environmental Integrity Project and Earth Justice ("The Commenters") during this period. These public comments have been included in Appendix C. Responses to these comments from MDE are included in Appendix D.

7. Concluding Statements

On July 21 and 22, 2016 smoke associated with wildfires located in northwestern Canada occurred that generated ozone precursors. These precursors was subsequently transported east and southeastward towards Maryland and impacted most of the monitoring sites across the Maryland ozone network. The monitored 8-hour ozone concentrations reaching as high as 78 and 87ppb on July 21 and 22, respectively, established the highest observed MD8AO concentration at five sites in the Maryland ozone network during the 2016 season and were within the four-highest ranked 8-hour average observations of 2016 at 11 monitors, (Table 1), though only 10 of those monitors exceeded the 70 ppb NAAQS to be included in this analysis and to be considered for exclusion.

Exclusion of the MD8AO concentrations on July 21 and 22, 2016 lowers the DV at several monitors in Maryland. Excluding the July 21 and 22 MD8AO at the 12 requested monitors (Table 2 and 8) would immediately reduce five monitors' DV, including the Fair Hill monitor (240150003), which would drop below the 2008 75 ppb level (from 76 to 74 ppb) and also bring the PG Eq Cntr monitor (240338003) into attainment of the 70ppb 2015 standard (71ppb to 70ppb). Reduction of all the sites' DVs would potentially be used to demonstrate compliance through 2018.

Additionally, MDE also recognizes the importance of the fourth highest value in a given year potentially determining future year DVs. Exclusion of the July event will impact not only DVs in 2016, but also in 2017 and 2018, particularly in light of MDE's May exceptional event demonstration. An exclusion of the requested data in July will decrease five monitors' DV and fourth-highest observations in 2016. However, if the May event was also excluded a total of 12 monitors' DV would decrease with 3 monitors' DV decreasing only if both are concurred. An additional seven monitors' fourth-high would decrease further with both exclusions than if only the July or May events were concurred alone. Given the fourth high value will impact the DV calculation through 2018, the exclusions have large ramifications for regional attainment.

The analyses provided in this demonstration support MDE's position that the wildfire events affected air quality in such a way that there exists a clear causal relationship between the specific event (fires in northwestern Canada) and the monitored ozone exceedance on July 21 and 22, 2016 and thus satisfies the clear causal relationship criterion for recognition as an exceptional event. Based on these facts, MDE requests that EPA recognize the 15 MD8AO concentrations between July 21 and 22, 2016 (Table 8), exceeding the 70ppb NAAQS at the following 12 monitors: Fairhill (240150003), Frederick (240210037), Hagerstown (240430009), HU-Beltsville (240330030), PG Equestrian Center ("PG Eq Cntr", 240338003) Aldino (240259001), Edgewood (240251001), Furley (245100054), Rockville(240313001), S. Carroll (240130001), Glen Burnie (240031003), Beltsville CASTNET (240199991), as impacted by an exceptional event. MDE formally requests that the data from these 12 monitors on these days be flagged as such and be excluded from use for regulatory determinations.

Table 8. The 12 ozone monitors at which MDE is seeking data exclusion.
Local names and Air Quality System (AQS) identification numbers (AQSID) identify monitors in the text. Also given are the maximum daily 8-hour average ozone (MD8AO) concentrations in ppb along with that day's rank in the 2016 season in parentheses. A rank of (1) indicates the MD8AO was the highest recorded at that site in the season. The final columns indicate the 2016 fourth high and design value with no exclusion of data (Including) and if the requested data from July 21 and 22 are excluded from fourth high and design value calculations (Excluding). Sites with an asterisk indicate the site does not have a valid design value in 2016. Blank cells ("-") are MD8AO at sites which did not exceed 70ppb and therefore cannot seek exclusion.

		2016							
SiteName	AQSID	MD8AO[ppb] (rank)		Fourth High [ppm]			Design Value [ppm]		
		July 21	July 22	Including	Excluding	Excluding May & July	Including	Excluding	Excluding May & July
Aldino	240259001	77 (3)	72 (9)	0.077	0.077	0.074	0.073	0.073	0.072
Beltsville CASTNET	240339991	78 (1)	-	0.070	0.070	0.069	0.068	0.068	0.068
Edgewood	240251001	72 (9)	82 (1)	0.079	0.079	0.077	0.073	0.073	0.072
Essex	240053001	75 (7)	72 (13)	0.078	0.078	0.077	0.072	0.072	0.072
Fair Hill	240150003	-	87 (1)	0.080	0.076	0.075	0.076	0.074	0.074
Frederick	240210037	75 (2)	-	0.070	0.067	0.067	0.067	0.066	0.066
Furley	245100054	74 (5)	-	0.075	0.075	0.067	0.069	0.069	0.066
Glen Burnie*	240031003	76 (4)	-	0.076	0.076	0.074	0.076	0.076	0.074
Hagerstown	240430009	74 (1)	-	0.070	0.068	0.068	0.066	0.065	0.065
HU-Beltsville	240330030	78 (1)	-	0.070	0.069	0.069	0.069	0.068	0.068
Padonia	240051007	73 (4)	-	0.073	0.073	0.073	0.072	0.072	0.072
PG Eq Cntr	240338003	-	76 (4)	0.076	0.074	0.073	0.071	0.070	0.070

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Andreae, M.O., and P. Merlet. 2001. Emission of trace gases and aerosols from biomass burning. Global biogeochem.Cycles 15(4): 955–66. doi:10.1029/2000GB001382

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Appendix: A

Letter of request to EPA CAMD to flag CASTNET monitors in Maryland.

Maryland
Department of
the Environment

Larry Hogan
Governor

Boyd Rutherford
Lieutenant Governor

Ben Grumbles
Secretary

May 4, 2017

Timothy Sharac
USEPA Headquarters
William Jefferson Clinton Building
1200 Pennsylvania Avenue, N.W.
Mail Code: 6204M
Washington D.C. 20460

Tim

Mr. Sharac,

MDE requests placement of RF data flags indicating the influence of Canadian wildfire smoke on air quality be placed on the two CASTNET monitors residing in Maryland. The dates and times at the following sites are as follows:

- Beltsville (240339991):

  May 25, 2016, hour 0 to May 26, 2016, hour 23
  July 21, 2016. hour 0 to July 22, 2016, hour 23

- Blackwater NWR (240199991):

  May 25, 2016, hour 0 to May 26, 2016, hour 23

Per the requirements to pursue data exclusion, the EPA requires flagging of data prior to submitting an exceptional event demonstration package to the EPA. Maryland is finalizing demonstrations showing the impact of two wild fires on the regulatory monitor sites. In May, fires near Fort McMurray, Alberta lofted a smoke plume which impacted ozone concentrations across the entire state of Maryland and much of the northeast US. In July, a large number of fires in aggregate across northwestern Canada lofted a smoke plume which again subsided over the northern Mid-Atlantic. Both instances were tied to ozone exceedances of the 70ppb NAAQS in Maryland. Maryland has determined exclusion of these data points will impact current and future design values and possibly the future attainment status of the state.

Sincerely,

David Krask
Manager, Ambient Air Monitoring Program

1800 Washington Boulevard | Baltimore, MD 21230 | 1-800-633-6101 | 410-537-3000 | TTY Users 1-800-735-2258
www.mde.maryland.gov

Appendix: B

Table 9. Ozone monitors at which MDE recognizes potential impacts on future year designations.
Table description is identical to Table 8.

		2016							
SiteName	AQSID	MD8AO[ppb] (rank)		Fourth High [ppm]			Design Value [ppm]		
		July 21	July 22	Including	Excluding	Excluding May & July	Including	Excluding	Excluding May & July
Beltsville CASTNET	240339991		70 (4)	0.070	0.070	0.069	0.068	0.068	0.068
Rockville	240313001	68 (4)		0.068	0.068	0.068	0.068	0.068	0.068
South Carroll	240130001	70 (5)		0.072	0.072	0.068	0.068	0.068	0.067

These monitors did not exceed 70ppb on July 21 or 22, 2016. However, they observed MD8AO concentrations which were within the fourth highest of the season. Therefore, exclusion of these data points could lower future year DVs since they depend on the fourth highest over three years. Exclusion of these data points, even though they are not above 70ppb could lower these monitor's DV for the next 3 years.

Appendix: C

Comments letter from the Sierra Club, Environmental Integrity Project and Earth Justice.

June 26, 2017

VIA ELECTRONIC MAIL

Ms. Janice Lafon
Maryland Department of the Environment
1800 Washington Blvd., Suite 730
Baltimore, MD 21230-1720
Email: Janice.Lafon@maryland.gov

RE: State of Maryland Exceptional Event Demonstration and Analysis of the Northwestern Canada Wildfires' Impact on Maryland's Air Quality, July 21 and 22 2016: Comments of the Sierra Club, Environmental Integrity Project, and Earthjustice

Dear Ms. Lafon:

The Sierra Club, Environmental Integrity Project, and Earthjustice respectfully submit the following comments regarding the May 26, 2017 exceptional events demonstration provided by the Maryland Department of the Environment (MDE or the Department) for July 21 and 22, 2016. As discussed below, Maryland has not supported exceptional event treatment for all requested monitors on the requested days. The Department disregards and deemphasizes information that undercuts its explanation of the observed monitor values during the July 21 and 22, 2016 ozone episode while attempting to give greater weight to data that the Department had previously dismissed as anomalous. Ultimately, the practical impact of excluding the requested monitor-days from ozone design values is to diminish public health protections to the detriment of air quality in Maryland. The citizens of Maryland breathe the air on all days, whether or not the monitored ozone levels from these days are included in design values for compliance with National Ambient Air Quality Standards (NAAQS). Achieving paper compliance with the 2008 ozone NAAQS without achieving actual compliance with that standard serves to jeopardize the health of Marylanders by reducing or eliminating both Maryland and upwind states' obligations to ameliorate air quality in the state. The Sierra Club, Environmental Integrity Project, and Earthjustice urge Maryland to withdraw the July 21 and 22, 2016 exceptional events demonstration.

The data presented by Maryland do not support exceptional events treatment for all requested monitors on all requested days during the July 21 and 22, 2016 ozone episode. A close examination of ozone monitor trends during the July 21 and 22, 2016 ozone episode undercuts MDE's contention that all Maryland monitors were influenced by exceptional events during both days of this episode and undercuts the Department's contention that all fourteen monitor-days that exceeded the 70 parts per billion (ppb) ozone standard should be treated as being influenced by exceptional events. Indeed, based on the Department's explanation and the actual monitor

data, it is not possible to determine which, if any, monitors were influenced by the wildfire smoke on July 21 or 22.

First, MDE has not supported its contention that the Essex monitor was influenced by exceptional events on July 21 or July 22. MDE acknowledges that on July 19, 2016, the Essex monitor recorded a maximum daily 8-hour average ozone concentration that exceeded 70 ppb, at 75 ppb, but attributes this to local influences.[1] The Department fails to note, however, that the Essex monitor recorded levels at or above the 2015 ozone standard every day from July 19th through July 22nd and that these monitored concentrations were highly consistent day-to-day during this period:

Table 1: Maximum daily 8-hour Average Ozone Concentrations at Essex Monitor: July 19 – July 22, 2016

Date	Concentration
7/19	75 ppb
7/20	70 ppb
7/21	75 ppb
7/22	72 ppb

Given that conditions during this period were uniformly conducive to ozone formation[2] it is unclear what the Department's basis is for claiming that the Essex monitor concentrations on July 21 and 22—which closely mirror those from the prior two days during which MDE claims no exceptional events influence and instead cites local influences—were influenced by wildfire smoke.[3] Rather, given the similar monitor values and similarly conducive conditions for ozone formation, the reasonable inference is that the Essex monitor values on July 21 and 22 shared a similar cause to those on July 19 and 20.

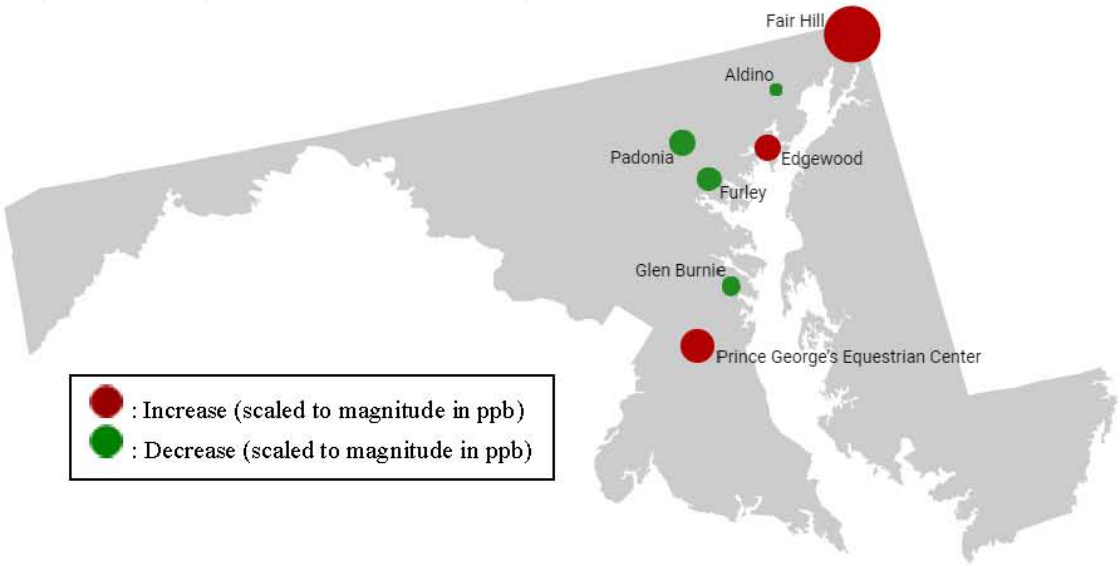
Moreover, the broader monitored ozone trends observed in Maryland on July 21 and 22 belie the Department's claim of uniform wildfire smoke influence. If the smoke plume uniformly influenced Maryland monitors on July 21 and 22, one would anticipate a consistent trend in monitor values between the two days (e.g., monitored values would uniformly increase or uniformly decrease across the state's monitors as a result of the influence of the smoke). Table 1 of Maryland's July exceptional events demonstration shows that this was not the case. Three quarters of Maryland monitors recorded higher ozone concentrations on July 21 than July 22, while one quarter recorded higher ozone concentrations on July 22 than July 21.

Such a result, while plainly inconsistent with uniform influence of wildfire smoke in the state, could still be consistent with a more limited influence from exceptional events if there were a geographical pattern to the increases and decreases between the two days. For example, if the smoke plume drifted east through Maryland, one could envision a pattern in which more western monitors in the state showed elevated concentrations on July 21 and lower concentrations on July

[1] MDE July 2016 Exceptional Events Demonstration (July EED) at 31.
[2] Temperatures remained elevated (near or above 90 degrees F) before, during, and after the ozone exceedance days. July EED at 14.
[3] Indeed, the Department claims that regional maximum daily 8-hour ozone concentrations were 15 ppb higher as a result of the smoke, a massive difference simply not observed at Essex. July EED at 57.

22, while more eastern monitors showed elevated concentrations on July 22 compared to the day before. Yet this pattern does not manifest either. As illustrated in Figure 1 below, the Prince George's Equestrian Center, for example, which is located south-southwest of Baltimore, showed a 13 ppb increase between July 21 and 22, while Glen Burnie, located just south of Baltimore (and northeast of PG Equestrian Center) showed a 7 ppb decrease, Furley, located in Baltimore City showed a 9 ppb decrease, and Padonia, located north of Baltimore experienced a 10 ppb decrease. Similarly, the Aldino monitor, located northeast of Baltimore, decreased by 5 ppb from July 21 to July 22 while the nearby Fair Hill monitor increased by 22 ppb between the two days, and Edgewood, located between Aldino and Baltimore increased by 10 ppb. The absence of a uniform trend in monitor values between July 21 and 22 undermines MDE's claim that all monitors in the state were influenced by the smoke event. And the absence of any geographical pattern to the monitor trends between July 21 and 22 undercuts even a more limited claim that monitors in certain regions of the state were influenced by the smoke event. The elevated PG Equestrian Center monitor value on July 22 and the divergent trends in monitors in northeastern Maryland are particularly difficult to reconcile with the Department's smoke-plume-based explanation of the event.

Figure 1: Increase/Decrease in Maximum Daily 8-Hour Ozone Concentrations Between July 21 and July 22, 2016 for Seven Maryland Ozone Monitors



MDE's explanation of the July 21 and 22 ozone episode is premised on the contention that insufficient ozone precursors are present as a result of local and regional anthropogenic emissions to generate significant ozone exceedances in Maryland.[4] Yet the state experienced several ozone episodes in 2016 for which it has not claimed influence from exceptional events. For example, on July 27, 2016, just five days after the July 21-22 episode, eight monitors in Maryland (and three additional monitors in nearby DC and northern Virginia) registered exceedances of the 2015 ozone NAAQS, including an 8-hour daily maximum ozone

[4] *See* July EED at 16 (explaining that local and regional anthropogenic "emissions alone regularly fall short of producing ozone capable of MD8AO concentrations above 70 ppb in Maryland").

concentration of 99 ppb recorded at the Essex monitor and 88 ppb at the Furley monitor. The peak ozone concentration during the July 27th ozone episode exceeded that during the allegedly smoke-influenced July 21-22 ozone episode. Similarly, on September 23, 2016, thirteen Maryland monitors (and an additional four in DC and northern Virginia) exceeded the 2015 ozone NAAQS, including an 8-hour daily maximum ozone concentration of 87 ppb recorded at the Aldino monitor. Temperature data in northeastern Maryland, where the highest ozone concentrations were recorded, were comparable across the four days. Maximum temperatures at the Conowingo Dam and Aberdeen Phillips Field are shown in Table 2 below. The additional ozone episodes on July 27 and September 23, which occurred under similar temperature conditions, suggest that local and regional emissions of ozone precursors coupled with appropriate meteorological conditions can still cause not only exceedances, but actually very large exceedances, of the 2015 and 2008 ozone standards.

Table 2: Maximum Daily Temperature (Fahrenheit) for Select Days in 2016

	July 21	July 22	July 27	Sept. 23
Conowingo Dam	84	86	88	82
Aberdeen Phillips Field	85	88	90	83

Source: https://www.climate.gov/maps-data/dataset/past-weather-zip-code-data-table

MDE's comparison of regional nitrogen oxide (NOx) output for July 2010-2016 to maximum Maryland 8-hour ozone concentrations (Figure 5) fails to support the Department's contention that the July 21 and 22 episode was influenced by exceptional events. As an initial matter, it is unclear why the Department considered data only from July of each ozone season in trying to understand the relationship between regional NOx emissions and Maryland ozone values. While July has the highest total regional NOx emissions (per Figure 4 of MDE's exceptional events demonstration), this is likely attributable to July having the highest average temperatures. Given that ozone episodes occur on the order of one or two days, it makes little sense to disregard data from other months during which regional NOx emissions could peak on shorter time scales and be equal to or exceed those on a daily basis in July. Moreover, even considering only the July data, there is an imperfect correlation between monthly regional NOx emissions and maximum ozone concentrations in Maryland. This is not surprising, as other meteorological conditions must align in order to produce ozone episodes, which typically do not last an entire month. Thus, the trend of monthly NOx emissions provides no rational basis for arguing that this two-day period of exceedances was clearly caused by an exceptional event. As noted above, the fact that a significant ozone episode occurred in Maryland only five days after the allegedly fire-influenced July 21-22 ozone episode, and again in September, suggests that local and regional emissions of ozone precursors, coupled with ozone-formation-conducive conditions, can still lead to significant exceedances of the 2015 and 2008 ozone standards.

Further, several aspects of MDE's exceptional events analysis lack robustness and provide limited support for the Department's proffered explanation of the event:

- Speciation analysis: MDE's speciation analysis is missing critical data.[5] The PM2.5 analysis also indicated a "consistent increase across the entire Maryland network"[6]; yet,

[5] July EED at 69.
[6] July EED at 70.

as discussed above, ozone levels do not appear to be uniformly elevated on July 21 or 22 across the ozone monitor network.

- Ozone to NOx ratio: MDE claims that the ozone to NOx ratio is particularly elevated on July 21 and 22, 2016. But viewed in context—as presented by MDE in Figure 38—the ozone to NOx ratio has been increasing for years and the July 21 and 22, 2016 values were not anomalous at all for the 2015 or 2016 ozone seasons.[7]

- Quantity/distance (Q/d) ratio: MDE estimates values ranging between 1.8 tpd/km and 3.5 tpd/km for the July 21-22, 2016 ozone event, both of which are well below the value of 100 tpd/km that EPA recommends indicates clear causality.[8]

In addition, in conducting its 99th percentile analyses using data from the past five ozone seasons the Department attempts to discount data from 2012 as non-representative, while including data from 2013 and 2014.[9] However, in other contexts, the Department has acknowledged that both temperatures and weather patterns in 2014 were anomalous for Maryland and not conducive to ozone formation. For example, the Department has previously acknowledged that 2014 was "one of the coolest and climatologically different summers we've ever seen" and that "[w]e did not see the traditional weather patterns in MD that transports ozone and ozone precursors from the south and west . . . i.e. . . . We had no transport."[10] It is inconsistent for the Department to attempt to discount the relevance of data from 2012 and elevate the relevance of data from 2014 in this context while acknowledging in other contexts that 2014, rather than 2012, was the anomalous ozone year for Maryland.

Finally, it is unclear whether MDE provided the requisite notice regarding the comment opportunity on the Department's exceptional event demonstrations. Pursuant to 40 C.F.R. § 50.14(c)(3), states are required to provide "notice and opportunity for public comment" for exceptional events demonstrations. MDE states that it posted the demonstration on its website on May 26, 2017, but it does not appear that the agency provided notice to the public in any way other than via its website. For example, the May 26, 2017 Maryland Register does not notify the public of the exceptional events demonstration or the opportunity to comment.[11] In addition, MDE maintains email lists of parties interested in air quality actions to which the agency regularly distributes notices regarding upcoming rulemakings. To commenters' knowledge, MDE has not sent notice to any stakeholders – including environmental groups and elected officials – of its proposed exceptional events demonstration. Rather, commenters stumbled across the exceptional events demonstration while visiting the Department's website. At minimum, when addressing these comments, MDE must explain how and to whom it sent notice of this exceptional events demonstration.

Ultimately, while we recognize the Department's desire to demonstrate paper compliance with EPA's 2008 ozone NAAQS through the May and July 2016 exceptional events

[7] July EED at 79.
[8] July EED at 67.
[9] *See* July EED at 49.
[10] Tad Aburn, Transport Team Update to Ozone Transport Commission (Sept. 24, 2014), at Slide 31.
[11] *See* Maryland Register (May 26, 2017), available at http://www.dsd.state.md.us/MDR/4411/Assembled.htm.

demonstrations, we do not believe that achieving "compliance" through exceptional events demonstrations serves to benefit the State or its residents. Whether or not the excessive levels of ozone on July 21 and 22, 2016 are counted toward Maryland's monitor design values, these ozone levels were still dangerous. Paper compliance with the 2008 standard not only affects Maryland's obligations to take steps to ameliorate ozone pollution, it also affects upwind states' obligations to takes steps to improve Maryland's air quality. As the 2017 ozone season monitor data to date have shown, Maryland has not resolved its ozone attainment challenges, even under the 2008 ozone NAAQS. Less than two months into the 2017 ozone season, there have already been nine days during which at least one monitor in Maryland exceeded the 2015 ozone NAAQS, and the Fair Hill monitor has already recorded seven exceedances of the 2015 standard including three exceedances of the 2008 standard and an 8-hour daily maximum of 90 ppb. We urge Maryland to withdraw its July 2016 exceptional events demonstration.

Thank you for your consideration.

Respectfully submitted,

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Appendix: D

MDE Response to Comments of the Sierra Club, Environmental Integrity Project, and Earthjustice

The Maryland Department of the Environment (MDE or the Department) would like to thank Sierra Club, Environmental Integrity Project and Earthjustice (collectively "the Commenters") for comments on the ***Exceptional Event Demonstration and Analysis of the Northwestern Canada Wildfires' Impact on Maryland's Air Quality, July 21 and 22, 2016*** submitted to EPA, May 26, 2017. MDE has taken this opportunity to respond to comments and further bolster its claim that the Maryland network was influenced by wildfire smoke that led to an exceptional ozone event. MDE addresses the comments here-in and continues to contend the severity of the ozone event would not have occurred without the presence of wildfire smoke and its associated ozone precursors.

Despite claims made by the Commenters, Maryland has made significant strides in real compliance with federal standards to protect public health. The original exceptional event (EE) demonstration and the subsequent response to comments discussed a non-controllable, natural event that fulfilled the definition of an exceptional event which caused the days in question to be an exception to the strides made to improve air quality in Maryland.

The Commenters state: *"…based on the data, it is not possible to determine which, if any, monitors were influenced by the wildfire smoke on July 21 or 22."* [pg. 98] Interestingly, the Commenters follow this statement with an acknowledgement that evidence at some monitors supported exceptional event treatment saying *"The data presented by Maryland do not support exceptional events treatment for all requested monitors on all requested days during the July 21 and 22, 2016 ozone episode."* [pg. 98] To clarify, the Department contends all monitors were in fact impacted by smoke. However, the final EE rule says state agencies may only pursue exclusion of monitors that exceed a national ambient air quality standard (NAAQS). Additionally, not all monitors were impacted equally; those listed in the EE demonstration were impacted to a degree which raised ozone concentrations above the NAAQS. MDE further justifies these claims at monitors the Commenters question in their letter to MDE, included in Appendix C.

In summary, the Commenters allege that MDE failed to adequately explain the spatial and temporal pattern of ozone during the exceptional event, and that MDE did not adequately support claims made through evidence, citing several specific issues with the MDE's EE demonstration. These comments are addressed as follows:

1) Inconsistencies at Essex and Non-uniform Ozone within the Maryland Network:

The Commenters suggest data presented in the EE demonstration does not support treatment of the data as an exceptional event at all monitors on both requested days due to spatial and temporal inconsistencies. Essex is their primary example, based on ozone concentration comparisons prior to and during the event. Comments presented state: *"First, MDE has not supported its contention that the Essex monitor was influenced by exceptional events on July 21 or July 22."* [pg. 99] The Commenters go on to support their assertion by raising issue that Essex had 8-hour average ozone at or above 70ppb on the two days prior to the exceptional event. That, they claim, suggests the ozone

concentrations on July 21 and 22 were due to the same mechanisms that generated high ozone on July 19 and 20, in contradiction to the claim that July 21 and 22 were an exceptional event.

The underlying assumption by the Commenters is that the conditions were nearly identical on all four days (July 19 – July 22) at Essex and these similar conditions resulted in similar ozone concentrations on all four days. The Commenters state: "*Given that conditions during this period were uniformly conducive to ozone formation it is unclear what the Department's basis is for claiming that the Essex monitor concentrations on July 21 and 22 – which closely mirror those from the prior two days … were influenced by wildfire smoke."* [pg. 99] While logically concluded, these assumptions are not factually based. This statement, in fact, was a gross mis-interpretation of the EE demonstration, an unfounded assumption, and exhibits a lack of understanding of the variability of changing air quality conditions. First, the EE demonstration states:

"Temperatures remained elevated (near or above 90°F) before, during, and after the ozone exceedance days. Ozone concentrations changed significantly only in the presence of the smoke." [pg. 14]

The Department made no claim conditions were "uniformly conducive to ozone" in the EE demonstration. The Commenters arrived at this incorrect conclusion on their own. To assume ozone production to be uniformly conducive solely based on temperature is inconsistent with the significant number of daily changing variables that impact ozone production. Temperatures at 90°F can produce maximum 8-hour ozone concentrations of both 90ppb or 50ppb, depending on numerous other factors (e.g. amount of sunshine, wind speed, presence of smoke, etc.). Furthermore, the above quote by the Department was in the "summary of key findings" section of the EE demonstration and applied to the entire MDE network, and not necessarily just the Essex monitor. The Commenters are therefore using a general statement as the foundation for their argument at one monitor. Still, MDE shows here-in that conditions were not uniformly conducive to ozone at Essex over the four days, but distinctly diverse conditions associated with similar high temperatures were able to produce ozone at or above the 70ppb threshold on all four days. As referred to in the "summary of key findings", even as the Essex monitor observed conditions leading to ozone at or above 70ppb, the remainder of the Maryland network remained low on July 19 and 20, distinctively increasing on July 21 and 22. Thus, this single monitor does not invalidate or contradict the influence of smoke on ozone production across Maryland.

One of the biggest factors leading to different ozone concentrations even with similar air temperature is the aloft air transport pattern. The air transport pattern to Essex changed significantly between each of the four days (Figure 1) and on no two days was the surface back-trajectory (red, 10m) remotely similar. A different transport pattern leads to different concentrations of ozone depending on the emissions the air carries into Maryland. And those emissions themselves change daily. Clearly no two days are exactly alike in Figure 1, which immediately calls into question the Commenters claim of *"uniformly conducive to ozone."* For example, on July 19 northerly winds delivered degraded air to the surface of the Chesapeake Bay (Bay) via a thermal circulation (a phenomenon explained in the following paragraphs). Air directly over the surface of the Bay moved back northward in a process called the Chesapeake Bay Breeze, explaining the higher ozone concentrations at Essex. On July 20, northerly flow above the surface persisted, but the surface air

impacting the Essex monitor (red trajectory, Figure 1b) came from the northeast (the wind direction that eventually brought smoke to the surface) and was cleaner (prior to the smoke) than the day before. By July 21, pollutant transport at low levels was weak (the airmass remained local); ozone increased rapidly after sunrise (see Figure 2) due to abundant ozone precursors present in the smoke that was transported into Maryland at the highest levels and subsided [sank] to the surface late on July 20. On July 22, winds were from the south and west and the Essex monitor experienced an ozone exceedance without the influence of the Bay, where a special purpose monitor observed ozone 20ppb higher than at Essex. That higher ozone remained east of the monitor through the day (See "D" in Figure 2) showing Essex exceeded without Bay influence. In this case then, the lingering presence of smoke kept the local ambient air dirty despite smoke slowly being removed by southerly winds (Figure 1d). The Commenters suggest that all days represent the exact same atmosphere, set-up, and chemistry by stating conditions were "*uniformly conducive to ozone*". This statement is misleading and incorrect.

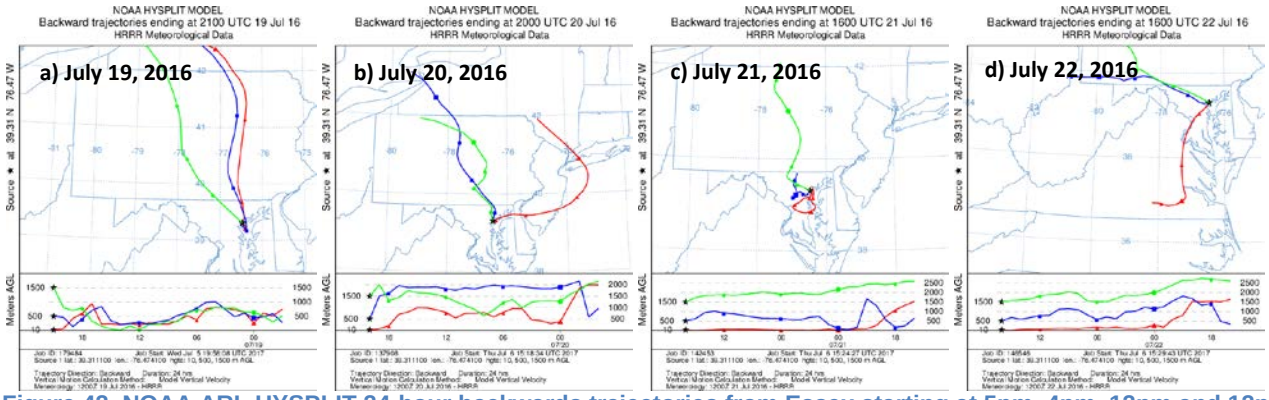

Figure 42. NOAA ARL HYSPLIT 24-hour backwards trajectories from Essex starting at 5pm, 4pm, 12pm and 12pm for each day from July 19-22, respectively. Trajectory heights are 10m(red), 500m(blue), 1500m(green).

The Commenters claim that MDE failed to note Essex's ozone concentrations at or near 70ppb on July 19 and 20. However, these days are not a relevant comparison to July 21 and 22 and should not be considered as contrary to the evidence presented in the EE demonstration. As stated in the EE demonstration and above, Essex was impacted by local effects (i.e., the Bay) on these earlier days. The Commenter's concede this point. Yet, the Commenters do not acknowledge or address these local effects in their comments as explanation for the consistently high ozone and pre-event exceedance at the Essex monitor, which only occurred there and nowhere else in the Maryland monitoring network. They make no attempt to acknowledge MDE's explanation of local effects and ask for no additional explanation. We instead volunteer the explanation below.

Local impacts at the Essex monitor were primarily the effects of a Chesapeake Bay Breeze. Air over the Bay is typically dirtier than air over nearby land sites for a variety of reasons, the most prominent of which is the lower mixing heights and subsidence over the water's surface. The dirtier air which collects over the Bay can move onshore behind or along the "Bay Breeze," the thermally driven meso-scale circulation created by different thermal properties and differential heating of the land and water. Where the air over the Bay moves on land, ozone monitors often record ozone increases. This was the case on July 19, 2016 at the Essex monitor and is clearly shown by time series of ozone and wind direction at the Essex and Hart Miller Island (HMI) monitors (Figure 2:

"A"). HMI is an island within the Chesapeake Bay containing a special purpose ozone monitor sited approximately 12.5km east-southeast of the Essex monitor.

On July 19, 2016, a wind shift to the south was first observed at HMI, along with an increase in ozone. This verified higher ozone first existed over the Bay. When the wind shifted to the same direction at the Essex monitor approximately an hour later, the ozone increased at Essex as the thermal circulation moved ozone inland and matched ozone concentrations observed at HMI. Thus, local effects of the Bay impacted the ozone concentration at the Essex monitor on July 19. This is labeled "A" in Figure 2. Referencing the trajectories in Figure 1 which have an ending time at the hour of highest ozone at the Essex monitor (for all dates) on July 19 show that at 10 m (red line, approximate height of the HMI monitor above water-level) the air descended into the Bay from the north. This aloft air was mixed to the surface due to the thermal circulation along the Bay.

On July 20, 2016, the aloft air traveling to the monitor at 10 m came from the east. This is consistent with the claims made in the EE demonstration that smoke was brought downward to the surface from the northeast late in the day on July 20, 2016, and with the surface wind observations at Essex on that day, but also indicates the air reaching Essex was from a different direction (and cleaner prior to the smoke's arrival) on July 20. No Bay Breeze occurred at Essex as a result of the northeast wind. Without the influence of a Bay Breeze, Essex did not exceed the 70ppb standard. Essex ended the day with a higher 8-hour average ozone concentration than the HMI monitor ("B" on Figure 2). Thus, in no way was July 20 like July 19 and refutes the Commenters' claims. This also shows that smoke was a necessary component for excessive ozone production.

No Bay Breeze occurred on July 21, yet the Essex and HMI monitors had greater ozone than the previous day. Ozone dropped to near 0ppb on the morning of July 21, due to significant ozone precursors within the smoke present overnight (having mixed to the surface the previous evening). The ozone increase observed at the Essex and HMI monitors was already well underway by very early morning (right with sunrise). Concurrent southerly winds at these monitors were driven by synoptic (large scale) conditions and were unassociated with a Bay Breeze. Proof of this is that the southerly wind began before any thermal circulation similar to July 19 could develop. Therefore, high ozone concentrations were not due to local emissions interacting with the Bay but were instead the result of a change in regional (Maryland area) atmospheric composition due to the introduction of wildfire smoke late in the day on July 20. The change in composition is most evident in the ozone peak near mid-day. If local emissions were a more prominent factor, they would build-up through the day and not create substantial ozone before peak daytime heating. This explanation clearly has shown a different chemical and meteorological make-up was in place at the Essex monitor, thus refuting the Commenters' claims of "uniform [ozone production] conditions." Indeed, the smoke presence altered ozone concentrations not only at Essex but much of the Maryland network.

As detailed in the EE demonstration, smoke subsided to the surface in Maryland from aloft late on July 20. The late arrival prevented an exceedance on July 20, but set the stage for wide spread ozone production on July 21. This was exemplified in the hourly ozone data at the Essex monitor quite clearly. On July 19 and 20 the maximum daily hourly ozone concentration occurred late in the day (5-6pm on July 19; 4-7pm on July 20). By contrast, on July 21 and 22 the maximum hourly ozone concentration occurred at 12-1pm on both days. This indicates a fundamental change in the air

chemistry, leading to differences in ozone production efficiency between those two days. In addition, smoke plumes develop more ozone with greater age and interaction with anthropogenic NOx emissions. Said another way, smoke enables anthropogenic emissions to generate more ozone than otherwise possible due to the additional ozone precursors within the smoke. The presence of additional ozone precursors delivered by the smoke was previously shown in the EE demonstration. This was clear on the final day of the exceedance, before the smoke affected airmass was completely removed from the region. The HMI site saw its greatest ozone concentration of the four day period due to the residence of the smoky airmass over the Bay on July 21 through July 22. This allowed the air to age and its chemical composition to change as it interacted with otherwise inadequate local emissions (as exemplified on July 20). To say that conditions at the Essex monitor were uniformly conducive (i.e., similar) to ozone formation on all four days in question is inaccurate.

The observed ozone at Essex the two days prior to the Maryland exceptional ozone event should not be considered as comparable to July 21 and 22, nor should they be used as evidential support contrary to that in the EE demonstration showing that the wildfire smoke supported higher than would be ozone concentrations, creating an exceptional ozone event.

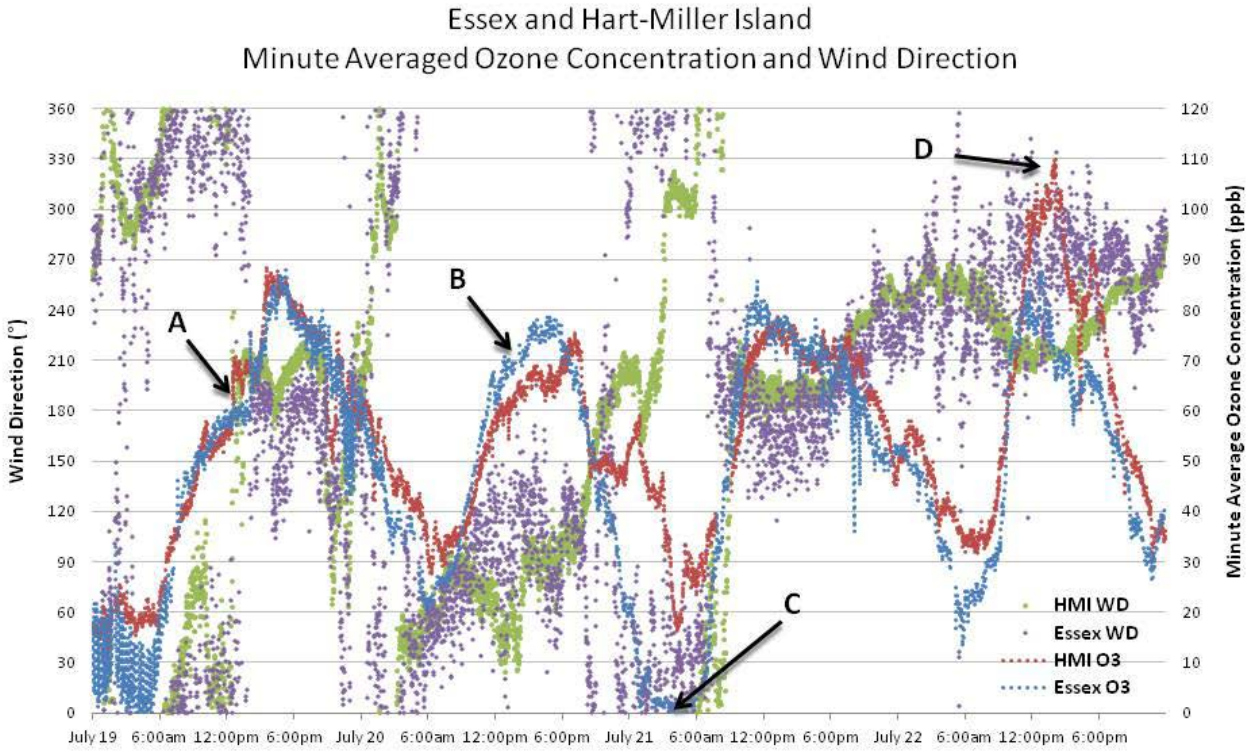

Figure 43. One-minute averaged ozone (dashed lines) and wind direction (dots) data from Essex (purple and blue, respectfully) and Hart-Miller Island (green and red, respectfully). Points A, B, C, and D are relative time periods discussed in the text.

2) Temporal and Spatial Inconsistencies of Ozone within the Maryland Network:

The Commenters argue that *"…broader monitored ozone trends observed in Maryland on July 21 and 22 belie the Department's claim of uniform wildfire smoke influence. If the plume uniformly*

influenced Maryland monitors on July 21 and 22, one would anticipate a consistent trend in monitor values between the two days." [pg. 99] The Commenters go on to provide what they see as evidence to the contrary of an EE based on this premise.

First and foremost MDE challenges the Commenters to directly cite where the direct claim of "uniform smoke influence" was made in MDE's EE demonstration. MDE claimed that smoke impacted Maryland's monitors across the state in such a way that overall concentrations were increased by approximately 15ppb above what was forecasted by the NOAA model, a far different assertion than what the Commenters are alleging here. Specifically the EE demonstration states:"… *quantify the ozone impact from the smoke and shows a wide area from at least Maryland through the northeast with ozone under predictions of at least 5ppb and as much as 10-15ppb over wide spread areas on July 21."* [pg. 81] In no way does MDE state or imply that smoke influence will uniformly affect all Maryland monitors. Local emissions when combined with the transported smoke will significantly alter the local air chemistry to create inhomogeneities (even within a homogenous smoke plume). But an assumption of homogenous smoke concentrations across Maryland is unreasonable. The Commenters disregarded the inhomogeneity inherent in air quality, meteorology, and ozone generation. No assumption of uniform impacts to monitors should be made.

Ozone chemistry is non-linear. This means that minute or local changes in the concentration of any environmental gas or compound could have an exponential effect on the ozone concentration. Both emissions and meteorology naturally possess inhomogeneities in ozone concentrations. The Commenters take no account of this natural spatial and temporal variability inherent in these systems. The Commenters also state that a smoke plume moving west to east through the state should show a pattern of ozone which moves west to east through the state. Such a circumstance is a reasonable assumption but is irrelevant to the case at hand. In the July EE, smoke subsided (mixed) from above and east of the state, stayed over at least the eastern part of the state on July 21, then dispersed (exited) during the day on July 22. Due to the way smoke was transported into Maryland there was no smooth transition from west to east nor a consistent pattern of ozone concentrations at monitors in the affected region. The assumptions made by the Commenter's ignore the facts of this July EE outlined in the EE demonstration.

Furthermore, the Commenters are assuming the smoky airmass has well defined "borders" such that the smoke-affected air has a clear line of influence, and once that line passes, a clear ozone signal would be evident. Such an occurrence is not reasonably possible. The properties of dispersion diffuse and blur the boundaries and concentrations at both the edges of and within the plume itself complicating pollution distribution and the resultant 8-hour average ozone concentrations. The Commenters are assuming a smooth transition from hour to hour at all Maryland monitoring sites such that west to east movement of the proposed well defined "plume" would cause 8-hour averaging to change similarly across all air monitors. Even on the cleanest of days with only background ozone concentrations (such as very rainy days) 8-hour averages are not identical or homogenous across the state. The Commenters expectation that 8-hour averages would systematically change as this "perfect" smoke plume moves from west to east is unreasonable, unrealistic, and unrepresentative of the July EE case.

Ozone concentrations exceeding NAAQS in the July EE were not otherwise possible except in the

presence of smoke. On July 22, ozone concentrations did not uniformly increase across the state as clearly stated in the July EE demonstration. As stated in Section 1 of this response, smoky air lingered over the Bay and was allowed to age in the presence of otherwise deficient NO_x emissions. A preponderance of research shows that smoke plumes produce the most ozone after a few days of aging, particularly while in the presence of anthropogenic emissions. As stated previously in Section 2, inhomogeneities in both ozone and ozone precursors naturally develop due to emissions and meteorological inhomogeneities. As such, ozone and its precursors may gather and be available for more efficient ozone production the following day in some areas more than others. For instance, it was likely Edgewood and Fair Hill had higher concentrations on July 22 due to the influences from Bay air, in contrast to those monitors farther from the Bay.

MDE would also like to point out that the Commenters placed the Glen Burnie monitoring station in the incorrect location in their Figure 1 [pg.100].

3) Insufficient Regional Emissions

The Commenters state: *"MDE's explanation of the July 21 and 22 ozone episode is premised on the contention that insufficient ozone precursors are present as a result of local and regional anthropogenic emissions to generate significant ozone exceedances in Maryland. Yet the state experienced several ozone episodes in 2016 for which it has not claimed influence from exceptional events. [Other exceedances] … under similar temperature conditions, suggest that local and regional emissions of ozone precursors can still cause not only exceedances but actually very large exceedances of the 2015 and 2008 ozone standards."*

First, corrections and clarifications are necessary. MDE does specifically claim that Maryland emissions are insufficient to create ozone exceedances by themselves (see page 16 of the EE demonstration). However, here the Commenters are misusing MDE's claims. MDE goes on to state that "*the majority of Maryland exceedances historically have been associated with such transport [from out of state.]*" [pg. 16] Historically the combination of local emissions and transported emissions were sufficient for prodigious exceedance days in Maryland. MDE goes on to note in the EE demonstration, however, that upstream NOx emissions and ozone concentrations have fallen to record low levels and that Maryland now rarely experiences ozone concentrations comparable to those of the past.

The Commenters selectively choose dates to prove a point which in turn, actually supports MDE's contention that the declining ozone precursor emissions are driving a decrease in ozone values. The Commenters' claim that regional emissions are still capable of creating exceedances, cite two examples of hot days associated with 8-hour ozone exceedances, and claim that these two days show holistically that emissions reductions are insufficient and emissions continue to be sufficient for ozone exceedances. In MDE's EE demonstration, MDE states emissions "regularly fall short", but not "always" because there are indeed instances where emissions are adequate to produce ozone exceedances from regional sources. But not from local sources only, however. MDE stipulates ozone exceedances can happen from increased regional NO_x output but never claims ozone exceedances don't or can't occur from this output within the EE demonstration. Instead, MDE disagrees with the Commenters efforts to discount the progress made to reduce ozone concentrations

due to NO_x reductions. We illustrate our disagreement by examining the two days the Commenters provide and by presenting additional emissions and temperature data.

First, the days the Commenters have chosen as counter-examples to the facts of reduced emissions actually corroborate MDE's claims that typical emissions are not usually capable of exceedances. The July 27 and September 23 dates the Commenters list are indeed "surges" in regional NOx compounded by favorable meteorology which exasperated conditions by stagnating air across Maryland. In fact, the preponderance of data evidence, both long-term historical, in 2016 and now continuing in 2017 show that monthly seasonal NOx emissions are the lowest they've ever been and that only in these emissions "surge" periods result in widespread high ozone concentrations throughout Maryland.

In addition, the Commenters made no mention that 2016 had the fifth lowest number of exceedance days, ever, despite being the sixth warmest summer, ever. There were 48 days at Baltimore-Washington International (BWI) Airport that were at or above 90°F in 2016 (Table 1). This was the highest number of hot days since 2010 (59 days) and similar in number to 2011 and 2012 (40 and 45). Yet, despite the heat in 2016, the Commenters made no mention of the 29 days listed in Table 1 that were at or above 90°F and did not result in an ozone exceedance day in Maryland. They also make no mention that the summer of 2016 had the highest ratio of 90°F days to ozone exceedance days ever observed in Maryland, which indicates that the air chemistry composition has indeed changed due to ozone precursor emissions reductions.

Table 10. A list of days with temperatures at or above 90°F at Baltimore-Washington International Airport (BWI) along with the corresponding highest Maryland ozone network monitor maximum 8-hour average. The list does not include the Hart-Miller Island special purpose monitor located in the Chesapeake Bay.

DATE	Tmax	O3
5/26/2016	90	84
5/27/2016	90	73
6/11/2016	96	72
6/12/2016	93	63
6/19/2016	90	70
6/20/2016	91	80
6/21/2016	91	62
7/6/2016	92	74
7/7/2016	91	68
7/8/2016	91	63
7/9/2016	90	61
7/14/2016	96	59
7/15/2016	90	61
7/16/2016	92	71
7/17/2016	90	65
7/18/2016	94	63

7/19/2016	90	75
7/21/2016	90	78
7/22/2016	94	87
7/23/2016	98	66
7/24/2016	94	68
7/25/2016	100	77
7/26/2016	96	74
7/27/2016	95	99
7/28/2016	95	60
7/29/2016	92	72
7/31/2016	91	55
8/6/2016	90	52
8/10/2016	93	43
8/11/2016	96	55
8/12/2016	96	60
8/13/2016	98	53
8/14/2016	98	42
8/15/2016	93	70
8/16/2016	94	57
8/17/2016	91	53
8/26/2016	93	63
8/27/2016	90	75
8/29/2016	93	82
8/30/2016	90	63
8/31/2016	91	73
9/6/2016	92	67
9/7/2016	92	71
9/8/2016	96	64
9/9/2016	95	61
9/10/2016	96	59
9/14/2016	93	78
9/23/2016	90	87

The Commenters go on to state that *"MDE's comparison of [NOx] output for July 2010-2016 to maximum Maryland 8-hour ozone concentrations (Figure 5) fails to support the Department's contention that the July 21 and 22 episode was influenced by exceptional events. As an initial matter, it is unclear why the Department considered data only from July of each ozone season in trying to understand the relationship between regional NOx emission and Maryland ozone values."* [pg. 101]

MDE disagrees with the Commenters assessment that the NOx output presented does not support the Department's contention that regional emissions were insufficient to support exceedance magnitudes

on July 21 and 22 except with the aid of smoke. In this section the Commenters are again taking sections of the EE demonstration out of context. By showing the monthly NOx emissions year-on-year, MDE solidified its argument that regional NOx emissions (an ozone precursor) are at an all time low in 2016. Also, since July is the month of maximum total emissions and is the month in which the exceptional event occurred, MDE chose to solely compare other Julys in an effort to build a stronger case. That being, if the month containing the highest emissions annually has decreased to its lowest monthly level in each of the last seven years, the regional NOx concentration was also reduced which in-turn would reduce ozone concentrations. To suggest MDE compare another month's emissions (such as May for example) to July is undermining the Commenters own argument. As the Commenters state, July is the warmest month of the year and is also the climatological maximum for ozone. Thus a comparison of July emissions to previous years' July (both daily and monthly) is more than justifiable as a comparison of the ozone production maximum potential. Since the EE occurred in July, MDE feels there is no merit to compare emissions in other months. The Commenters go on to state that "*Given that ozone episodes occur on the order of one or two days, it makes little sense to disregard data from other months during which regional NOx emissions could peak on shorter time scales and be equal to or exceed those on a daily basis in July*." [pg. 101] This comment is unclear. MDE shows both daily and monthly emissions within the EE demonstration. The Commenters go on to further state, "*…there is an imperfect correlation between monthly regional NOx emissions and maximum ozone concentration in Maryland*." [pg. 101] MDE provided Figure 5 in the EE demonstration to show that daily NOx emissions for the entire month of July in 2016 were lower compared to previous years. Thus the 2016 emissions, either on a daily basis, considering multi-day periods or considering the entire month are lower. If considering years of similar meteorology, lower emissions is especially true in 2016 when comparing with the next most recent match: 2012 (further discussion on this below). This comparison (compare daily emissions in 2012 to 2016 in the EE demonstration's Figure 5) should therefore further justify excluding statistics from 2012 as not equally comparable to 2016, another contention that the Commenters make [pg. 102], discussed later.

The Commenters claim MDE should use additional months of data but state July to have the highest emissions due to it being one of the hottest months of the year. MDE agrees with the Commenters on this latter assessment. Why then would comparing July emission to any other month provide evidence that another month's emissions are comparable to July? Based on Figure 3, such a comparison shows that July clearly has greater regional emissions which are not comparable to other months. More so, the EE period occurred during a period of greatest seasonal regional NOx emissions in 2016. However, Figure 5 in the EE demonstration showed that a comparable year (2012) had significantly greater emissions during that time.

Are the Commenters trying to build an argument that the July EE and associated ozone exceedances occurred simply because the temperature in July was warmer, leading to greater emissions? Temperature has already been shown to no longer reliably predict ozone exceedance days. In fact, since 2012, the annual number of 90 degree days in Maryland has always exceeded the number of exceedance days, and the disparity is INCREASING, even into 2016, DESPITE 2016 being one of the hottest years on record. MDE acknowledges the emissions on a daily basis will certainly change and on occasion daily rates may be comparable between the early season warm days and mid-summer cool days (such as a cool July day and warm May day), neither of which has a high

probability of being an ozone exceedance day. The composition of the atmosphere also changes significantly between May and July (for example, changing stoichiometry due to changing NOx and biogenic [natural] VOC emissions). However, July day-to-day variability and NOx output remains incomparable between 2016 and 2012 a year with similar meteorology. 2016 NOx emissions around Maryland were the highest of the season as typically is expected in July, but these emissions were still lower than all the most recent previous years.

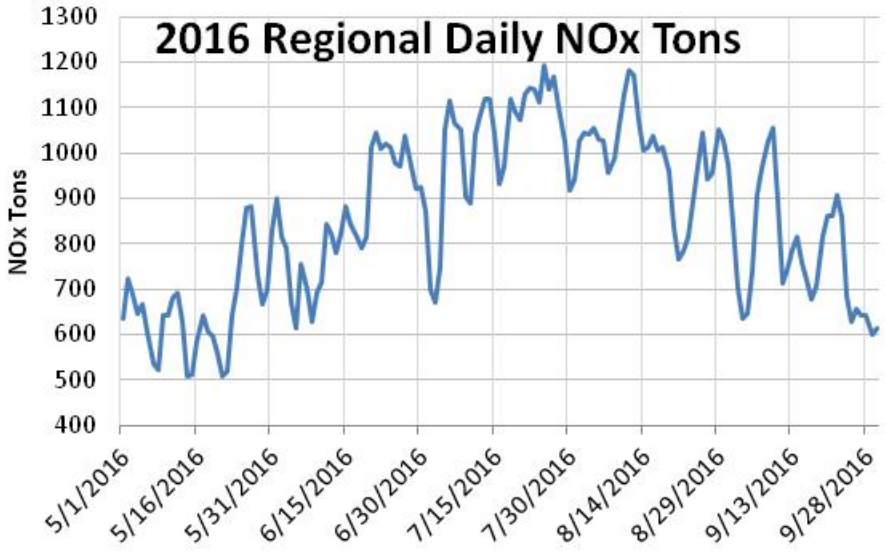

Figure 44. Daily NOx tons emitted by EGUs from 7 states (Indiana, Ohio, West Virginia, Pennsylvania, Virginia, DC and Maryland) in 2016 from May 1 – September 30.

4) Speciation Data

The Commenters make no mention of what specific speciation data is missing or which species they would like to see, only that MDE *"is missing critical data."* [pg. 101] Ignoring the comment's vagueness, MDE concedes it did not include $PM_{2.5}$ speciation data within the analysis. EPA made the particle speciation data available less than one week prior to the EE submission deadline. Ultimately, the 1 in 3 sample days of the speciation data set missed the two day event in Maryland anyway. Therefore there was no speciation data collected during the smoke event. Furthermore, no upstream data would be of assistance in tracking the plume because the plume subsided from aloft (i.e., at the surface no west to east tracking of wildfire speciated particles would have been possible). Instead of the particle speciation data, MDE offered other compelling evidence of the presence of wildfire smoke using Black Carbon (BC), Volatile Organic Compounds (VOC) and also NOy/NOz data. All these compounds are strong indicators of wildfire smoke, but were unfortunately not mentioned or overlooked by the Commenters.

Additionally, MDE offered observations of $PM_{2.5}$ mass taken at MDE Beta Attenuation Monitors (BAM) which are a Federal Equivalent Method (FEM). The BAMs showed an increase in $PM_{2.5}$ mass which demonstrated the smoke was being mixed to the surface. Note, however, that such an increase will not necessarily be equaled by ozone in space and time since $PM_{2.5}$ is a primary

emission from wildfire smoke where ozone is a secondary pollutant.

5) Ozone to NOx ratio

The Commenters take issue with the MDE analysis using the ozone to NOx ratio. However they offer no specific explanation or refutation to why these ratio values, to them, were not "*anomalous*" during the July EE. Instead they stipulate the ratio has been increasing for years. Indeed, it generally has, which itself is evidential support of less NOx in the environment. However, MDE would contend the ratio as a whole was approximately 0.125 prior to 2013, was in transition in 2013 and was closer to 0.2 through July 2014, 2015, and 2016, in contrast to 0.218 and 0.248 on July 21 and 22, 2017, respectively. MDE also points out that the ratio is not only higher but much more variable since 2014 which indicates that ozone has become much more sensitive to other factors (i.e., transported wild fire smoke) in the atmosphere than just NOx (which is now substantially lower). The point of the analysis was not proving a level of statistical significance, but instead it was meant to show that an increase in the ratio associated with a specific event indicates extra production capacity to form ozone and thus, implies changed airmass characteristics during that event. With lower overall NOx concentrations in the atmosphere, sudden increases in the ratio are due to "event" time scale changes in the atmosphere. This was clearly explained in the EE demonstration. The 24th and 13th highest ratios ever occurred on July 21 and 22, respectively, and both ratios were quantitatively in the top 10% of days.

6) Q/d Analysis

As stated in the EE demonstration, MDE feels the EPA guidelines for the required Q/d analysis are unrepresentative for long range transport cases. Instead, MDE offered other cases in the EE demonstration where smoke impacted Maryland from long distances and showed that these cases have values of Q/d of just over one(1), which strongly refutes EPA's claim of 100 to show clear causality. A Q/d analysis following strict EPA guidelines is not appropriate for East Coast long distance smoke transport events. MDE explains this thoroughly in the EE demonstration. Essentially the Commenters are in agreement with MDE's conclusion that the analysis does not fit EPA's required 100 value. The Commenters however ignore the impacts on ozone from several cases of other wildfire smoke events in Maryland offered by MDE, which had remarkably consistent Q/d ratios among all cases, including the July EE.

7) 99th Percentile

The Commenters argue that *"…the Department attempts to discount data from 2012 as non-representative, while including data from 2013 and 2014. However, in other contexts, the Department has acknowledged that both temperatures and weather patterns in 2014 were anomalous for Maryland and not conducive to ozone formation."* [pg. 102]

The Commenters here argue that MDE should not have dismissed the 2012 ozone data from calculations of the 99th percentile when comparing ozone concentrations on July 21 and 22, 2016. However, MDE has displayed that emissions from 2012 were clearly not similar to 2016 emissions, despite the two years having similar meteorology (see Figures 4 and 5 of the EE demonstration).

2013 and 2014 were indeed cooler than normal across much of the United States. Since that time Maryland has also seen ozone precursor emissions and ozone exceedance days continue to decrease despite a return to above normal summer temperature patterns in 2016.

The Commenters claim 2014 was anomalous due to meteorology (cooler temperatures, atypical transport patterns and synoptic pattern set-up). Therefore, by logical extension, 2014 was also more anomalous than 2012 when comparing both years to 2016. MDE understands this viewpoint and claim. However, based on emissions data, 2012 was in fact a stronger outlier compared to the rest of the five year dataset (2012-2016). MDE felt emissions represented a stronger use of the term "outlier" than relating only to the seasonal temperature in this analysis, but acknowledge the Commenters' justifiable perspective in this case.

However, the elimination of 2012 in calculating the 99th percentile ozone concentration at Maryland monitors does little to change the overall statistical results. There were still seven monitors above the 99th percentile using 2012-2016 July data only (there were seven monitors above the 99th percentile excluding 2012 also) on July 21 and there are still three above the 99th percentile on July 22 using only July data (the same three when using data excluding 2012). MDE attempted to show this within the EE demonstration by providing all three statistical lines on the scatter plots. Thus MDE sees the issue raised as moot, since there is little bearing on the extracted conclusions to this EE demonstration.

8) Public Comment Period.

"Finally, it is unclear whether MDE provided the requisite notice regarding the comment opportunity on the Department's exceptional event demonstrations... At minimum, when addressing these comments, MDE must explain how and to whom it sent notice of this exceptional events demonstration." [pg. 102]

MDE provided the requisite notice and opportunity for public comment by posting the Department's EE demonstrations to the MDE website on May 26, 2017 for the required 30 day public comment period.

The preamble to the 2007 final Exceptional Event rule provides that "The State or designated local agency should consider the public comments prior to the final demonstration being submitted to EPA for a decision concerning whether to exclude the data from regulatory consideration. Notice and availability of such data and demonstrations must be adequate and consistent with States' administrative procedures governing similar submissions. The EPA does not require that public hearings be held on exceptional events demonstrations but leaves this matter to the States' discretion consistent with their administrative procedures." 72 Fed. Reg. 13574. In addition, the preamble to EPA's recent amendment to 40 CFR 50.14, notes that most states accomplish public notice and comment by posting the draft demonstration "on a Web site." 81 Fed. Reg. 68222.

There is no requirement under the rule that a state provide a specific kind of notice and opportunity for public comment. The Exceptional Event rule simply requires that a state requesting to exclude data from regulatory consideration provide for notice and an opportunity for public comment that is

consistent with a "State's administrative procedures governing similar submissions" regarding notice and opportunity for public comment. In Maryland, there is no specific provision under Title 2 of the Environment Article, Annotated Code of Maryland, or in Title 26 of COMAR that governs notice and public comment of this type of agency action, which does not rise to the level of rulemaking. Accordingly, for an agency action not governed by specific notice and comment provisions, statutory requirements for notice and comment in analogous provisions shed light on the Department's notice and comment obligations. Specifically, §§ 2-103.2 and 2-303 provide that MDE publish air quality monitoring data "through the Internet" and, after October 1, 2014, provide notice of its rulemaking on its MDE website. The Department is guided by these provisions and the public is made aware that data related to air quality monitoring and other regulatory functions may be found on the Department's website.

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