Maryland
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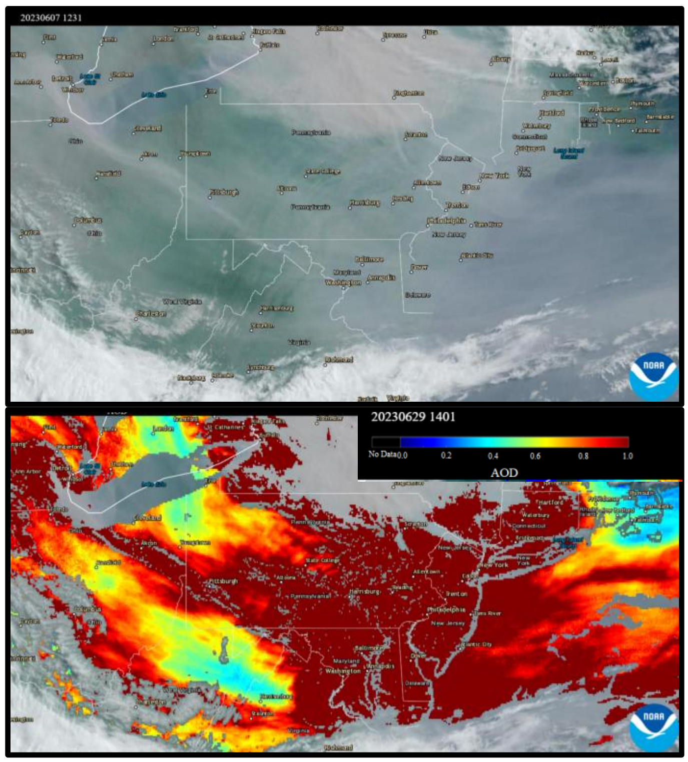
State of Maryland
Exceptional Event Demonstration and Analysis of the June 2023 Quebec Canada Wildfires and their Impact on Maryland's Ozone Air Quality on June 7, 2023



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i. Acknowledgements

The Maryland Department of the Environment (MDE) would like to thank Region 3 for their efforts to respond to this demonstration in the face of a windfall of demonstrations across the region in a historic year of air quality. We acknowledge the use of imagery from the Worldview Snapshots application (https://wvs.earthdata.nasa.gov), part of the Earth Observing System Data and Information System (EOSDIS). The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and/or READY website (https://www.ready.noaa.gov/HYSPLIT_traj.php) used in this publication.

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1. Overview

1.1. Introduction

Hundreds of wildfires were ignited by lightning across wildland areas of Quebec on June 1, 2023. Well over 100 fires were still burning across the province on June 4, with over 430 separate fires reported across the province by June 7[1]. Strong and persistent winds behind the system responsible for igniting the fires permitted numerous fires to grow to enormous sizes and spread uncontrolled. Two conglomerate areas of fires established over southwestern and northern Quebec, both of which burned out of control throughout the month of June. In the weeks preceding the event which impacted Maryland on June7, nearly 1 million acres of land, or roughly the size of Rhode Island, burned across Quebec. Between June 5 and June 8, waves of smoke were transported directly towards the Northeast and Mid-Atlantic United States (U.S.) on northerly winds. Diurnal cycling of the fires would cause an increase in emissions during the day, with decreases at night. In aggregate with northerly flow, the scenario resulted in literal “walls” of smoke visible on satellite, and several pulses of smoke of increasing severity striking between Maryland and New York. The wildfire smoke[2] produced record setting fine particle concentrations and a noticeable increase in ozone in the Mid-Atlantic and triggered air quality alerts throughout the region. Ozone concentrations exceeded the 2015 70 ppb National Ambient Air Quality Standard (NAAQS)[3] on June 7, 2023, across the southern tier of Maryland, but with widespread ozone pushing towards the exceedance threshold, including a 69 ppb concentration at Essex, Maryland (Figure 1). Exceedances and widespread elevated ozone occurred despite weather conditions unfavorable for ozone, with high temperatures reaching only 81°F, and weak direct sunlight due to smoke attenuation. In Maryland, the maximum daily 8-hour average ozone (MD8AO) concentration reached a peak of 76 ppb with three Maryland ozone monitors exceeding the 70 ppb standard due to the influences of the Quebec wildfire smoke. Those monitors that exceeded the 70 ppb standard are highlighted in Table 1, along with Essex which peaked at 69 ppb, which will affect future design values for that site. Of the three Maryland sites with MD8AO concentrations above 70 ppb on June 7, all were among the four-highest 8-hour ozone observations at those sites during the 2023 season, with the Essex 69 ppb ranking ninth.

[1] https://www.google.com/url?q=https://edition.cnn.com/us/live-news/us-air-quality-canadian-wildfires-06-07-23/h_e1a588e47fc6d9c8ef1388399da56194&sa=D&source=docs&ust=1699824967531320&usg=AOvVaw1RBnIXG6jI1Mn2oVXSVFf9
[2] Smoke from biomass burning contains volatile organic compounds (VOCs) and nitrogen oxides (NO_x), which react to form ozone.
[3] 42 U.S.C. 7401 et seq,

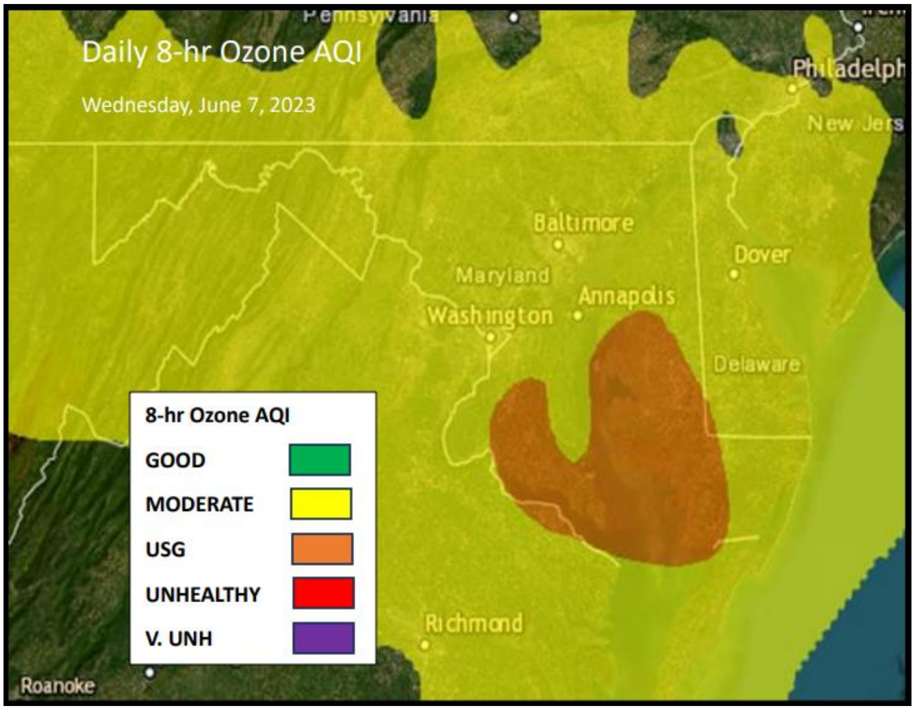

Figure 1. AQI map from June 7, 2023.

Following the U.S. Environmental Protection Agency's (EPA) regulatory process for the Exceptional Events Rule (40 CFR 50.14), the Maryland Department of the Environment (MDE, or "The Department") flagged the data as being influenced by a Canadian wildfire and communicated to EPA Maryland's intention of submitting an exceptional event package for ozone on June 7, 2023. This analysis demonstrates that Maryland's 8-hour ozone concentrations that exceeded the 2015 standard or have an effect on attainment status, 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. Exceptional Events Summary of Approach

The Exceptional Events Rule[4] states that an event and its resulting emissions may be excluded from regulatory use if it has the following characteristics:

- there exists a clear causal relationship between the specific event(s) and the monitored exceedance(s) or violation(s),
- (the event) is not reasonably controllable or preventable,
- (it) is an event(s) caused by human activity that is unlikely to recur at a particular location or a natural event(s),
- (the event) is determined by the Administrator in accordance with 40 CFR 50.14 to be an exceptional event, and
- (the event) does not include air pollution relating to source noncompliance.

[4] 40 CFR 50.1(j)

Table 1. Maximum Daily 8-hour average ozone (MD8AO) concentrations and ranks on June 7, 2023, for all Maryland sites. Maryland sites are listed using the common site name and Air Quality System (AQS) identification number (AQSID). MD8AO concentrations in ppb are shown with that day's rank in the 2023 ozone season in parentheses. A rank of (1) indicates the MD8AO was the highest recorded at that site in the 2023 season. The final columns indicate the current fourth high and estimated design value with no exclusion of any data. 2023 data are not final as of this writing, and therefore all DVs are estimated. Monitors exceeding 70 ppb during the event are highlighted according to AQI, as is Essex at 69 ppb due to the effect on attainment status.

Site Name	AQSID	MD8AO, ppb (rank)	2023	
		7-Jun	Fourth High (ppb)	EST DV (ppb)
Essex	24-005-3001	69 (9)	75	73
Calvert	24-009-0011	69 (2)	66	62
Aldino	24-025-9001	64 (21)	73	71
Edgewood	24-025-1001	65 (11)	75	71
Fair Hill	24-015-0003	61 (21)	70	67
Frederick	24-021-0037	66 (12)	74	67
Glen Burnie	24-003-1003	61 (10)	67	66
Hagerstown	24-043-0009	60 (14)	68	62
Lake Montebello	24-510-5253	66 (13)	72	69
Millington	24-029-0002	62 (14)	72	66
S. Maryland	24-017-0010	75 (2)	69	65
Rockville	24-031-3001	62 (13)	68	63
Piney Run	24-023-0002	61 (14)	67	62
HU-Beltsville	24-033-0030	64 (14)	70	65
Padonia	24-005-1007	61 (28)	71	68
PG Equestrian Ctr	24-033-8003	69 (7)	73	65
S. Carroll	24-013-0001	63 (20)	71	67
Horn Point	24-019-0004	76 (1)	71	66
Beltsville CASTNET	24-033-9991	65 (13)	72	67
Blackwater CASTNET	24-019-9991	71 (2)	68	64

Finalized revisions to the Exceptional Events Rule were established by the EPA in September of 2016.[5] The revised rule describes the procedures for treating data that has been influenced by an exceptional event.[6] These were further clarified in an Exceptional Events Guidance Document[7] released by EPA on September 16, 2016. Accordingly, an exceptional events demonstration must include all the following elements:

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, 40 CFR 50.14(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 standards 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 approach to the analysis, providing evidence of "Key Factors" in each tier. Following the elements suggested in the Exceptional Events Guidance Document[8]

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[5] 81 FR 68216, October 3, 2016. *Treatment of Data Influenced by Exceptional Events.*

[6] Ibid. Page 68217

[7] *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentration*s. EPA-HQ-OAR-2015-0229-0130, U.S. Environmental Protection Agency. Page 1: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf

[8] *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentration*s. EPA-HQ-OAR-2015-0229-0130, U.S. Environmental Protection Agency: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf

outlined above, MDE contends and demonstrates herein, that transported wildfire smoke had a direct role in amplifying ozone concentrations to a level that would not have been possible in the absence of smoke and related constituents, and satisfies the three core exceptional event criteria (narrative model, clear causal relationship, not controllable/preventable/recurrence). Based on recommendations from the EPA and the Guidance Document, 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. The EPA Guidance Document offers suggestions for appropriate analyses to demonstrate the clear causal relationship between the wildfire and excessive ozone levels. In addition, EPA 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 includes some of the suggested analytics and variations on those methods to support our conclusion that the high ozone concentrations throughout Maryland were caused or worsened by the wildfire smoke from Quebec fires in early June of 2023.

1.3. Regulatory Significance of the Exclusion

1.3.1. June 2023 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 June 7, 2023, 3 monitors exceeded the 70 ppb ozone NAAQS across the state of Maryland and met the criteria for further analysis and potential exclusion according to 40 CFR 50.14(a)(1)(i). A fourth monitor (Essex) reached 69 ppb. Although this does not exceed the NAAQS, it would increase the Design Value to a level that would cause the area to be out of attainment (40 CFR 50.15(a)(1)(B)). MDE asks for exclusion of all the MD8AO observations above 70 ppb and the MD8AO observation of 69 ppb at Essex on June 7, 2023, as listed on Table 2. While MDE does not operate the CASTNET monitors, MDE requested 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 the exclusion of four MD8AO observations on June 7, 2023, that exceeded 70 ppb at the following three monitors: Horn Point (240190004), S. Maryland (240170010), and the one CASTNET site – Blackwater NWR (240199991), as well as Essex (240053001), at 69 ppb. MDE requests that these measured ozone data on June 7, 2023 at these monitors as listed in Table 2 be flagged as impacted by an exceptional event and be excluded from regulatory use.

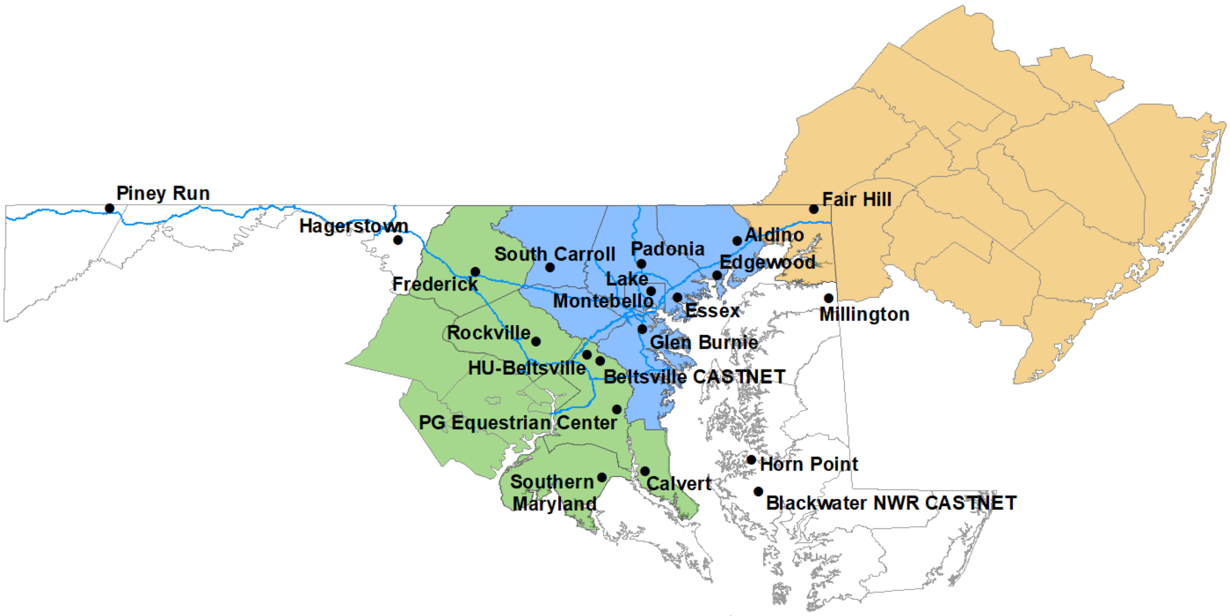


Figure 2. The Maryland ozone air quality monitoring network as of June 7, 2023. Black dots indicate the location of ozone monitors. Metropolitan Statistical Areas (MSAs) for Baltimore-Towson (Blue), Washington-Arlington-Alexandria (Green) and Philadelphia-Wilmington-Atlantic City, NJ (Orange) show that Maryland monitors include three policy relevant areas and several states; all areas of which are above the new 70 ppb standard as of the end of the 2023 season with no data exclusions considered. Remaining Maryland counties are outlined. The blue lines show major interstates in Maryland. Gray lines are county political boundaries.

Table 2. The four ozone monitors at which MDE is seeking EPA data exclusion concurrence. Local names and AQS IDs identify monitors in the text. Also given are the MD8AO concentrations in ppb along with that day's rank in the 2023 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 2023 fourth high and design value with no exclusion of data (Including) and if the requested data from June 7 are excluded from fourth high and design value calculations (Excluding).

			2023			
Site Name	AQSID	MD8AO, ppb (rank)	Fourth High (ppb)		EST DV (ppb)	
		7-Jun	Including	Excluding	Including	Excluding
Essex	24-005-3001	69 (9)	75	75	73	73
S. Maryland	24-017-0010	75 (2)	69	69	65	65
Horn Point	24-019-0004	76 (1)	71	71	66	66
Blackwater CASTNET	24-019-9991	71 (2)	68	68	64	64

1.3.2. Design Value and Fourth High Impacts, and Demonstration Regulatory Significance

The 2023 burn season across Canada was unprecedented. By the end of September 2023, nearly 18,000,000 hectares had burned across the country, equivalent in area to the U.S. state of Missouri (18,054,030 ha). Fires were essentially continuous in various parts of Canada from early May through September 2023, sending waves of smoke across the continental United States (CONUS) throughout the summer, as meteorological conditions dictated. Frequent episodes of smoke across Maryland throughout the summer created periods of heightened ozone to values or frequencies not seen in over a half decade. As a result, several monitors across Maryland had their fourth-high and design values raised, and three monitors within the Baltimore Nonattainment Area (BNAA) developed design values in violation of the NAAQS. Because of the frequency of smoke events, several sites had their fourth-high impacted in such a way that numerous events became regulatorily significant, raising fourth-high, fifth-high, etc., greater than the fourth-high value needed to maintain the 2015 ozone NAAQS. The Essex [240053001] site is the driving monitor for non-attainment in Maryland, where six independent smoke events in 2023 (June 2, 7, 29-30, July 11-12, 17-18, 28) created eight MD8AO concentrations greater than the 68 ppb needed as a fourth-high to maintain the 2015 ozone NAAQS. As a result, Maryland needs at five of these six events to be excluded to bring the BNAA into attainment by bringing down Essex monitor’s 2023 fourth-high to 68 ppb with a resulting 3-year design value of 70 ppb.

In a cascading and compounding manner, each successive smoke event and corresponding exceptional event demonstration concurred will lower Essex’s design value closer to 70 ppb, as the fourth-high in 2023 gets closer to 68 ppb. Two other violating sites due to the smoke this summer, (Aldino [240259001] and Edgewood [240251001]), in the course of these cascading demonstrations will also be brought into attainment with Design Values at or below 70 ppb. Table 3 shows how Design Values may be reduced by each successive exceptional event concurrence. All three monitors are located in the BNAA, and Essex is the leading monitor that drives the DV for this Area. Table 4 shows the effect of successive excursions on 4th highest values.

The BNAA requires concurrence of a series of smoke impacted ozone events for attainment in 2023. In a cascading and compounding manner, each successive smoke event and corresponding exceptional event demonstration concurred will lower Essex’s design value closer to 70 ppb, as the fourth-high in 2023 gets closer to 68 ppb. Two other violating sites in the BNAA due to the smoke this summer, (Aldino [240259001] and Edgewood [240251001]), in the course of these cascading demonstrations will also be brought into attainment with Design Values at or below 70 ppb. Table 3 shows how Design Values may be reduced by each successive exceptional event concurrence. All three monitors are located in the BNAA, and Essex is the leading monitor that drives the DV for this area and for the state of Maryland. Table 4 shows the effect of successive exclusions on 4th highest values at these three sites.

Table 3. Estimated design values (in ppm) following the exclusion of successive Exceptional Events in the Baltimore Nonattainment Area (NAA). Order of events reflects the approximate preparation order by MDE. Order of exclusion does not alter the outcome of the regulatory significance.

	Aldino	Edgewood	Essex
DV as of 10/25/2023	0.071	0.071	0.073
Removing			
June 29 & 30	0.070	0.071	0.073
July 17 & 18	0.070	0.071	0.072
July 11 & 12	0.070	0.069	0.071
June 7	0.070	0.069	0.071
June 2 or July 28	0.069	0.068	0.070

Table 4. Fourth-highest MD8AO values (in ppm) in 2023 following the exclusion of successive Exception Events in the Baltimore Nonattainment Area (NAA)

	Aldino	Edgewood	Essex
4th high as of 10/25/2023	0.073	0.075	0.075
Removing			
June 29 & 30	0.071	0.075	0.075
July 17 & 18	0.071	0.074	0.072
July 11 & 12	0.07	0.068	0.069
June 7	0.07	0.068	0.069
June 2 or July 28	0.069	0.067	0.068

Specifically for this event, exclusion of the MD8AO concentrations on June 7, 2023 had no direct design value influence *on this event alone* but will lead to lower DVs at several monitors in Maryland by way of *additive, or cascading exclusions* of the smoke throughout the summer. The June 7, 2023 smoke event is one of if not the strongest smoke events of 2023, fostering ozone production across the entire Maryland network. Due to the large amount of smoke during the 2023 season, there were more than four smoke impacted events at the highest monitors in Maryland (Essex, Edgewood, and Aldino, all located in the BNAA). 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 June 7 were within the fourth-highest 8-hour average observations of 2023 at three monitors on June 7 (Table 1). Excluding the June 7 MD8AO at the 4 requested monitors (Table 2) would not lower any monitors' DV or 4th high but would be necessary to keep Essex (in the Baltimore NAA) below 71 ppb as part of the package of exclusions that Maryland is requesting.

Eleven wildfire smoke events impacted Maryland ozone during the 2023 season (MDE will present this evidence across additional exceptional event demonstrations). Excluding all the requested MD8AO concentrations associated with the June 7 event will not reduce any monitor's DVs immediately in 2023. However, it will reduce the Essex monitor's 2023 fourth high MD8AO and have future implications in 2023, 2024, and 2025. For example, an EPA concurrence of the June 7 exceptional event at the Essex site (240053001) does not change its fourth high nor reduce the 2023 DV. However, if any four additional exceptional event demonstrations at Essex receive EPA concurrence, the fourth high is reduced and the 2023 DV drops to 0.070 ppm.

What is most critical for this demonstration is the compounding impact exclusion has at Maryland monitors. In particular, the Essex monitor sees no direct benefit from this single episode. However, considering a summer filled with smoke and multiple smoke events, an exclusion of data on June 29-30, July 17-18, June 2, and July 11-12, 2023, on top of that requested here for June 7 has a required cascading impact to the fourth high at Essex. The event alone actually does NOT drop the fourth highest at Essex because there are two days with MD8AO at 69 ppb. However, this day must be excluded with the other events above to affect the fourth high at Essex. If this event were not concurred, the fourth high would remain at 0.069 ppm for 2023, even if all other Maryland demonstrations were concurred. Attainment for Essex depends on a 2023 fourth high below 69 ppb. As such, concurrence of this current demonstration is required for a 2023 Essex DV below 71 ppb. Details of specific site DVs with and without exceptional event concurrence along with changes in the fourth highest MD8AO concentrations for the 2023 season are provided in Table 2 for all nine Maryland monitors that MDE is requesting exceptional event status for July 17 and 18, 2023. Reduction of these sites' DV would potentially be used to demonstrate compliance through 2025. 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 additional sites based solely on their fourth high values or future potential DVs, MDE reserves the right to revisit monitors from the June 6-8 episode which may impact attainment of 70 ppb.

Excluding the ozone concentrations associated with the June 7 event, in addition to other data exclusions, will impact not only DVs in 2023, but also in 2024, and 2025, particularly in light of additional wildfire smoke events impacting Maryland in 2023. MDE is currently planning demonstrations of five smoke-impacted ozone events in 2023, though more than a dozen such cases were present. MDE expects to submit ozone demonstrations for June 29-30, July 17-18, July 11-12, June 7, and June 2, all in 2023. If the additional demonstrations are also concurred, Maryland (in particular, the Baltimore NAA) will be in attainment of the 70 ppb ozone NAAQS. This and successive demonstration exclusions will bring the highest 2023 monitor in Maryland - Essex (240053001) - into attainment by dropping the fourth-high in 2023 below 69 ppb. In doing so, exclusions associated with the smoke episodes will bring all other sites in Maryland into attainment as well. Given that the current and forthcoming demonstrations will impact DV calculation through 2025 and will mean the difference between a "Clean Data Determination" or a "Serious" reclassification, this and future exclusions have large ramifications for regional attainment. For example, if EPA does not concur on Maryland's June 7 demonstration, concurrence on any future demonstrations will not be able to bring Maryland into attainment of a 70 ppb DV.

1.3.3. NAAQS Attainment Considerations

The Baltimore, Maryland Non-Attainment Area needs to demonstrate continued attainment of the 2015 ozone standard by January of 2024. This continued attainment of the 2015 ozone standard might only occur if EPA concurs with this exceptional event demonstration for June 7, 2023. In addition, if EPA does not concur with this exceptional event determination, the Baltimore area designation might change from the precipice of a clean data determination to a bump up to "serious" nonattainment resulting in a significant workload and focus change for the state of Maryland, simply due to fires out of the state of Maryland's control.

EPA concurrence of the requested MD8AO observations on June 7, 2023 in Maryland, in addition to concurrence on four additional events, will bring the Essex monitor (240053001, Baltimore Non-Attainment Area (BNAA)) into attainment of the 2015 ozone standard. Due to repeated smoke events and their impacts on ozone, the June 7, 2023 demonstration is one of many potentially impacting attainment of the Washington D.C. (DC), Baltimore, and Philadelphia Attainment areas. It is therefore uncertain if these areas will achieve attainment of the 70 ppb standard even if EPA concurs with MDE's demonstration for June 7, 2023 due to dependence on multiple concurrences and other agencies providing their own demonstrations. However, concurrence of the current demonstration is a requirement of the current process towards demonstrating the impacts of smoke on ozone design values and fourth-high values in 2023 in our region as exceptional. The EPA evaluation of the current June 7 exceptional event in the greater Mid-Atlantic region will affect multiple designation statuses, which are due in 2024. At the very least, if this demonstration, along with several to follow, are not concurred, the DC and Baltimore areas will be reclassified as "Serious" nonattainment of the 2015 ozone NAAQS. No Maryland monitors' Design Value or attainment status of the 2015 70 ppb standard will change due to this single event. However, depending on future year ozone concentrations, this demonstration may significantly impact Maryland's attainment status in regard to the 2015 ozone NAAQS and potential lower ozone NAAQS through 2026.

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 a natural event;
- The smoke event in question was not reasonably preventable and is unlikely to recur;

Key findings and evidence supporting these assertions include the following:

- An ozone event which formed in a non-traditional manner, with air coming out of an area of Canada typically associated with clean air and Good air quality
- Copious, network-wide ozone was generated due to the presence of wildfire-smoke-generated ozone transported into Maryland with rapid local generation due to precursor containing smoke
- Ozone is higher than historical norms within an environment of historically low anthropogenic precursors and weak in-situ meteorological support (e.g., very low temperatures) for ozone.
- A Q/d analysis which meets EPA thresholds for clear causal influence.
- Record setting fine particle ($PM_{2.5}$) concentrations

- Carbon Monoxide (CO), and Nitrogen Oxides (NO_x) were elevated during the event, consistent with a wildfire smoke plume.
- Elevated $PM_{2.5}$ surface concentrations tracked from the wildfire region.
- Satellites captured a visual smoke plume transported to the northeastern U.S. which was also associated with satellite retrieved CO, both of which tracked from the Quebec area.
- Operational photochemical modeling during the event showed significant ozone streaming from the fire locations in Canada

Several analysis methods were used to develop a weight-of-evidence demonstration that the 8-hour ozone concentrations in the June 7, 2023 event meet the rules for data exclusion as an Exceptional Event. In summary, satellite, meteorological data, trajectory analysis, and emissions data and numerical air quality model comparisons were used to assess whether conditions were favorable for transport of smoke from the Quebec, Canada wildfires, to monitors that showed 8-hour ozone concentrations near and above 70 ppb. The data also showed that the smoke degraded air quality immediately downwind of the fires, then was transported southward directly to Maryland (~24 hour period), with waves of smoke from June 6 through June 9, with the highest ozone period on June 7 across the eastern Mid-Atlantic.

Substantial changes in chemistry in the eastern United States due to regional NO_x 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 reductions, and in comparison, to ozone in previous months of June. Comparison of emissions during June of 2023 show that aggregate Electric Generating Unit (EGU) NO_x emissions were lower than any other year on record during the smoke event. Yet, ozone concentrations in June of 2023 exceeded ozone concentrations in earlier years during meteorology LESS conducive (cooler, less sunlight reaching the surface) compared to years under heavier anthropogenic precursor emissions. Analysis of the airmass associated with Maryland ozone exceedances on June 7, 2023 revealed an atmospheric composition characteristic of wildfires, with an abundance of ozone precursors despite substantial reductions in anthropogenic sources.

MDE's analysis strongly supports that all monitors, regardless of MD8AO concentration, were impacted by smoke, that all the MD8AO concentrations above 70 ppb in Maryland plus the regulatorily significant 69 ppb at Essex from June 7, 2023 meet the rules as an Exceptional Event, and that the four monitors and MD8AO observations in Table 2 should be excluded from DV calculations. The following documentation 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 a natural event that is unlikely to recur. Section 5 fulfills the requirements that demonstrate the event was not reasonably controllable or preventable. Section 6 documents the public comment process. Section 7 summarizes and concludes the analysis.

2. Conceptual Model and Overview of the June 7, 2023 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 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 June 30, 2023 (Figure 2) (including two EPA CASTNET sites, (EPA, 1997)), nine hourly fine particle ($PM_{2.5}$) Beta Attenuation Monitors (BAMs) with additional regional coverage of ozone and $PM_{2.5}$ hourly observations locations in Washington, D.C. and northern Virginia, as well as various $PM_{2.5}$ Federal Reference Method (FRM) filter speciations, VOC canisters, and three 915 MHz radar wind profilers (RWP; Ryan, 2004; MDE, 2015) in Maryland. A full description of the various instrumentation used by MDE is available in the MDE Network Plan (MDE Ambient Air Monitoring Plan, 2023).

The dense MDE network exists to account for a densely populated area of the United States between Washington, D.C. 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 9,382,000 people reside in the region, primarily along the I-95 corridor (including DC (671,800) and Northern Virginia (2,545,000) [https://www.census.gov/quickfacts/fact/map/, retrieved August 22, 2023]) as of 2022. Statewide, Maryland's population was estimated to be 6,164,600 as of 2022 by the U.S. Census Bureau.

Figure 3 below illustrates the variety of physiographic regions of the state. Maryland's geography can broadly be divided into three larger regions; coastal plains near sea level to the east that border the Chesapeake and Atlantic, a central plateau region along the Fall Line with large urban centers, and mountains up to approximately 3,000 ft in the west. Outside of urban areas, Maryland is characterized by a mix of farmland to the east and southeast, 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 U.S. East Coast.

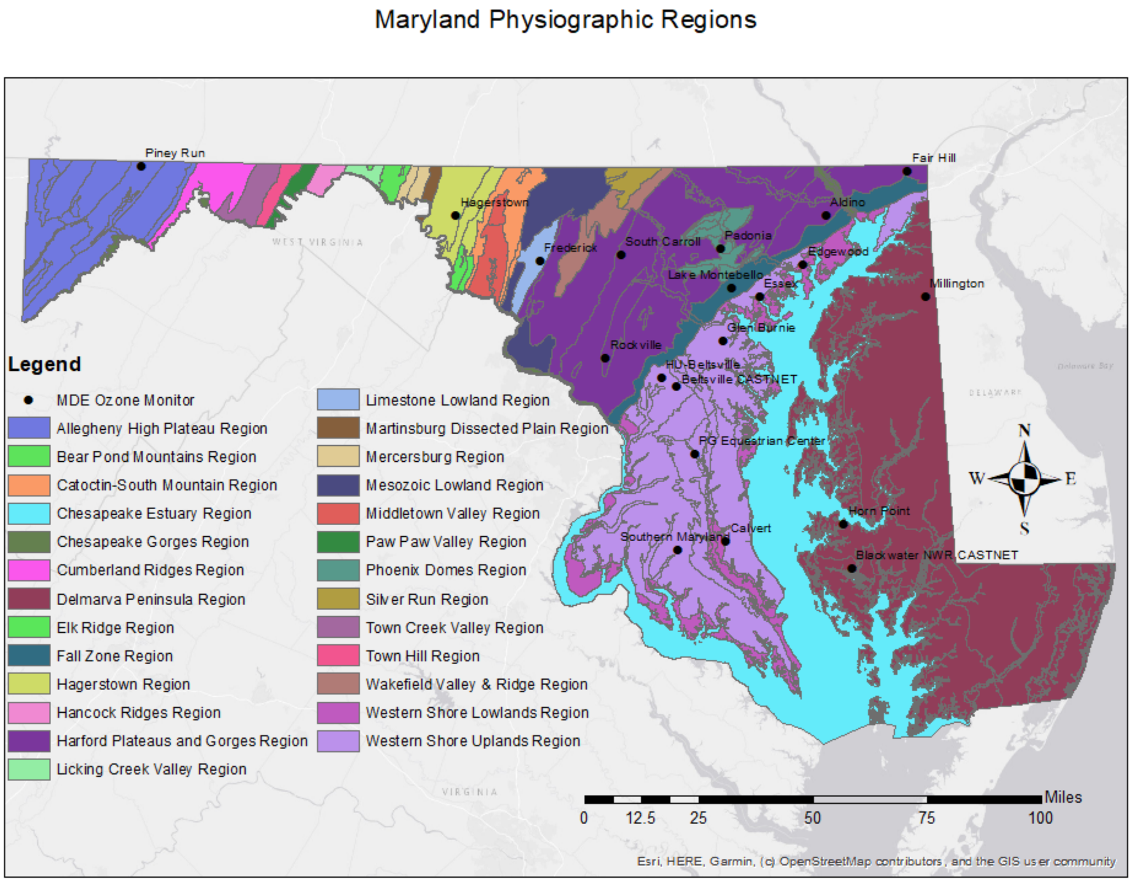


Figure 3. Physiographic map of Maryland. Black dots indicate the location of ozone monitors.

2.2. Characteristics of Typical, Non-Event Ozone Formation

For over two decades, MDE has engaged in partnerships with universities located in and around Maryland to conduct comprehensive research on air quality within the state. This collaborative effort has primarily centered on investigating the source of ozone in Maryland. This investigative work involved utilizing balloon-borne ozonesondes and aircraft flights to capture vertical atmospheric composition profiles. By utilizing computer models based on these collected data, our comprehension of the origin of ozone in Maryland has significantly deepened. The insights gained from years of measuring both surface and vertical ozone levels indicated that a substantial portion of ozone and its precursors, observed in Maryland, originated from neighboring states, and were transported by winds into Maryland. These compounds, when mixed with local emissions, exacerbate the existing air quality concerns. The outcomes of this research led to substantial legislative changes, which, over the last 15+ years, have resulted in significant improvements in air quality across the eastern United States. For comprehensive details regarding this ongoing collaboration, please refer to the RAMMPP[9] webpage. The subsequent section describes the current understanding of ozone formation in Maryland.

In the absence of atypical air mass composition (for instance, extraordinary events or smoke plumes), the primary mechanism driving ozone formation in Maryland stems from the photolysis of volatile organic compounds (VOCs) and a combination of regionally and locally originated anthropogenic NO_x. This interplay is often accentuated by the densely populated areas and topographical features, leading to concentrated regions that historically have caused ozone-related challenges, particularly to the east and northeast of DC and Baltimore. The key contributors to these challenges are human-made emissions from various sources: fixed point sources such as EGUs (electric generating units), mobile sources like cars, trucks, boats, locomotives, and non-road equipment, and area sources encompassing industrial processes and consumer goods. The predominant share of locally generated NO_x, a precursor to ozone, originates from urban pollution plumes that form along the I-95 corridor between DC and Baltimore, along with surrounding point sources, like EGUs. Nonetheless, these emissions alone frequently fall short of generating ozone concentrations exceeding 70 ppb in Maryland as measured by the MD8AO standard. Photochemical modeling underscores the argument that, excluding instances of light winds and recirculation that result in the accumulation of local emissions, the emissions from EGUs and mobile sources within Maryland are insufficient to cause ozone levels to surpass regulatory thresholds. However, Maryland also lies at the downstream end of the EGU-rich Ohio River Valley (ORV), where a large density of EGU point sources generates a regional NO_x plume upstream, transporting NO_x and/or ozone into Maryland. Historical instances of ozone exceedances in Maryland are predominantly associated with this kind of transport phenomenon. Hence, the influx of ozone and ozone precursors, notably NO_x, within the residual layer (the layer of air immediately above the surface, typically situated around 500-2,000 meters above ground level) that enters Maryland through transport contributes to elevating local ozone levels, often surpassing NAAQS thresholds. In the absence of substantial transport, Maryland has experienced a reduction in widespread or frequent ozone exceedances of NAAQS standards.

Over the past five years, Maryland has experienced a dearth of pollution transport cases. In the time frame of 2019 to 2023, the concentration of ozone and its precursors in the residual layer has reached its lowest recorded levels. This reduction has led to a decrease in the maximum daily ozone concentration in Maryland, resulting in a decline in the frequency of ozone exceedance days. As a consequence, local factors such as meteorology and emissions, which used to be overshadowed by regional signals, have gained more significance. Overall, this has led to isolated and infrequent exceedances, as illustrated in Figure 3. Emissions of NO_x from point sources in states upstream of and including Maryland (such as Maryland, D.C., Virginia, West Virginia, Pennsylvania, Ohio, and Indiana, represented as "Total NO_x" in Figure 3) during the ozone season have reached historically low levels. In fact, total 2023 emissions in these upwind states were the lowest ever recorded. This decline has been consistent on a monthly basis throughout the season, resulting in a significant regional reduction of almost 50% over the past five years, as shown in Figure 4. NO_x emissions from mobile sources have also decreased during the same period. However, this reduction is

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

overshadowed by the substantial decrease in EGU-related NO_x emissions. It is important to note, that while mobile-source NO_x has decreased less compared to EGU-related NO_x, the current emissions from mobile sources in Maryland, even when combined with additional local EGU emissions, are insufficient to cause anything but isolated and infrequent ozone exceedance days within the state.

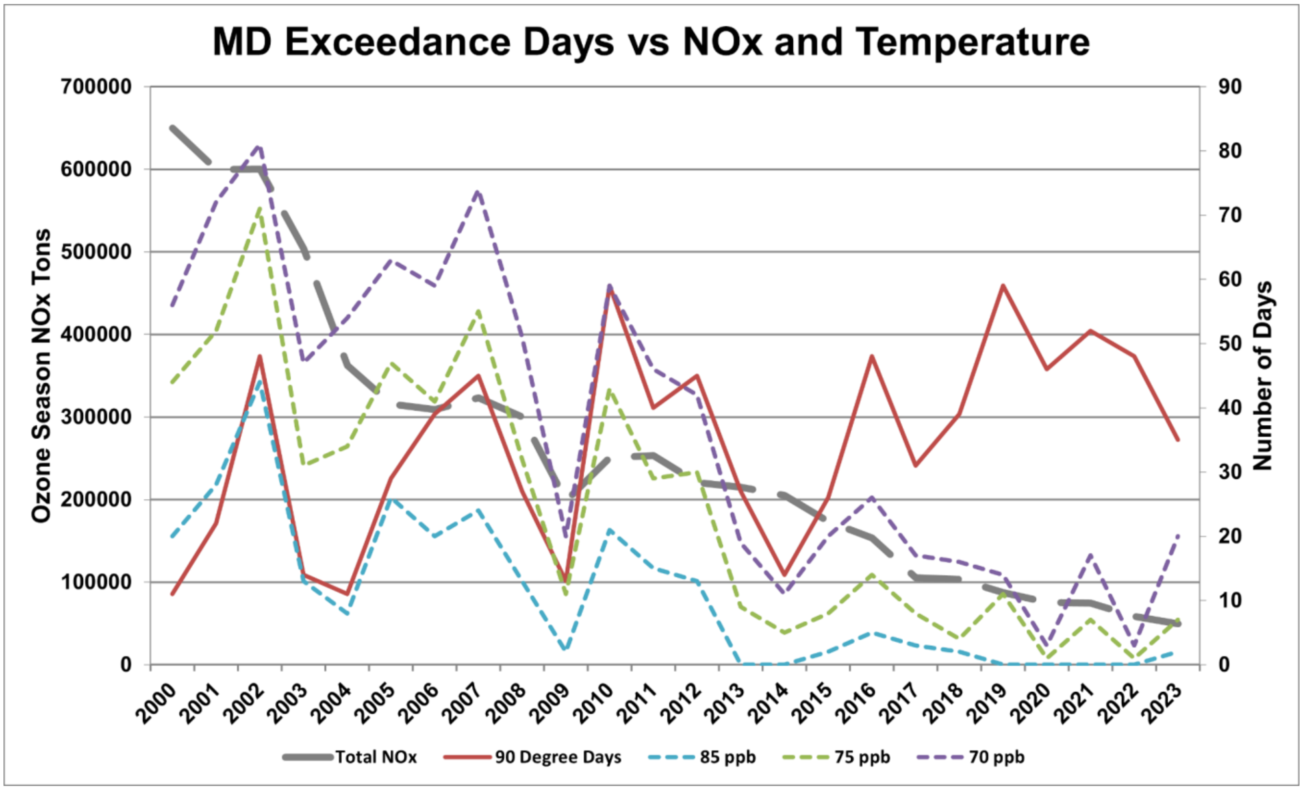


Figure 4. Total Ozone Season EGU NO_x from Maryland and upwind states, number of days at or above 90°F at Baltimore-Washington Airport (90 Degree Days) and exceedance days at various standards.

2.2.1. Emissions Trends

In the context of a standard scenario involving a Maryland ozone exceedance day, as described earlier, the primary source of NO_x transport into the state stems from upwind EGU point sources. These source emissions can result in next day elevated ozone concentrations, which compound the local emissions issue. The Clean Air Markets Database (CAMD) records the NO_x emissions originating from EGU point sources across the nation. Over the past 15-20 years, there have been notable and sustained reductions in NO_x emissions throughout the eastern United States, as illustrated in Figure 4. In 2023, the cumulative NO_x emissions from upstream states had dwindled to a mere 20% of their 2010 levels, marking a substantial decrease of approximately 80%. Furthermore, the collective monthly total NO_x emissions during the 2023 ozone season (May to September) were the lowest ever recorded from upwind states, including Indiana, Ohio, West Virginia, Virginia, Pennsylvania, the District of Columbia, and also Maryland, as depicted in Figure 5. These states together constitute a significant source region for ozone or ozone precursors transported into Maryland during typical summer conditions of favorable meteorology. In June 2023, NO_x emissions from these areas were approximately 15% of what was observed in 2010.

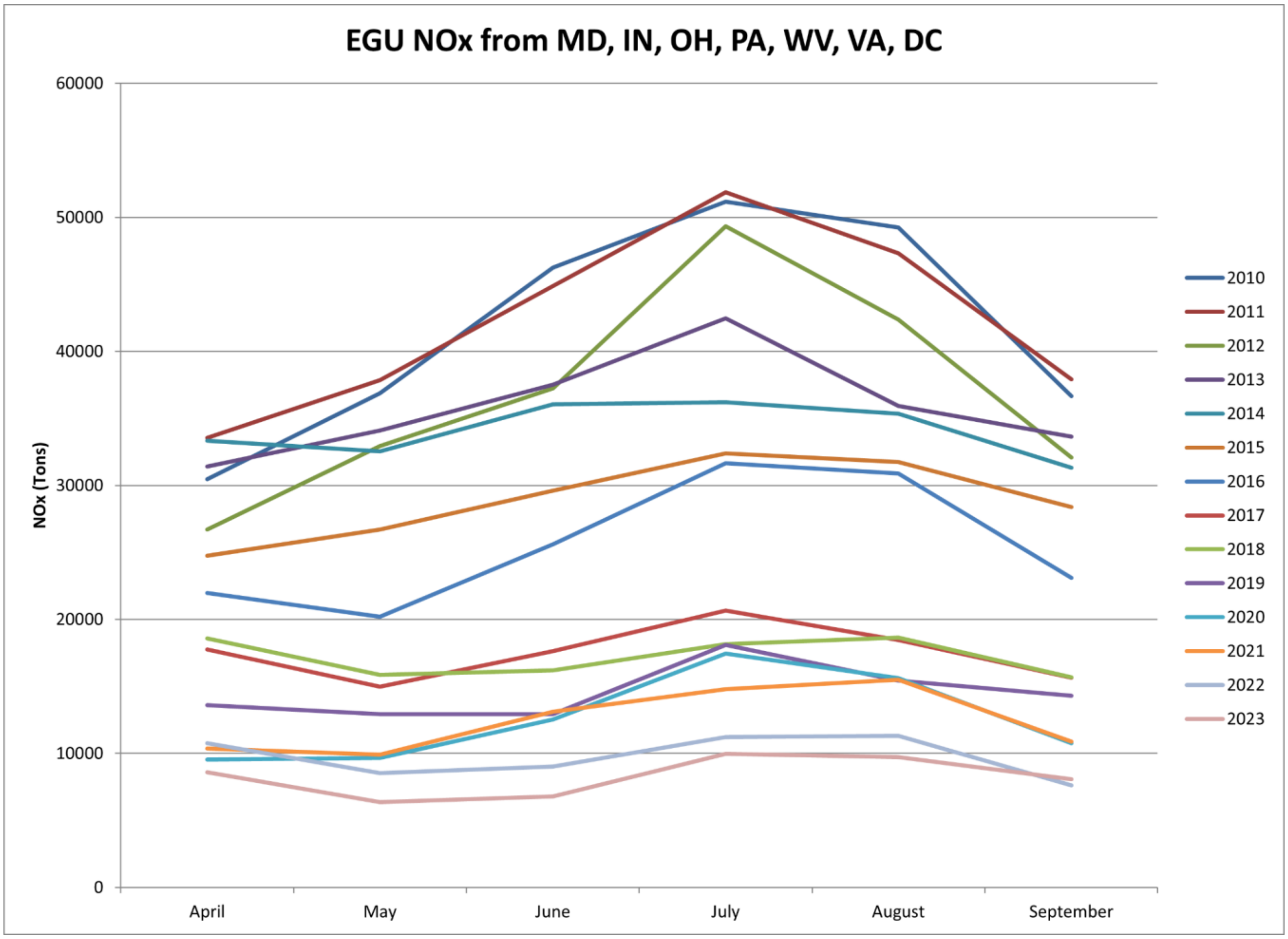


Figure 5. Monthly NO_x emissions aggregated from the group of upwind states, including Maryland, by month of ozone season.

The daily emissions data for these upwind states reflects the same reductions. However, since the path of the smoke was primarily transported across New York, Pennsylvania, and New Jersey in this case, it was instructive to look specifically at these states. Note that direct transport out of Canada is regularly associated with Good air quality in Canada with low precursor concentrations and cooler temperatures. When we examine the daily combined NO_x emissions from New York, Pennsylvania, and New Jersey, focusing solely on the month of June from 2017 to 2023 as extracted from CAMD, it becomes evident that the total emissions in June 2023 reached an all-time low (indicated by the black line in Figure 6). A fairly steady downward trend is observed. Despite the low emissions in June 2023, Maryland experienced an exceedance of the ozone NAAQS with average temperatures (81°F) on arguably the worst air quality day ever experienced in Maryland when measured by particle concentration (June 7th, 2023), with 3 of Maryland's 20 ozone monitors exceeding the daily maximum 8-hour ozone standard of 70 parts per billion (ppb) (as represented by the red bars in Figure 6), and the entire network in the elevated Moderate AQI range.

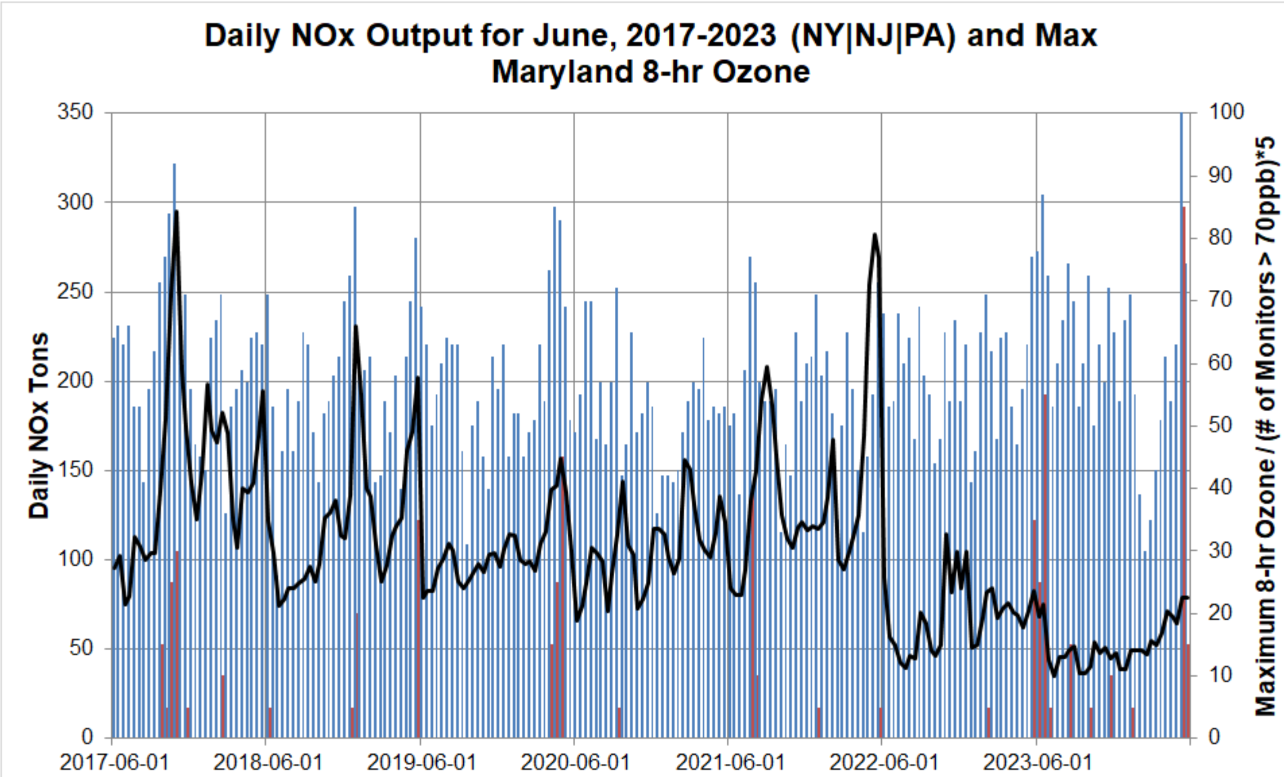


Figure 6. Daily aggregate NO_x, maximum Maryland ozone, and monitors exceeding 70 ppb in July, 2017-2023. Aggregate NO_x emissions from EGU point sources for states upwind of Maryland (New York, New Jersey, and Pennsylvania) from the CAMD database for 2017 – 2023 are shown with a thick blue line. The maximum 8-hour average ozone at any monitors in Maryland for each day in July 2017-2023 (blue bars) and the number of monitors exceeding 70 ppb in Maryland (red bars) is also shown. Number of exceeding monitors is multiplied by 5 for scale purposes. A downward trend in emissions is noticeable from 2017-2023.

2.2.2. Ozone Production in Maryland

Research has found that the generation of ozone in Maryland involves a complex interplay between volatile organic compounds (VOCs) and nitrogen oxides (NO_x), and the atmospheric balance of each required to produce bi-products like ozone. In the past, the balance between these two precursor groups was of little significance compared to their absolute concentrations in the atmosphere. Both precursors were consistently abundant for ozone exceedances and were primarily influenced by weather conditions. For instance, the fluctuations in exceedances depicted in Figure 4 at the 70 parts per billion (ppb) level exhibited a strong correlation with the number of days reaching 90°Fahrenheit between 2000 and 2015. However, in more recent years, this correlation diminishes. Maryland has now transitioned into a NO_x-limited regime due to regional reductions in NO_x emissions. Consequently, the stoichiometry of ozone production is no longer in equilibrium, and daily ozone production depends on the availability of either precursor group and/or the quantity of ozone already formed upstream and transported into the state. As a secondary consequence, high temperatures are no longer a dependable predictor of daily ozone exceedances of the NAAQS.

Ozone production hinges on the availability of NO_x, and VOCs, as well as favorable meteorological conditions of ample heat and sunlight. In Maryland, the VOCs relevant to ozone production encompass both naturally occurring and human-made sources. Although there has been a noticeable reduction in anthropogenic VOCs in tandem with the decrease in NO_x emissions, it's crucial to acknowledge that daily ozone production driven by biogenic (naturally occurring) VOCs cannot be controlled and remains a significant contributor to ozone chemistry in Maryland. For example, isoprene, 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 emitted by the biosphere, particularly trees, in response to environmental stressors such as elevated temperatures. NO_x emissions from stationary sources also tend to rise on warm summer days due to increased energy demand, while mobile emissions exhibit relative consistency on workdays and diminish over the weekend, unaffected by temperature. Simultaneously, as NO_x output increases relative to temperature, biogenic VOCs are released into the local environment. When exposed to sunlight and heat, these biogenic VOCs facilitate the creation of local ozone. When this locally generated ozone and ozone precursors mix with those transported into the state, Maryland observes MD8AO above 70 ppb and exhibits its fundamental non-event ozone exceedance. In this NO_x-constrained environment, absent additional transported ozone or ozone precursors, Maryland's local emissions are insufficient to produce ozone exceedance days.

2.2.3. Weather Patterns Leading to Ozone Formation

Maryland experiences variable meteorological conditions during the summer. While occasional April days may witness ozone levels surpassing standard limits, the majority of such instances occur mainly from May to September. Changing weather conditions within the ozone season result in diverse meteorological patterns that favor ozone formation. These include lee-side troughing (where downward air movements on the lee side of the Appalachian Mountains create a zone of pollutant convergence along the I-95 corridor). Other such meteorological patterns or processes include airmass and ozone transport and mixing, as well as local recirculation and stagnation, including reverse I-95 corridor flow from the northeast. Ozone production within each pattern depends on favorable local weather conditions, such as warm, sunny days with light to moderate surface winds. The positioning of the Bermuda High ultimately dictates which of these scenarios prevails. During an average summer, the Bermuda High is positioned off the southeast Atlantic coast of the United States, resulting in westerly transport of air towards Maryland, varying in direction depending on altitude. This creates conditions favorable for cross-Appalachian flow. Leeside troughing relies on weak cross-mountain flow, creating compressional heating and column stretching on the mountains' lee side, often aligning with the I-95 corridor, and leading to ozone concentration increases. Both transport and lee troughing can occur simultaneously or independently. In the presence of downward mixing of transported ozone, lee troughing may lead to ozone exceedance days. Over several days, recirculation and stagnation can also elevate local pollution concentrations, exceeding NAAQS levels. These patterns are most likely to occur during the summer months of June through August, historically the peak period for ozone production in Maryland. Shoulder seasons, like Spring and Fall, are typically cooler with active weather patterns that prevent the buildup of local or regional emissions. Winter, on the other hand, is too cold for ozone exceedances, and Maryland's Appalachian peaks are not high enough to facilitate Stratospheric ozone intrusions that could lead to ozone exceedance days.

Differential heating occurring at the interface between land and water creates a thermally induced circular flow that recirculates both local and transported pollutants near coastal regions. This circulation pattern is believed to be responsible for the elevated levels of ozone northeast of Baltimore. As temperatures rise, there is an increase in the release of super-regional NO_x emissions from power plants located upstream, such as those in the Ohio River Valley (ORV) and western Pennsylvania. This elevated output leads to higher concentrations of ozone and ozone precursor compounds in the residual atmospheric layer. Over time, these substances mix down and blend with locally sourced pollutants, contributing to instances of ozone exceedances in Maryland. The solenoidal circulation of the Chesapeake Bay Breeze (BB) amplifies this downward mixing process. Subsequently, lower mixing heights over the water cause an intensification of precursor reactions, resulting in greater concentrations of these compounds over the Bay compared to nearby land areas. Consequently, coastal locations experience higher ozone concentrations because both regional and local emissions are concentrated due to the interactions between land/water and 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 meteorological dynamics.

2.3. Exceptional Event Description: Early June 2023 Quebec Fires

The June 7 event in Maryland description significantly strays from the "typical, non-event ozone production" scenario described above (section 2.2) due to ozone associated with cool, northerly flow from Canada. Abnormally warm and dry conditions during the winter and early spring of 2023 set the stage for a record Canadian wildfire season. North American snow cover in May was the lowest it has ever been since measurements began being taken in 1966 (over 55 years) (see Figure 7). The little amount of snow which fell across Quebec melted sooner, exposing fire fuels sooner than typical. The Canadian wildfire season typically runs from May through October, peaking in July. However, with snowpack far less than average, wildfires across Canada started considerably earlier with seasonal fires being detected as early as March.[10] Eventually, firefighters from New Brunswick, the U.S., and France assisted local teams in battling the flames.[11] A June 1st weather system produced copious lightning strikes across the parched timber areas of Quebec and favorable meteorology led to an extremely rapid uptick in the area burned with associated smoke (Figure 8). Hundreds of wildfires resulted, and fires burned out of control for the entire month of June and beyond. Two main conglomerate fire regions quickly dominated, with one in north central Quebec and the other southwestern Quebec. Surges of smoke from the hundreds of fires, particularly from the two large fire regions pushed into the northeastern quarter of the United States during the month of June 2023. By June 7th, 1.6 million acres of land burned across the province of Quebec, a burn area larger than the size of Delaware (circled area on Figure 8). Smoke from this period stretched as far as Europe, a distance of over

[10] https://ciffc.net/national
[11] https://www.bbc.com/news/world-us-canada-65850628

3000 miles.[12] Hundreds of fires were analyzed by the NOAA Daily Hazard Mapping System (HMS) smoke analyses (McNamara, et al., 2004) in Quebec over this timeframe as well as by the Canadian Wildland Fire Information System or CWFIS (Figure 9a). Fires and associated smoke plumes analyzed by HMS and CWFIS were derived from the GOES Imager, the POES AVHRR, MODIS, VIRRS, and SNPP satellites and expert subjective analysis. The analysis for the remaining demonstration will focus on the emissions from the early June Quebec fires alone, which were extremely large, long-lasting, and produced prolific smoke (Figures 9b-d, and Figure 10a-10c).

From June 1 to June 6, 2023, 648,149 hectares (1.6 million acres) burned across Quebec (Figure 9a, circled).[13] The fires produced prolific smoke (Figure 10). Streams of smoke poured into the United States on June 4, but weather patterns prevented impact in Maryland until June 6. Smoke was initially diffuse enough to narrowly avoid $PM_{2.5}$ exceedances on June 6 for much of the Maryland network, but by June 7 and 8, direct flow from the fires to Maryland brought coherent "waves" of smoke (Figure 10c). No single fire was responsible for the large smoke plume which moved into Maryland from June 6-9. Forthcoming analyses track a unique "wave" of smoke hitting Maryland on June 7, related to the ozone exceedances and design value significance. As such, fires burning from June 4-6 were assumed to be primarily responsible for the creation of the plume impacting Maryland and Maryland air quality on June 7. The forthcoming analysis will focus on the emissions from the June 4 - 6, 2023 Quebec Canada fires which generated this plume over Maryland on June 7 (Figure 10d).

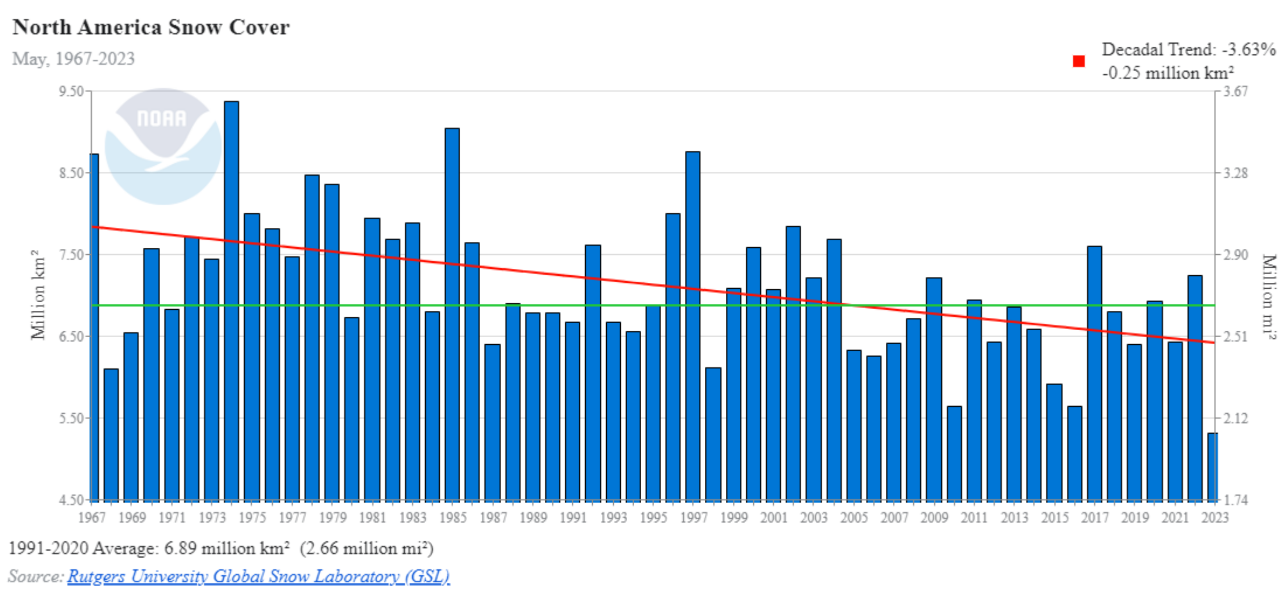


Figure 7. North American snow cover (Millions km²) each May between 1967 and 2023. Average line in green and decadal trend line in red.

[12] https://earthobservatory.nasa.gov/images/151507/canadian-smoke-reaches-europe
[13] Burn information is provided by the Canadian Wildland Fire Information System (CWFIS): http://cwfis.cfs.nrcan.gc.ca/home

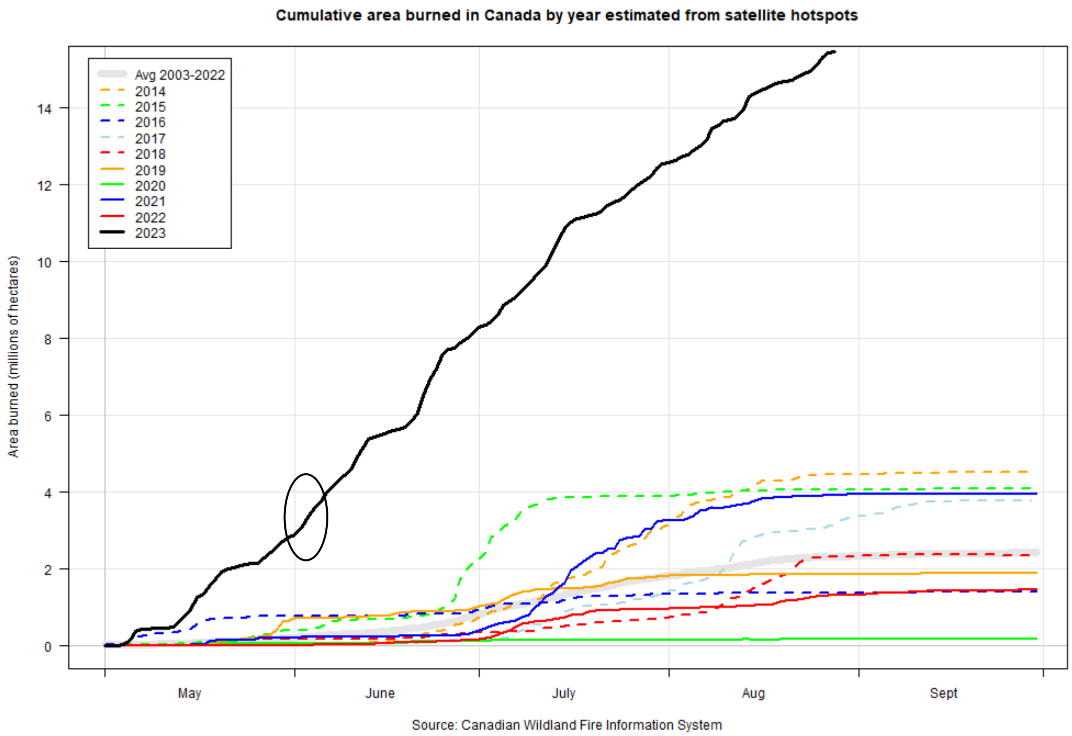


Figure 8. Accumulated hectares burned reported by [Canadian Wildland Fire Information System (CWFIS)] by day over the last 10 years. Burn area is estimated by satellite. By June 8, 2023 the cumulative burn area across Canada was approximately the size of the entire state of Maryland, with increased emissions during that time period. Area circled highlights the early June period of intense burning across Quebec. Burning across Canada in 2023 is unprecedented compared to any recent year. Source: https://cwfis.cfs.nrcan.gc.ca/downloads/hotspots/burnarea_chart_10yr.png

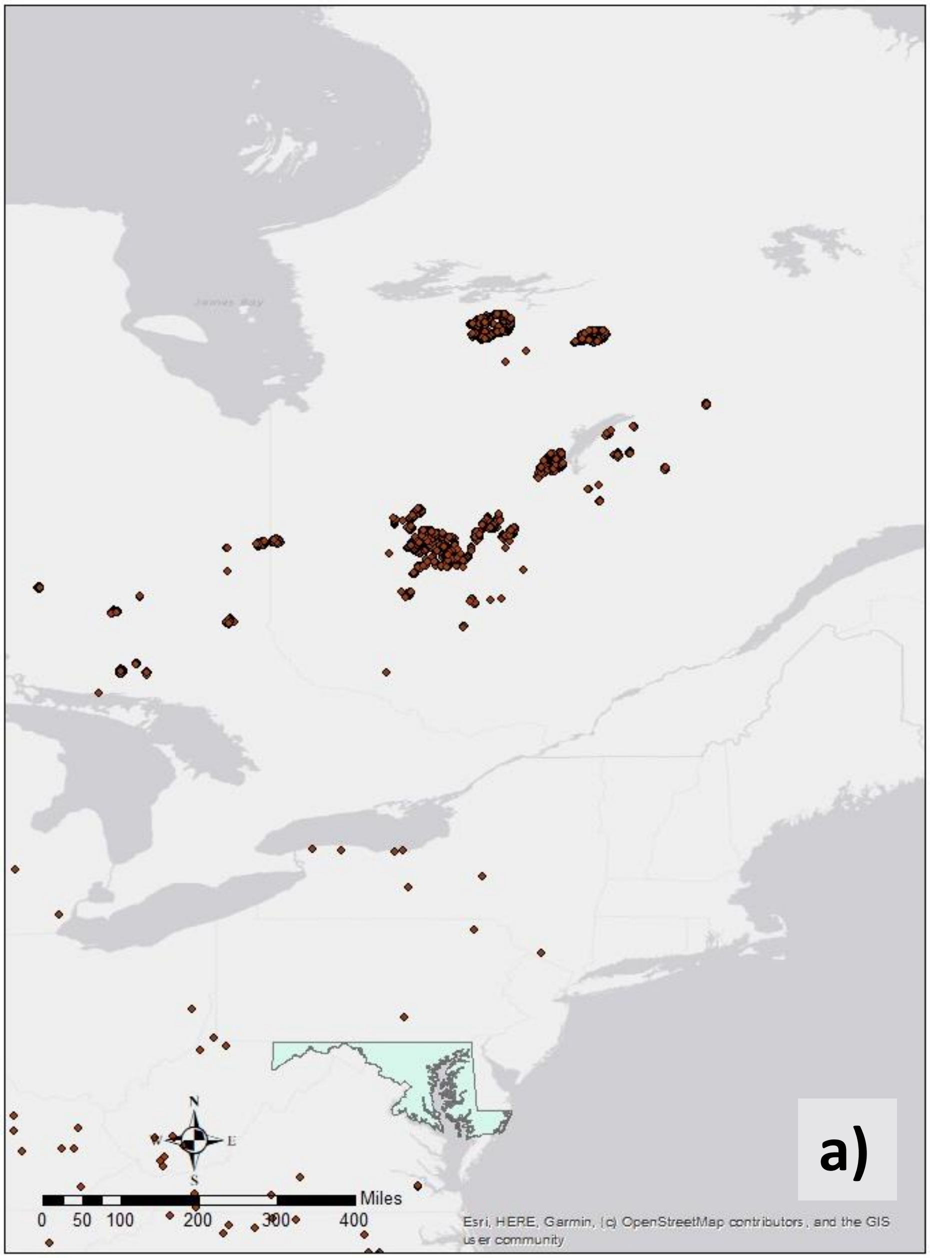
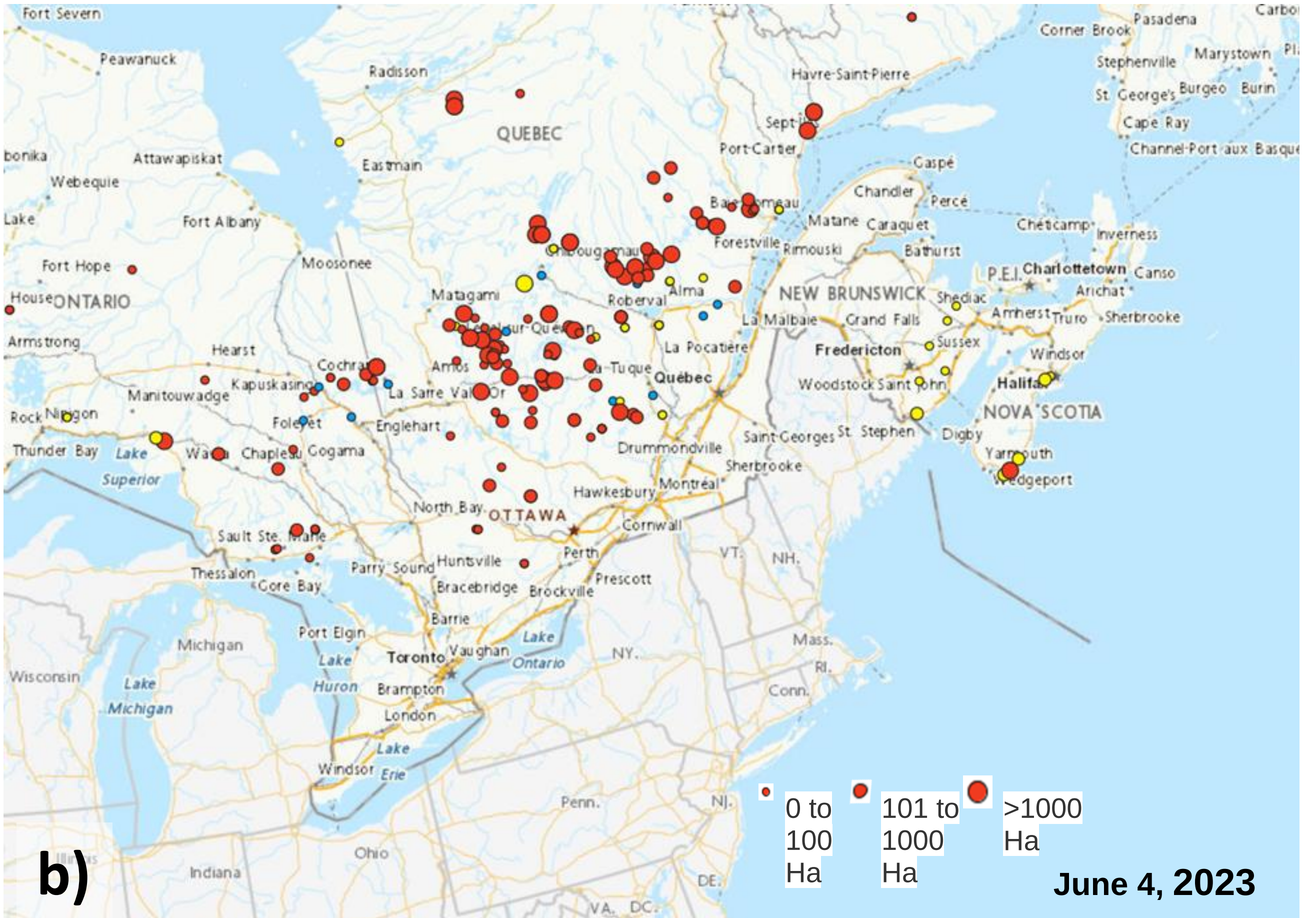


Figure 9a. Hazard Mapping System (HMS) analyzed fires, June 7-8, 2023. Fires analyzed by HMS derived from the GOES Imager, the POES AVHRR, MODIS satellites and expert subjective analysis between June 7-8. Maryland has been colored to emphasize its location compared to the fire sources.


b)
0 to 100 Ha
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June 4, 2023
QUEBEC
ONTARIO
NEW BRUNSWICK
NOVA SCOTIA
P.E.I.
OTTAWA
Québec
Montréal
Toronto
Fredericton
Charlottetown
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
Michigan
Wisconsin
Indiana
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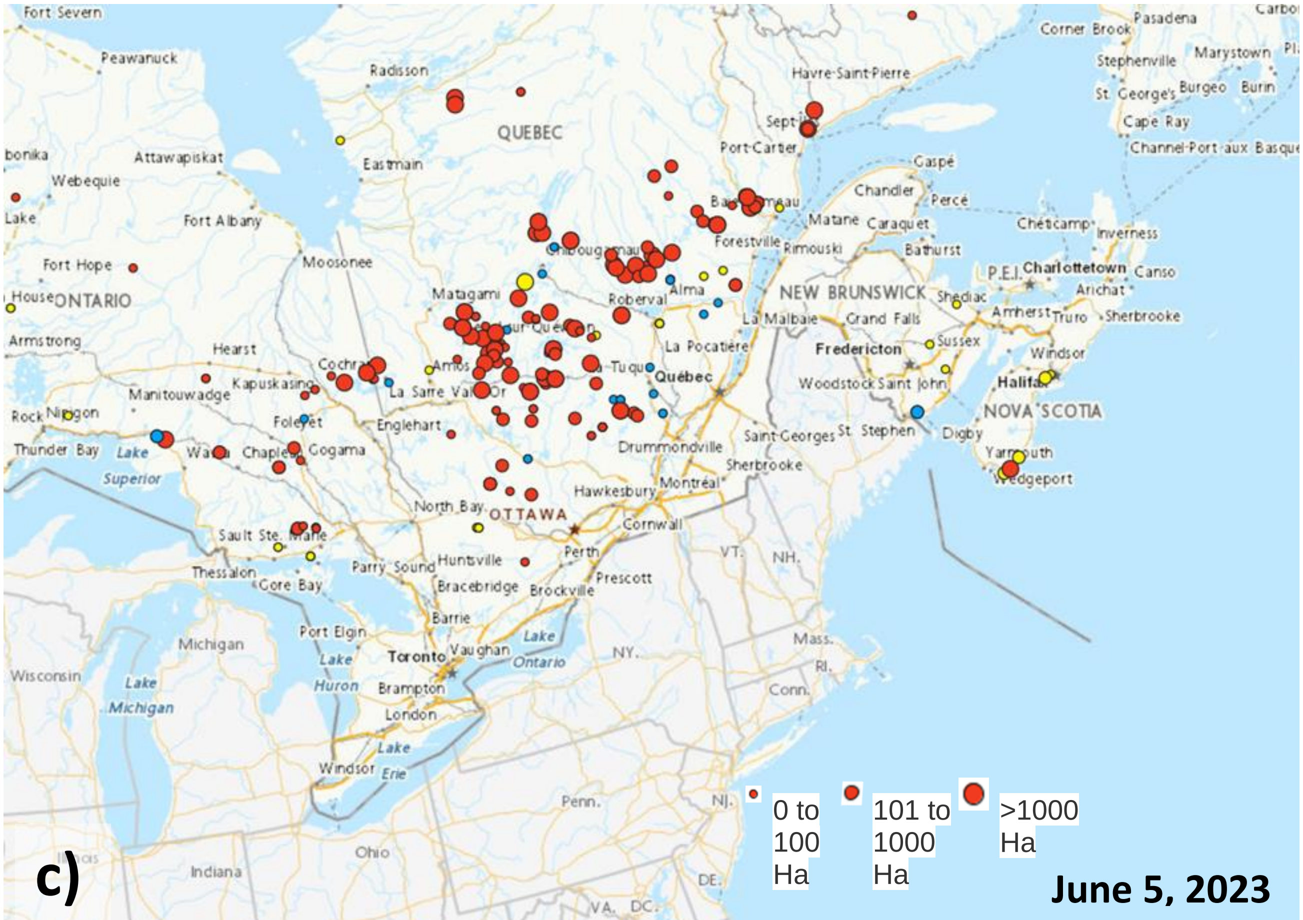
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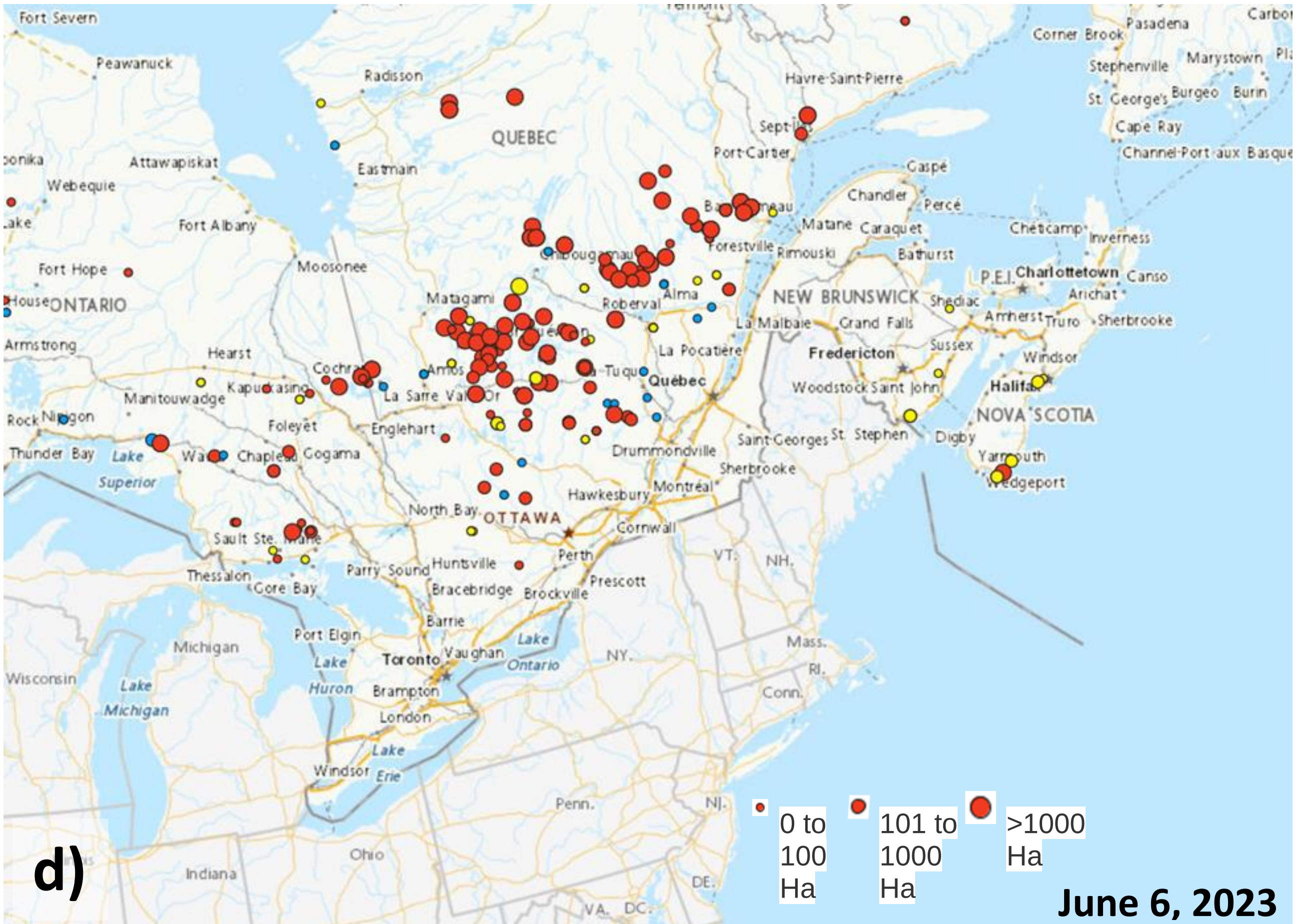
June 5, 2023



Figures 9b, 9c, 9d. Canadian Wildfire Information System map of active fires for June 4, 5, and 6, 2023, respectively. Red indicates an active fire, yellow indicates contained fire, blue indicates a fire under control, and orange other.
https://cwfis.cfs.nrcan.gc.ca/interactive-map?zoom=2&center=1339676.4255546457%2C-119570.75972920202&month=06&day=07&year=2023#iMap

Figure 10a. June 2023 Quebec Wildfire. Image showing smoke filling the sky as fires approach the municipality of Normetal, in Quebec's Abitibi-Ouest region, on Wednesday, June 7, 2023. One of over 100 fires burning across the province of Quebec at the time. [Source*:* Marie-Michelle Lauzon/Noovo Info/CTV News Montreal] https://montreal.ctvnews.ca/more-evacuations-in-quebec-as-record-breaking-fires-continue-to-burn-1.6431211

Figure 10b. June 6, 2023 wildfire Number 334, near Mistissini, Quebec. (Source: Genevieve Poirier, SOPFEU | La Presse Canadienne)

https://www.iheartradio.ca/la-progression-des-feux-de-foret-ralentit-au-quebec-selon-les-autorites-1.19791840

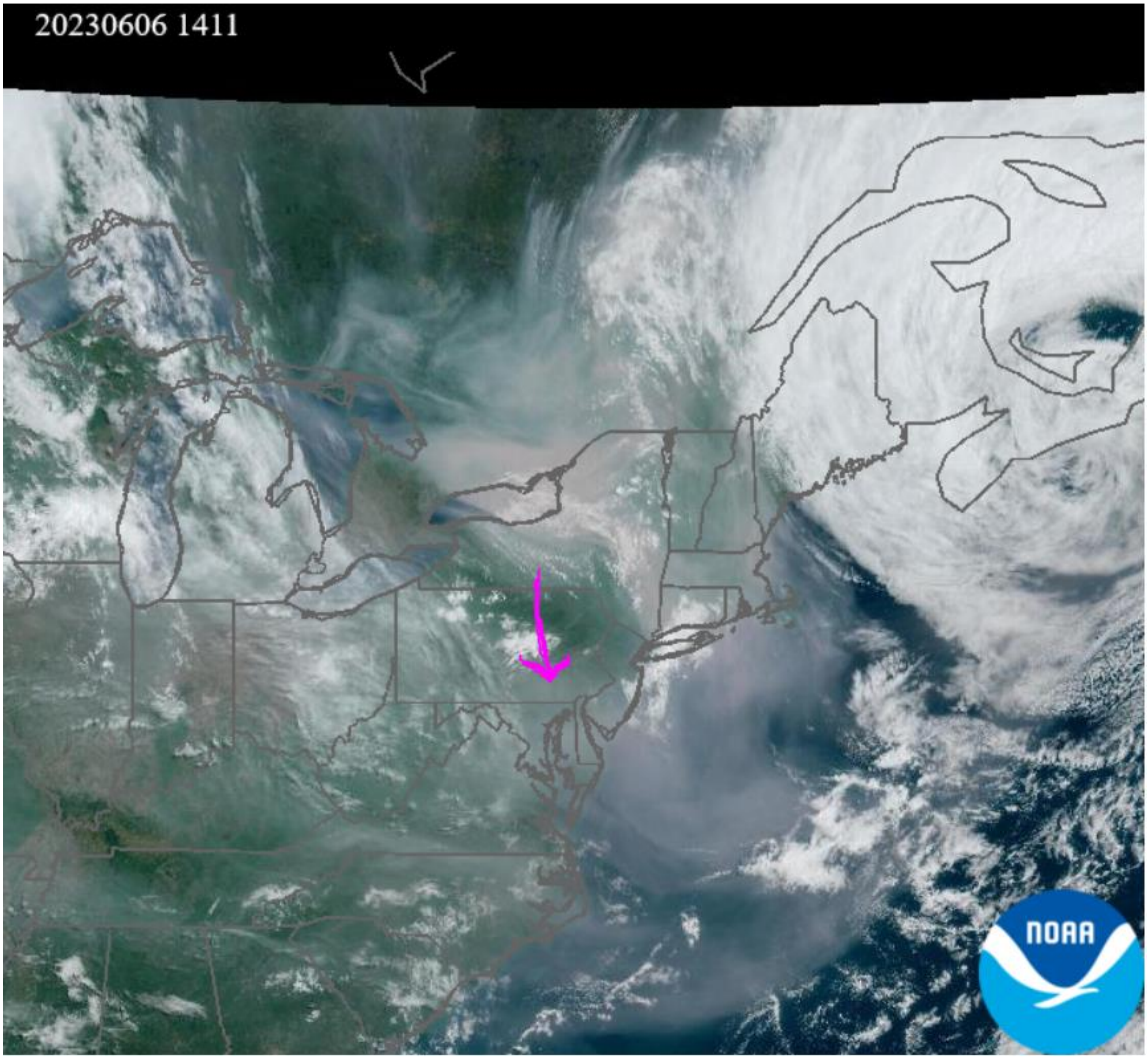


Figure 10c. Aerosol Watch Image using the GOES ABI visible imagery for the morning of 2023-06-06. The purple arrow shows the movement of the wave of smoke impacting Maryland on June 7, the brownish area over Lake Ontario. Images can be viewed online:
https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/?product_date=20230606&zoom=6&lat0=41.801248853664305&lon0=-79.82397460937506&layers=134217729&region=conus&start_time=1141&end_time=1801

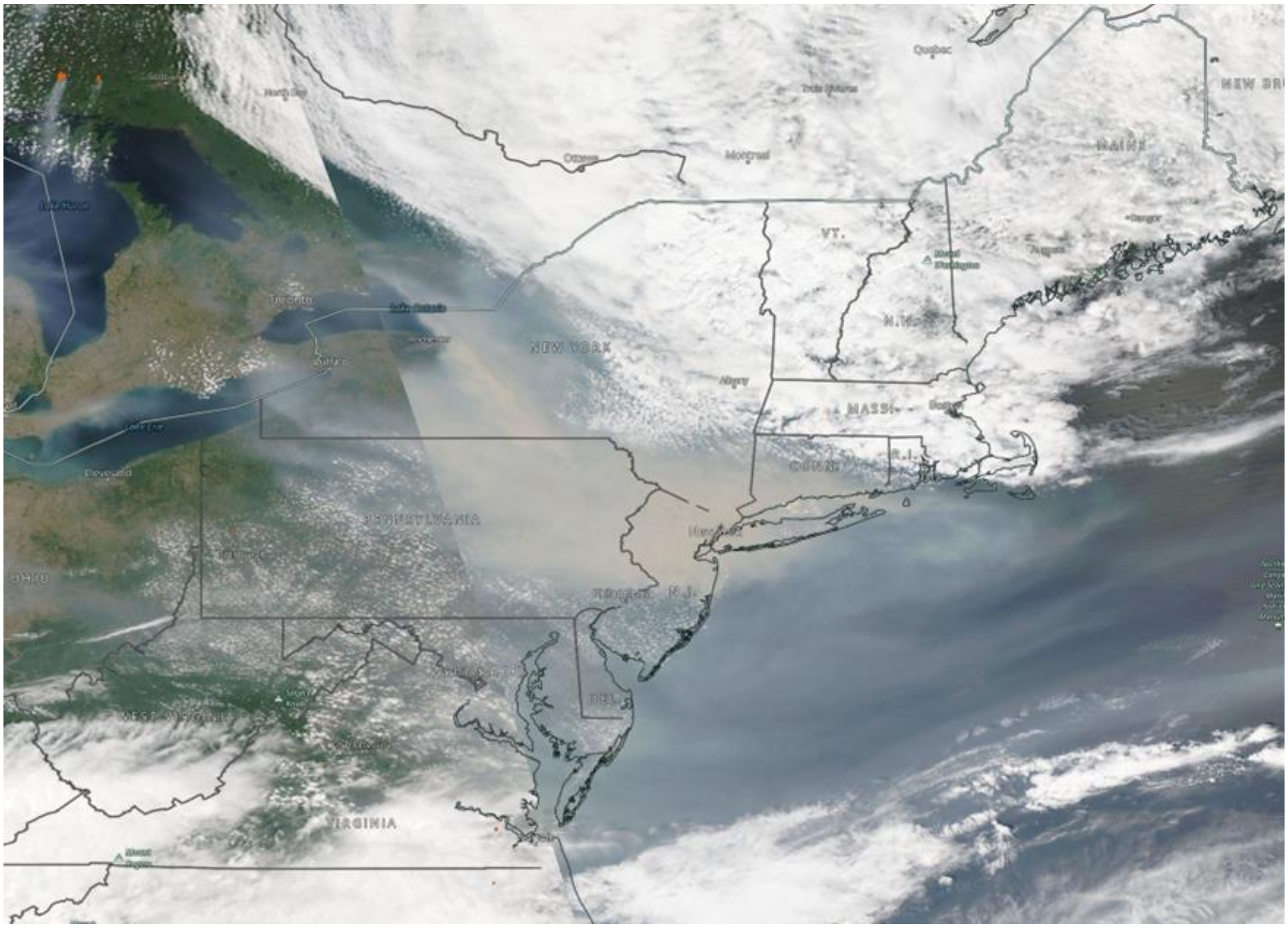


Figure 10d. Worldview Satellite Image including Maryland for 2023-06-07. The orange dots are thermal anomalies. Images can be viewed online: https://wvs.earthdata.nasa.gov/api/v1/snapshot?REQUEST=GetSnapshot&TIME=2023-06-07T00:00:00Z&BBOX=35.8381,-83.0181,47.5136,-66.7939&CRS=EPSG:4326&LAYERS=MODIS_Aqua_CorrectedReflectance_TrueColor,MODIS_Combined_Thermal_Anomalies_All,Coastlines_15m,Reference_Features_15m,Reference_Labels_15m&WRAP=day,none,x,x,x&FORMAT=image/jpeg&WIDTH=1846&HEIGHT=1328

2.4. Conceptual Model of Ozone Formation from June 2023 Quebec Fires

2.4.1. Overview and Literature Review

Wildfires are known sources of emissions responsible for both primary and secondary pollutants including CO, $PM_{2.5}$, NO_x, 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., 2004; Dreessen et al., 2016) 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 United States. More recently, Dreessen et. al., (2016) presented a case where a Saskatchewan, Canada wildfire smoke plume amplified ozone in Maryland in June of 2015. While historically 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; Marlons et al., 2009; Westerling et al., 2006; Spracklen et al., 2009; Pechony and Shindell, 2010), decreasing regional NO_x emissions (77Gégo, et al., 2007) and tighter ozone NAAQS (https://www.epa.gov/ground-level-ozone-pollution).

2.4.2. Ozone Generation from the Fire

Wildfires generate precursors that may directly lead to ozone formation or indirectly foster ozone through atmospheric composition that disproportionately generates ozone when impacted by anthropogenic precursors. Dreessen et. al. (2016) previously showed that smoke plumes from Central Canada are capable of transporting ozone to the Mid-Atlantic and causing NAAQS exceedances, even in the contemporaneously low NO_x emission environment. As in the June 2015 ozone case covered in Dreessen et al., (2016), the June 2023 ozone events across the Northeast and Mid-Atlantic U.S. were characterized by smoke plumes associated with ozone, increasing in concentration as the smoke plume aged.

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 NO_x 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 NO_x contribution from the fire itself, though focused on the plume's interaction with anthropogenic sources, noting ozone production beyond what may be typically expected from such 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 70 ppb 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 11).

During the early June 2023 Quebec wildfire event, smoke traveled quickly to Maryland, relative to other events impacting the region. However, ozone was generated directly from the fires and/or quickly when interacting with sunlight and transported into Maryland. Furthermore, active chemistry due to copious precursors within the plume exacerbated any local de minimis emission contributions (in relation to the plume concentrations) to foster rapid ozone chemistry. In other words, in addition to "already formed ozone" transported in the smoke, chemistry in the smoke enhanced local ozone production beyond expected concentration outcomes. The smoke was relatively "fresh" in the current June 7 case when it reached Maryland. As such, the ozone production from the fires themselves and/or downwind upon activating photochemistry indicates more than sufficient NO_x and VOCs were generated by the Quebec fires in early June 2023 for "primary" ozone concentrations well into the Moderate range with further exacerbation as the plume aged and mixed with anthropogenic NO_x (albeit the lowest NO_x on record). This caused ozone concentrations near and above levels exceeding the NAAQS not possible without the smoke.

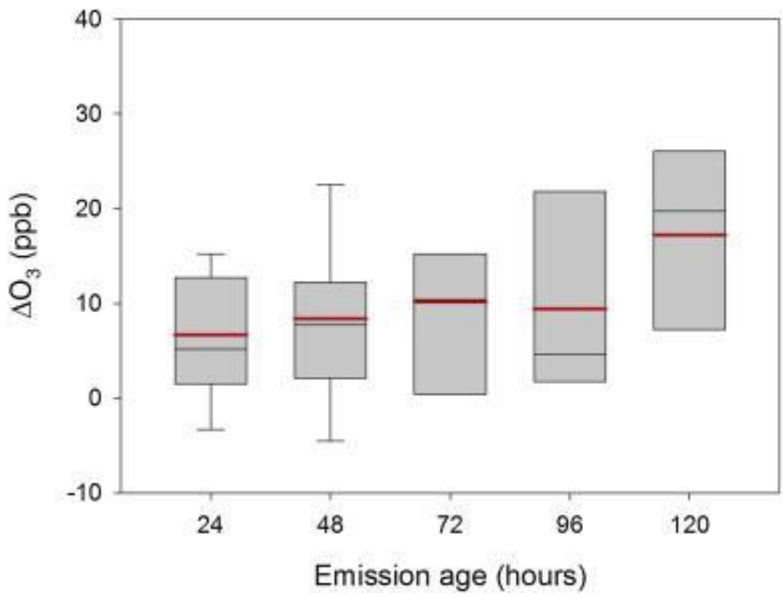


Figure 11. Ozone enhancement with smoke plume age (Putero et al. (2014), Figure 7).

While ozone exceedance days in early June in Maryland are not unusual due to increasing sun angle, length of day, and climatological increase in seasonal temperatures, the magnitude and spatial scale of the June 7, 2023 ozone event in spite of cooler than typical temperatures and diffuse sunlight at the surface were beyond contemporary norms or expectations. Meteorological conditions and emissions on June 7, 2023 in Maryland were not sufficient to cause the large spatial scale, multi-day, and intense magnitude exceedance event without additional wildfire-related ozone precursor emissions. Historical comparisons during the month of June show ozone concentrations and the number of monitors exceeding the standard at these magnitudes are rare (reference Figure 5), even rarer considering massive emissions reductions evident during that time period across the entire eastern U.S. Thus, it is unlikely such a widespread area exceeding the standard would have occurred without additional supportive atmospheric chemistry provided by the wildfire smoke.

2.4.3. Meteorological Conditions Driving Smoke and Ozone Transport

2.4.3.1. Conceptual Model Overview

An omega-like pattern existed for much of June across the North American continent with strong high pressure dominating the central continent. A weak storm system moving southeastward over the central North American ridge across Quebec caused copious lightning strikes across the province on June 1, igniting fires that burned through the month of June 2023. Thereafter, continued northerly flow across Quebec, fostered continued low pressure across the Canadian Maritimes. This area of low pressure deepened, causing an increased pressure gradient across Quebec, which resulted in persistent and increasing winds into June 4-7. The newly ignited fires across the province, with parched fuels and low moistures quickly intensified in the strong and persistent winds, waning only with lower winds and higher humidity at night.

Initially northerly flow around the Canadian Maritime low had a small easterly component, pushing many of the smoke plumes southwestward towards the Great Lakes. The northerly flow also pulled cooler temperatures southward pushing a cold front across northeast CONUS. This front passed through Maryland around June 4. Little smoke was associated with this first front. However, strengthening of the Canadian Maritime low caused northwest transport by June 5 and 6, which pulled the diffuse smoke across the Great Lakes southeastward. As such, diffuse smoke was in place across the Mid Atlantic on June 6, with $PM_{2.5}$ concentrations generally in the 20-30 $\mu g/m^{-3}$ statewide. The continued strengthening of the Canadian Maritime low tapped into additional colder air, pulling down another front across the fire area. This front and the strong northerly winds behind it created a "puff" or what could be construed as a "wall" of smoke which pushed out of Canada on June 6, was transported across New York and Pennsylvania, arriving in Maryland by midnight on June 7. An additional wave of smoke arrived around midnight on June 8, creating another exceptional day of high $PM_{2.5}$ concentrations on June 8, though ozone was not as high as on June 7, keeping the regulatory significance for ozone isolated to June 7.

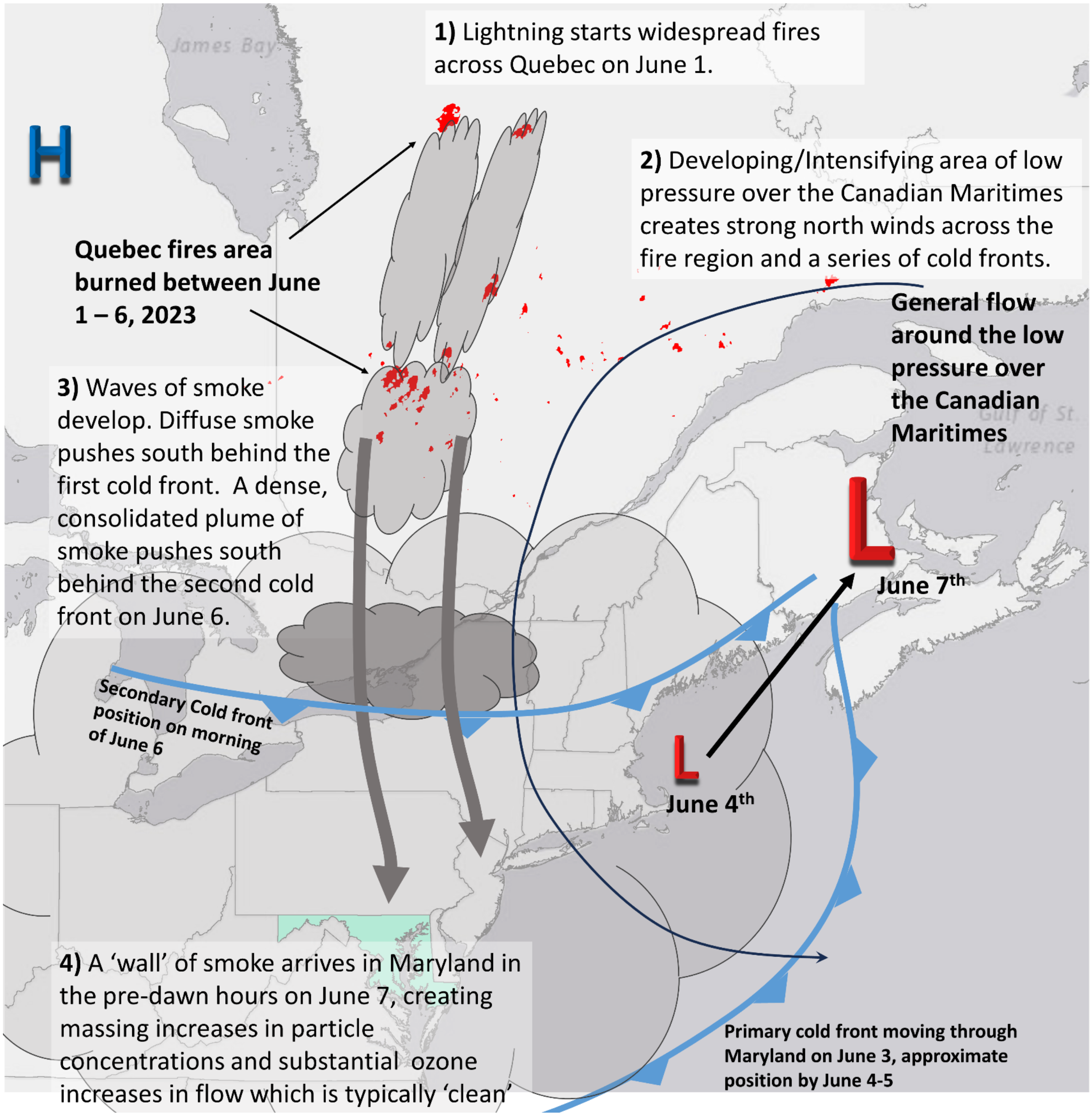


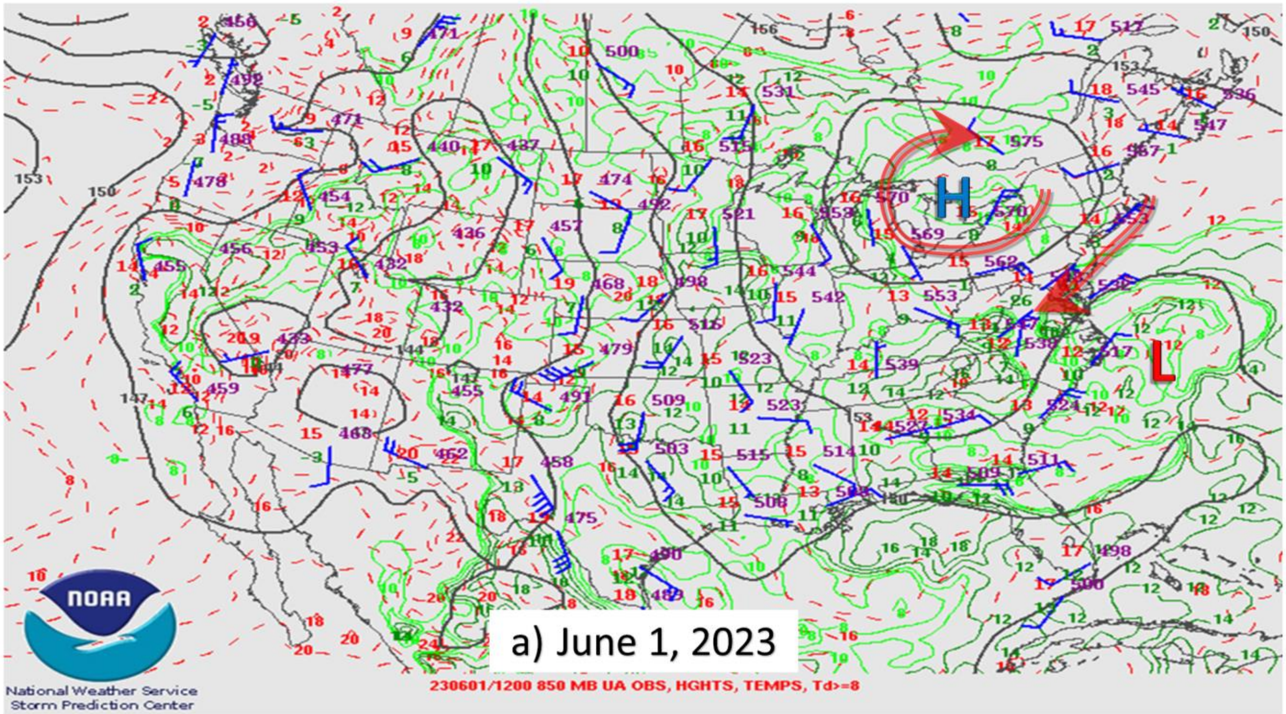
Figure 12. A simplified, illustrated, conceptual model of the June 7, 2023 wildfire influenced ozone event.

2.4.3.2. Upper Level Pattern Overview

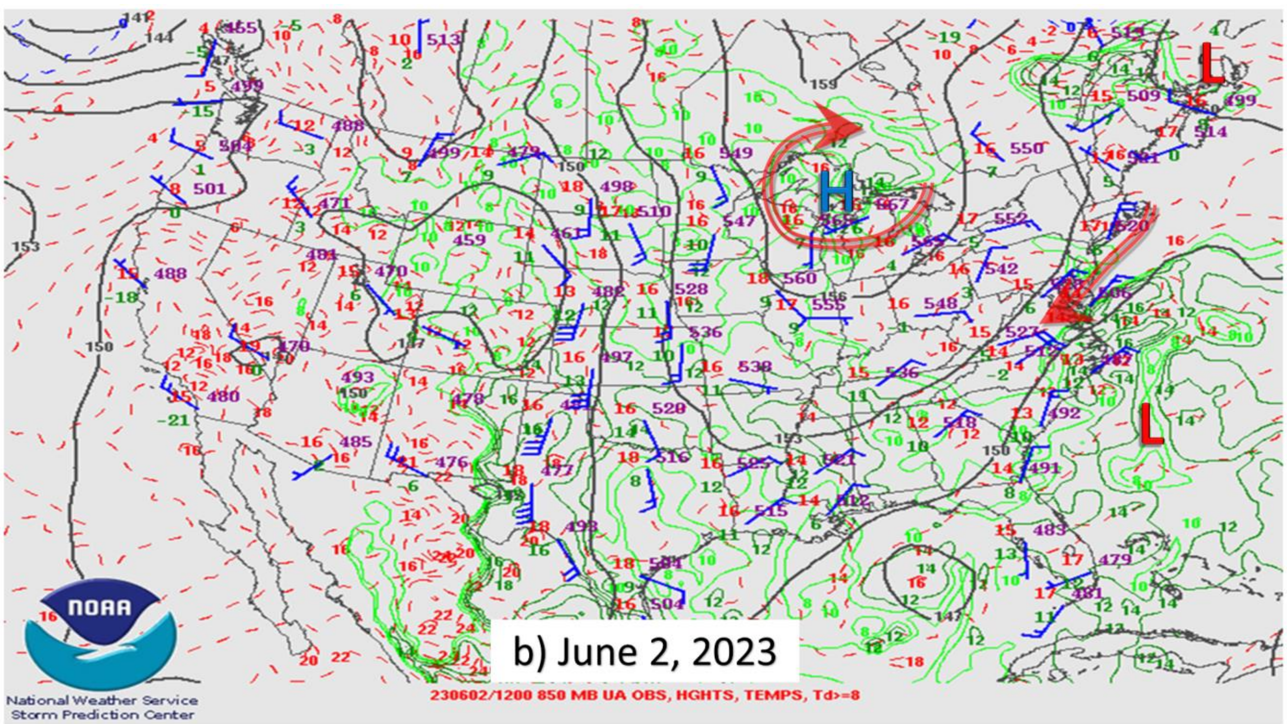
The 850 mb level (approximately 1500m above sea level) sits near the top of the planetary boundary layer, the atmospheric layer in which ozone pertinent to surface observations and human health develops. The 850 mb height level can serve as a guide for the transport of pollutants. The June 7 event started with a weak wave at 850 mb (associated with a surface cold front) which initiated thunderstorms ultimately leading to the start of the fires (Figure 13a). This rounded a persistent high pressure over extreme southern Ontario.

The position of the high brought northeasterly flow into Maryland at the time. The high retrograded, that is, moved westward into July 2 (Figure 13b). Thus began the process of slowly backing transport (more northerly) into Maryland leading up to June 6. By June 3, the retrograding high pressure opened up and was absorbed into the larger-scale central North American ridge (Figure 13c). At the same time, the pressure gradient across the northeast U.S. and Canadian Maritimes began tightening slightly, resulting in an increase in winds across that region and into Quebec. A similar trend continued through June 4 and 5 (Figure 13d, 13e).

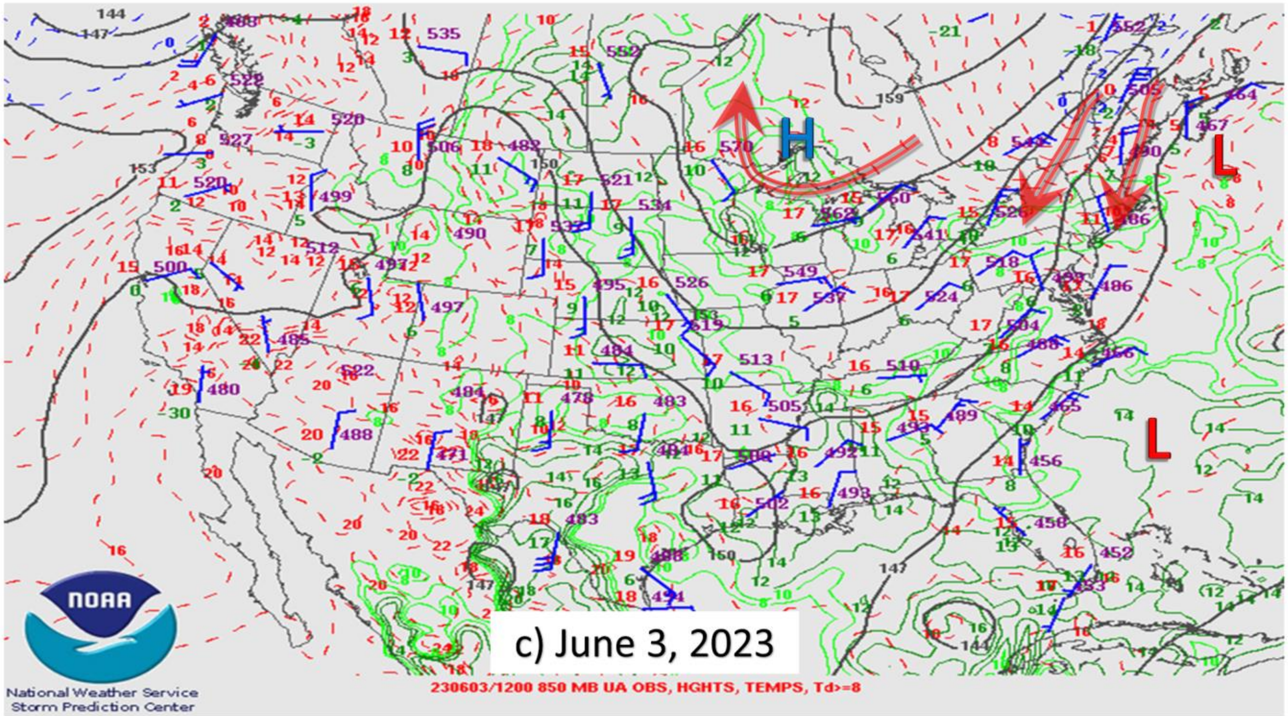
On June 4, 850 mb winds over the fire region in Quebec were northeasterly causing smoke to be blown to the Great Lakes region. By June 5, winds across Quebec were nearly due northerly as they wrapped around the intensifying low over the Canadian Maritimes. Similar northerly winds extended into the Mid Atlantic as well. This same morphology caused northwesterly winds across the Great Lakes by June 6, causing the initial influx of smoke across the region by that time (Figure 13f). Concurrently, strong northerly flow is evident across Quebec, with a relatively tight thermal gradient across the same area, indicative of a cold front which would be responsible for the influx of smoke into June 7. The pressure gradient continued to strengthen into June 7 across the northeast U.S., causing persistent northwest flow over the fire region and into the Mid-Atlantic, causing continued transport to Maryland.



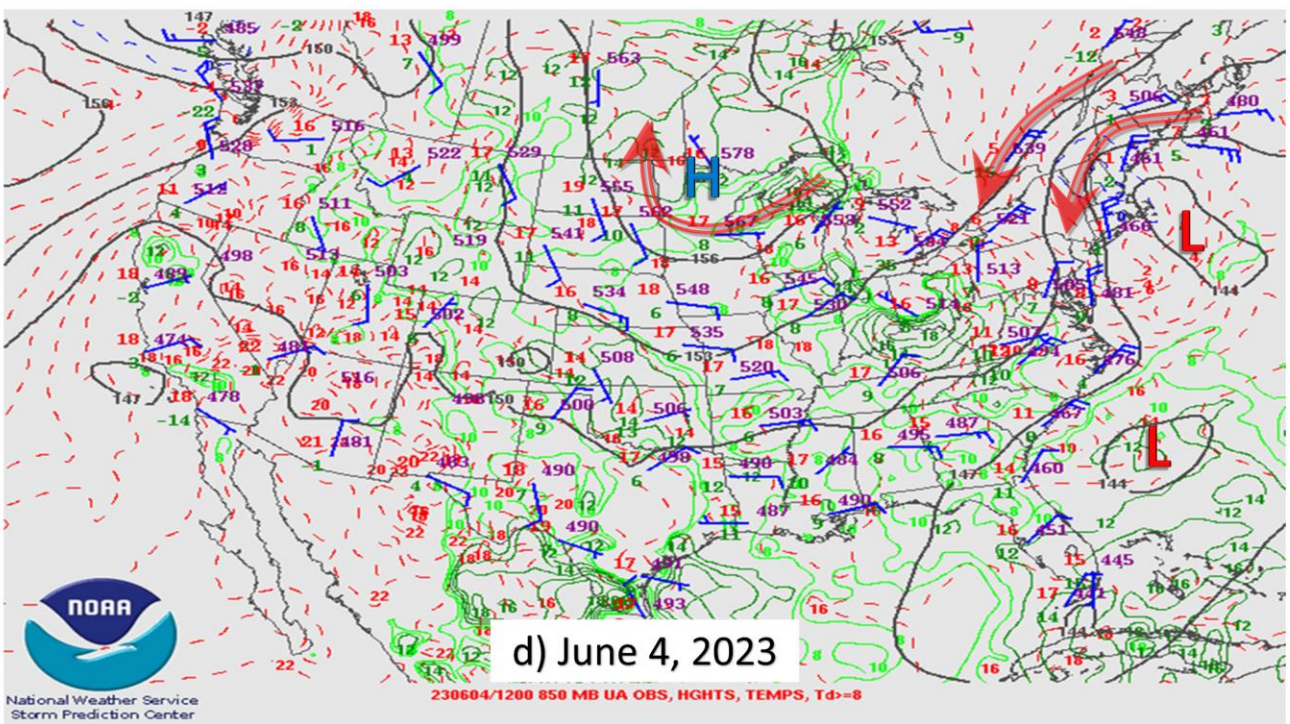
a) June 1, 2023



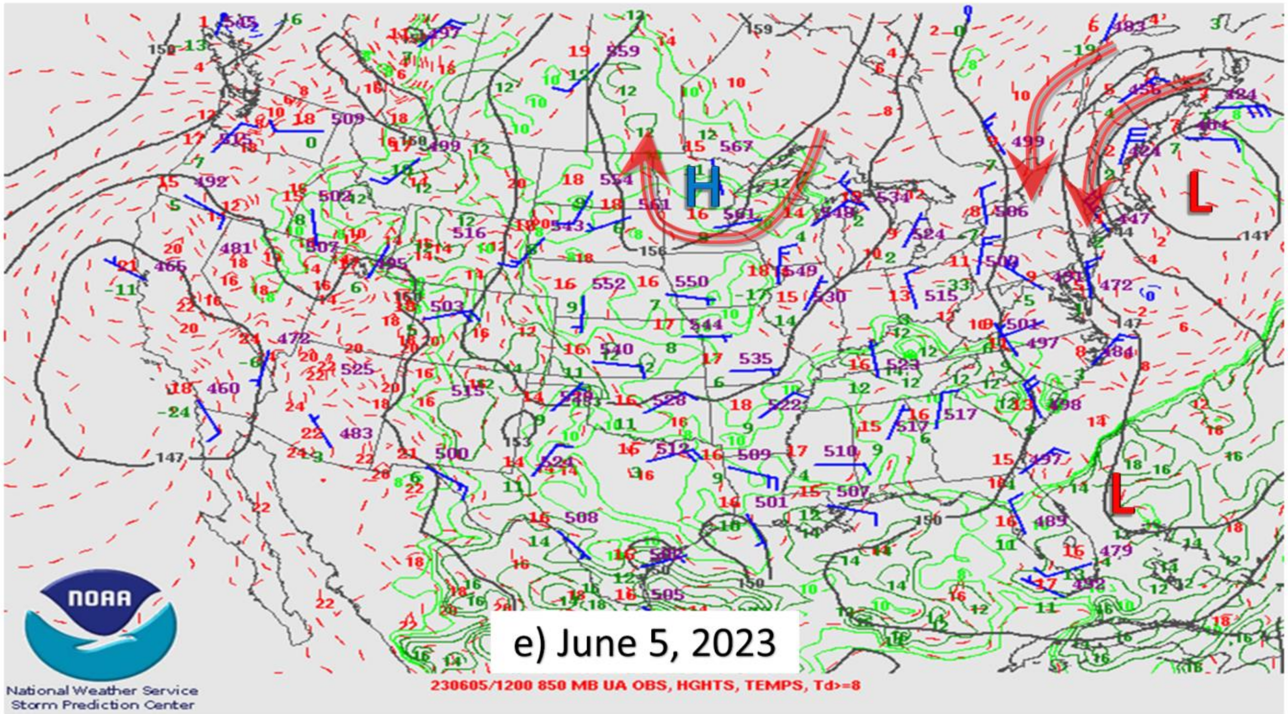
b) June 2, 2023

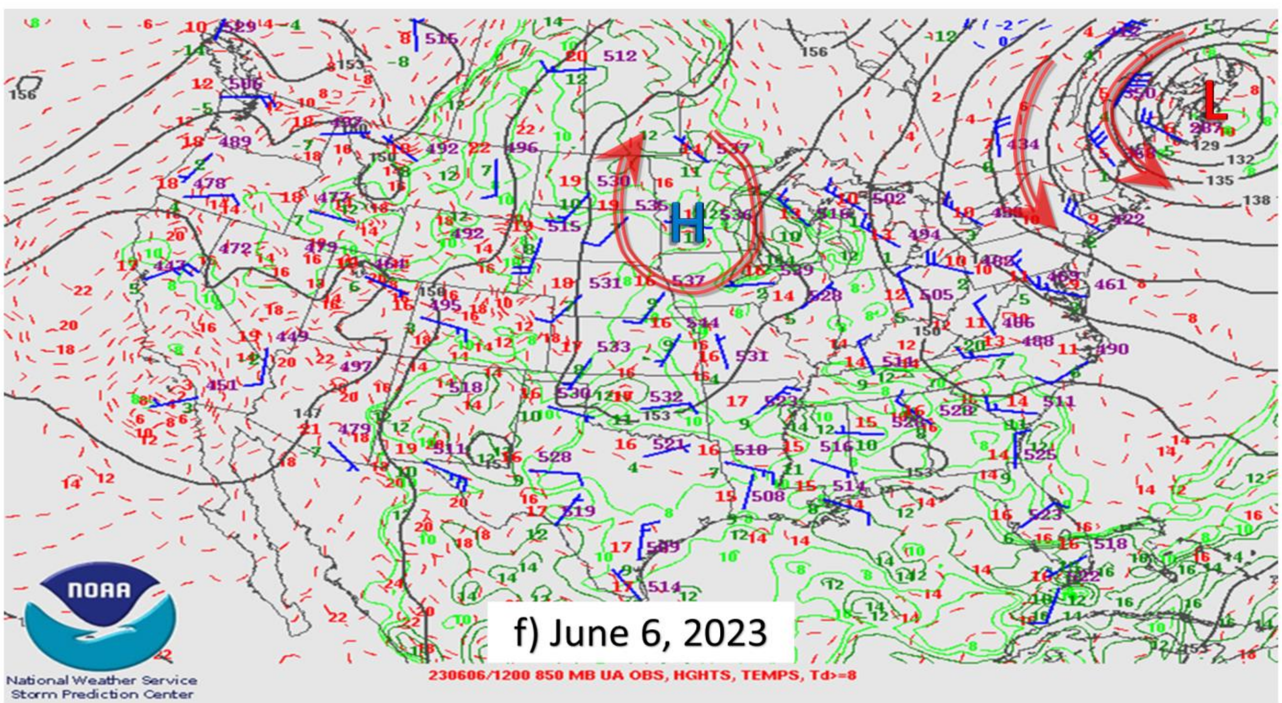


c) June 3, 2023



d) June 4, 2023


e) June 5, 2023
H
L
L
NOAA
National Weather Service
Storm Prediction Center
230605/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8


f) June 6, 2023
H
L
NOAA
National Weather Service
Storm Prediction Center
230606/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8

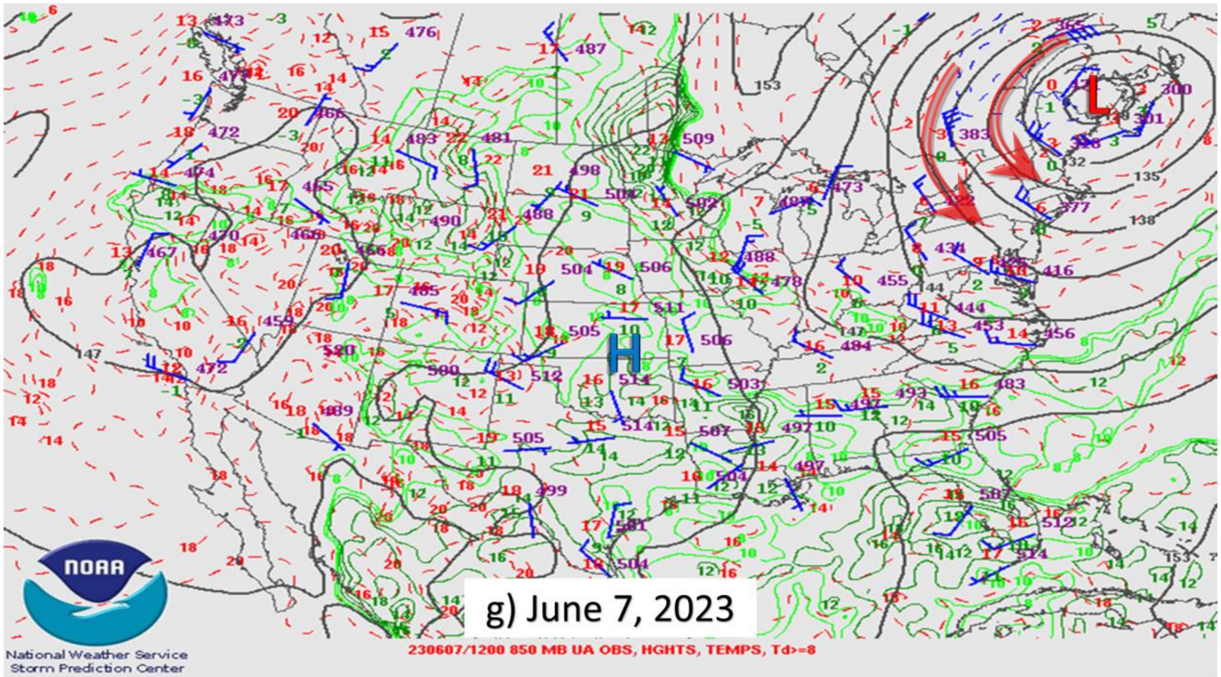
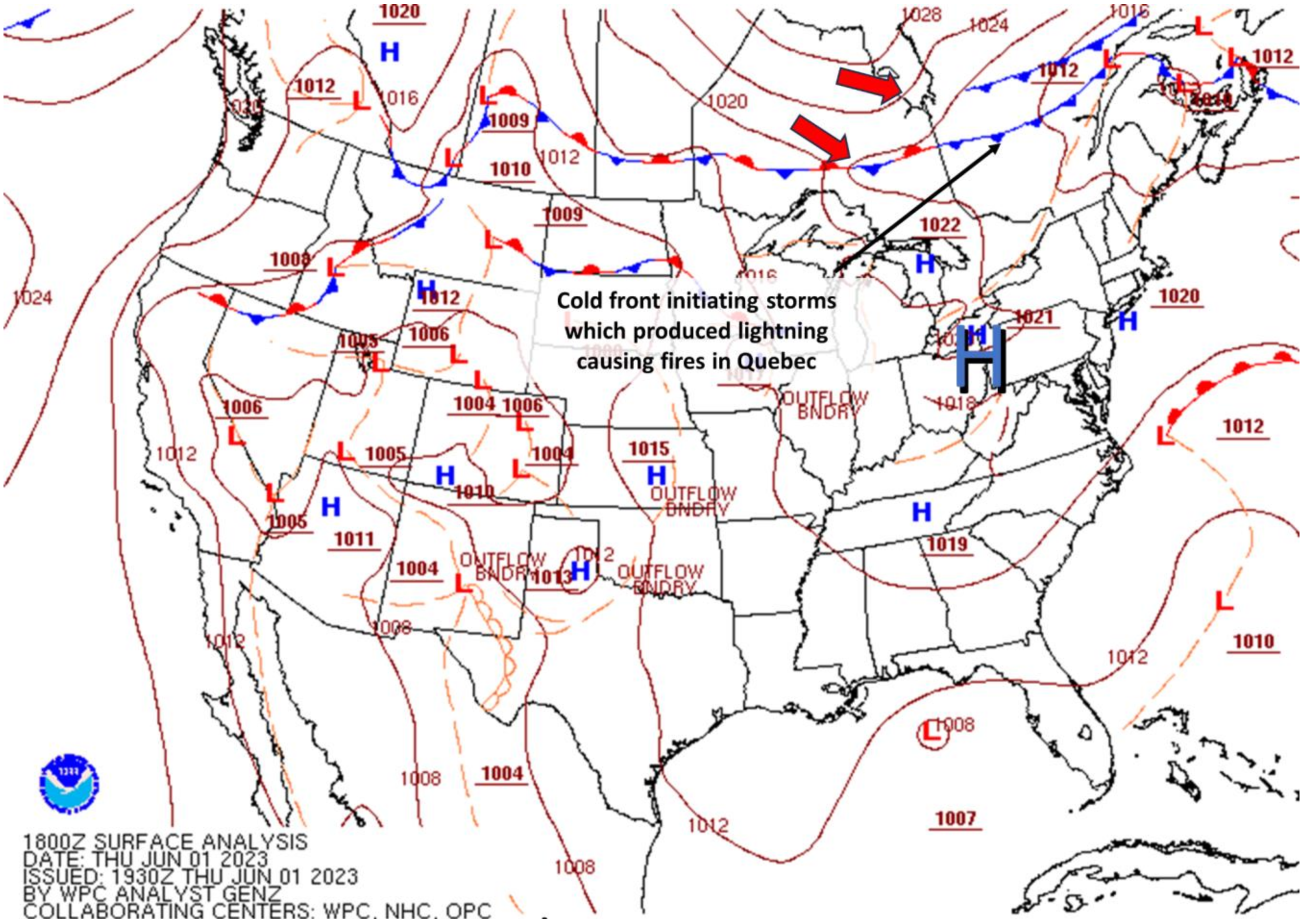


Figure 13. The 1200 UTC 850mb pattern for CONUS on a) June 1 and b) June 2, c) June 3, d) June 4, e) June 5, f) June 6, and g) June 7, 2023. Red arrows show the general transport pattern. Capital letter "H" is high pressure, capital letter "L" is low pressure. Heights (black lines), temperatures (dashed red lines), dewpoint (green lines), and winds (blue barbs) are also analyzed.

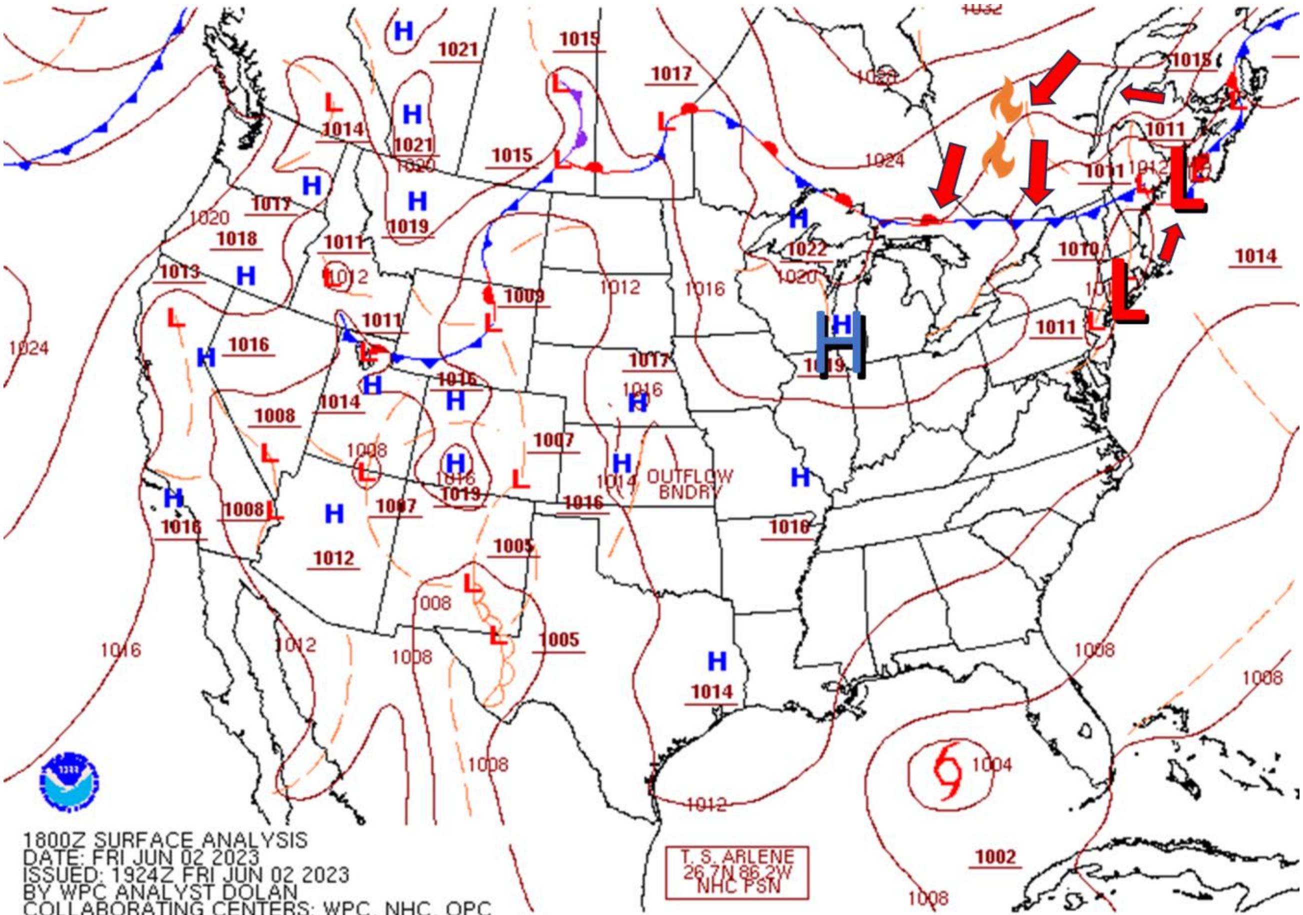
2.4.3.3. Surface Pattern Overview

While transport winds at 850 mb provide information on the movement of airmasses and weather systems, surface conditions and features dictate whether an airmass is capable of ozone production. The surface layer (ground level) where ozone monitors and humans reside, makes the layer paramount to understanding ozone morphology. In simplest terms, transport patterns follow lines of equal pressure, or isobars, as winds tend to follow paths of "equal pressure", or if looking at the atmosphere at a constant pressure field, such as 850mb, transport follows lines of equal height. Unlike at 850mb and upper levels, where winds are parallel to these lines, at the surface, friction with the surface causes winds to turn slightly left towards lower pressure.

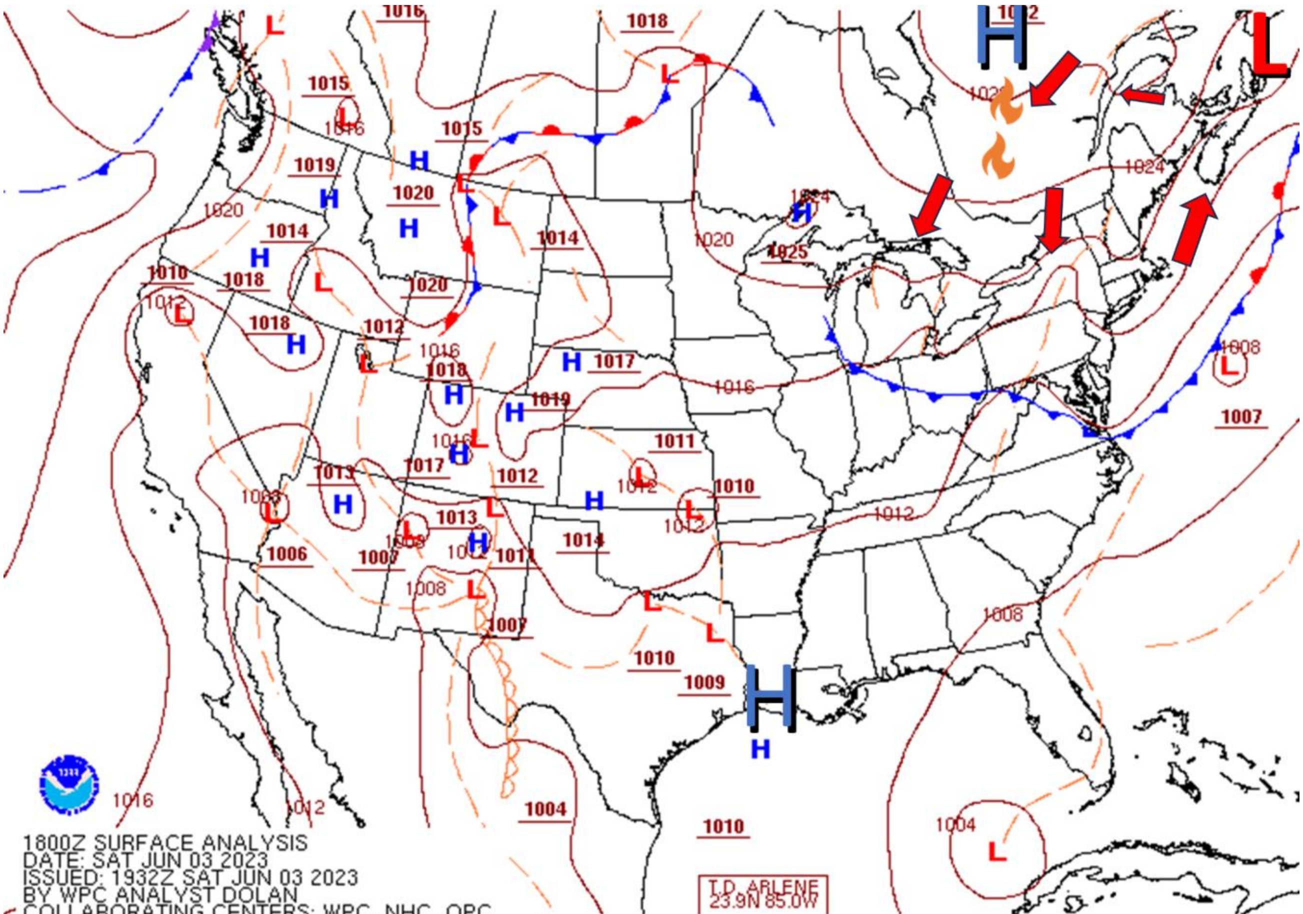
Thunderstorms which caused the major fires across Quebec were initiated on June 1 by a cold front moving southeastward across the province (Figure 14a). This cold front continued to push south, and a tightening pressure gradient fostered fire development behind the front on June 2 (Figure 14b). The cold front outpaced the smoke in the Mid-Atlantic on June 3, moving through benignly with cooler temperatures as typified by Canadian airmasses in Maryland (Figure 14c). Nearer the fire region, however, northeast flow dominated, and pushed smoke into the Great Lakes behind the front. Flow stagnated in this area into June 4, keeping smoke across the Great Lakes (Figure 14d). Another polar cold front pushed across the fire region on June 5 (Figure 14e). Ahead of the front, light northerly to northwesterly flow existed across the eastern Great Lakes and upper Ohio River Valley. Consistent with upper-level support, this allowed diffuse smoke to move into Maryland by June 6. The polar front on June 5 was the front which brought smoke into Maryland on June 7. The polar front was draped across Pennsylvania on June 6 (Figure 14f). A tremendous smoke gradient existed across this front, explaining why the smoke appeared to move into the Mid-Atlantic like a "wall". Literally, the smoke was pushing up against the frontal boundary, creating a "wall" of smoke. This front and associated dense smoke moved into Maryland on June 7 (Figure 14g), with the actual frontal clearing the area, while dense smoke remained present.


Cold front initiating storms which produced lightning causing fires in Quebec
1800Z SURFACE ANALYSIS
DATE: THU JUN 01 2023
ISSUED: 1930Z THU JUN 01 2023
BY WPC ANALYST GENZ
COLLABORATING CENTERS: WPC, NHC, OPC

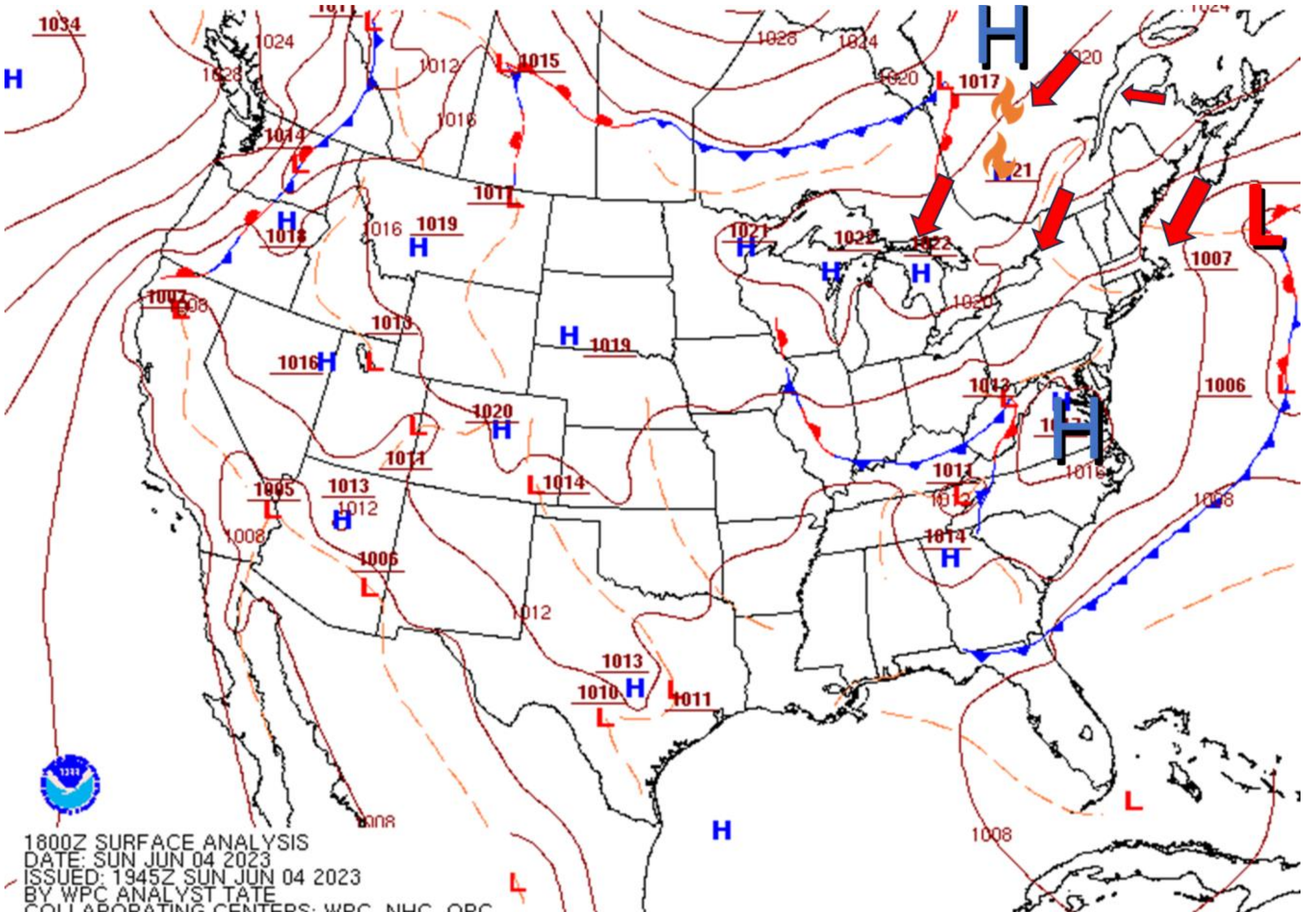
a) June 1, 2023


OUTFLOW
BNDRY
T. S. ARLENE
26.7N 86.2W
NHC PSN
1800Z SURFACE ANALYSIS
DATE: FRI JUN 02 2023
ISSUED: 1924Z FRI JUN 02 2023
BY WPC ANALYST DOLAN
COLLABORATING CENTERS: WPC, NHC, OPC

b) June 2, 2023

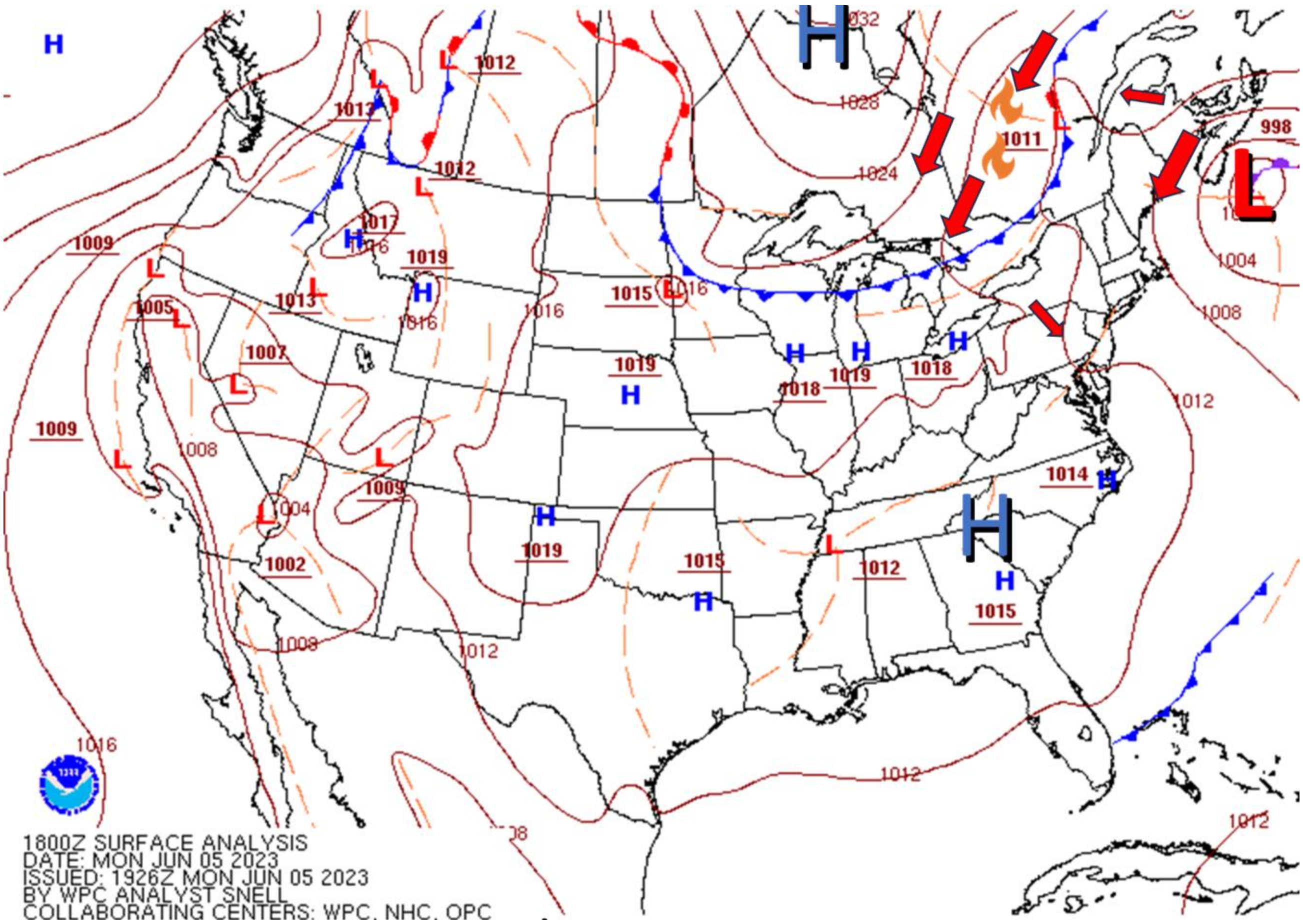

1800Z SURFACE ANALYSIS
DATE: SAT JUN 03 2023
ISSUED: 1932Z SAT JUN 03 2023
BY WPC ANALYST DOLAN
COLLABORATING CENTERS: WPC, NHC, OPC
T.D. ARLENE
23.9N 85.0W

c) June 3, 2023

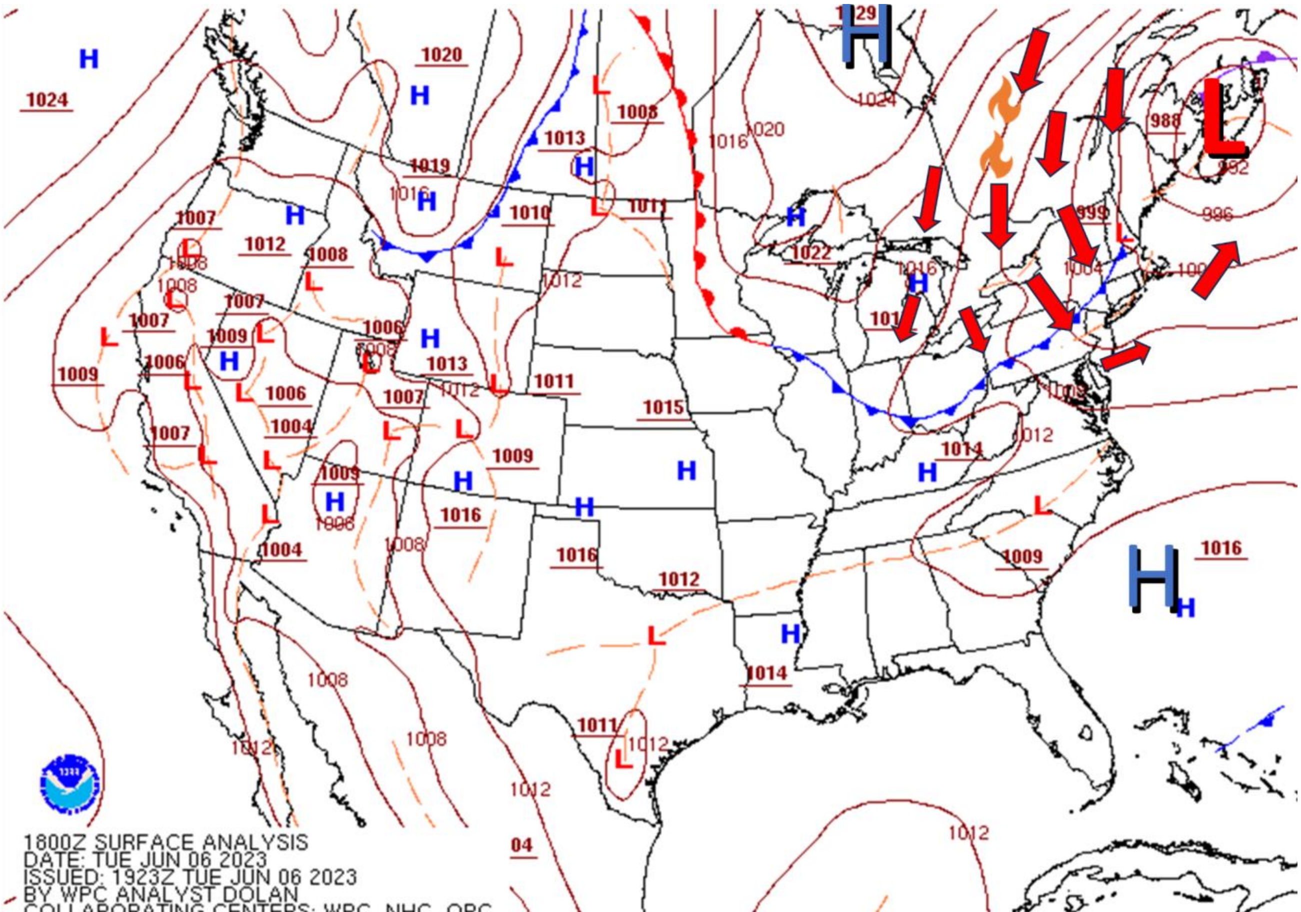


1800Z SURFACE ANALYSIS
DATE: SUN JUN 04 2023
ISSUED: 1945Z SUN JUN 04 2023
BY WPC ANALYST TATE
COLLABORATING CENTERS: WPC, NHC, OPC

d) June 4, 2023


1800Z SURFACE ANALYSIS
DATE: MON JUN 05 2023
ISSUED: 1926Z MON JUN 05 2023
BY WPC ANALYST SNELL
COLLABORATING CENTERS: WPC, NHC, OPC

e) June 5, 2023


1800Z SURFACE ANALYSIS
DATE: TUE JUN 06 2023
ISSUED: 1923Z TUE JUN 06 2023
BY WPC ANALYST DOLAN
COLLABORATING CENTERS: WPC, NHC, OPC

f) June 6, 2023

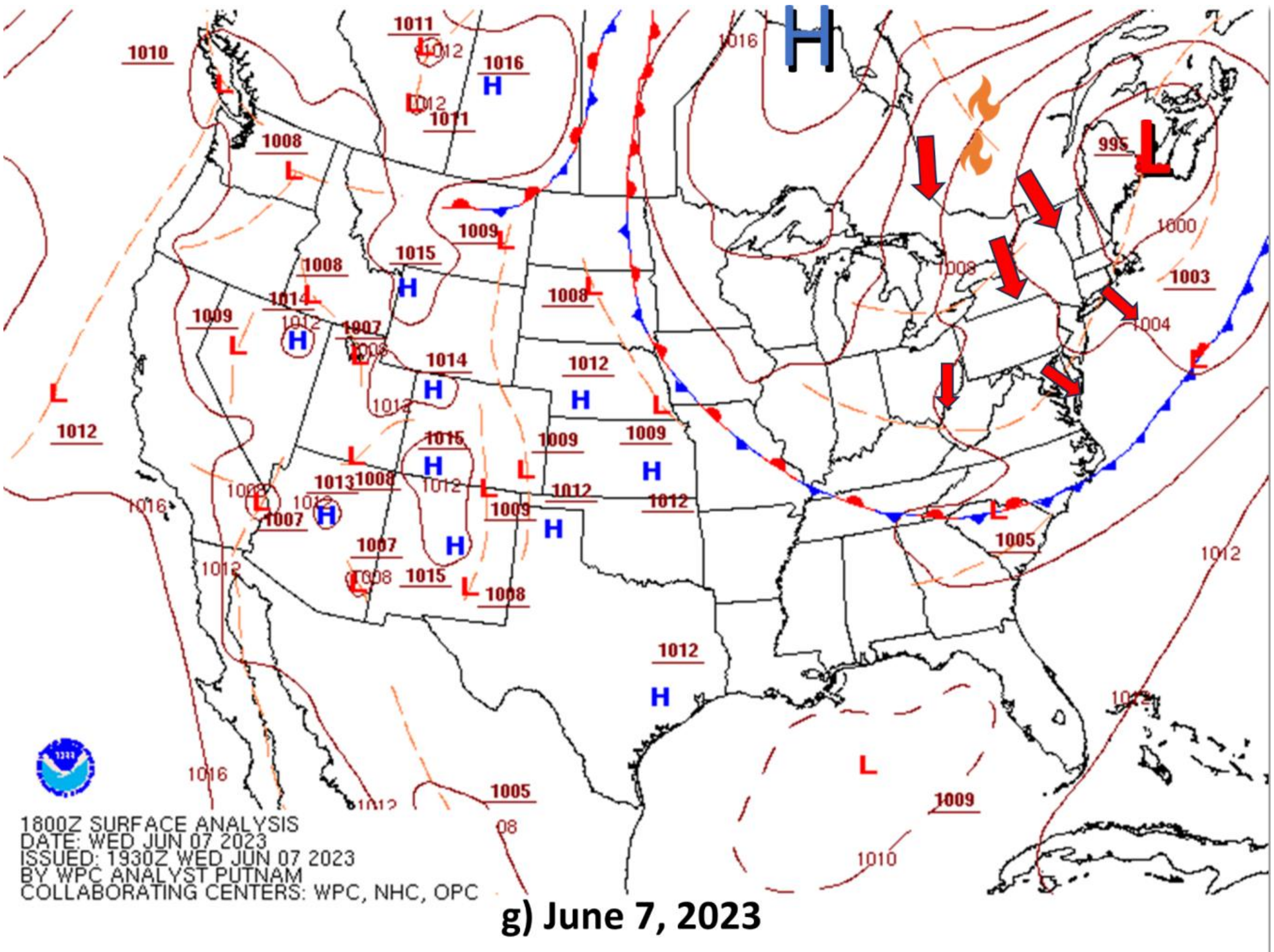


Figure 14. Surface analysis at 1800 UTC for June 1-7, 2023 (a-g), respectively. Red arrows show the general pattern of surface winds. Capital letter "H" is high pressure, while the capital letter "L" is low pressure. Isobars (brown lines) and fronts are also analyzed.

2.4.3.4. Temperature

Temperatures were at or below normal in Maryland for the duration of the ozone exceedance event on June 7 (Table 5). Temperatures were just above 80°F in the Baltimore area on June 7, which is a relatively benign temperature for high ozone, based on the ozone conceptual model. Temperatures were even cooler where the highest ozone was produced in Maryland. The highest concentrations of ozone were produced across southern Maryland and the lower eastern shore of Maryland. Data available at Salisbury may be representative of the regional weather for the lower eastern shore and on June 7 measured temperatures below normal (79°F) in a region experiencing ozone exceedance. This explicitly shows the influence of smoke in this case. As such, ozone near Baltimore, with similar temperatures was similarly influenced.

Table 5. Maximum daily temperature, normal maximum daily temperature, departure from average (observation minus average) and area maximum daily 8-hour average ozone for the area in which the temperature is measured for the Baltimore area via BWI airport and southern Maryland exceedance area via Salisbury MD on the eastern shore, when impacted by the smoke on June 6-8, 2023. All temperatures are in degrees Fahrenheit.

Date	6-Jun	7-Jun	8-Jun
BWI, MD (°F)	83	81	80
Normal (°F)	81	82	82
Departure (°F)	2	-1	-2
MD8AO (ppb)	67	69	70
Salisbury, MD (°F)	80	79	76
Normal (°F)	80	80	81
Departure (°F)	0	-1	-5
MD8AO (ppb)	63	76	50

2.4.4. Smoke and Ozone Transport Overview

Smoke was pushed from the fire region towards the Great Lakes on June 3-5, 2023. This smoke was evident across the Great Lakes and upper Ohio River valley on June 5 (Figure 15). Relatively high $PM_{2.5}$ concentrations were noted at the surface throughout the spatial coverage of the visible plume, with a few sites pushing in the 50-100 µg/m^3 across the area. Smoke had not yet moved into Maryland by midday on June 5. Smoke pushed into Maryland during the morning of June 6, covering the state by midday (Figure 16), Concentrations rose with a few sites in Maryland nearing the exceedance threshold. Winds were turning northerly during the day from northwesterly. An extremely dense wave of smoke was situated across southeastern New York. Concentrations in this plume were greater than 200 µg/m^3 in some locations at 2 p.m. EDT. This plume of smoke continued southward to Maryland, arriving around midnight on June 7. By midday on Jun 7, widespread smoke was evident across the Mid-Atlantic, including coverage over Maryland (Figure 17). Concentrations in Maryland were greater than 50 µg/m^3 essentially everywhere in the state, with some locations still pushing 100 µg/m^3 around the 2 p.m. EDT hour. Another round of smoke is evident across eastern Pennsylvania and northern New Jersey where concentrations were again in excess of 200 µg/m^3. For clarity, note the dense plume on June 7 over Pennsylvania was not the same as that on June 6. These were distinct “waves” of smoke originating from the fire region.

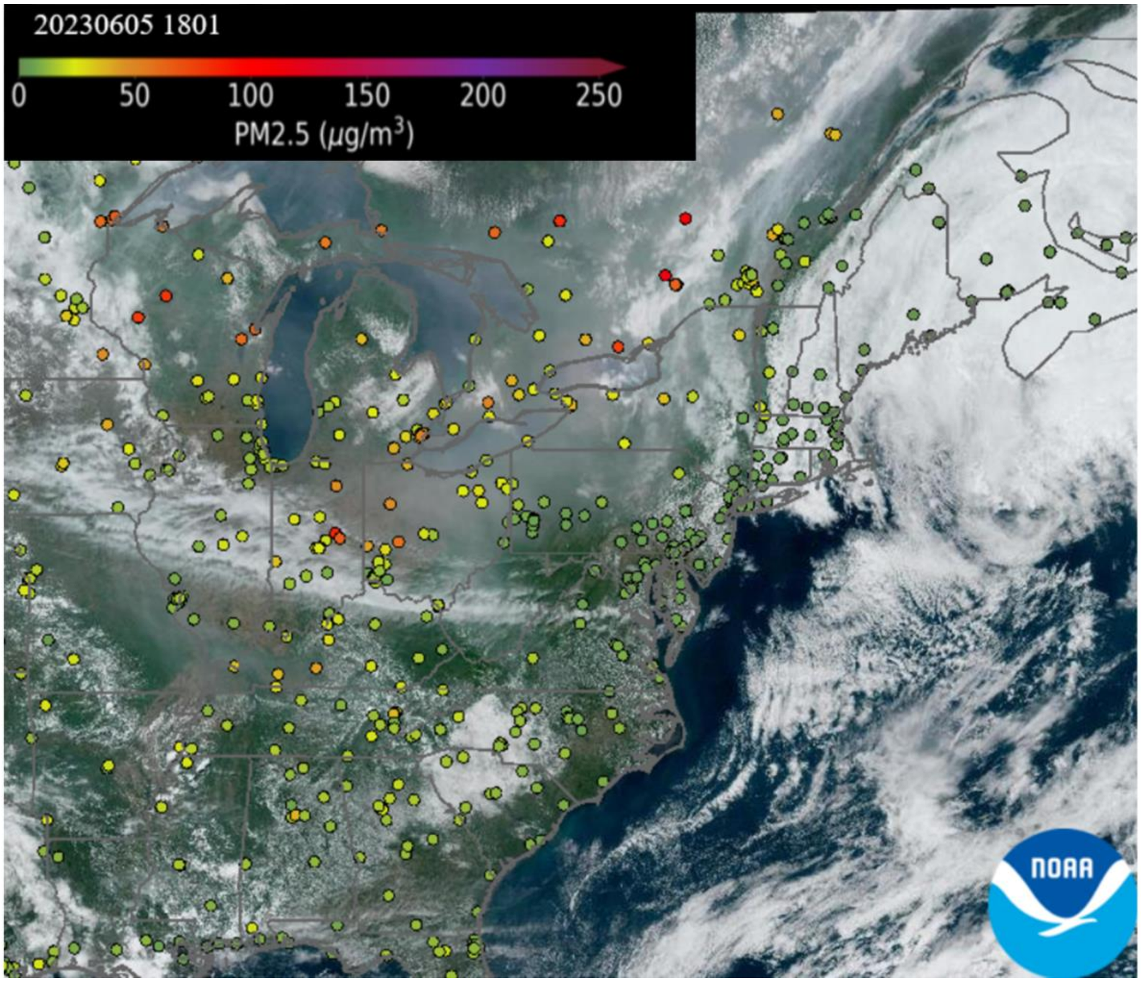


Figure 15. GOES-16 visible imagery at 1801 UTC (2 p.m. EDT) on June 5, 2023, overlaid with hourly $PM_{2.5}$ concentrations (circles) colored by magnitude. Redder colors indicate higher $PM_{2.5}$ concentrations.

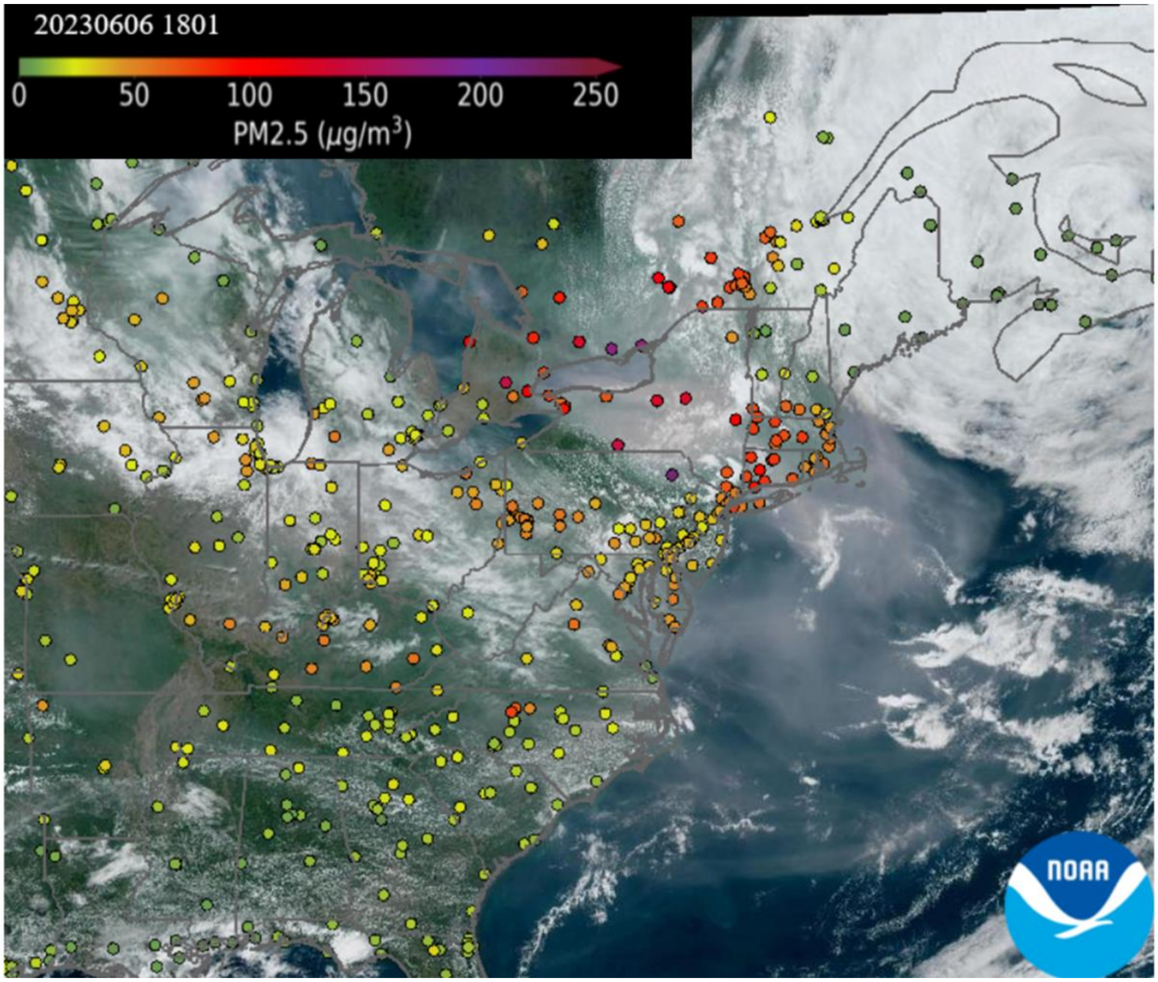


Figure 16. As in Figure 15 except for June 6, 2023.

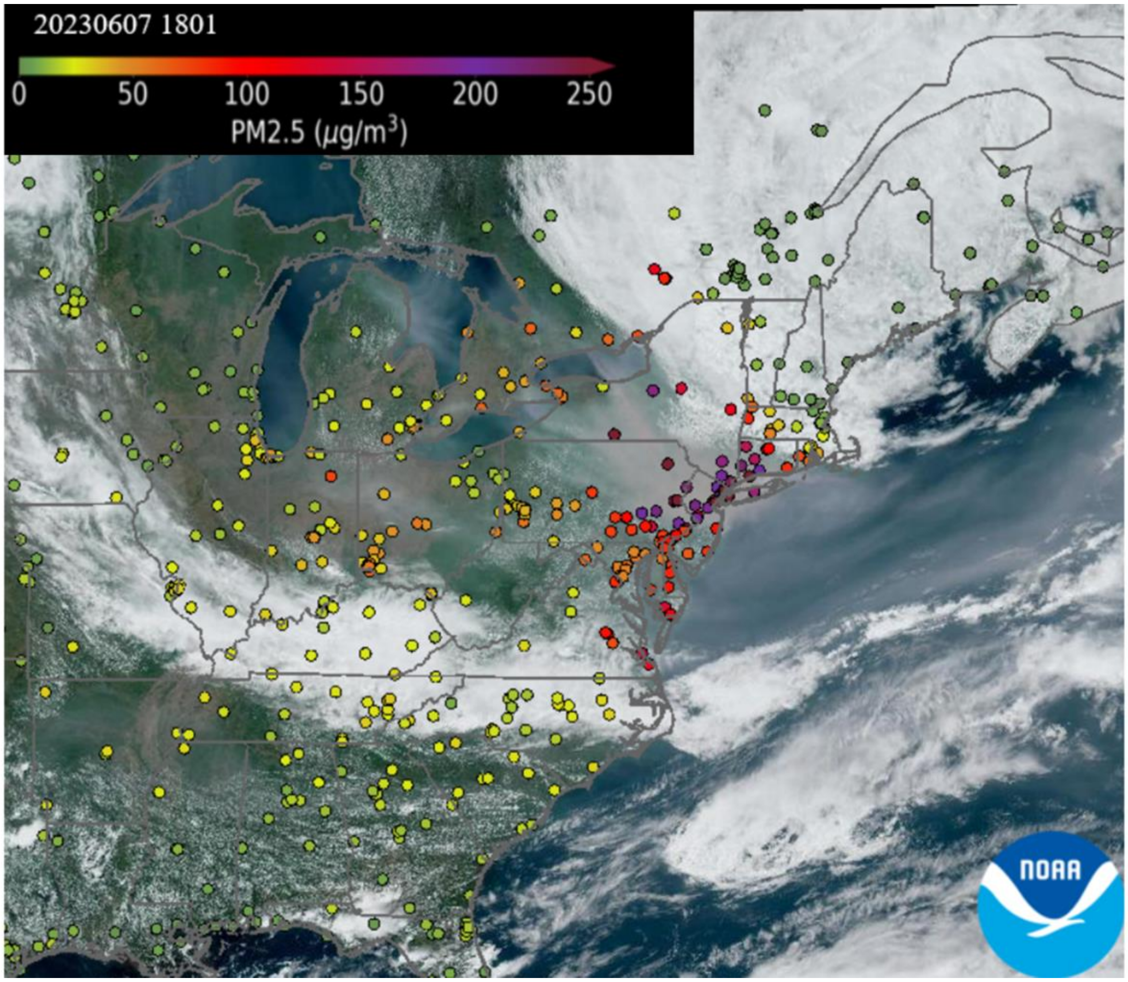


Figure 17. As in Figure 15 except for June 7, 2023.

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

Maryland contends that the June 7 smoke event had a clear causal relationship between the smoke and heightened ozone concentrations because elevated ozone concentrations of this magnitude should not be expected with high temperatures of only 80°F in Maryland with transport of air from Canada, a historically clean direction of air transport. As such, the case presented in this analysis illustrates an example of the impact of smoke on Maryland ozone concentrations via the transport of precursor laden smoke into Maryland. While MDE believes the evidence already presented demonstrates this clear causal relationship, MDE here presents additional 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. Comparisons to historical concentrations and a Q/d analysis (Tier 1 and 2 steps) are provided. MDE believes these analyses alone show a causal relationship between the ozone and smoke. After conversations with EPA, a few additional analyses were contributed to further 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 Maryland monitors exceeding the 70 ppb NAAQS on June 7 showed the exceptional nature of the exceedances (Figures 18 - 21). All ozone data during the 2019-2023 ozone seasons (April 1 to September 30) were plotted for each monitor against that monitor's multi-season and June-only 99th percentile. Recall that significant and sustained reductions in ozone precursors across the eastern U.S. have occurred in the past 10 years. These reductions have been particularly evident in NO_x, leading to lower ozone concentrations. Consequently, this has led to a noticeable decrease in ozone exceedance days, despite an increasing number of hot days; four of the lowest five years based on exceedance days have occurred in the 2018-2022 period due. COVID lock downs lowered exceedance frequency in 2020, but 2022 had an equal number of exceedance days as 2020. June 2023 had the lowest aggregate EGU emissions ever (Figures 4 and 5). Even so, 2022 EGU emissions experienced a substantial decrease of 30% compared to the 2019-2021 daily average (per Figure 5). The 2023 average daily output for June was 225 tons per day, or 47% lower than the 2019-2021 average (428 daily tons). Since 2019-2021 is within the previous five years of data that EPA requests for historical comparisons, MDE feels the data from 2019-2021 raises the 99th percentile higher than what is otherwise now representative of Maryland's ozone. Thus, MDE also offers two additional 99th percentiles to compare each monitor's MD8AO on June 7 (see Table 7 in Section 3.4.) These additional 99th percentiles are calculated using data from only June in 2022 or June 2022 and 2023 combined. MDE believes this increases the robustness of the historical comparison.

All exceeding monitors exceeded all 99th percentile thresholds. Many sites exceeding 70 ppb during this event have 99th percentiles at or below the 70 ppb standard, showcasing the cleaner environment Maryland has experienced in recent years. The Essex monitor, while not meeting the 99th percentile metric, was still significantly impacted by smoke, raising the ozone values to still impact the design value at Essex.

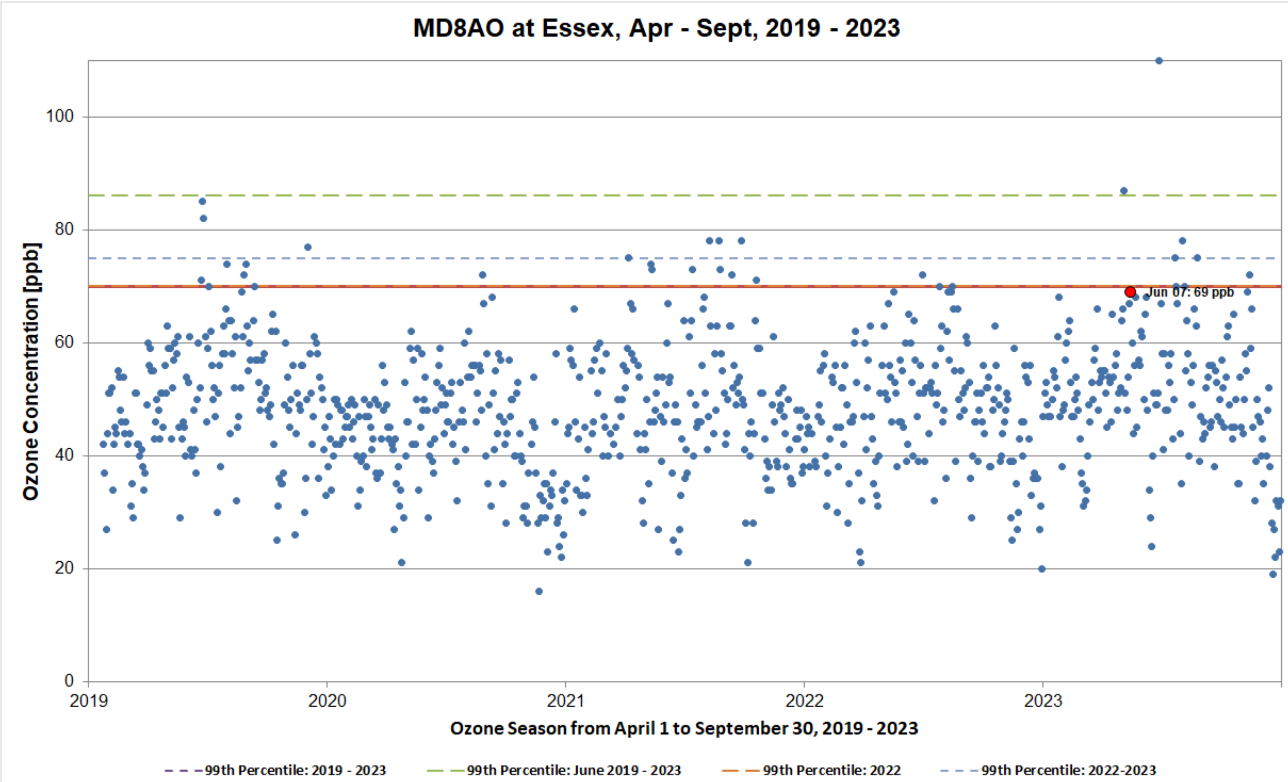


Figure 18. Scatterplot of Maximum Daily 8-hour Average Ozone (MD8AO) concentrations at Essex (blue dots), April 1 – September 30, 2019-2023. The days that exceeded the NAAQS on June 7, 2023 and for which MDE is seeking exclusion of the data are colored red. Textual annotations give the MD8AO for the red colored data points. Along with the 70 ppb NAAQS (red solid line), four additional lines provide the 99th percentiles to account for the changing NO_x emissions and ozone levels in Maryland over the past 5-years. The 99th percentile for all ozone season data 2019-2023, is given in dashed purple. All June ozone data 2019-2023 is given in green dash. Data from June 2022 only is given in dashed orange, while all June ozone data from 2022 and 2023 combined is given as a blue short-dashed line.

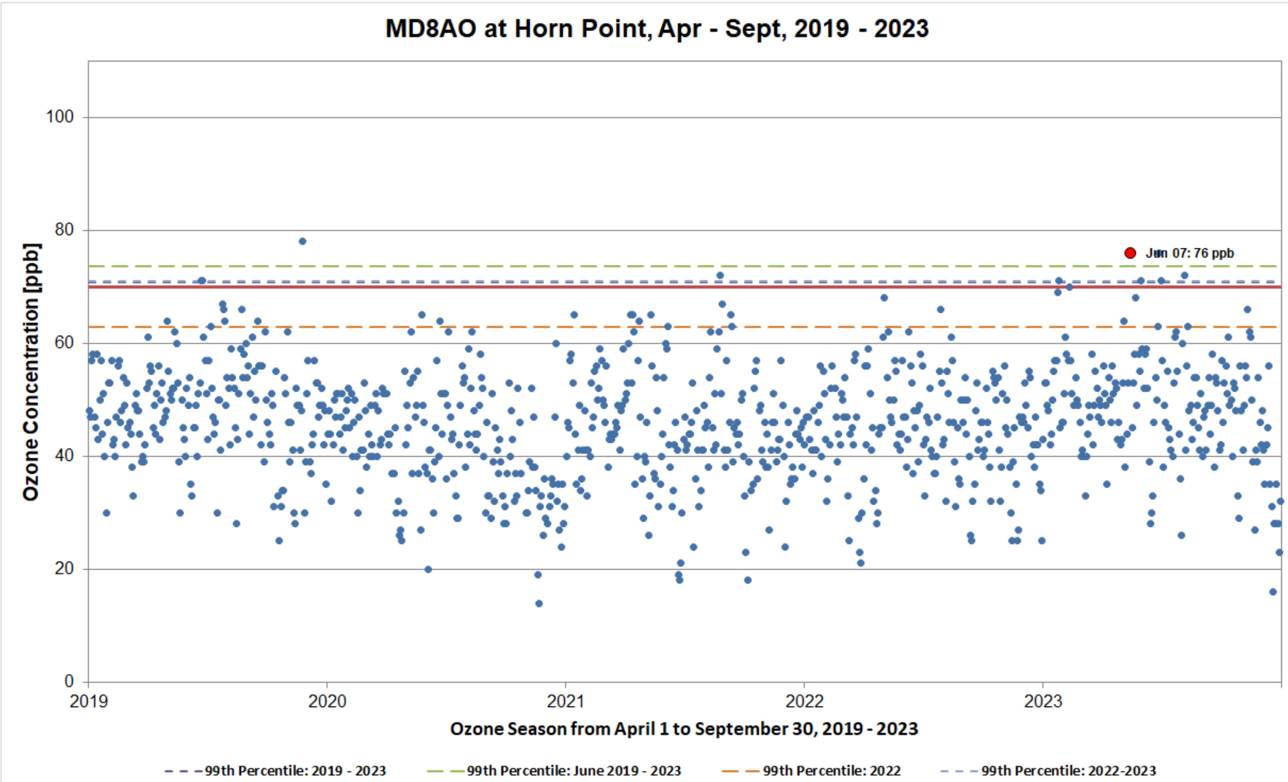


Figure 19. As in Figure 18 except for Horn Point.

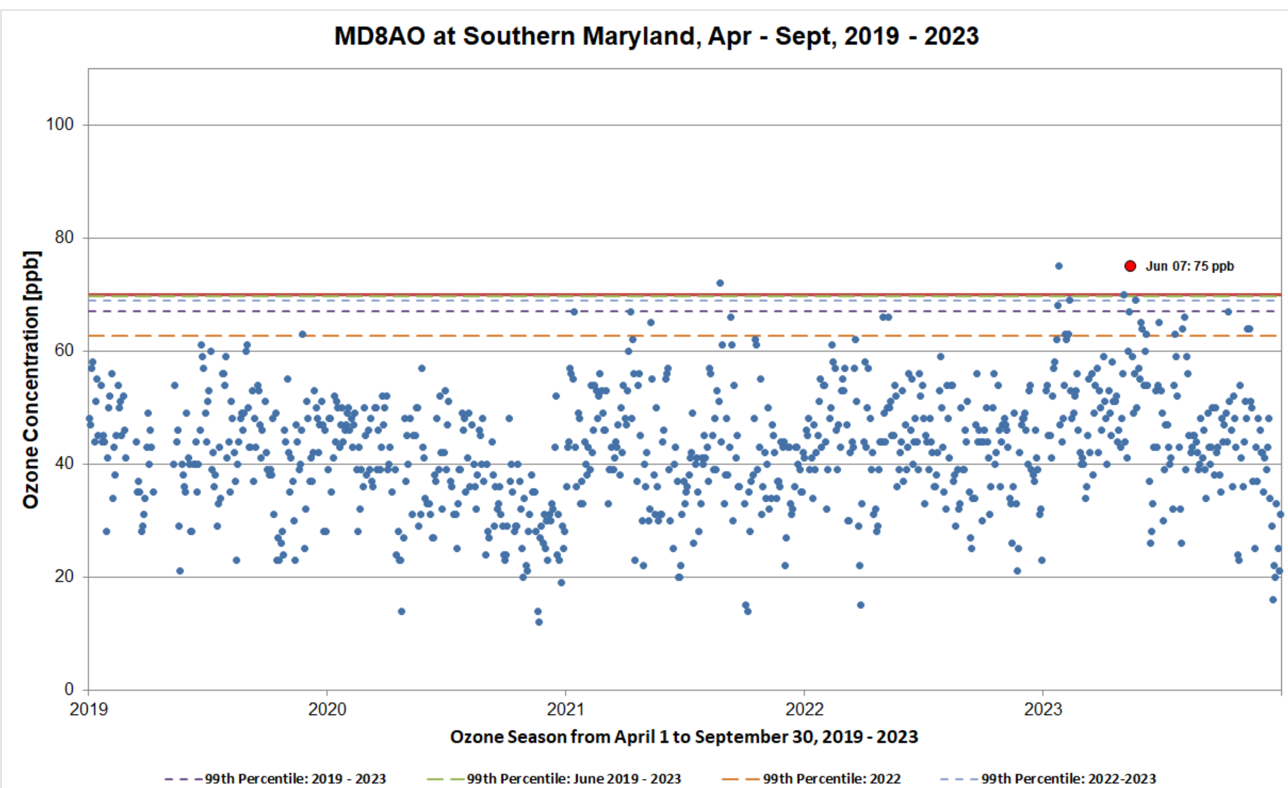


Figure 20. As in Figure 18 except for Southern Maryland.

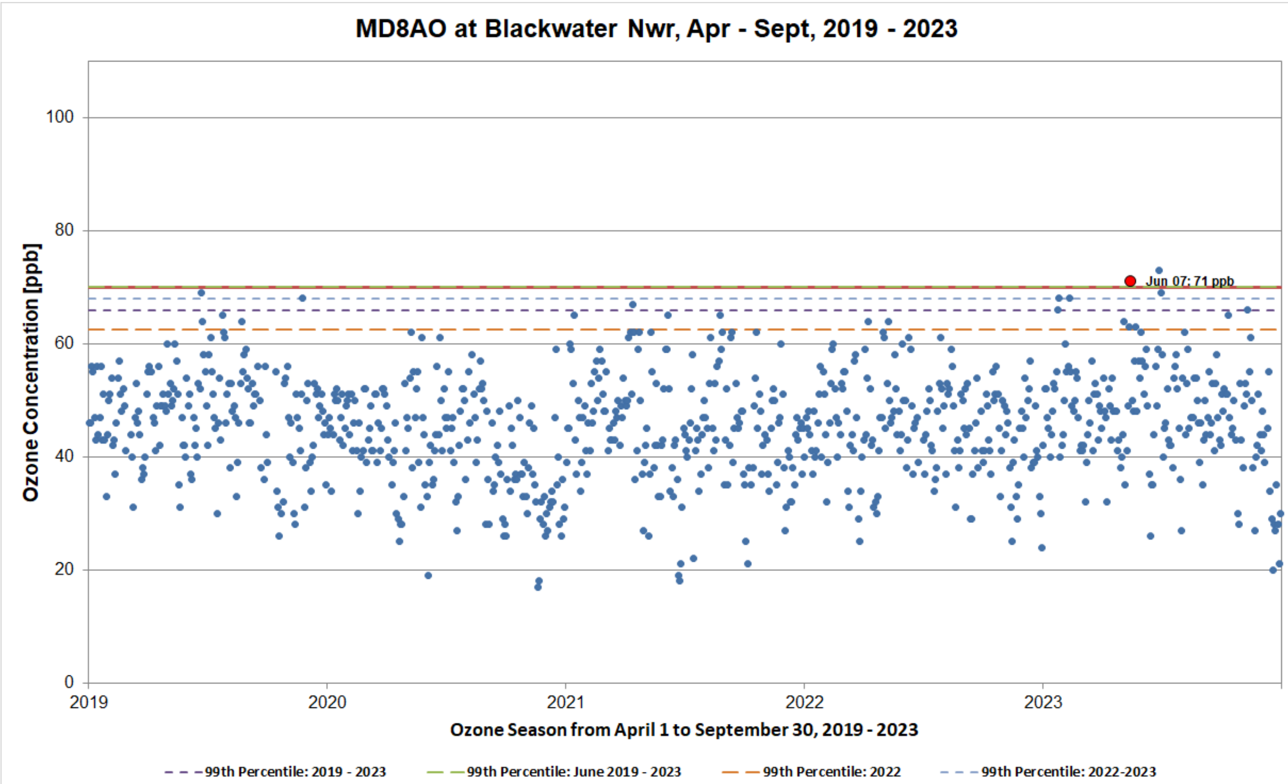


Figure 21. As in Figure 18 except for Blackwater NWR CASTNET.

The fact that all monitors exceeding on June 7 all surpass the 99th percentile for show the June 7 data was influenced by an exceptional event and show a "distinctive level" of monitored ozone concentration above the 99th percentile and which were also within the top four highest MD8AO concentration of the 2023 season. 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 Quebec wildfire emissions were transported to Maryland, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT; Rolph, 2015; Stein et al., 2015) model was used to approximate the movement of air parcels both forward from the fire and smoke region and backwards from Maryland. According to the conceptual model, a dense plume behind a cold front moved over Maryland. This plume was evident, for example, in Figure 22 over New York. Backward trajectories on June 7 from exceeding sites in southern Maryland show a path of air across the track of the smoke plume which existed across Pennsylvania on June 6.

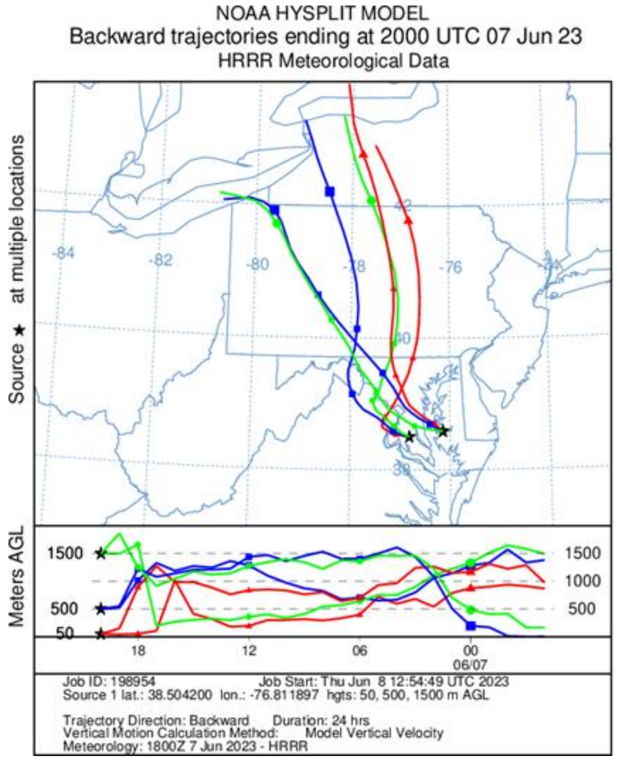


Figure 22. Backward Transport Trajectories from the High Resolution Rapid Refresh (HRRR) model with starting points centered around the location of the maximum ozone concentrations on June 7, 2023, beginning at 4 p.m. The trajectories show transport from the area of the smoke that existed across New York and Pennsylvania on June 6. Trajectories also show strong subsiding motion for the surface air (red trajectories, bottom), indicating smoke was well constrained to the surface.

3.2.1. Visibility

Aside from the surface observations of $PM_{2.5}$, smoke impacted visibility in dramatic fashion in Maryland. Visibility was so impaired in fact, that a coordinated research flight with the University of Maryland had to be conducted using Instrument Flight Rules (IFR) instead of the usual Visual Flight Rules (VFR). Locally, visibility was reduced to under 4 miles, and at times, below 2 miles. In southwestern Baltimore County, 7a.m. visibility was roughly 2+ miles during the morning of June 7 (Figure 23). An orange hue covers the image, due to the smoke, with the distant hillside approximately 1 mile away in severe haze.

Figure 23. Photo from southwest Baltimore County, Md. on the morning of June 7, 2023, looking east, at approximately 07:00 am EDT. The distant hillside is approximately 1-mile from the camera. A hazy sun and orange sky typified the morning of June 7 around Baltimore.

3.2.2. Evidence of Ozone Transport via Ozonesondes

MDE contends ozone formation from the Quebec fires occurred quickly and upwind of Maryland and was then transported to the state as a cause of the ozone exceedances above the 99th percentile of recent historical data. With a heavy smoke burden evident by $PM_{2.5}$ concentrations greater than 100 µg/m^3 across the entire upstream airmass over New York and Pennsylvania, MDE requested ozonesondes be launched on June 7 from the Howard University (HU-)Beltsville site (see Figure 2). One launch was completed on the afternoon of June 7 and showed elevated ozone concentrations through the planetary boundary layer (Figure 24). What is striking in the profile is the incredibly low temperatures within the profile (Red line Figure 24). Though ozone concentrations greater than 70 ppb exist through 2.5 km, the temperature at the top of the residual layer was less than 0°C (32°F, or lower than the freezing point!!). This was an incredibly cool temperature to achieve ozone over 70 ppb at that altitude. Wind speeds were also greater than 5m/s through most of the layer, or roughly 10 mph or greater. As with temperature, these conditions are typically unfavorable for high ozone concentrations except in the presence of smoke. As such, MDE offers this ozonesonde as further evidence of the clear causal relationship between the smoke and high ozone concentrations in Maryland.

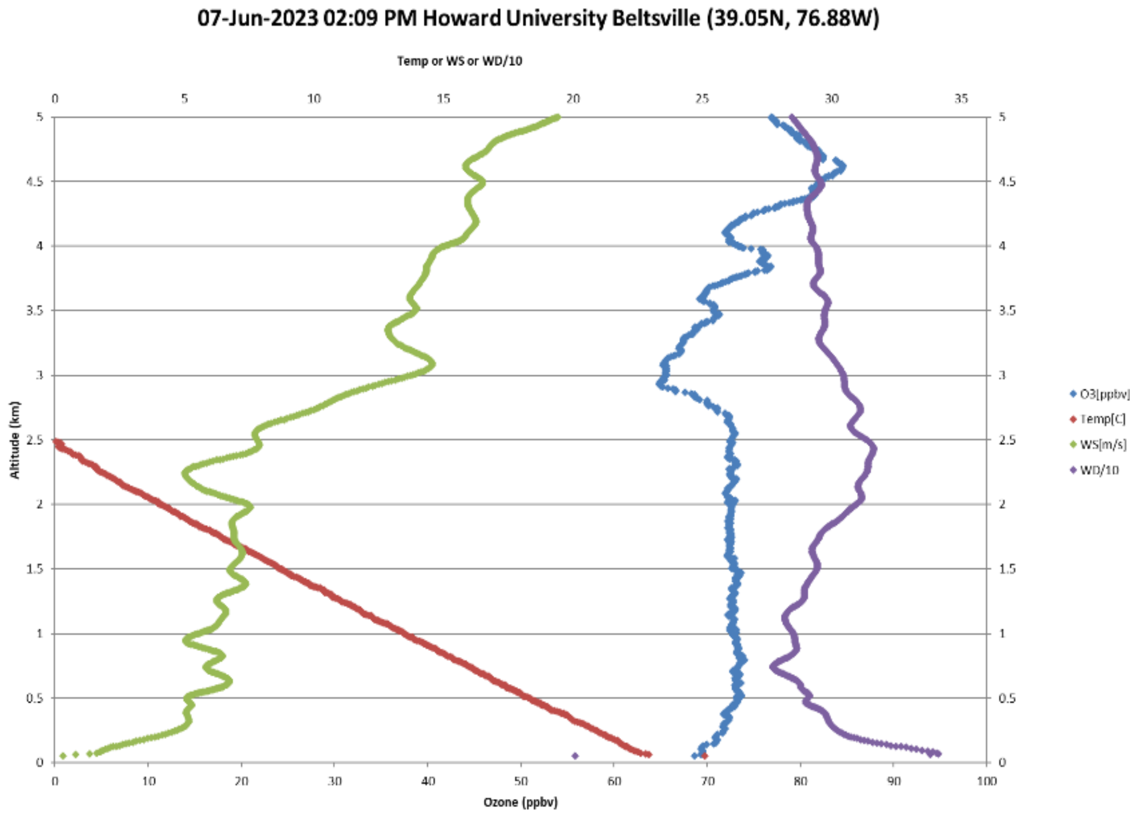
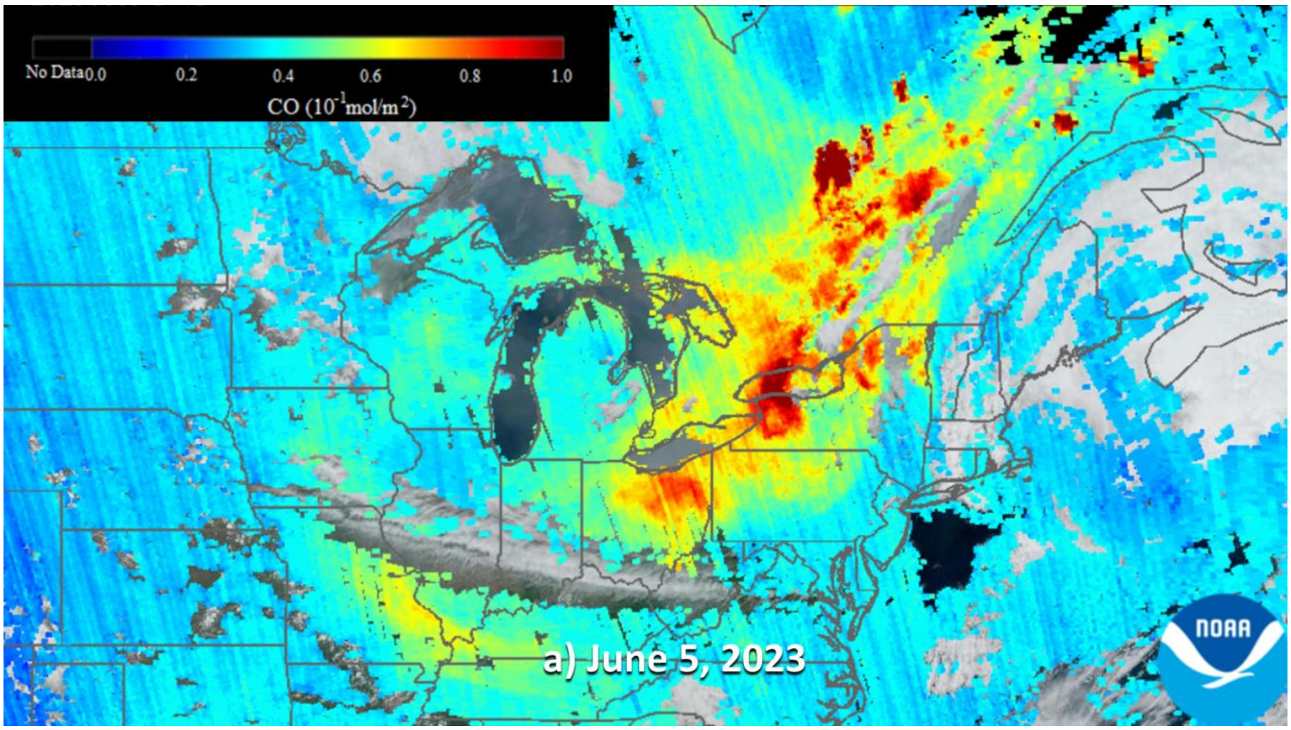


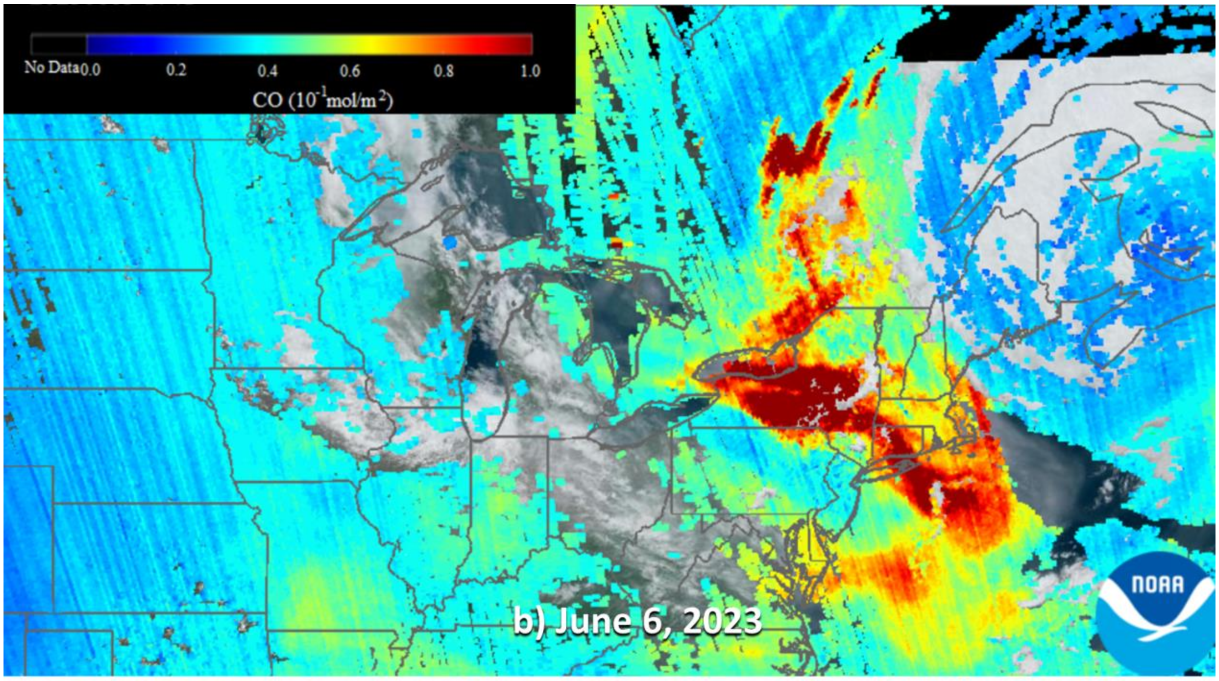
Figure 24. Ozonesonde launched from Howard University Beltsville on the afternoon of June 7, 2023. 2:09 p.m. is equivalent to 18:09 UTC. Temperature and winds are given by the top horizontal axis. Temperature (°C, red), wind direction (degrees divided by 10 [180° is shown as 18 on graph], purple), wind speed (m/s, green), and ozone (ppb, blue) are shown from the surface through 5 km AGL. Ozone is given on the bottom horizontal axis. Temperature and winds are given by the top horizontal axis.

3.2.3. Evidence of Wildfire Emissions via Satellite

Smoke as viewed from satellite visible wavelengths or tracked by surface concentrations already revealed a plume of smoke being transported from Quebec, across New York, Pennsylvania, and to Maryland. Satellite retrievals are capable of tracking wildfire species as well. When in combination with other analyses, they can 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) and can play a large role in ozone production (EPA, 2006). Total column CO (the sum of 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 that of the ozone exceedance conceptual model (Figure 12). Transport of smoke was noted by satellite in the conceptual model section of this document. For completeness, below are CO retrievals from TROPOMI for June 5, 6, and 7. A diffuse area of CO was noted northwest of Maryland on June 5 (Figure 25a). This was consistent with diffuse smoke across the Great Lakes that moved into Maryland on June 6. This smoke and related CO was thus evident on June 6 over Maryland (Figure 25b). An area of high CO concentrations was noted north of Maryland on June 6, with concentrations beyond the default scale provided by the source. Concentrations of

CO were more diffuse as this smoke tracked through Maryland on June 7, but nonetheless showed presence of the smoke (Figure 26c). The CO network in Maryland tracked this large CO increase well (shown later). A dense CO plume was again noted north of Maryland, which was the next wave hitting Maryland on June 8, but was not relevant to the demonstration here. CO tracking by satellite provides further evidence that wildfire emissions influenced ozone in Maryland on June 7, 2023.





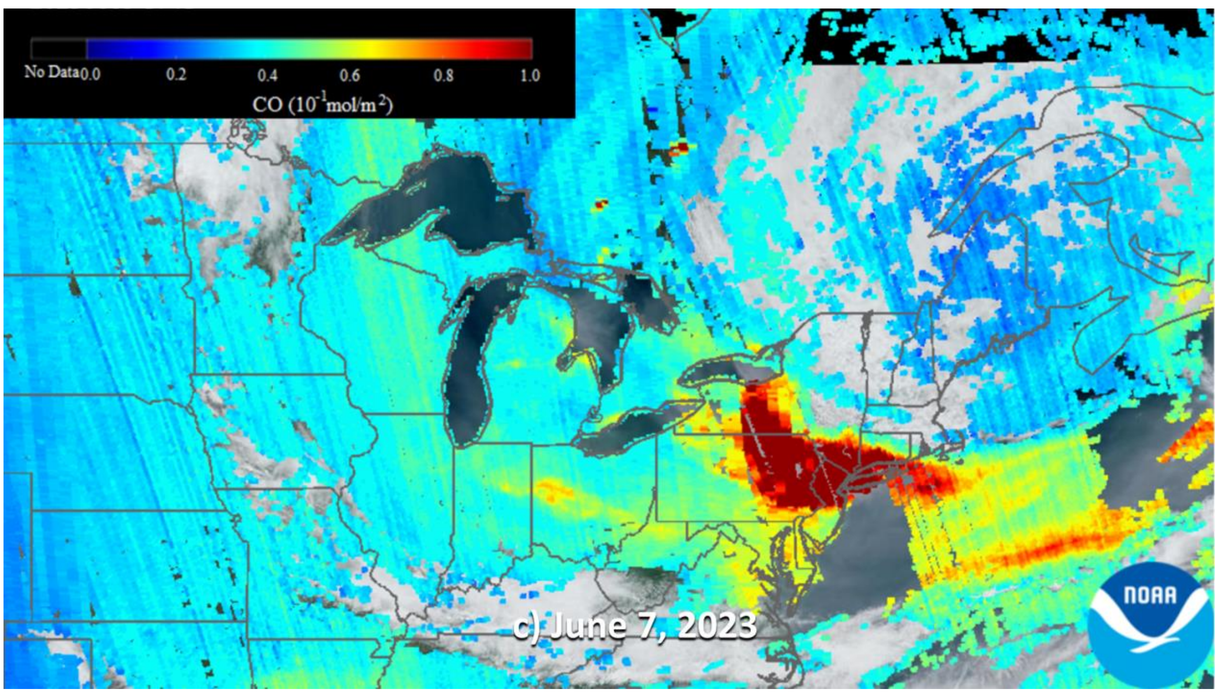


Figure 25. Carbon monoxide: column concentrations for June 5-7, 2023 (a-c). Wildfires are inefficient sources of combustion, often producing copious amounts of carbon monoxide (CO) as a result. From June 5-7, a plume of CO associated with the movements of the visible smoke plume traveled from Quebec, southward to the Mid-Atlantic. Darker reds indicate greater CO concentrations in the atmospheric layer. Greens and blues indicate low concentrations of CO in the column. The dense CO plume north of Maryland on June 7 is a secondary plume which hit on June 8 and is not considered in this demonstration. Satellite source is TROPOMI. Concentrations are given as Mole Fraction in Air. Source of the images was NOAA's Aerosol Watch: https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/.

3.3. Q/d Analysis

EPA guidance[14] 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 a simple comparison of the ratio of Q, the daily tons of VOC and NO_x 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[15] 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 CH_4)
= 2 kg/Mg (4 lb/ton) for nitrogen oxides (NO_x)

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

[14] *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentration*s. EPA-HQ-OAR-2015-0229-0130, U.S. Environmental Protection Agency, Section 3.5: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf
[15] Ibid.

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 U.S. conifer forests. Note that our results could increase by a factor of 6 were the high end of emissions expected.

Between June 4 and June 6, 586,520 hectares (1,449,322 acres) burned across Canada, according to satellite measurement techniques employed by the Canadian Wildland Fire Information System (CWFIS)[16]. Fires were most active within Quebec at this time and of the 586,520 hectares burned across Canada, 437,360 hectares (~1,080,741 acres), or equivalent area of the U.S. state of Rhode Island (400,125 hectares) burned across Quebec (Figure 26). Daily area burned across Quebec showed an intense period of burning during the June 4-6 period, peaking at over 180,000 hectares in one day on June 5, 2023.

Assuming a lower threshold of emission per area burned 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 * 1,080,741 acres
Ehc = 259,377,840 pounds of HC
Ehc = 129,689 tons of HC emitted during the period from June 4 to June 6, 2023

Similarly for NO_x:
Enox = 4 lbs of NO_x / ton of forest fuel consumed * 10 tons fuel / acre * 1,080,741 acres
Enox = 43,229,640 pounds of NO_x
Enox = 21,615 tons of NO_x emitted during the period from June 4 to June 6, 2023

[16] https://cwfis.cfs.nrcan.gc.ca/datamart [Retrieved August 29, 2023]

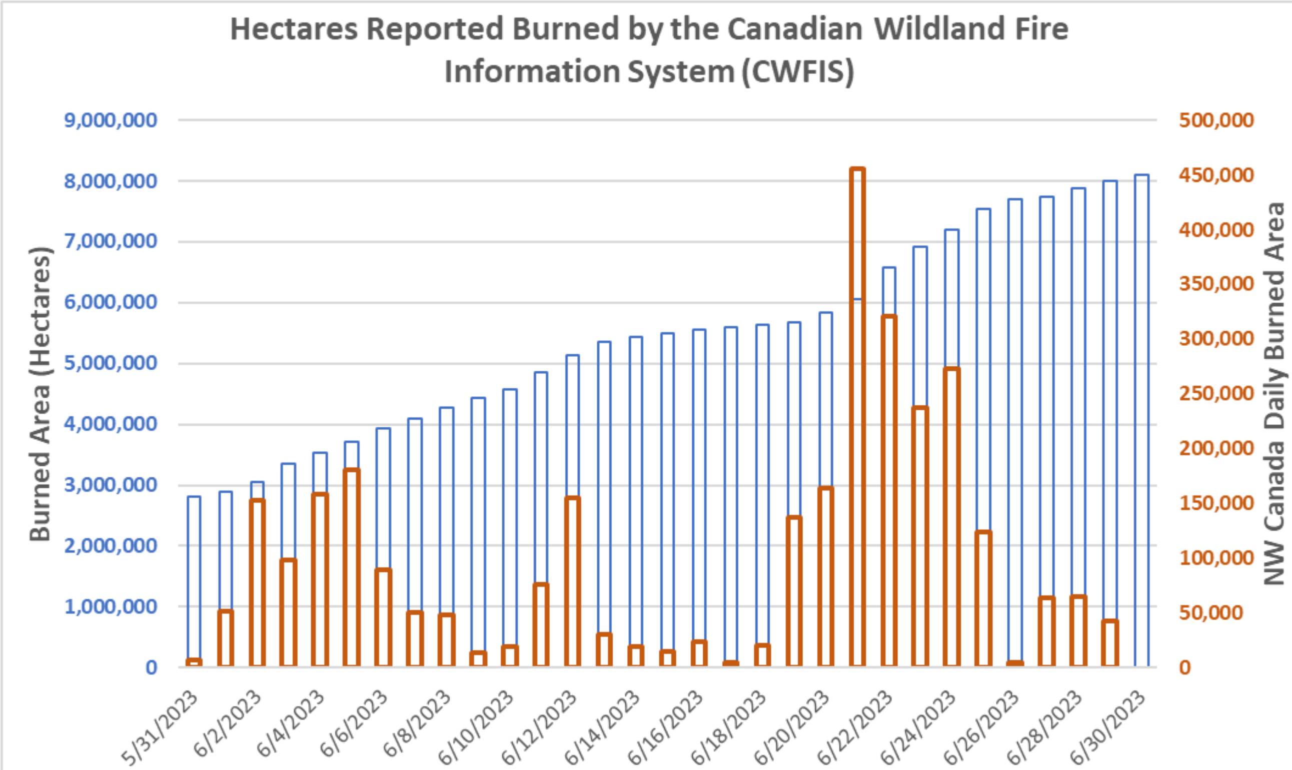


Figure 26. Hectares burned reported by Canadian Wildland Fire Information System (CWFIS). Burn area is estimated by satellite. Cumulative burned area for all of Canada is given as blue bars while daily area burned in Quebec is given in hallowed orange bars. There is a burn area increase equivalent to nearly the size of Rhode Island between June 4 and June 6, 2023, leading to a large increase in emissions in that time period.

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 * 129,689 = 77,813 tons of reactive HC emitted during the period of interest. No adjustments are suggested for the NO_x emissions. Total rHC and NO_x emissions over the period would therefore be 77,813 + 21,615, or 99,428 tons over the three days. On average, this results in a daily emission rate, or Q, of 33,143 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 centroid of the fires (~48.16°N, 77.52°W) will be calculated to MDE's Essex monitoring site. The Euclidean distance between the two points yields a length of 614 miles, or 988 km.

3.3.3. Q/d Estimate

Using the values determined above, Q/d becomes 33,143 tpd divided by 988 km or 34 tpd/km (Table 6). This value is below the EPA recommended level of 100 tpd/km indicating clear causality. However, this value is eight times the magnitude of the concurred demonstration done by Maryland in 2017, when the Q/d value from the Fort McMurray fires was only 4.1. If instead we aggressively assumed emissions from the out-of-control fire just on June 5, with 180,381 hectares (445,731 acres) burned, Maryland's Q/d value climbs to 42; still below 100, but now within the range of Q/d values within demonstrations cited within the exceptional events guidance[17]. Lastly, a less conservative approach of assuming 60 tons fuel per acre while just using the emissions from the worst burn day on June 6, (very similar acreage was burned on June 5 as well), the Q/d value makes a very large jump to 249. This seems a more reasonable value given the massive amount of smoke in the air. This more than satisfies the recommendation of 100 for a clear causal relationship between smoke and ozone.

Table 6. Q/d analysis for various scenarios.

Acres	Ehc (tons)	Enox	Q	No. days burning	d	Q/d	Description
1,080,741	129,689	21,615	33,143	3	988	33.5	Standard Q/d
445,731	53,488	8,915	41,007	1	988	41.5	June 6 only
445,731	320,926	53,488	246,044	1	988	249.0	June 6 only with 60 tons/acre

Taking a slightly different approach, MDE considered the basis for the EPA guidance and looked at emissions from one of the four fires EPA relied on in developing their guidance. Appendix A2 of the EPA Exceptional Event Guidance Document indicates that EPA based their conclusions on 12 km grid CMAQ modeling of four 2011 multiday fires: Wallow, Waterhole, Big Hill, and Flint Hills. Emissions from the fires were based on a program called SMARTFIRE. Using information available on the Wallow Fire, MDE approximated the emissions that might be calculated for the Quebec fires.

The Wallow Fire was located in eastern Arizona and western New Mexico from May 29, 2011 through July 8, 2011, and burned 841 square miles (538,240 acres) by June 26th. The maximum daily emissions from that fire were reported as approximately 15,000 tons of rVOC and 1,000 tons of NO_x. [Simulating Fire Event Impacts on Regional ozone and $PM_{2.5}$ and Looking Forward Toward Evaluation, Kirk Baker, EPA October 5, 2015 and Using SOAS and related field study data for scientific and regulatory modeling, Kirk Baker, EPA, undated; both are slide presentations] If this fire were scaled up by a factor of two to approximate the total acreage burned in the Quebec fires, then the daily emissions were as high as 30,000 tons for rVOC and 2,000 tons for NO_x. These emissions produce a Q of 49,518 tpd and Q/d becomes 50 for Maryland. As stated in exceptional events guidance[18]: "The O3 values within the approved demonstrations generally were associated with Q/D values above 50 tpd/km (Figure A2-1)". A value of 50 while below 100, is within the

[17] *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentration*s. EPA-HQ-OAR-2015-0229-0130, U.S. Environmental Protection Agency: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf
[18] Ibid. Page 17.

range of accepted concurrences, and is over 10x higher than Maryland's concurred Fort McMurray demonstration in 2017. Taking a less conservative approach and recalling that a worst case fuel loading would increase our Q results by a factor of six, Q/d would in this case result in ~300 tpd/km, well above EPA's threshold of 100 tpd/km. Several of the potential scenarios show direct causal relationships given the EPA Q/d criteria. Such findings satisfy both Key Factors 1 and 2 in the EPA Exceptional Events Guidance and further suggest the smoke plume's impact on Maryland was exceptional in nature.

EPA guidance indicates that if a Q/d analysis 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., 2015); 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 May and July 2016 was done in those exceptional event analyses. 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 3100 km 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 7). The May event demonstrated here 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. In the June 7, 2023 event the Q/d value was 33, well below 100, despite immense smoke impacts indicated by fine particulate values in excess of 100 µg/m^3. However, in the least conservative approach, the Q/d was nearly 2.5 times the threshold of 100 for Q/d, indicating a clear causal relationship. The obvious smoke impacts logically lends to a much higher calculated Q/d value than the recommended value. At 33, the Q/d calculated as a baseline value for June 7 compared consistently and favorably with other fire events in Maryland, and MDE believes this shows a clear causal relationship between the ozone and smoke.

Table 7. Q/d Analysis for three Canadian Wildfire events impacting Maryland.

ACRES	Ehc	Enox	Q	No. days burning	d	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 easily apply to long-range transport scenarios in Maryland to clearly fit the expectation of a clear causal impact, other evidence presented below continues to demonstrate that the smoke plume from the Quebec fires caused elevated ozone levels in Maryland.

3.4. 99th Percentiles

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 established 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[19], the 99th percentile was calculated for all Maryland monitors for all days of the ozone season (April – September) from 2019-2023. Additional 99th percentiles were calculated using subsets of days as summarized and presented previously in section 3.1 and in Figures 19-34. For convenience, a summary table with comparisons of all the 99th percentiles is given in Table 8.

Table 8. 99th percentile values and comparisons to observations on June 7, 2023.
The 17 Maryland monitors for which MDE is seeking exclusion due to exceptional event influence have their 99th percentiles presented based on data from April 1 – September 30, 2019-2023, and other subsets as defined in section 3.1. The final six columns highlight which monitors exceed their 99th percentile level ("YES") for a given data set and day. Blanks indicate the monitor did not meet the 99th percentile for that dataset.

		99th Percentile [ppb]				June 7, 2023			
Name	**AQScode**	**All Data**	**June Only**	**2022**	**2022-2023**	**All Data**	**June Only**	**2022**	**2022-2023**
Essex	240053001	75	86.02	70	75				
Pg Equestrian Center	240338003	72	74.06	65	72.46			YES	
Hu-Beltsville	240330030	70	72.89	62.88	70			YES	
Rockville	240313001	67.86	71.51	67.4	69.74				
Calvert	240090011	63.86	67.28	59	66	YES	YES	YES	YES
South Carroll	240130001	68.86	73.53	64.2	71				
Hagerstown	240430009	65	69.68	62.25	67.47				
Glen Burnie	240031003	71.86	80.18	64.22	67.4				
Piney Run	240230002	64.86	67.65	62.5	67.55				
Southern Maryland	240170010	67	69.58	62.72	69	YES	YES	YES	YES
Padonia	240051007	71.86	76.02	65.48	72.26				
Aldino	240259001	72	75.51	68	71.82				
Millington	240290002	68.86	75.08	67	71.4				
Fair Hill	240150003	70.86	72	67	70.4				
Frederick Airport	240210037	69	76.68	63.27	74			YES	
Edgewood	240251001	75.86	79.54	66.23	75				
Blackwater Nwr	240199991	65.86	70.08	62.44	68	YES	YES	YES	YES
Beltsville	240339991	72.86	75.04	66.72	71.71				
Horn Point	240190004	70.86	73.65	62.8	71	YES	YES	YES	YES
Lake Montebello	245105253	69	83.24	69.88	73.39				

[19] *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations*. EPA-HQ-OAR-2015-0229-0130, U.S. Environmental Protection Agency: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf

3.5. Evidence that the Fire Emissions Affected the Monitors

3.5.1. 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 easily track their transport, they do not necessarily confirm the existence of smoke at the surface, by themselves. The MDE monitoring network observes total $PM_{2.5}$ mass, as well as other pollutants like CO and NO_x, which can act as tracers of wildfire emissions. Analyses of these various species which can be attributed to wildfires are presented below. The analyses show the ozone episode in Maryland was characterized by enhanced concentrations of wildfire species.

3.5.2. Particles

$PM_{2.5}$ can be both a primary pollutant and a resultant secondary pollutant of wildfire emissions downstream, as photochemistry within the plume converts certain species to aerosols. The entire MDE network showed a correlated increase in $PM_{2.5}$ 24-hour averages from June 6-9, which aligned with the onset of the smoke plume in Maryland (Figure 27). An additional episode of smoke is visible on June 29-30. No other period of the month exhibited such a large, coherent increase across the entire Maryland network. The early June event possessed the highest particle observations of the month. The fine particle observations therefore provided additional evidence that along with ozone and ozone precursors, fine particles were transported within the smoke-affected airmass and were a distinct indicator of wildfire emissions.

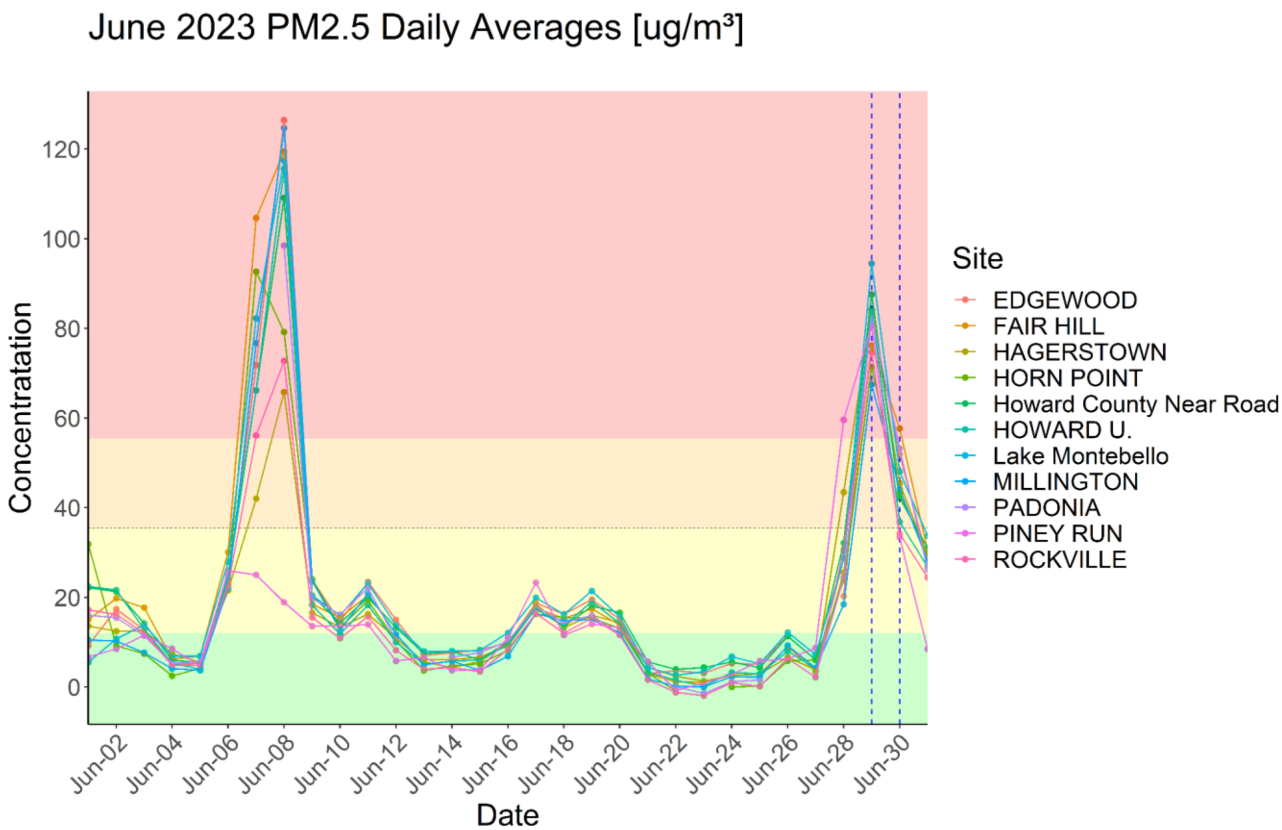


Figure 27. Daily averaged fine particle ($PM_{2.5}$) concentrations for all sites available in Maryland for the month of June, 2023. June 7-8 had the highest daily average concentrations for the month of June, and possibly in the entire historical record of MDE. The two vertical lines highlight the second event at the end of the month. Colored backgrounds are AQI colors.

3.5.3. Carbon Monoxide (CO)

CO, previously identified as a wildfire smoke indicator, can play a role in ozone production, and followed similar trends to other pollutants over the lifetime of the event (Figure 29). Essex, HU-Beltsville, and the Howard County (HoCo) Near Road sites all experience the second highest CO concentration of the entire month of June on June 7 and 8, with the highest concentrations experienced during the June 29-30 event. All monitors across the state except Piney Run showed a nearly uniform increase in CO. Piney Run was not similarly affected because it was located far enough west to not be in the densest plume hitting eastern locations. The increase in CO at eastern monitors coincided with increased wildfire related fine particle concentrations, providing irrefutable evidence for the direct impact of the smoke at the surface. Consistent with these surface observations were total column CO retrievals from satellite data generated via Aerosol Watch, Figure 26). The satellite showed a plume of enhanced CO starting over Canada, moving southward to reach Maryland in line with the time frame outlined in the conceptual model (see section 2) and CO concentrations observed by the MDE network (Figure 28). Together, these observations indicated that wildfire-related ozone precursors were present to contribute to ozone production in Maryland on June 7, 2023.

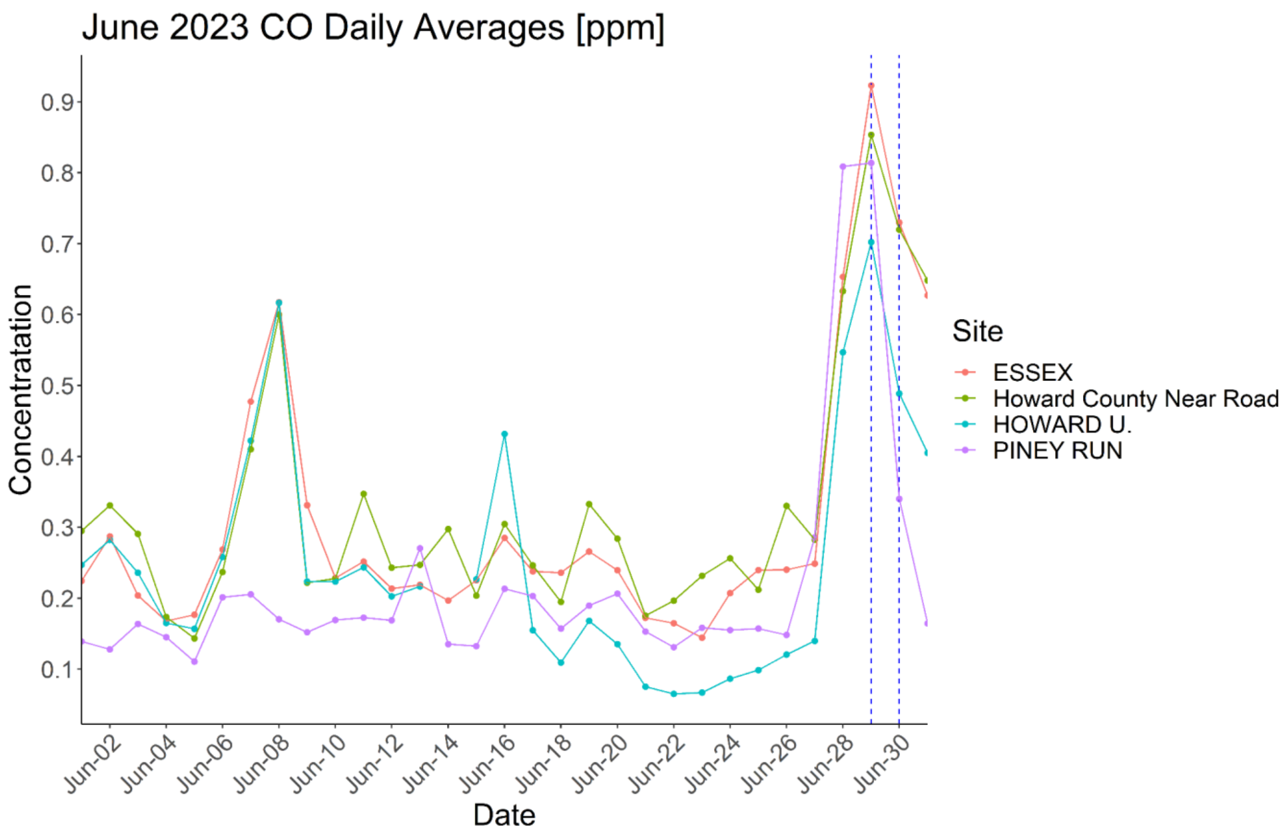


Figure 28. Daily carbon monoxide (CO) at available sites in Maryland. June 7-8 were the second highest event in the month of June. The two days highlighted by the vertical lines were the June 29-30 event and were the highest event in the month. The June 7-8 event was roughly 2-4 times higher than the typical CO daily concentration in Maryland. Piney Run was on the western fringe of the dense smoke, and thus did not have as high concentrations of CO.

3.5.4. Nitrogen Oxides Historical Context: Local June Aged Nitrogen, and Total Reactive Nitrogen

Singh et al. (2012) showed that ozone production rates from wildfires in California were dependent upon available NO_x (NO_x = sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2)) and that NO_x from the fires themselves was relatively low. However, NO_x emissions from fires can vary greatly and research has noted the uncertainties in the influence of wildfire emissions from one to another (e.g., Hu et al., 2008). In smoke, ozone production may occur more rapidly than otherwise would occur due to additional precursors present. As such, NO_x in urban areas may augment ozone production within the smoky and already ozone laden airmass. The key point is that ozone will not have reached as high MD8AO concentrations without the presence of the smoke. NO_x emissions across the upstream region of Maryland were already shown to be the lowest on record in June of 2023. However, as Dreessen et al. (2016) predicted as a result of the June 2015 case:

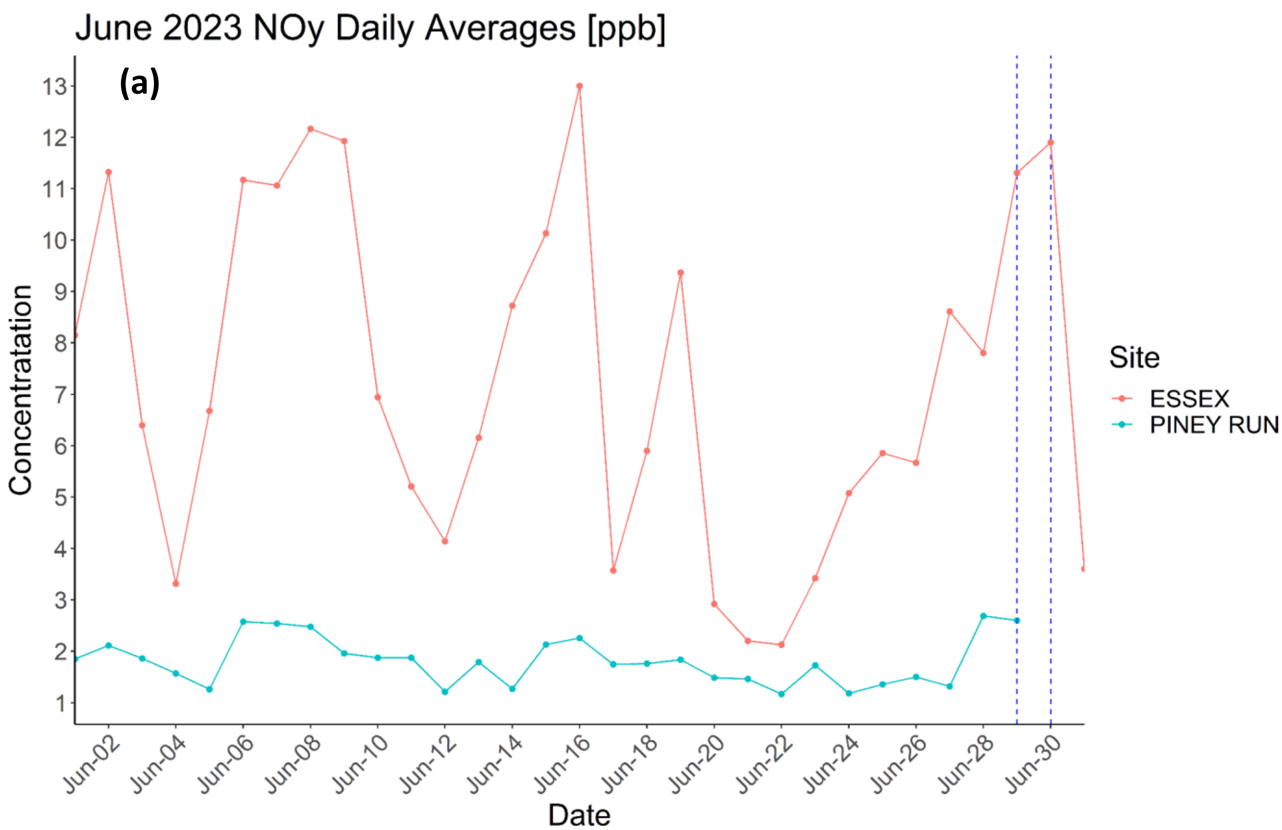
> "This [June 2015 smoke event] shows that the drastic NO_x reductions across the [Ohio River Valley] may not be enough in future wildfire events and that future events [may impact NAAQS compliance]."

An ozone exceedance was unlikely to occur in Maryland and/or to such a degree, without the burden of smoke. As the smoky airmass aged, photochemical reactions within the plume made it “ozone-ripe”, creating an airmass easily creating ozone even by minimalistic NO_x contributions. Then as suggested by Dreessen et al. (2016), any additional NO_x, either traceable to the fire source itself or any anthropogenic source, was stored within the smoke plume via the abundance of VOCs.

If wildfire NO_x was stored within the smoke plume due to the abundance of VOCs as discussed in Dreessen et al (2016), strong evidence of aged NO_x would be present. Further study of the composition of the Nitrogen in the airmass showed that the total active nitrogen (NO_y) was one of the largest daily NO_y observations in June of 2023 (Figure 30a). Furthermore, NO_z, ($NO_z = NO_y\text{-}NO_2\text{-}NO$) a measure of the reactivity and NO_x storage within an airmass was also the highest daily average concentration among the last six years (Figure 30b). All this despite the lowest monthly June EGU NO_x emissions upstream to-date (Figure 5). Daily average NO_y concentrations for all June days in 2023 at Maryland monitors showed that June 7,2023 had one of the highest NO_y 0\observations at both urban and rural background sites over the entire period, including the other strong smoke periods in late June of 2023. There was no doubt the airmass was characterized by abundant NO_x (NO_y includes all NO_x plus reservoir species) not seen even when upstream EGUs were emitting larger amounts of NO_x prior to the 2017-2023 era.

Analysis of nitrogen species allows some qualitative source attribution. Generally, it is difficult to distinguish NO_x sources from each other (i.e., point, mobile, wildfire). Fresh NO_x emissions tend to be dominated by Nitrogen Oxide (NO) or even Nitrogen Dioxide (NO_2) rather than other non-NO_x speciations. NO has a shorter lifetime due to its high reactivity, and NO_2 will eventually react within the smoke plume into other species (ozone) or more complicated nitrogen species, thus an airmass with elevated NO_z tends to indicate aged emissions amid a reactive airmass.

The concentration of NO_z on June 7 was the highest in June over the past 6 years at Essex, and the second highest in the past six years at Piney Run (Figure 29b). These daily averages overwhelmingly show the smoke was composed of older, “storage” nitrogen species on June 7. Since NO_z may dissociate and give up NO_2 for ozone reactions, a high NO_z value indicates a higher ozone potential. MDE therefore contends the increased NO_z observed during the ozone event was a result of efficient NO_x storage within the smoke plume sourced from the fire itself and diminutive regional NO_x contributions, both which caused NO_y and NO_z to be beyond contemporary concentrations in Maryland, further leading to ozone at statistically extreme concentrations.


June 2023 NOy Daily Averages [ppb]
(a)
Concentratation
Date
Site
ESSEX
PINEY RUN
13
12
11
10
9
8
7
6
5
4
3
2
1
Jun-02
Jun-04
Jun-06
Jun-08
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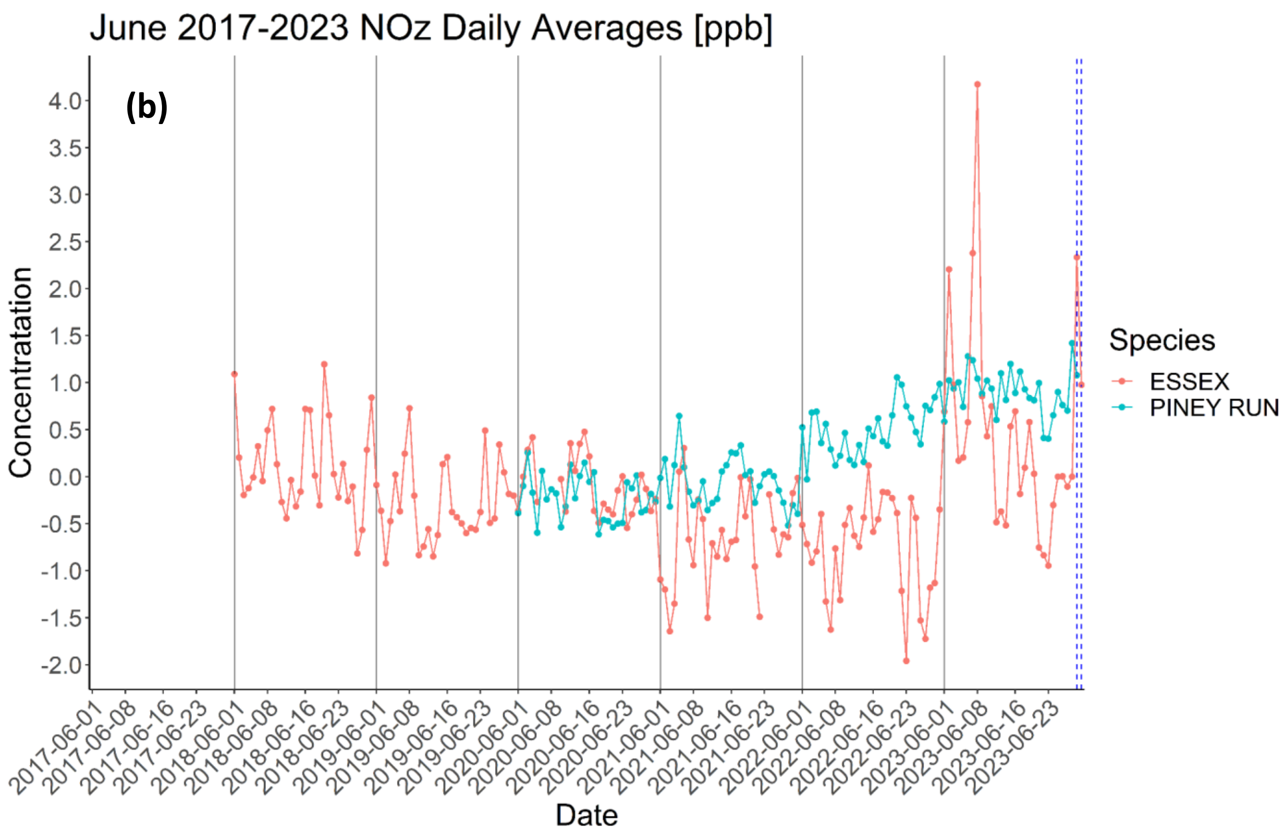

Figure 29. (a) NO_Y and (b) NO_Z for all available Maryland monitors for days in June from 2017 to 2023. June 7 had one of the highest daily NO_Y concentrations at both Piney Run and Essex sites (rural and urban) and the highest NO_Z concentrations in the past six years. The two days highlighted by the vertical dashed lines were the June 29-30 event.

3.5.5. Model Data: CMAQ Ozone Direction from the fires

As a last example that the smoke contributed to ozone production, MDE offers fire specific modeling done by the University of Maryland College Park (UMD). UMD and MDE have a long-standing research partnership in Maryland to understand the dynamics of Maryland air quality. Prior to this ozone season, UMD, at the direction of MDE, was tasked with modeling contribution to ozone concentrations in Maryland from wildfires. In serendipity, this allowed some "head start" on some ozone events in 2023 influenced by fires. While this capability is still under development as of this writing, some cases are available for presentation.

Modeling of the fires across Quebec in early June show ozone "plumes" similar to the smoke emanating from the fires. On June 6, an area of heightened ozone with concentrations of 50-60 ppb covered all eastern New York and northeastern Pennsylvania. More important than the magnitude of this modeling was the spatial coherency of the heightened ozone to the smoke plume during peak photochemistry hours on June 6, prior to arriving in Maryland. While the magnitude of the smoke from the fires changes based on the emissions inventory, which is a significant component under development for this process with UMD, the modeling shows ozone directly from the fires, spatially correlated with peak smoke prior to arrival of the plume of smoke that would hit Maryland on June 7 (Figure 30).

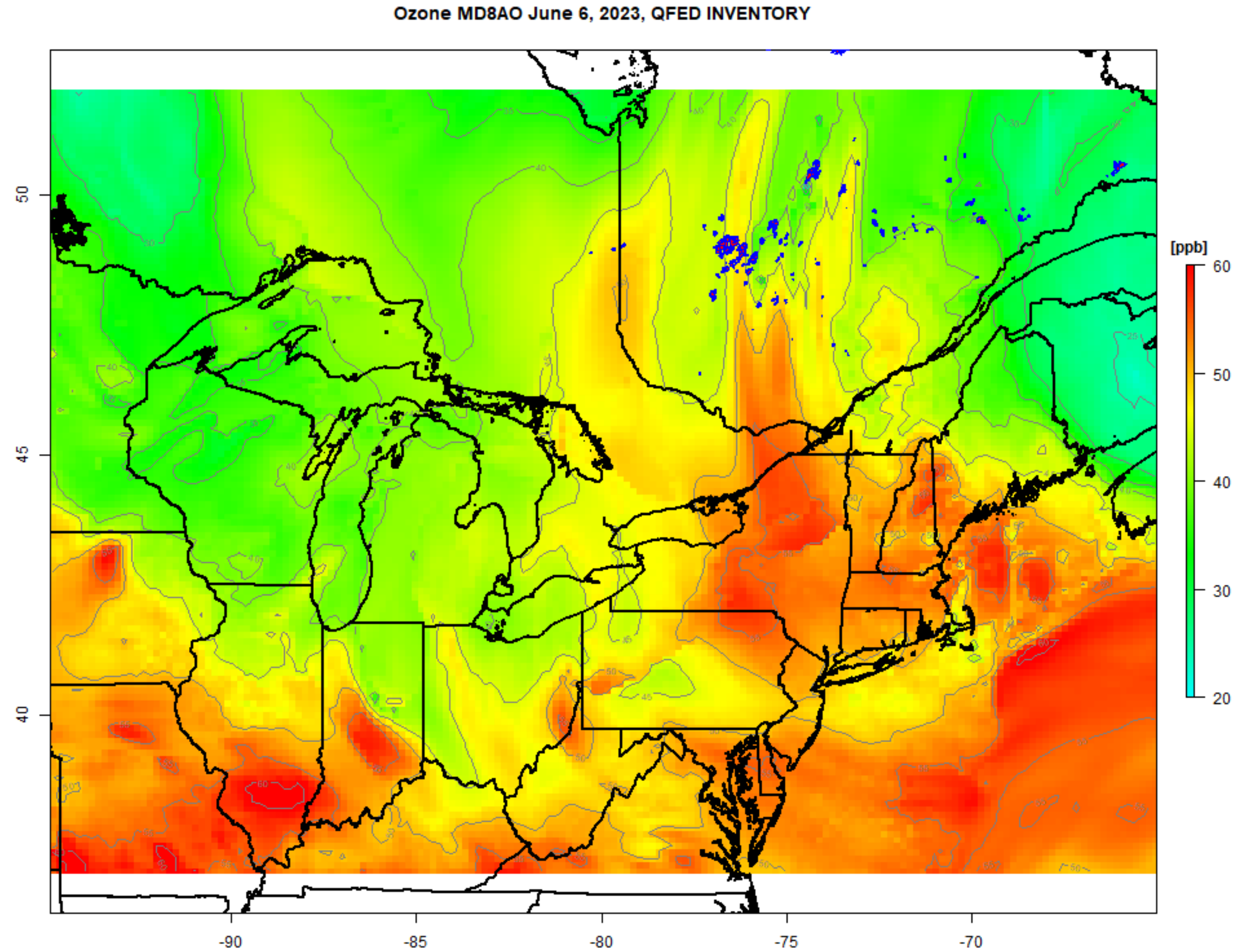

Figure 30. Plumes of ozone (colored fill and contours) streaming south from the fire locations (blue areas) in Quebec on June 6 using the CMAQ modeling done at University of Maryland College Park, with the QFED emissions inventory.

4. The Occurrence was a Natural Event

According to the Clean Air Act (CAA)[20] and the Exceptional Events Rule[21], an exceptional event must be "an event caused by human activity that is unlikely to recur at a particular location or a natural event"[22]. The Quebec fires were a "natural event". The Exceptional Events Rule defines a wildfire as "…any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions, or a prescribed fire that has developed into a wildfire. A wildfire that predominantly occurs on wildland is a natural event."[23] Based on the documentation provided in section 2 of this submittal which discusses the origin and evolution of the wildfire events, the Quebec fires qualify as a

[20] 42 U.S.C. 7401 et seq

[21] 40 CFR 50.14

[22] 42 U.S.C. 7619(b)(1), *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations*, EPA, September 2016, Page 30: https://www.epa.gov/sites/production/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf

[23] 40 CFR 50.1(n)

“natural event” because they were unplanned fires on wildland ignited by lightning. EPA generally considers the emissions of ozone precursors from wildfires on wildland to meet the regulatory definition of a natural event as defined in the NAAQS[24]. Accordingly, MDE has shown that the event is a natural event and 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 fires relevant in this demonstration were due to lightning that caused wildfire events on wildland. These fires were considered natural wildfire events by the EPA, 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 xxxxx on the MDE website for a comment period of 30 days**.** MDE received a letter of comments from yyyy (“The Commenters”) during this period addressing the June EE demonstration.

7. Conclusions

On June 7, 2023 smoke associated with wildfires across Quebec, Canada was transported to Maryland. This smoke produced ozone exceedances in southern Maryland, and heighted ozone across the state. Ozone precursors were present within the smoke, and ozone production directly downwind from the fires in the smoke plume was well modeled. NO_z was measured as one of the highest if not the highest June concentration in the past 6 years, meaning that in addition to ozone from the fires, NO_x reservoir species were present, supporting ozone potential in the plume. Upon arriving in Maryland, the smoke impacted all monitoring sites across Maryland’s air monitoring network, hitting eastern areas hardest. The monitored MD8AO concentrations reached 76 ppb on June 7, and resulted in at least one of the fourth highest concentrations of 2023 at 3 sites and met or beat the 99th percentile at these three sites. Additionally, the regionally heightened ozone concentrations became regulatorily relevant at Essex with a MD8AO of 69 ppb. The comparisons and analyses, provided in sections 2 and 3 of this demonstration support MDE’s position that the June 7 wildfire event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored ozone concentrations on June 7, 2023 and thus satisfies the clear causal relationship criterion.

The analyses provided in this demonstration supports MDE’s position that the Quebec wildfires, particularly from June 4 - 6, affected air quality in Maryland by June 7 in such a way that there exists a clear causal relationship between the event (June 4-6, 2023 burn period in Quebec) and the monitored ozone exceedances in Maryland on June 7, 2023, and thus satisfies the clear causal relationship criterion for

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recognition as an exceptional event. Based on these facts, MDE requests that EPA concur that the three MD8AO concentrations on June 7, 2023 (Table 9) exceeding the 70 ppb NAAQS at Horn Point (240190004), S. Maryland (240170010), the CASTNET site –Blackwater NWR (240199991) and the regulatorily significant 69 ppb at Essex (240053001),were impacted by an exceptional event. MDE formally requests that the data from these four monitors on June 7 be flagged as such and be excluded from use for regulatory determinations.

Table 9. The four ozone monitors at which MDE is seeking EPA concurrence for data exclusion of event influence air quality 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 2023 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 design value with no exclusion of data (Including) and if June 7 values are excluded from design value calculations (Excluding). Green highlighting indicates the monitors which MDE seeks exemption, based on the 4th high rankings.

			2023			
Site Name	AQSID	MD8AO, ppb (rank)	Fourth High (ppb)		EST DV (ppb)	
		7-Jun	Including	Excluding	Including	Excluding
Essex	24-005-3001	69 (9)	75	75	73	73
S. Maryland	24-017-0010	75 (2)	69	69	65	65
Horn Point	24-019-0004	76 (1)	71	71	66	66
Blackwater CASTNET	24-019-9991	71 (2)	68	68	64	64

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Appendix: A

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

Maryland
Department of
the Environment

Wes Moore, Governor
Aruna Miller, Lt. Governor

Serena McIlwain, Secretary
Suzanne E. Dorsey, Deputy Secretary

August 29, 2023

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

Mr. Sharac,

MDE requests 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 two CASTNET sites are as follows:

- Beltsville (240339991):

  June 2, 2023, hour 0 to hour 23
  June 29, 2023, hour 0 to hour 23
  July 12, 2023, hour 0 to hour 23
  July 17, 2023, hour 0 to hour 23

- Blackwater NWR (240199991):

  June 7, 2023, hour 0 to hour 23
  June 29, 2023, hour 0 to 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 multiple wildfires on the regulatory monitor sites. In early June, smoke from a local fire in New Jersey combined with smoke from fires in Nova Scotia and impacted ozone concentrations in Maryland. At several other times in June, transported smoke from numerous fires across Quebec impacted Maryland monitors. Later into July, smoke from a large number of fires in aggregate across central and western Canada influenced Maryland air quality as a transported plume subsided over the Mid-Atlantic. Instances of requested RF flags 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, particularly under considerations of a tighter ozone NAAQS.

Sincerely,

Ryan Auvil
Manager, Ambient Air Monitoring Program