# Exceptional Event Demonstration and Analysis of the June 2023 Western Canada, Nova Scotia, and New Jersey Wildfires and Their Impact on Delaware's Ozone on June 2, 2023

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## Acknowledgements

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# 1. Overview

The state of Delaware is located on the Delmarva Peninsula in the Mid-Atlantic region of the East Coast of the continental United States of America (CONUS). Delaware consists of three counties. The northernmost county, New Castle County, is included in the 2015 ozone National Ambient Air Quality Standard (NAAQS) Philadelphia-Wilmington-Atlantic City Non-Attainment Area (Philadelphia-NAA). This area is also called the Philadelphia Metropolitan Statistical Area (MSA). In addition to New Castle County, this NAA also includes five counties in eastern Pennsylvania, one county in Maryland and nine counties in southern New Jersey.

On April 12, 2022, the United States (U.S.) Environmental Protection Agency (EPA) announced the Philadelphia-NAA was redesignated to moderate non-attainment, "*Determinations of Attainment by the Attainment Date, Extensions of the Attainment Date, and Reclassification of Areas Classified as Marginal for the 2015 Ozone National Ambient Air Quality Standards*". According to the federal Clean Air Act (CAA), this entire NAA must attain the 2015 ozone NAAQS by August 3, 2024. Preliminary monitoring data for the state of Delaware shows that all three counties in Delaware are monitoring in attainment with the 2015 ozone NAAQS, with the 3-year design value (DV) below the 0.070 ppm 8-hour standard. This is not the case for all monitors in the Philadelphia-NAA, therefore the NAA is facing a possible bump-up to serious nonattainment in August 2024.

A state is eligible to seek a 1-year attainment date extension if they meet certain requirements. The requirement for determining eligibility for a 1-year attainment date extension in 40 CFR 51.1307(a)(1) is, "for the first 1-year extension, the area's 4th highest daily maximum 8-hour average in the attainment year is no greater than the level of that NAAQS."[1] In 2023 one monitor in Delaware, the Lums monitor, has a 4$^{th}$ highest ozone reading that is above the NAAQS. In order to meet the requirements for an extension, Delaware would need to exclude one of the fourth highest ozone reading from the Lums monitor, through an exceptional event demonstration. Delaware determined that on June 2, 2023, the Lums monitor was influenced by wildfire smoke. Therefore, Delaware is pursuing an exceptional event demonstration to exclude the June 2, 2023 monitoring data for the Lums monitor, in order to meet the 1-year extension requirements.

The Delaware Department of Natural Resources and Environmental Control (Delaware) has prepared this exceptional event demonstration for the Lums monitor, because we seek concurrence from the EPA to exclude monitored air quality data that bears regulatory significance from use in determining Delaware's compliance with the 2015 NAAQS for ozone due to the influence from wildfire smoke. This demonstration has been prepared in accordance with the requirements outlined in 40 CFR 50.14 and EPA guidance from 2016.[2] This demonstration includes a conceptual model, shows a clear causal relationship between the smoke and the measured exceedance, the unlikeliness of recurrence, that the event was not controllable by Delaware and that this document has gone through a public notice process. This demonstration shows that the ozone exceedance at the Lums monitor on June 2, 2023 was influenced by wildfire smoke and that it meets the requirements of the exceptional event rule for exclusion.

Approximately 270 individual wildfires burned across Saskatchewan, Alberta, extreme southern Northwest Territories and northeast British Columbia in west-central Canada in mid-May of 2023. While a few fires had commenced in earlier May, the period from May 13-20 across this region effectively started the record setting wildfire season in Canada, nearly burning the cumulative area of the average annual burn area in Canada, and 50-60% of the previous highest years in just these 8-9 days. The fires were also intense, with one of the greatest collective and cumulative radiative power periods of the entire 2023 Canadian season. A prodigious smoke plume from these fires entered the CONUS on May 20. A potent central U.S. ridge, also responsible for above normal temperatures and dry weather across Canada as a

[1] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-51/subpart-CC

[2] *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

persistent blocking pattern, trapped the smoke in the lower troposphere for several days before finally arcing clockwise around the ridge to reach the Mid-Atlantic from the north-northeast in the May 30-June 2 period. While diffuse by this time, the smoke was well aged and spatially pervasive, with elevated upstream ozone existing and following the path of the smoke and persisting across nearly the entire northeastern quarter of CONUS by May 30 through June 2.

In cumulative fashion, several other fires in closer time and proximity to Delaware's exceedance event on June 2 existed in Nova Scotia, Canada, and New Jersey, United States. In the north-northeast US, transport bringing diffuse but regional aged smoke from west-central Canada, smoke from fires in southern Nova Scotia and several fires in New Jersey were similarly pushed into Delaware between May 30-June 2. These fires further contributed to smoke and precursor concentrations amidst a regional background of aged smoke, to further exacerbate ozone development.

Regional ozone concentrations, while supported by above average temperatures, were higher by greater than 20 parts per billion (ppb) than in similar situations without the smoke on June 2, 2023, exceeding statistical thresholds of recent years. Surface ozone was enhanced near sources with nitrogen oxide ($NO_x$) emissions such as urban centers during the event, but ozone increased in magnitude and scope everywhere as plumes of smoke moved across the Mid-Atlantic. Furthermore, enhanced ozone was pre-existing within the regional smoke plume and was observed tracking with it long before arriving in Delaware, with a clear causal relationship between the smoke and higher ozone leading to ozone exceedances throughout Delaware's New Castle and Kent Counites on June 2.

Maximum daily 8-hour average ozone (MD8AO) concentrations in Delaware on June 2, 2023 exceeded the 2015 ozone NAAQS, as the precursor-rich smoke plume moved into the region (Figure 1). Delaware MD8AO concentrations peaked at 85 ppb on June 2 at the Lums monitor, which was the highest MD8AO during the 2023 ozone season and was regulatorily significant (Table 1).

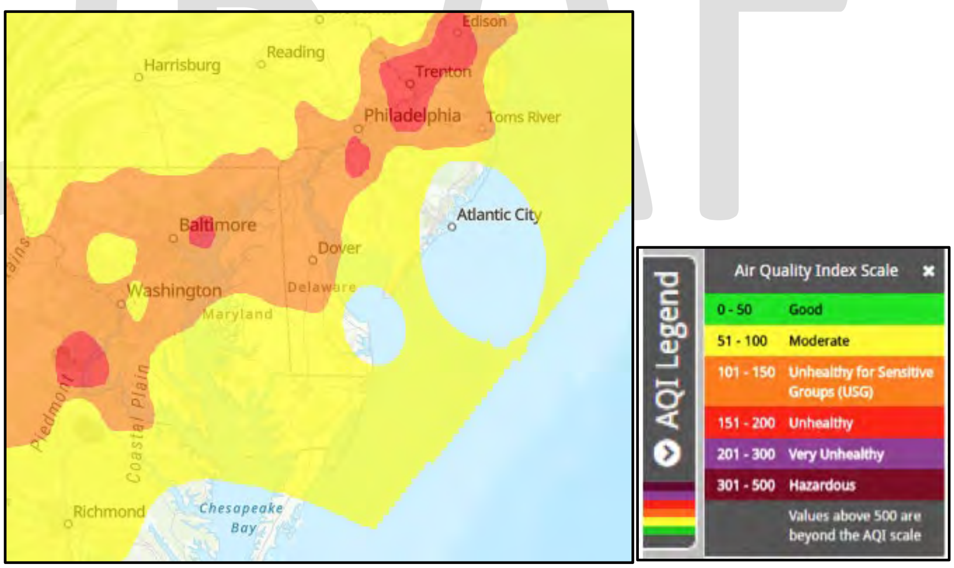



**Figure 1. Ozone Air Quality Index for Delaware, June 2.**
Ozone Air Quality Index (AQI) map from AirNow archives.

Following the EPA's Exceptional Events Rule (40 CFR 50.14), Delaware communicated to EPA our intention of submitting an exceptional event package by submitting an exceptional event initial notification on February 12, 2024 (Appendix A) and will flag the ozone data for the Lums monitor for June 2, 2023. Several neighboring states to Delaware, including Maryland, Pennsylvania, New Jersey, and the District of Columbia have also given notice of intent for exceptional event demonstrations for this day. For purposes of regulatory significance in Delaware, this event has been narrowed to focus only on the June 2 ozone exceedance at the Lums monitor. Although other sites in Delaware recorded exceedances on June 2, their 3-year design value and 4th highest reading for 2023 remain below the 2015 NAAQS, therefore Delaware is not requesting to flag this data at this time because it does not currently have regulatory significance. The analysis presented in this demonstration shows that Delaware's 8-hour ozone concentration for June 2 at the Lums monitor, meets the requirements for having been influenced by an exceptional event, and should therefore be excluded from DV calculations used to determine Delaware's ozone attainment status.

## 1.1 June 2, 2023 Exceptional Event Summary of Approach

The Exceptional Events Rule[3] 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.

| | | MD8AO, ppb | 2023 | |
|---|---|---|---|---|
| **Site Name** | **AQS ID** | **June 2nd** | **Fourth high, ppb** | **Preliminary Design Value 2021 to 2023, ppb** |
| Bellefonte 2 | 10-003-1013 | 77 | 69 | 62 |
| Brendywine Creek | 10-003-1010 | 71 | 70 | 63 |
| Lums | 10-003-1007 | 85 | 72 | 62 |
| Martin Luther King | 10-003-2004 | 80 | 69 | 61 |

**Table 1.** Ozone Exceedances in New Castle County Delaware on June 2.
Maximum 8-hour ozone concentrations on June 2, 2023 for all ozone monitors in New Castle County Delaware. Please note that the Lums monitor may not meet data completeness requirements for 2023, or the 3-year period from 2021 through 2023, however this demonstration remains necessary.

Finalized revisions to the Exceptional Events Rule were established by the EPA on October 3, 2016.[4] The revised rule describes the procedures for treating data that has been influenced by an exceptional event.[5] These were further clarified in an Exceptional Events Guidance Document released by EPA on September 16, 2016.[6] 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;

[3] 40 CFR 50.14
[4] Final Rule. *Treatment of Data Influenced by Exceptional Events. 81 FR 68216, October 3, 2016.* *https://www.govinfo.gov/content/pkg/FR-2016-10-03/pdf/2016-22983.pdf*
[5] Ibid. Page 68217
[6] *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. Page 1: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf

**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 standard at a particular air quality monitoring location and otherwise satisfies the requirements of this section. Provided the Administrator determines that there is no compelling evidence to the contrary in the record, the Administrator will determine every wildfire occurring predominantly on wildland to have met the requirements identified in paragraph (c)(3)(iv)(D) [item (4) above] of this section regarding the not reasonably controllable or preventable criterion."*

The guidance document also recommends following a tiered based approach to the analysis, providing evidence of "Key Factors" in each tier. Following the elements suggested in the Exceptional Events Guidance Document as outlined above, through this demonstration Delaware shows that the transported wildfire smoke had a direct role in amplifying ozone concentrations on June 2, 2023 to a level which would not have been possible in the absence of smoke constituents, and satisfies the three core exceptional event criterion. Based on recommendations from the EPA, Delaware used a Tier 3, weight of evidence approach for this analysis.[7]

Delaware addresses each of the necessary elements cited previously in the subsequent sections of this document. EPA guidance offers suggestions for appropriate analyses to demonstrate the clear causal relationship between the wildfire and excessive ozone levels and recognizes that appropriate levels of analysis will vary for particular locations and conditions. EPA does not intend for the guidance to constrain the analysis. Delaware therefore includes some of the suggested analytics and variations on those methods to support our conclusion that high ozone concentrations in Delaware on June 2, 2023 were caused and/or worsened by wildfire smoke plumes from fires across western central Canada, Nova Scotia, and New Jersey.

## 1.2 Regulatory Significance of the Exclusion

There are seven ozone monitors in the state of Delaware, and four of these monitors are located in New Castle County (Figure 2). On June 2, 2023, five ozone monitors in Delaware exceeded the 70 ppb including all four New Castle County monitors (Table 1). While all of these exceedances were influenced by an exceptional event, Delaware has focused this demonstration and our request on the one site with regulatory significance at this time, the monitor at Lums. The preliminary 3-year DV for Lums is below the standard, but as a part of the Philadelphia-MSA, all monitors (including those out of state) must have a DV below the standard for the MSA to be in attainment.

EPA will determine attainment status for the Philadelphia-NAA in August 2024, and the MSA is requesting an extension which requires data from 2023 to be in attainment. In 2023, the Delaware monitor at Lums has a 4$^{th}$ highest reading greater than the NAAQS, however because the exceedance on June 2, 2023 was influenced by wildfire smoke, this data should be flagged as an exceptional event. As such, June 2, 2023 meets the criteria for further analysis and potential exclusion if EPA concurs that an exceptional event occurred, according to criteria listed in 40 CFR 50.14(a)(1)(i). Delaware requests for exclusion of this, regulatorily significant MD8AO observation on June 2, 2023 (Table 2).

[7] *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

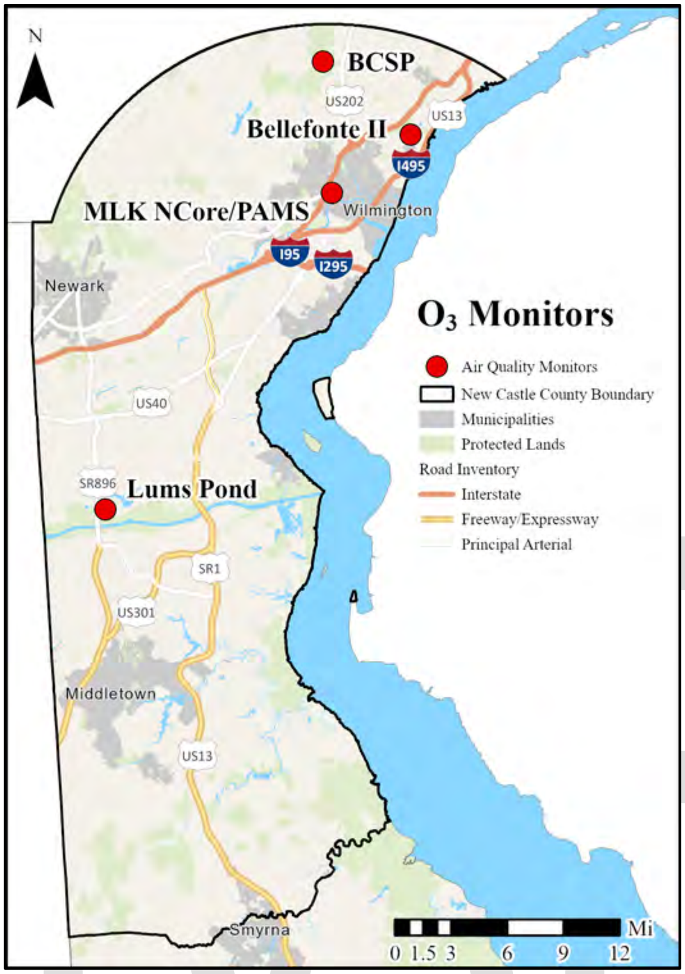



**Figure 2.** The New Castle County Delaware ozone air quality monitoring network as of June 2.



| | | MD8AO, ppb | 2023 Fourth high, ppb | |
|---|---|---|---|---|
| **Site Name** | **AQS ID** | **June 2nd** | **Including** | **Excluding** |
| Lums | 10-003-1007 | 85 | 72 | 70 |

**Table 2. Ozone Data that Delaware is seeking concurrence for.**
The ozone monitor at which Delaware is seeking EPA data exclusion concurrence.

The Philadelphia-NAA needs to demonstrate continued attainment of the 2015 ozone standard by August of 2024. Continued attainment of the 2015 ozone standard will only occur if EPA concurs with this exceptional event demonstration for June 2, 2023.

EPA's concurrence of the requested MD8AO observation on June 2 for Delaware's Lums site, will not by itself bring Philadelphia-NAA into attainment with the 2015 ozone standard. However, this demonstration is required as a series of demonstrations necessary due to impacts of smoke throughout the region. Concurrence with this June 2 demonstration is a requirement of the process towards demonstrating the exceptional nature of the impacts of smoke on ozone DV and fourth-high values in 2023 in the Philadelphia-NAA. The EPA evaluation of the current June 2 exceptional event in the greater Mid-Atlantic region will affect multiple designation statuses, as other states are pursuing demonstrations on this data as well. At the very least, if this demonstration, along with several companions, are not concurred, the Philadelphia-NAA will be reclassified as in "serious" nonattainment of the 2015 ozone NAAQS.

This report demonstrates that:

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

Key findings and evidence supporting these assertions include the following:

- Ozone development happened immediately downwind of the west-central Canada fires, and continued to increase in spatial extent and became well established under a smoke laden ridge upstream of Delaware for over a week prior to the exceedances that occurred in Delaware on June 2;
- Similar day analysis shows days of similar meteorology supported far less ozone than June 2;
- Heightened $PM_{2.5}$ concentrations were present throughout the event;
- Multiple days of elevated ozone associated with heightened particle concentrations, culminated in the hottest day of the smoke period;
- Ozone concentrations were higher than historical norms, beating the 99th percentile at the Lums monitor;
- Q/d analysis and conclusions were consistent with other previous long-range smoke and ozone transport events from northwestern Canada to the Mid-Atlantic Region, suitable for meeting exclusion criteria;
- Satellites captured a smoke plume transported to the northeastern United States, which tracked from west-central Canada, with Nova Scotia and New Jersey fires adding to the smoke locally;
- Aircraft and other observational data showed regionally high ozone within the atmospheric residual layer associated with smoke; and
- Spatially and temporally consistent Community Multiscale Air Quality modeling system (CMAQ) air quality model under-prediction with the smoke evolution.



Several analysis methods were used to develop a weight of evidence (Tier 3) demonstration that the 8-hour ozone concentrations above 70 ppb during the June 2, 2023 event met the rules for data exclusion as an Exceptional Event. In summary, satellite data, meteorological data, transport analysis, atmospheric in-situ and remote sensing observations, and emissions data, were used to assess whether conditions that were favorable for transport of smoke from west-central Canada wildfires to monitors that showed 8-hour ozone concentrations above 70 ppb. The data show that the transported smoke moved over the Mid-Atlantic region, creating a prolonged enhanced ozone period (May 30-June 3) including exceedances of the standard in Delaware on June 2.

The analysis strongly supports that Delaware monitors were impacted by smoke, that the requested data above 70 ppb in Delaware on June 2, 2023 meet the criteria to demonstrate an Exceptional Event. This monitor and the MD8AO observations above 70 ppb outlined in Table 2 should be excluded from DV calculations. The following analysis justifies these claims and is outlined as follows:

- Section 2 contains a conceptual model overview of the event including a synopsis of the meteorological and air quality conditions, emissions, transport and characteristics defining the event;
- Section 3 demonstrates a clear causal relationship between the exceedance via a tiered, weight of evidence approach;
- Section 4 demonstrates that this event fulfills the definition of a natural event, 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; and
- Section 7 summarizes and concludes the analysis.

# 2. Conceptual Model and Overview of the June 2, 2023 Smoke and Ozone Event

## 2.1 Delaware Network Description

As part of the CAA, both local and state air quality agencies are required to maintain and operate ambient air quality monitoring networks. Delaware's monitoring network consists of 11 air monitoring stations, including one National Core Monitoring Strategy (NCore) site, seven ozone monitoring sites, and eight sites measuring particulate matter (PM). A full description of the various instrumentation used by Delaware is available in the 2023 Delaware Ambient Air Monitoring Network Plan for Criteria Pollutants.[8]

The Delaware monitoring network is distributed throughout the state but favors New Castle County due to the historic density of population and the industry located in this county. Approximately 990,000 people live in Delaware with nearly 58% of the people living in New Castle County, per the 2020 census.[9]

## 2.2 Ozone Trends in Delaware

The number of days in Delaware with a MD8AO greater than 70 ppb has been decreasing for years (Figure 3). For the first time in more than 20 years, Delaware did not have any days that exceed the ozone NAAQS in 2022. 2023 was the seventh consecutive years with no MD8AO in the red Air Quality Index (AQI) category (or above) for ozone. In the absence of smoke influence, the primary mechanism driving ozone formation in Delaware comes from the photolysis of volatile organic compounds (VOCs) and a combination of regionally and locally originated anthropogenic $NO_x$. The key contributors to VOC and $NO_x$ are human-made emissions from various sources including fixed point sources such as energy generating units (EGUs), mobile sources including cars, trucks, boats, locomotives, and non-road equipment, and area sources encompassing industrial processes and consumer products. The predominant share of locally generated $NO_x$, a precursor to ozone, originates from mobile sources and large industrial sources (EGUs and the Delaware City Refinery). These emissions alone frequently fall short of generating ozone concentrations exceeding the 70 ppb 2015 ozone NAAQS in Delaware.

Photochemical modeling underscores the argument that, excluding instances of light winds and recirculation that result in the accumulation of local emissions, emissions from sources within Delaware are regularly insufficient to cause ozone levels to surpass regulatory thresholds. Additionally, Delaware has historically experienced ozone exceedances predominantly associated with the transport of $NO_x$ emissions from upwind sources. 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 enter Delaware through transport contribute to elevating local ozone levels, occasionally surpassing NAAQS thresholds. In the absence of substantial transport, Delaware has experienced a reduction in widespread or frequent ozone exceedances of NAAQS standards.

In the time frame of 2019 to 2023, the concentration of ozone and its precursors in the residual layer have reached their lowest recorded levels. This reduction has led to a decrease in the maximum daily ozone concentration in Delaware, 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 (Figure 3).

[8] https://documents.dnrec.delaware.gov/Air/monitoring/delaware-air-monitoring-network-plan.pdf
[9] https://www.census.gov/library/stories/state-by-state/delaware-population-change-between-census-decade.html

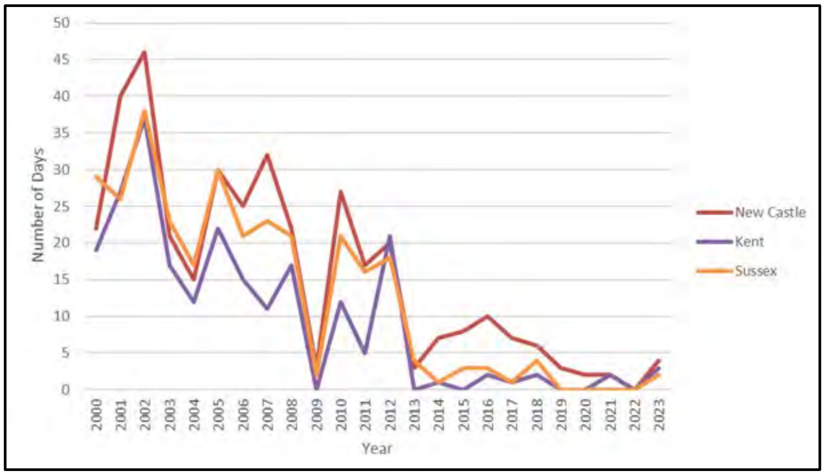



**Figure 3.** Annual Number of Days with Ozone greater than the 70ppb NAAQS.
Year-to-year frequency of MD8AO greater than 70 ppb in Delaware between May and September by county. Source: U.S. EPA Air (https://www.epa.gov/outdoor-air-quality-data).



## 2.3 Emissions Influencing Ozone in Delaware

Emissions of $NO_x$ from point sources in states upstream of and including Delaware (such as Maryland, the District of Columbia, Virginia, West Virginia, Pennsylvania, Ohio, and Indiana), 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 (Figure 4). $NO_x$ emissions from mobile sources have also decreased during the same period. However, this reduction is overshadowed by the substantial decrease in EGU-related $NO_x$ emissions. It is important to note, that while mobile-source $NO_x$ remain a significant percentage of the total $NO_x$ generated in the state, even when combined with additional local EGU emissions, are typically insufficient to cause ozone exceedance days within the state.

In the context of a standard scenario involving a Delaware 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. The Clean Air Markets Database (CAMD) records $NO_x$ emissions originating from EGU point sources across the nation. Over the past 15 to 20 years, there have been notable and sustained reductions in $NO_x$ emissions throughout the eastern United States (Figure 4). In 2023, the cumulative $NO_x$ emissions from upstream states had decreased to approximately 20% of their 2010 levels. Furthermore, the collective monthly total $NO_x$ emissions from May to September 2023 were the lowest ever recorded from upwind states. In Figure 4, upwind states were selected to mimic influential states within the pathway of the June 2 transport, which was atypically from the Northeast. Thus, the lowest ever recorded June emissions included New York, New Jersey, Pennsylvania, Massachusetts, Delaware, and Maryland (Figure 4). These states together constituted an insignificant anthropogenic source region for typical ozone or ozone precursors transported into Delaware on June 2. In June 2023, $NO_x$ emissions from these areas were approximately 11% of what were observed in 2010.

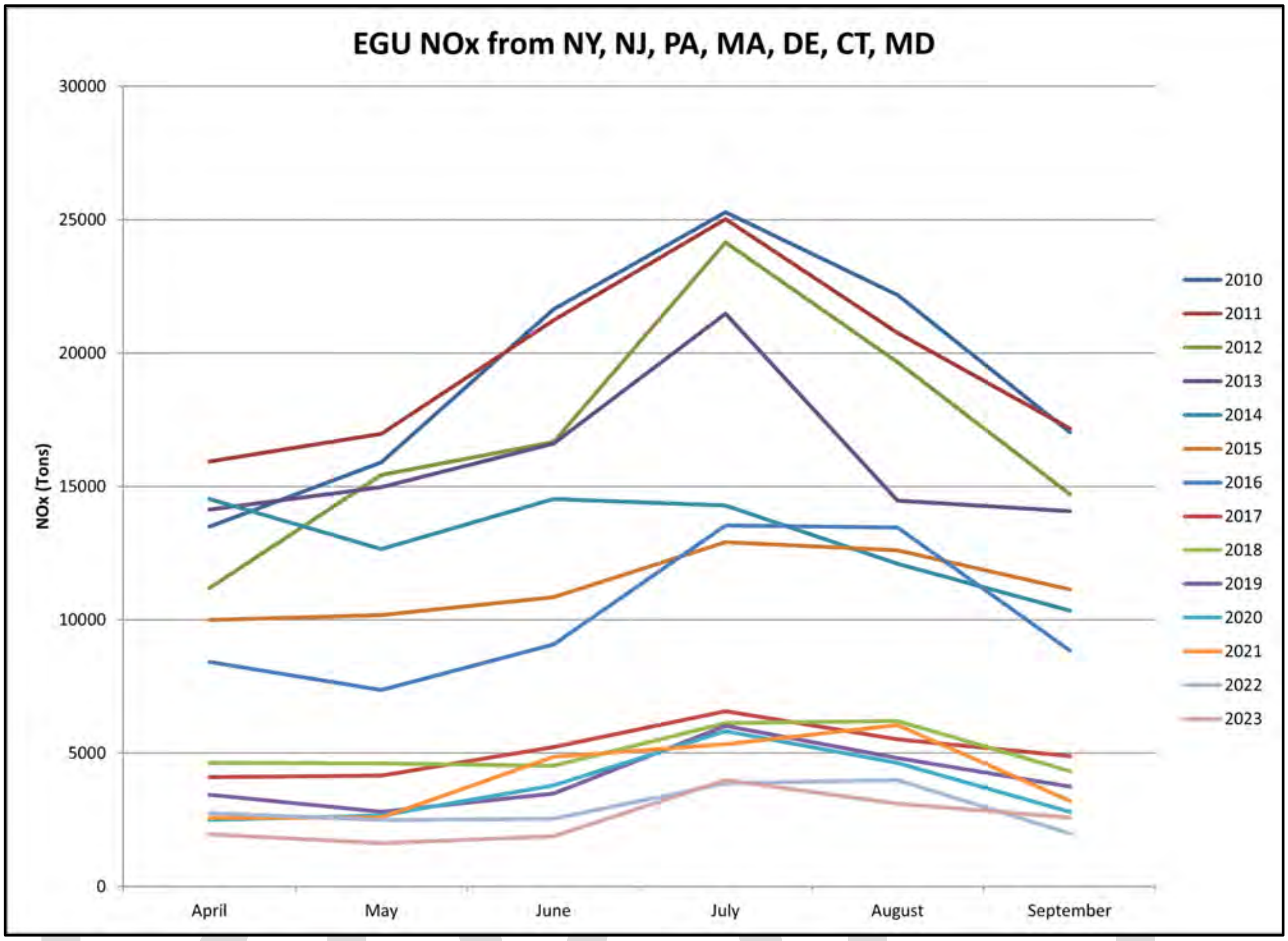



**Figure 4.** Monthly $NO_x$ emissions from CAMD.
Monthly $NO_x$ emissions aggregated from the group of upwind states for this event, including Delaware, by month of ozone season.

Daily emissions for the same states reflect similar reductions. The daily aggregate $NO_x$ emissions of New York, New Jersey, Pennsylvania, Massachusetts, Delaware, and Maryland for only the month of June from 2017-2023, based on CAMD data, showed emissions during June 2023 were some of the lowest daily emissions ever. There is a clear downward trend, most notable in 2022-2023. For the month as a whole, June of 2023 had the lowest EGU emissions (Figure 4). Even with these record low emissions, Delaware recorded several days of high ozone concentrations in June 2023.

## 2.4 Ozone Production in Delaware

From 2017 through 2023, daily ozone exceedances in Delaware have become a rare occurrence. Throughout 2023, when moderate or above ozone conditions are present, they are nearly always accompanied by smoke transport (Table 3).

| | May | June | July | August | September | Season |
|---|---|---|---|---|---|---|
| **Moderate+ Ozone Days** | 10 | 15 | 17 | 8 | 6 | 56 |
| **Moderate+ Ozone Days with smoke** | 10 | 15 | 17 | 7 | 6 | 55 |
| **Percent of ozone days with smoke influence** | 100% | 100% | 100% | 88% | 100% | 98% |

**Table 3.** Frequency of smoke influence on Ozone in Delaware.
2023 Moderate or higher ozone AQI days and NOAA Hazard Mapping System (HMS) analyzed smoke days.

## 2.5 Weather Patterns Leading to Ozone Formation in Delaware

Weather patterns can have a strong impact on ozone formation in Delaware. Generally, warmer than-normal temperatures and below-normal wind speeds can enhance ozone formation during the summer months. On the other hand, frequent frontal passages can result in increased cloud cover, cooler temperatures, rainfall, and enhanced vertical mixing, all of which hinder ozone development. When compared to the 1991-2020 climatological averages, temperatures across the Mid-Atlantic and Northeast regions for the summer 2022 ozone forecast season were warmer than normal, but Delaware did not have any exceedances of the ozone standard in 2022.

Ground-level ozone formation depends on a variety of meteorological factors, with the primary catalysts being sunlight and surface temperatures. In the spring, increasing daylight and warmer temperatures begin to enhance ozone production. As the summer continues, shorter days and the gradual, seasonal reduction in temperatures result in improved ozone levels, with Good AQI levels being recorded on most days.

## 2.6 May 2023 West-Central Canada Wildfires and Nova Scotia and New Jersey Wildfires

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 in 1966, a 57-year record (Figure 5). The little amount of snow which fell during the winter of 2022-2023 across Canada melted sooner, exposing fire fuels earlier than typical, with low soil moisture contributing further to fire danger due to parched vegetation. The Canadian wildfire season typically runs from May through October, peaking in July, though with snowpack far less than average, wildfires across Canada started considerably earlier, with seasonal fires being detected as early as March.[10]

Numerous wildfires broke out across Canada throughout the season. Fires were out of control over parts of the country for the entire summer. Firefighters from as far as Spain, Portugal, and France assisted local teams in battling the flames.[11] In May, fire concern was most concentrated around Alberta and Saskatchewan. A significant increase in the number and area of fires followed a period of lightning strikes across Alberta, Saskatchewan, and into British Columbia and the extreme southern Northwest Territories of Canada. The National Oceanic and Atmospheric Administration (NOAA) Daily Hazard Mapping System (HMS) smoke and fire analyses (McNamara, et al., 2004) as well as the Canadian Wildland Fire Information System (CWFIS) detected an increase in the number and intensity of fires, particularly across Alberta, Saskatchewan, the Northwest Territories, and British Columbia. Between May 13 and May 20, 270 fires burned across this region (Figure 6). While the fires covered a wide geographical area, meteorological conditions aggregated smoke from these fires into an eventual consolidated smoke plume from the region pushing into eastern Montana and western North Dakota on May 20, 2023.

[10] https://ciffc.net/national
[11] https://www.ctvnews.ca/canada/nearly-350-firefighters-from-the-eu-will-help-battle-relentless-canadian-wildfires-1.6437130

Between May 13 and May 20, 1,402,744 hectares (3,466,256 acres) were consumed across west central Canada (Figure 7).[12] Fire radiative power (FRP) also increased rapidly during this period, in one of the steepest periods of incline over the entire 2023 season, indicating the fires were intensely burning since FRP is a radiation measure by satellite proportional to fire temperature (Figure 8). Large areas of smoke were seen from space for several days during this burn period (Figures 9-10). At the surface, Canadian provinces such as Alberta dealt with smoky conditions, with immense visibility impact noted in surface images from news articles (Figures 11-13). Forthcoming analyses tracking smoke from west-central Canada will illustrate how this immense cloud of smoke was impacted by and caught within an unseasonably strong ridge of high pressure associated with a blocking pattern across the United States. Over the course of 13 days, this smoke remained over the central and eastern United States, impacting ozone concentrations from New England to the Gulf Coast.

Superimposed on this background smoke, several other fires impacted Mid-Atlantic air quality as well. The first in chronology and size was located on the southern tip of Nova Scotia (Figure 6). This fire burned 24,840 hectares (61,381 acres) between May 28 and June 2. The cause of these fires has not been definitively determined, though officials in Nova Scotia have said about 97% of fires in the province are of human origins.[13] Based on the chronology of the ozone event in Delaware to be demonstrated here, and the morphology of the atmospheric conditions over the Nova Scotia fire region, this demonstration shows that emissions from this fire from May 28 to May 31 impacted Delaware's air quality. Over this period, 19,670 hectares (48,606 acres) burned, of which 9,154 hectares (22,620 acres) burned on May 29 alone. Smoke and precursor emissions were delivered behind a cold front on northeast flow in the May 30 to June 2 period in Delaware.

Further complicating the ozone event on June 2, 2023 in Delaware were four fires in New Jersey occurring between May 29 and June 2. Chronologically, the first fire, known as the Box Turtle Fire, occurred on May 29 and burnt 158 acres( approximately 64 hectares). Unfortunately, this fire occurred beneath cloud cover, and therefore it's not possible to assess the amount of smoke emanating from it. It appears this fire contributed to heightened $PM_{2.5}$ concentrations late on May 29 and into May 30 throughout the Philadelphia-NAA, adding to the pool of smoke emissions in the local region and in Delaware on successive days. The next fire in New Jersey was the Allen Road Fire, which started on May 31 and was extinguished June 2, burning 2,215 acres (896 hectares) over that time, with 1,772 acres (717 hectares) burnt on June 1 alone (Figures 14-16). Emissions from May 31 and June 1 influenced Delaware air quality on June 1 and June 2, at minimum. This fire had the most prodigious smoke plume of the New Jersey fires (Figure 16). Another fire was visible on June 1, via satellite over Fort Dix in central New Jersey; no burn area was reported for this fire, but estimates based on satellite hot spot detection suggest around 77 acres (31 hectares) were burnt. Lastly, the Flat Iron fire on June 2, southeast of Philadelphia, burnt 86 acres (34 hectares). These fires, while orders of magnitude smaller than the Nova Scotia and west-central Canada fires, were orders of magnitude closer in proximity to Delaware.

In the end, no single fire was responsible for the smoke which existed across Delaware at the end of May and the beginning of June 2023. An aggregation of smoke from two larger, regionally impacting fires (west-central Canada and Nova Scotia) created a background environment with diffuse, chemically aged smoke associated with a regional extent of ozone enhanced air, to which localized additional fires along the I-95 corridor in New Jersey added additional smoke to create an airmass richly supportive of ozone generation. Together, the impact of the combined smoke resulted in the worst ozone day of 2023 in Delaware. The forthcoming analysis pulls these emission sources together and focuses on the impacts to ozone due to smoke on June 2, 2023.



[12] Burn information is provided by the Canadian Wildland Fire Information System (CWFIS): http://cwfis.cfs.nrcan.gc.ca/home
[13] https://www.cbc.ca/news/canada/nova-scotia/nova-scotia-most-devastating-wildfire-season-ever-1.7010205

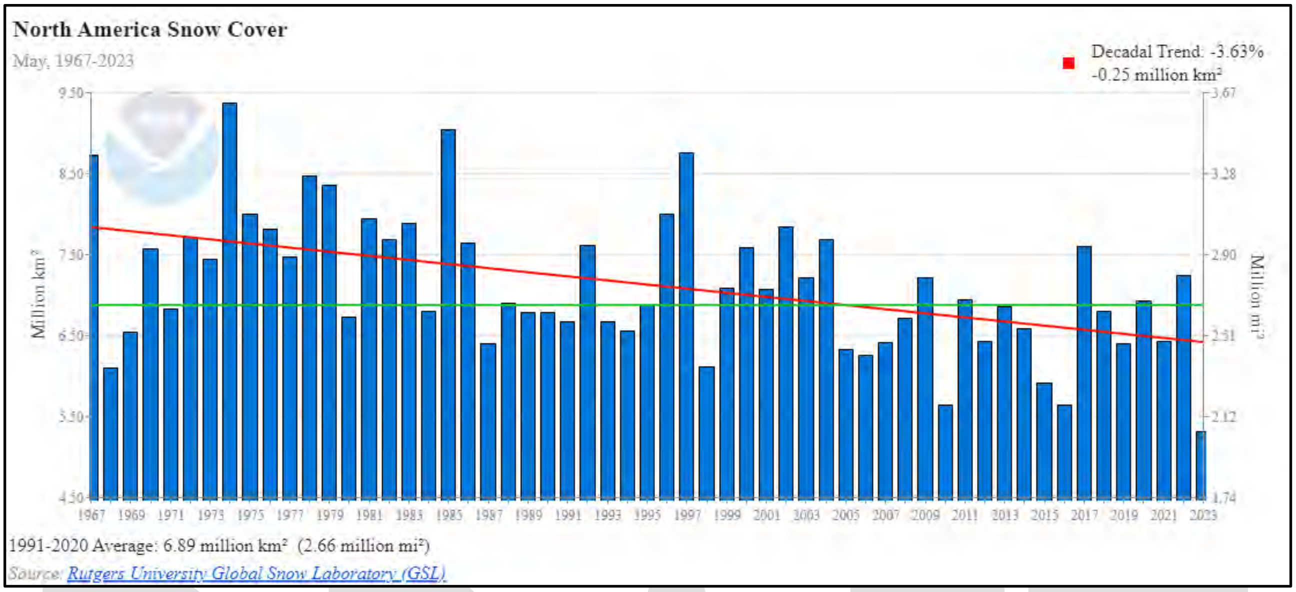



**Figure 5.** North American Snow Cover.
North American snow cover (millions km[2]) each May, between 1967 and 2023. Average line in green and decadal trend line in red.



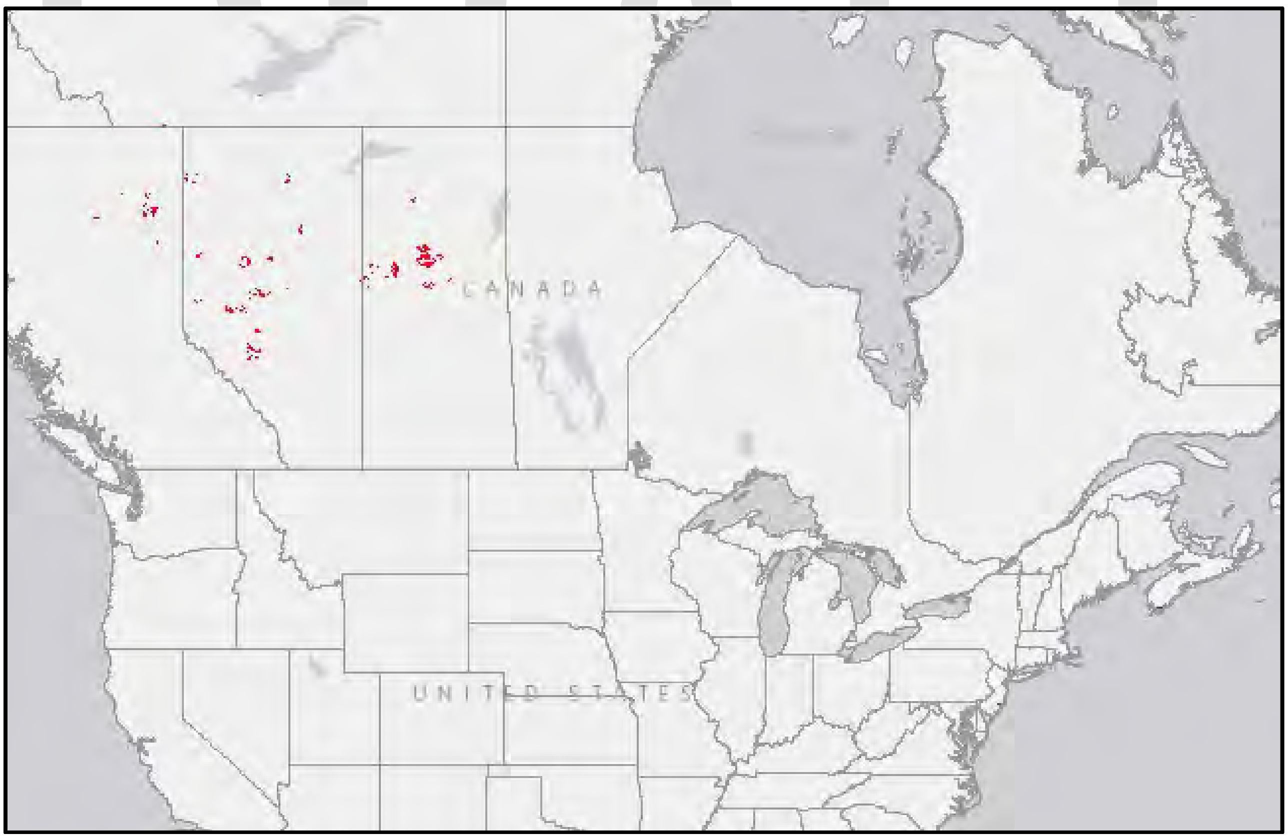



**Figure 6. Canadian Fire Locations, May 13-20.**
May 13-20, 2023 fire locations relevant to this demonstration. Fire areas burned (red) derived from the CWFIS, from satellites such as GOES Imager, the POES AVHRR, MODIS satellites, and expert ground reports and analysis are shown for the period from May 13-20, 2023. Note the fires in southern Nova Scotia and New Jersey, as well as west-central Canada.

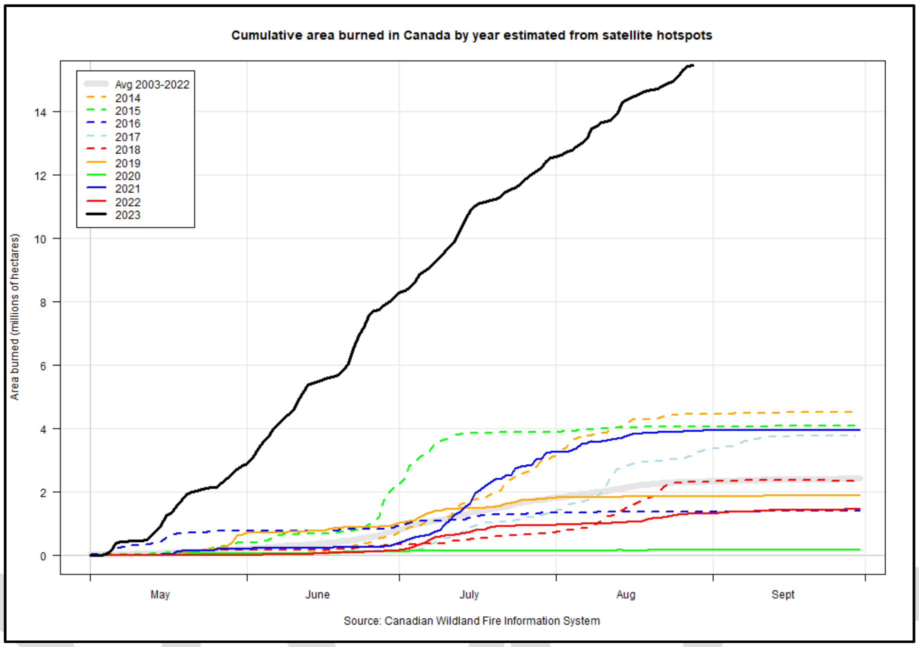



**Figure 7.** Cumulative Historic Area Burned in Canada.
Accumulated hectares burned reported by CWFIS, by day, over the last ten years. Burn area is estimated by satellite. https://cwfis.cfs.nrcan.gc.ca/downloads/hotspots/burnarea_chart_10yr.png

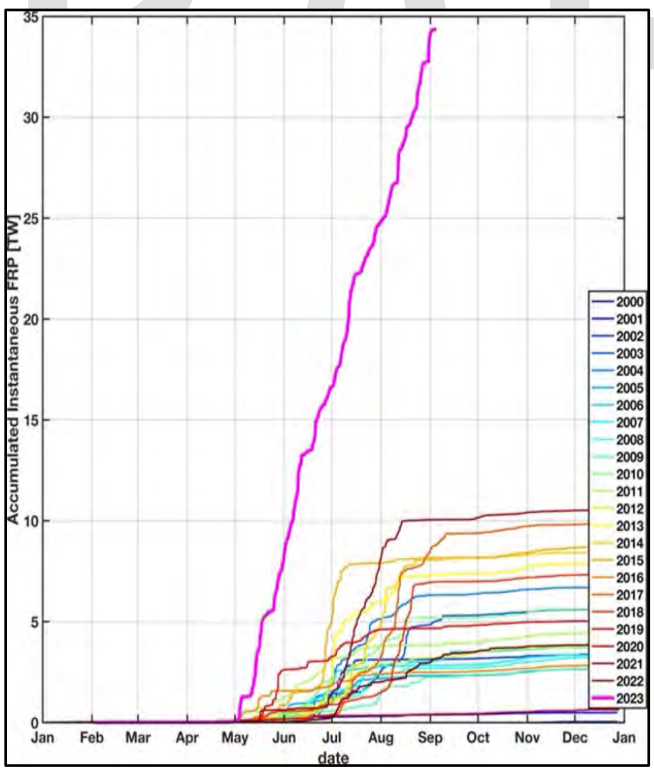



**Figure 8.** Historic Fire Radiative Power of Canadian Fires.
Fire Radiative Power (FRP) in Terawatts (TW) from satellite. FRP gives a measure of the fire intensity and burning temperature. A steeper slope signifies a greater number or greater intensity of fires. A steep upward increase occurred during the May 13-21 period due to the west-central Canada fires, indicating fires of high intensity.

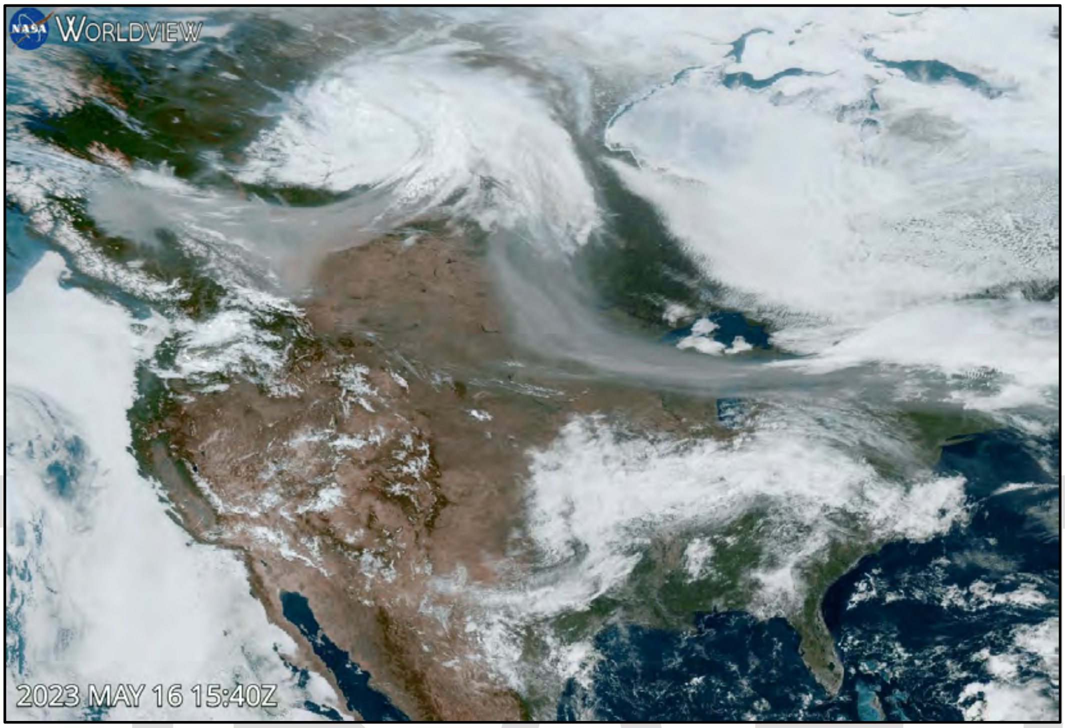



**Figure 9.** Satellite Image of smoke in mid-May 2023.
Smoke from fires in Alberta and British Columbia, Canada, 5/16/2023 (ABI instrument/GOES-East satellite).[14]

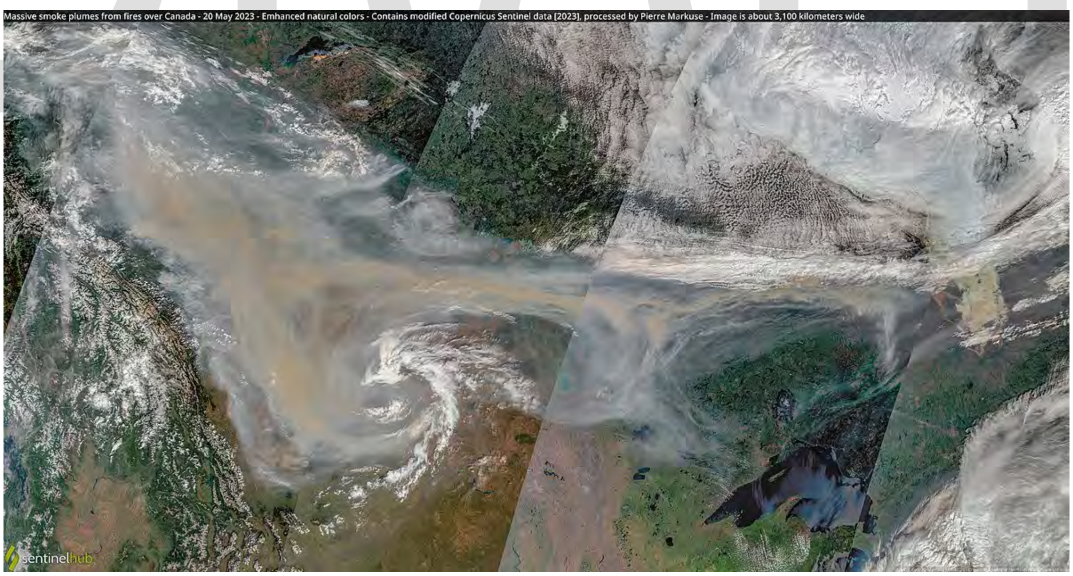



**Figure 10.** Satellite Image of smoke in late-May 2023.
Massive smoke plume from fires over Canada, 5/20/2023.[15]



[14] https://www.earthdata.nasa.gov/worldview/worldview-image-archive/canada-fires-16-may-2023
[15] https://en.wikipedia.org/wiki/File:Massive_smoke_plumes_from_fires_over_Canada_-_20_May_2023_%2852913795290%29.jpg

**Figure 11.** May 15, 2023 (Alberta, Canada).[16]

**Figure 12.** May 16, 2023 (Alberta, Canada).[17]

[16] https://www.reuters.com/pictures/wildfires-choke-alberta-skies-air-quality-deteriorates-2023-05-17/DQALRQTGAJKLNL2QBANXPJMJR4/

[17] https://www.reuters.com/pictures/wildfires-choke-alberta-skies-air-quality-deteriorates-2023-05-17/DQALRQTGAJKLNL2QBANXPJMJR4/

**Figure 13.** Smoke layer in Alberta, Canada, 5/16/2023.[18]

**Figure 14.** Allen Road Wildfire in Bass River State Forest, New Jersey, 6/1/2023.[19]

[18] https://www.reuters.com/pictures/wildfires-choke-alberta-skies-air-quality-deteriorates-2023-05-17/DQALRQTGAJKLNL2QBANXPJMJR4/
[19] https://www.inquirer.com/news/new-jersey/new-jersey-wildfire-pinelands-bass-river-state-forest-20230601.html

**Figure 15.** Allen Road Wildfire in Bass River State Forest, New Jersey, 6/1/2023.[20]

**Figure 16.** Satellite Image of Allen Road Fire smoke, New Jersey, 6/1/2023 (video screenshot).[21]

[20] https://www.inquirer.com/news/new-jersey/new-jersey-wildfire-pinelands-bass-river-state-forest-20230601.html
[21] https://www.fox29.com/news/allen-road-fire-uncontained-wildfire-torches-thousands-of-acres-in-nj-causes-traffic-changes

## 2.7 Conceptual Model of Ozone Formation in Delaware on June 2, 2023 due to May & June 2023 West-Central Canada, Nova Scotia, Canada, and New Jersey, U.S. Wildfires

### 2.7.1 Overview and Literature Review

Wildfires are known sources of emissions responsible for both primary and secondary pollutants including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), $NO_x$, 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 PM air quality was also previously reported (Adam et al., 2004; Colarco et al., 2004; Sapkota et al., 2005; Dreessen et al., 2016). 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 frequency has been increasing (Marlons, et al., 2009) and wildfire smoke has been an increasing fractional contribution to high-ozone exceedance days, particularly in light of increased fire frequency in a warming climate (Flannigan and Wagner, 1991; Marlon et al., 2009; Westerling et al., 2006; Spracklen et al., 2009; Pechony and Shindell, 2010), decreasing regional $NO_x$ emissions (Gégo, et al., 2007) and tighter ozone NAAQS.[22]

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 July 2023 ozone events across the 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 that a 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, 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 17).

In the present demonstration, we note that FRP increased proportionally greater than area burned (compare Figures 7 and 8) compared to other burn periods, suggesting hot fires in addition to evident smoke. Increased RFP suggests increased $NO_x$ output than may normally be expected; this will be explored in subsequent sections. The ozone content of the plume built steadily over the week leading up to June 2 with approximately 80 ppb ozone observed aloft as the smoke arrived in Delaware. Buildup was, of course, balanced with air mass diffusion, dispersion, and ozone deposition, but ozone nevertheless expanded in spatial coverage with relatively consistent concentrations. This was generally

[22] https://www.epa.gov/ground-level-ozone-pollution

consistent with increased ozone with smoke age, as the background smoke from Canada was aged more than 10 days by the time of arrival in Delaware.

Smoke arrived at the surface in Delaware behind a cold front late on May 29. Cool temperatures and cloud cover on May 30-31 prevented significant ozone production, but an increase in particles noted the smoke's arrival. Additional fires in Nova Scotia and New Jersey contributed smoke in the region as well. On June 1 and 2, at least Moderate AQI ozone was observed from upstate New York into at least Virginia, with higher concentrations embedded therein. Evidence suggests the smoke generally pushed ozone into at least the upper Moderate range all along the East Coast, if not to unhealthy for sensitive groups (USG). For example Shenandoah National Park, a rural elevated site in Virginia, hit 77 ppb for a max 8-hour average, before additive anthropogenic emissions were even considered. These diminutive anthropogenic emissions carried ozone further over the standard in Delaware. Thus, sufficient precursors were generated by the fires in May/June of 2023 for ozone production over the NAAQS standard, as the plume aged and mixed with anthropogenic $NO_x$ (albeit some of the lowest $NO_x$ on record). In so doing, ozone concentrations were augmented to and above levels exceeding the NAAQS not possible without the smoke.

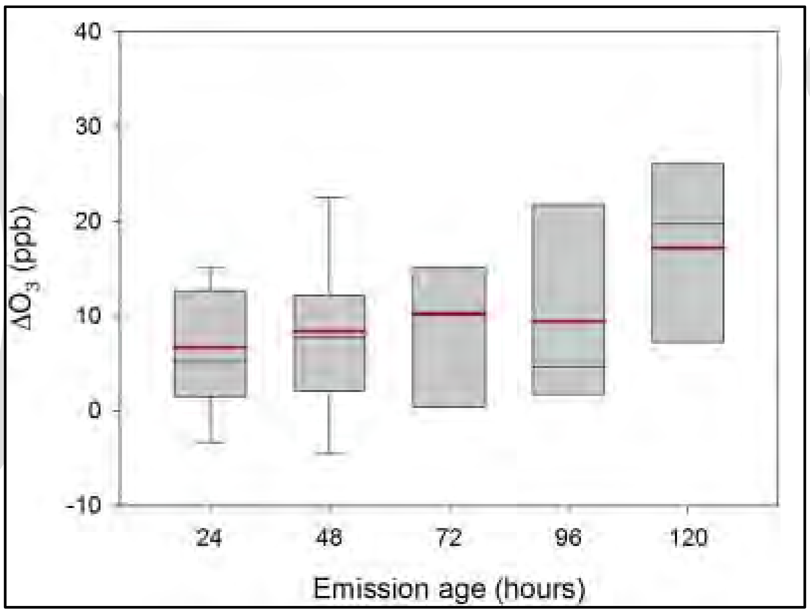



**Figure 17.** Ozone enhancement with smoke plume age.
(Taken from Putero et al. (2014), Fig. 7.)

Delaware contends that the abundance of recirculated, aged smoke from west-central Canada created a pool of ozone across a vast expanse of the northeastern United States. This pool of ozone stuck beneath a persisting area of high pressure was augmented further by smoke from the Nova Scotia and New Jersey fires, all of which caused additional smoke to arrive in Delaware beginning around May 30 through June 2. These latter fires were in closer proximity to Delaware, and thus caused an influx of denser smoke atop the regional background. The resulting chemical composition of the air was thereby highly reactive with favorable chemistry for ozone formation, which led to exceedances in Delaware on June 2.

While anthropogenic $NO_x$ emissions were not absent, EGUs for example, had $NO_x$ emissions lower than the previous years of emissions during the same period. Any influx of new $NO_x$ emissions from local anthropogenic sources act rapidly in these reactive atmospheres, exacerbating local conditions well beyond contemporary concentrations. Furthermore, ozone exceedance days in Delaware are not commonplace during early June. The magnitude and spatial scale of widespread ozone, stretching from the Great Lakes to the East Coast, was beyond contemporary norms. Therefore, it is unlikely such a widespread area of ozone exceedance could have occurred in the contemporaneously low emissions without additional supportive atmospheric chemistry (ozone precursors) provided by the wildfire smoke. Below, the event is described in detail.

### 2.7.2 Meteorological Conditions Driving Smoke and Ozone Transport

Fires were already ongoing in Alberta Canada in early May 2023 due to an early start. An immense increase in the number of fires and area burned occurred as widespread lightning strikes ignited hundreds of additional fires in Alberta, Saskatchewan, nearby areas of British Columbia, and the extreme southern Northwest Territories. Over 200 fires burned over 1.4 million hectares between May 13 and May 20 (Figures 6-8). A brief day or two period of recirculation occurred over the fire on roughly May 18 and May 19, before northerly flow pushed a thick, conglomerate smoke plume southward on the west side of a weak low-level, low-pressure system and ridging upstream. This smoke plume entered the northern United States on May 20, stagnated for a day or two along the north central U.S. and Canadian border before being pulled into and trapped under an immense (in spatial extent) and strong ridge of high pressure, effectively trapping the smoke in a clockwise recirculation for the next week (Figure 18). Some smoke at higher elevation managed to disperse farther southwards along the Canadian front-range. The end result was smoke from the Gulf of Mexico to the Great Lakes, covering the entire western half of the high-pressure system encompassing the central United States.

Over the course of about a week, smoke remained trapped within the high-pressure system centered across the northern tier of the United States, to arcing around the Great Lakes by May 31-June 2. Clockwise flow around this high-pressure system took smoke northward into Canada before the pattern would bring smoke back southward. However, north transport on the east side of the low kept bringing cleaner air from polar regions across the far eastern U.S., pushing the smoke back towards the high center, repeatedly. Eventually, as the center of high pressure moved eastward to be centered over southern Ontario, eastward transport aloft pushed smoke into and behind another cold front on May 29 passing through Delaware. The subsiding dynamics of this system pulled smoke to the surface, inundating the entire northeastern U.S. in diffuse smoke from May 30-June 2.

Concurrent to this large-scale transport, significant fires developed in Nova Scotia on May 28-June 2. Part of the smoke from these fires, particularly from burns occurring May 29-May 30, was pulled towards the Mid-Atlantic behind the cold front, further exacerbating the smoke concentration at the surface. Finally, local fires in New Jersey occurred May 31-June 2; at least one of these fires was significant in size, with all three or four fires in New Jersey providing further smoke into the region due to north-northeast flow behind the cold front moving through on May 29, with persisting smoke through June 2.

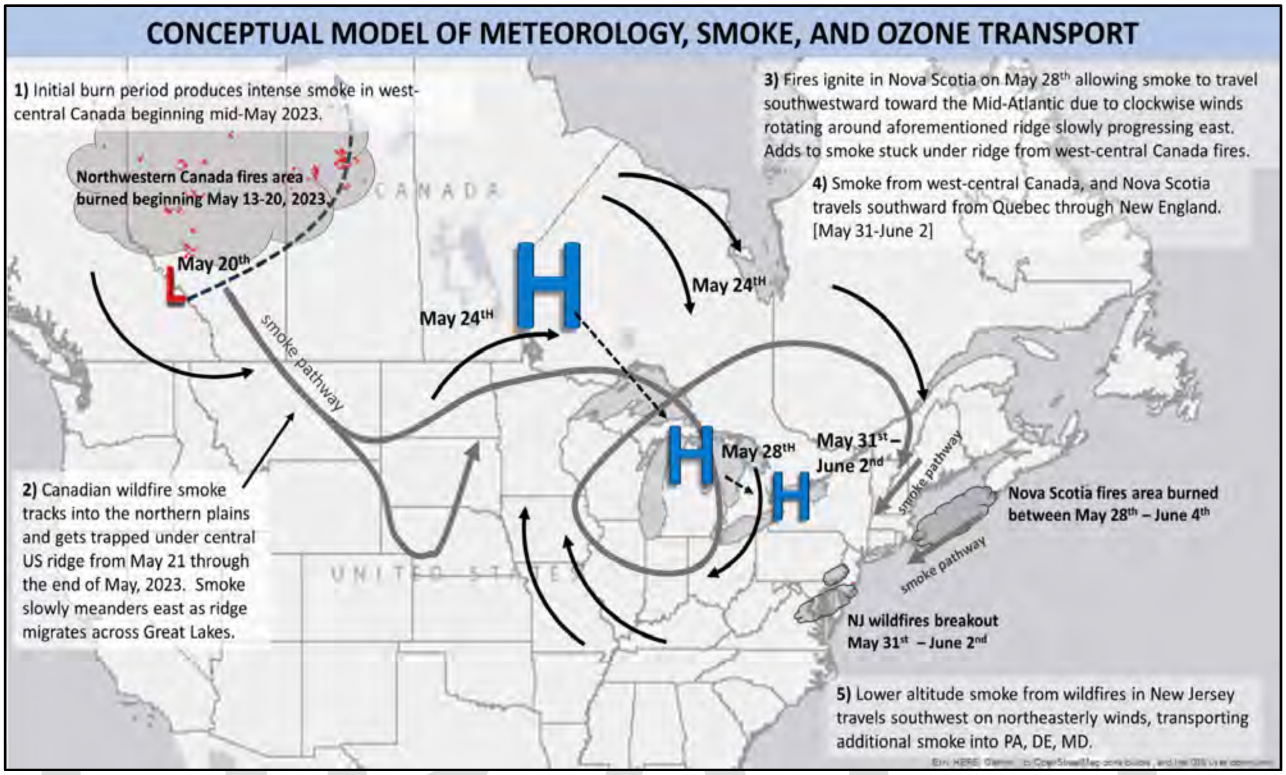



**Figure 18. Conceptual Model.**
A simplified, illustrated conceptual model of the June 2, 2023 wildfire influenced ozone event.



### 2.7.3 Upper Level Pattern Overview

The 850 millibar (mb) level (approximately 1500 m above sea level) sits near the top of the planetary boundary layer (PBL), 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 analysis of this atmospheric level is given for May 20-June 2 (Figure 19 parts a through t).

High pressure over western Canada existed in mid-May, driving warm and dry conditions over the fire regions from Saskatchewan to British Columbia. Lightning strikes across the region had previously ignited the fires some days prior. As of May 14, high pressure was centered just south of the fire area, providing southerly winds subsiding off higher terrain, fueling lower humidities in an already dry area (Figure 19a). The center of the high slid southeastward on May 15, though southerly winds persisted (Figure 19b). A cold front (tightening green isotherms to the north of the fires) approached from the north, but strong southwesterly winds continued across the fire area. On May 16, a low-pressure system formed and propagated along the aforementioned cold front noted on May 15 (Figure 19c). This changed the wind direction across the fire region and intensified speeds, fanning the flames and increasing the fire size. By May 17, the low had moved slightly farther east, but all the fires remained in strong northerly flow (Figure 19d), with bulk smoke transport from the fires pushing southward. Much of this smoke pushed into the United States and impacted air quality across a wide region of the central CONUS several days prior to the main smoke plume associated with the June 2 event in Delaware.

By May 18, the area of low pressure had moved eastward and the resulting pressure gradient across the fire and smoke region had significantly diminished (Figure 19e). As such, winds across the area were light, with little mean transport directly defined at 850 mb. Ridging quickly developed on May 19 to the south of the fire region, resulting in persisting light transport winds in the area (Figure 19f). Since 850 mb winds are nearly geostrophic, it can be inferred that light smoke transport occurred towards the southeast for western fires, and back towards the north-northeast for smoke and fires farther to the east and south, following the lines of geopotential heights, but at very slow speeds. As such, this may have acted to recirculate smoke on May 19, allowing smoke concentrations to build. This buildup culminated on May 20 as the ridge on the previous day moved southeastward, with the ridge axis tilting northeastward from eastern Colorado towards Ontario (Figure 19g). This is important to note as this positive tilting was also reflected in the approaching trough and associated cold front coming out of Canada. The resulting orientation of the height field was to push all smoke southwards from the fire region, together, in front of the approaching cold front. As the cold front was noted at 850 mb it would also be connected to the surface. As such, it essentially acted as a bulldozer of transport of the smoke towards the south in the mean northerly flow. This pattern, along with some recirculation the previous days, likely accounts for the very dense plume of smoke noted on satellite on May 20 moving out of the fire region and into northern Montana.

The pattern rapidly changed on May 21 (Figure 19h); the cold front moving out of Canada did not continue to push southwards. The overall pattern of the atmosphere acted to push the front east-southeastward across Canada towards Quebec, instead of sweeping the smoke southward. Instead, a significant closed ridge developed from southern Saskatchewan and Manitoba extending southeastward towards another closed ridge (high pressure) center in Missouri. As this occurred in the absence of a strong frontal passage over this region, the thick smoke plume across the northern CONUS was now “captured” within the ridge. Due to the strength of the ridge, and because the ridge was “closed”, smoke was now essentially trapped in at least the 850 mb layer.



The center of the southern portion of the ridge, previously located over Missouri, moved eastwards to be centered over Ohio on May 22 (Figure 19i). Weak winds exist within closed high-pressure systems, particularly within the vicinity of the center of the high. However, the closed center of the high pressure over Ohio was vast, extending northwestward arguably as far as southern Alberta, where another closed area of high pressure existed. Marginal eastward transport across the northern part of CONUS was supported by this setup, consistent with smoke movements at the time. The east-central CONUS ridge was pushed further eastward on May 23 (Figure 19j). It should be noted that ridges and centers of high pressure are associated with subsidence, or a sinking motion. As such, smoke may be transported vertically downwards where high pressure “reforms.” Said another way, a pressure system should not be thought of as a rigid object that moves in the wind, but rather as constantly reforming, much like a wave in the ocean. As such, smoke may not move as far east as the high-pressure forms. This seemed to be the case, as the center of high pressure moved to New York, but smoke was only as far east as western New York by this time, due to the weak southerly and westerly winds impacting the smoke region between May 21 and May 23. Concurrently, a cold front moved out of Canada, keeping smoke from moving northward back into Canada. In fact, this front eventually pushed the entirety of the smoke back southward across central CONUS, resulting in continental scale recirculation of the plume into May 24 and beyond.

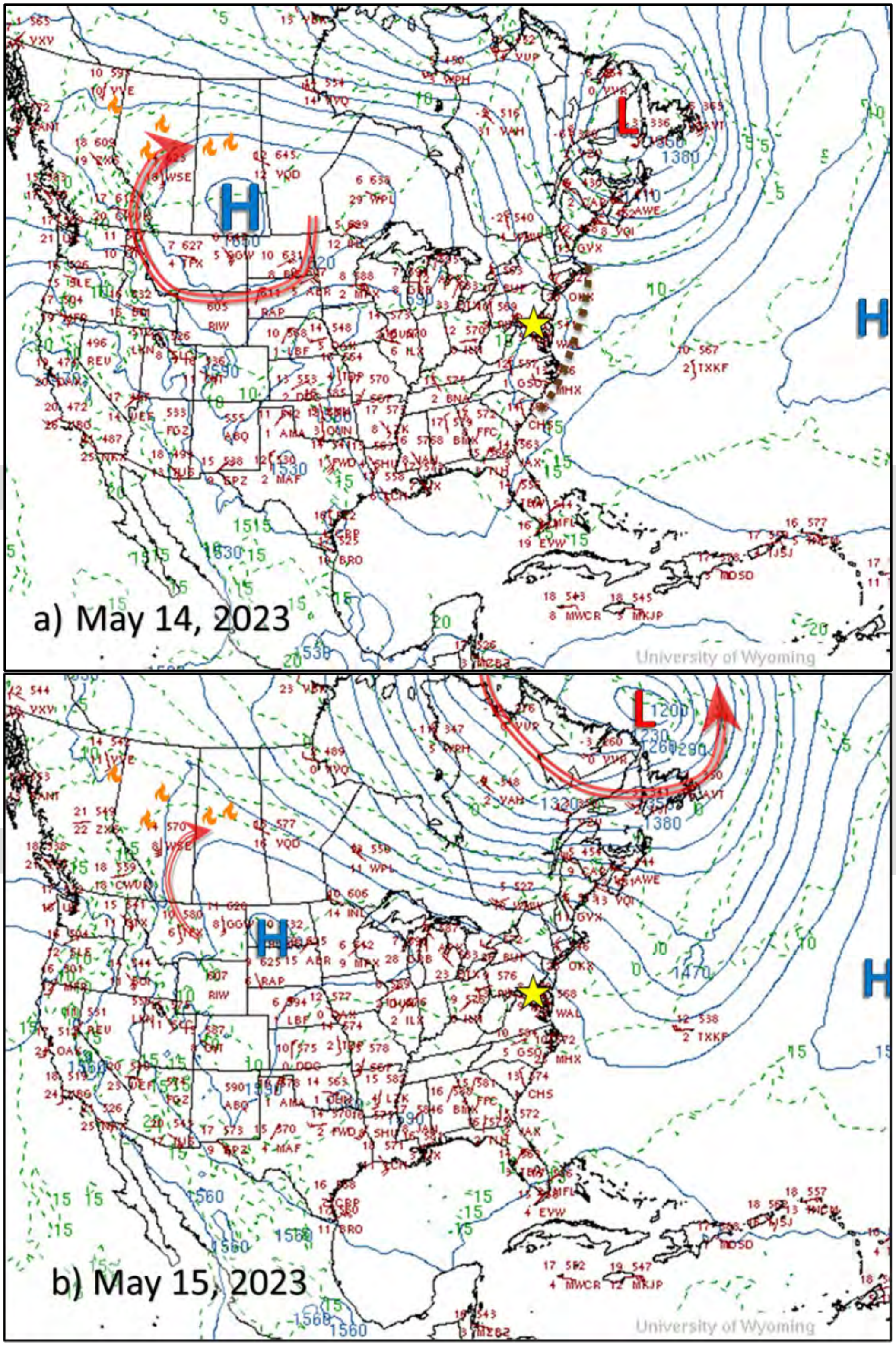
Incredible height gains were realized across southern Canada on May 24 (Figure 19k). Heights within the developing closed high were measured at 1590 m, an increase of over 60 m in 24 hours in some areas. This indicates incredible amounts of subsidence and strengthening of the ridge across central North America. The cold front sweeping south out of northern Ontario on May 23 continued its trek southeastward, weakening at least at 850 mb. However, the trough associated with the cold front acted to pinch off the high pressure which was previously located over New York. This resulted in northeasterly flow across northeast CONUS and the Great Lakes as the high center retreated west. As such, eastward progress of the smoke was again tempered, and instead pushed back westward. Furthermore, the cold front, while weak at 850 mb, can be effective at delivering new airmasses to large regions, removing air in front of it from the region. Behind the cold front on May 24, clean air moved into the northeast CONUS, while the front swept smoky air south and southwestward with clockwise flow around the high across the Great Lakes. Said succinctly, the west-central Canadian smoke was recirculated across the Great Lakes and upper Ohio River Valley to the Central Plains under the developing high pressure located across Canada and the central CONUS on May 24 as it was swept southwest by cleaner air arriving from northeastern Canada.

Smoke contained within the high pressure continued to be recirculated on May 25-June 2. In essence, smoke remained trapped within the slowly moving clockwise flow around the center of high pressure. On

May 25, the center of high pressure moved southward out of Canada to be located over Lake Superior (Figure 19l). On May 26, the center of high pressure was located over Wisconsin (Figure 19m) and by May 27 was centered over southern Ontario (Figure 19n). Note the slowing day to day progression. Farther to the west, just east of the Rocky Mountains, stronger winds indicative of a low-level jet in the lee of the Rockies was observed. This acted to transport smoke northward into Canada more quickly. While most smoke was located under the ridge, the low-level jet on the periphery acted to pull smoke located under the ridge out, and push it northward, expanding the area under the influence of smoke northward. A similar pattern persisted for May 28 (Figure 19o), May 29 (Figure 19p), and May 30 (Figure 19q).

A cold front approached the Mid-Atlantic from the north on May 29, but had not yet reached Delaware. On May 30, the cold front passed through and was able to bring an airmass laden with smoke in Delaware. This occurred as continued presence of high pressure west of the Mid-Atlantic started to “arc” smoke from within or west of the high pressure through Canada, and then southwards towards the Mid-Atlantic region. The persistent pattern then delivered diffuse smoke to Delaware by May 30, with weak but northeasterly flow with subsidence behind the front bringing the smoke to the surface. Northeast flow continued on May 31 with the center of high pressure strengthening, though not moving (Figure 19r).

Between May 29 and May 31, winds were favorable for transport of smoke from that region to the Mid-Atlantic. Smoke from the Nova Scotia fires was caught in the transport behind the cold front and northeasterly winds present on May 30-31 would have delivered smoke from that fire to Delaware beginning May 31 to June 1. On June 1, the center of high pressure had strengthened further, but retrograded westward to over southern Ontario. Delaware benefitted from moderate temperature and local cloud cover that limited ozone formation  (Figure 19s). Northeast flow at 850 mb continued on June 2, resulting in similar conditions as June 1. Temperatures increased on June 2 and clouds lifted in the northern part of the state. Northerly winds continued and all of these factors resulted in ozone exceedances in the north part of the state (Figure 19t).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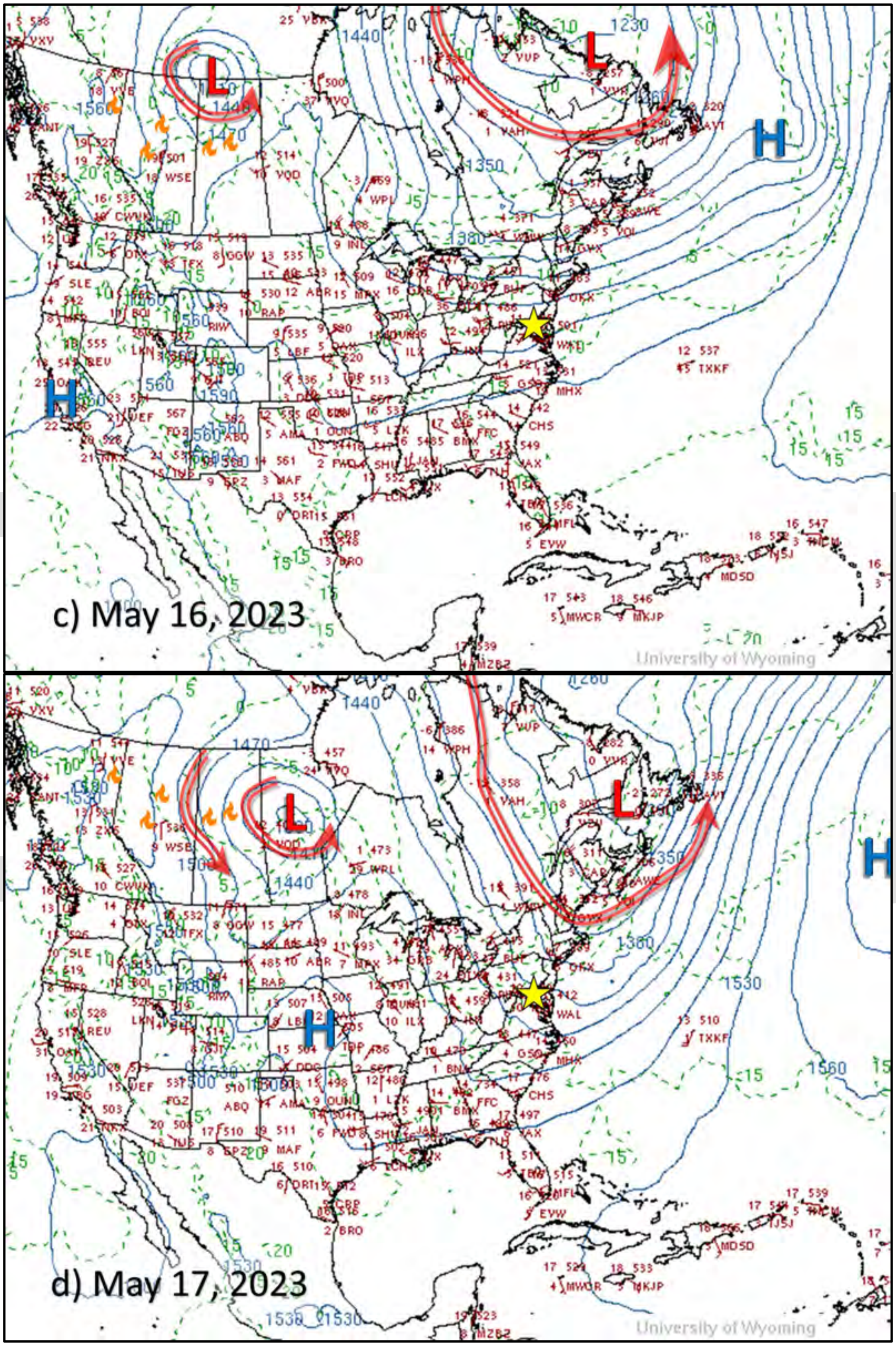
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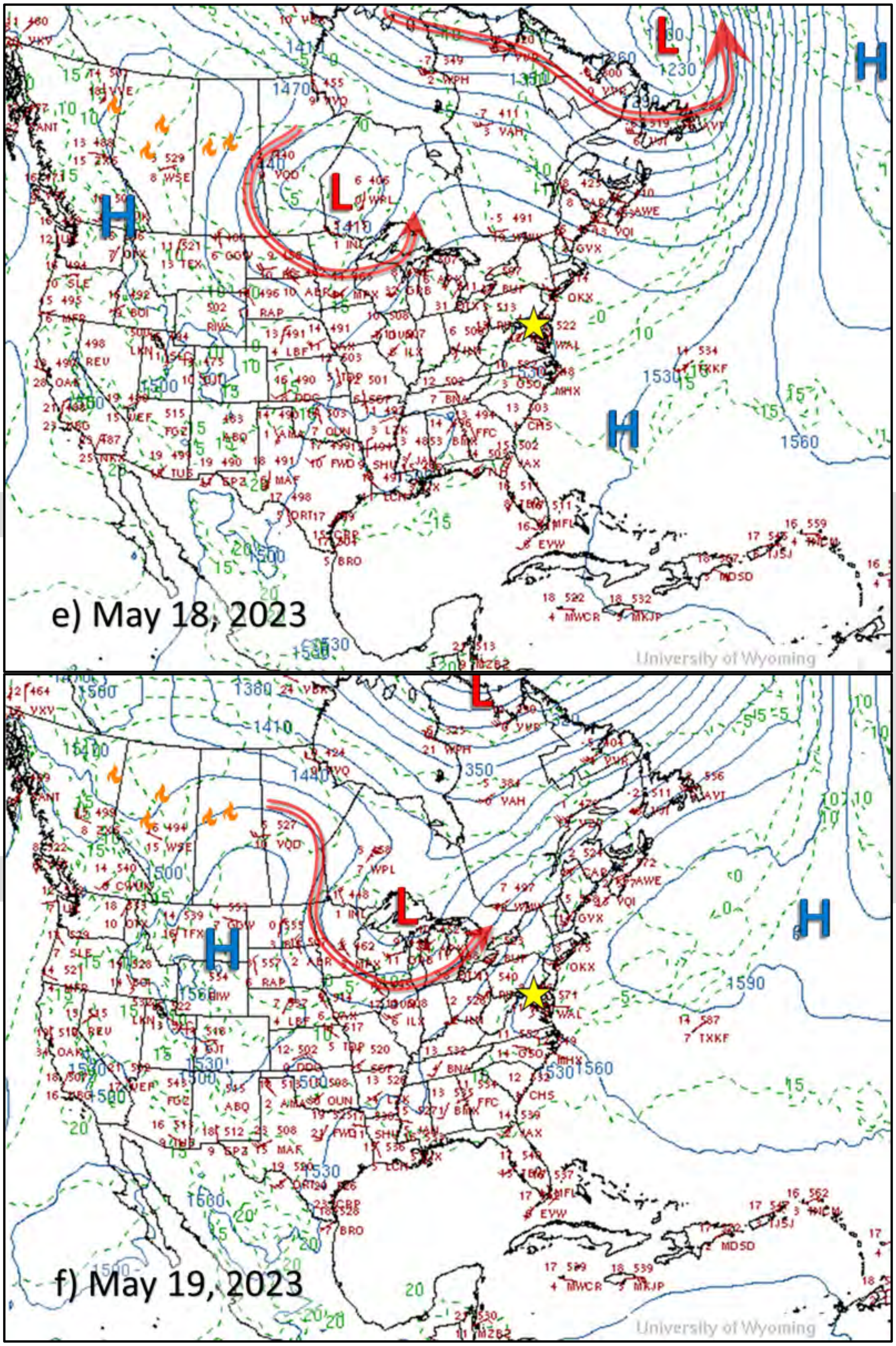
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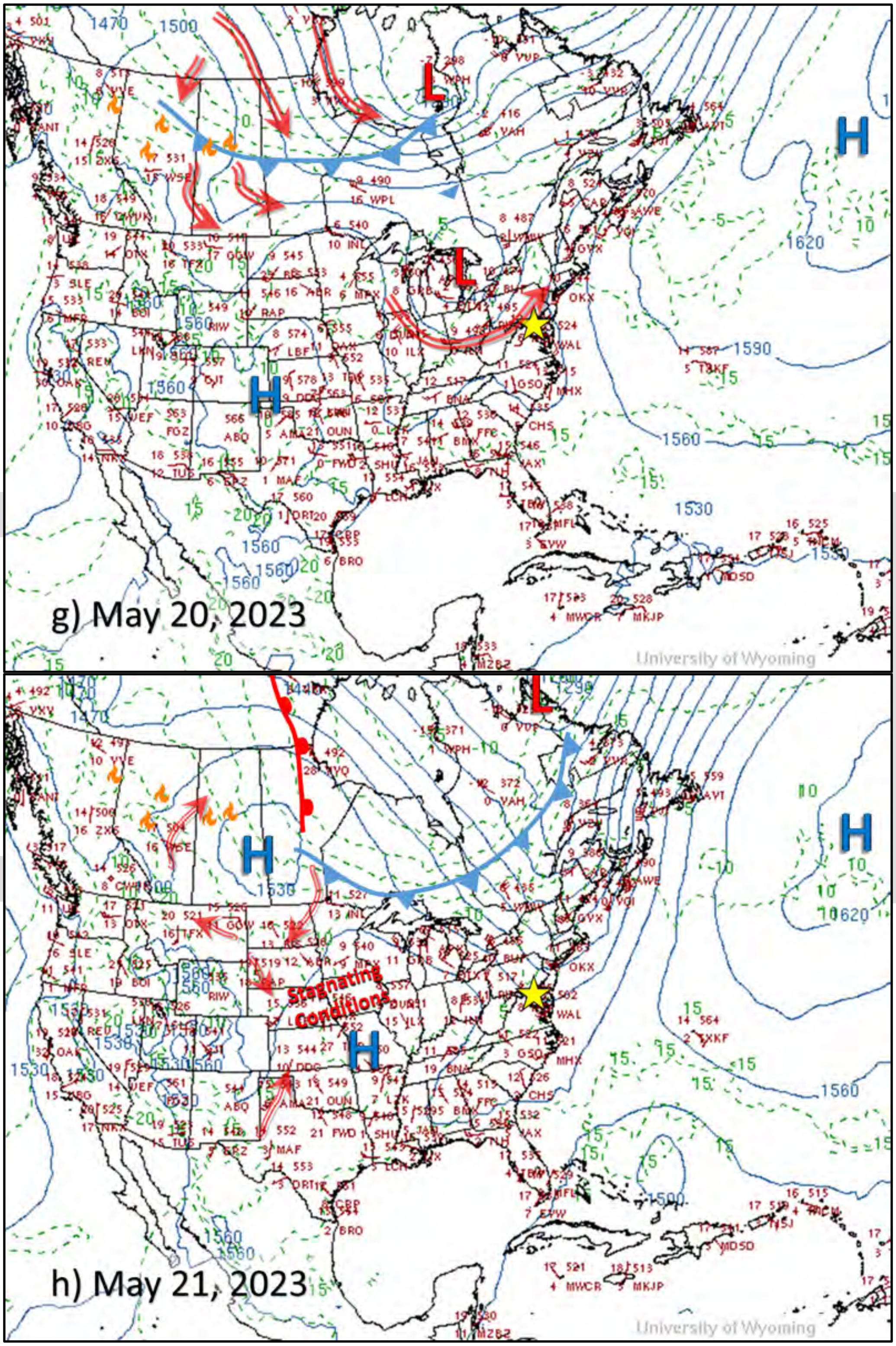
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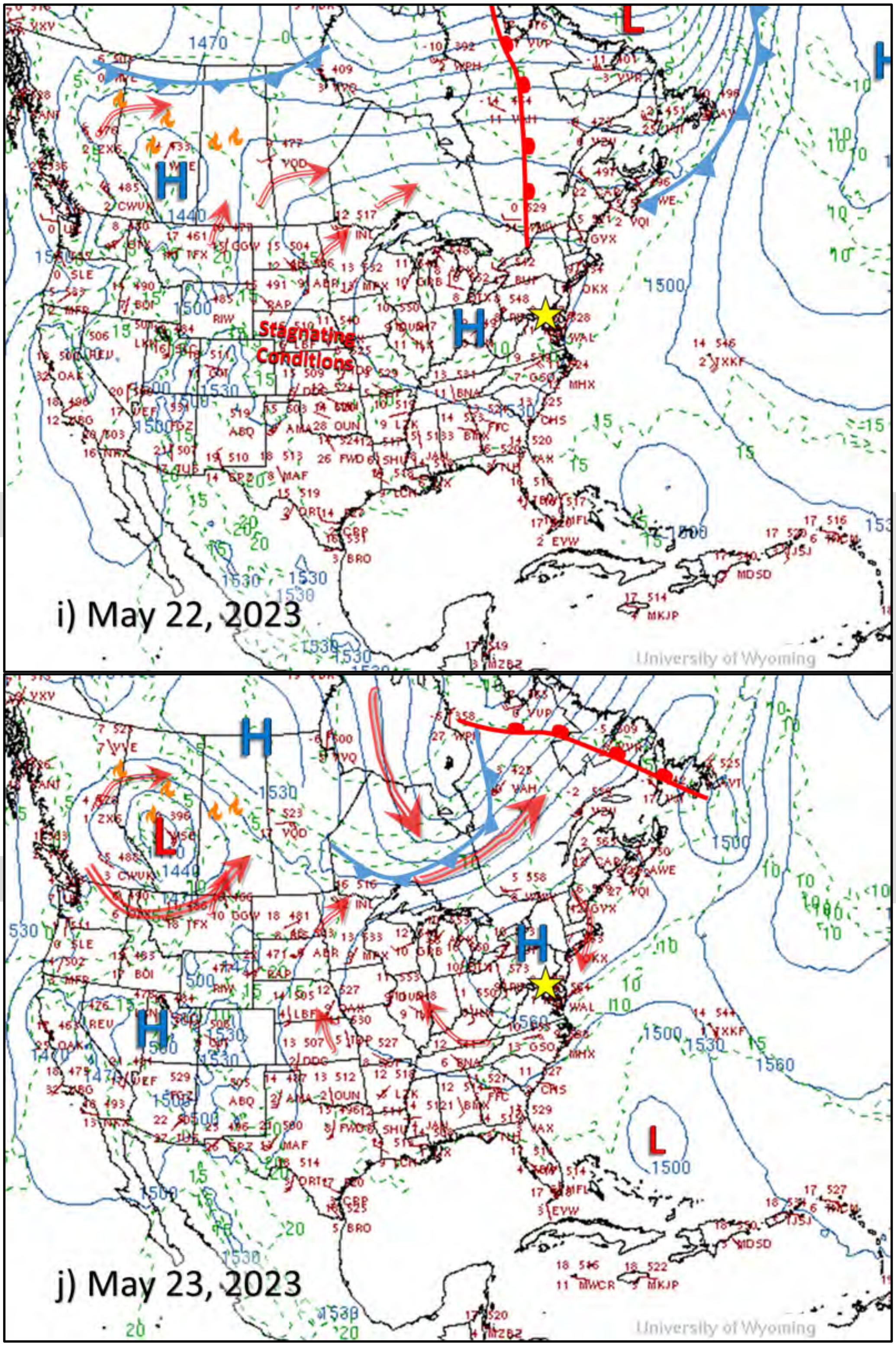
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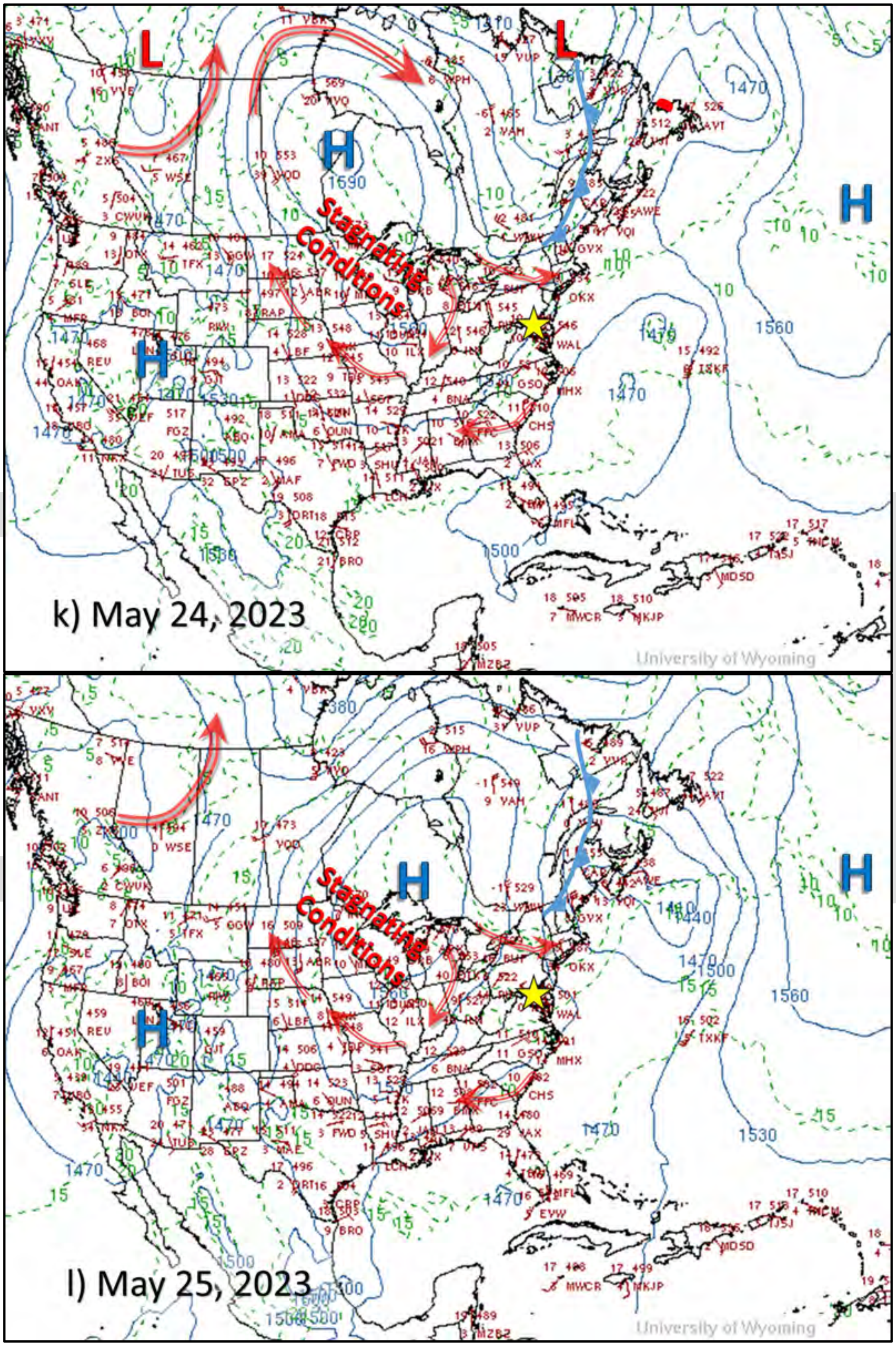
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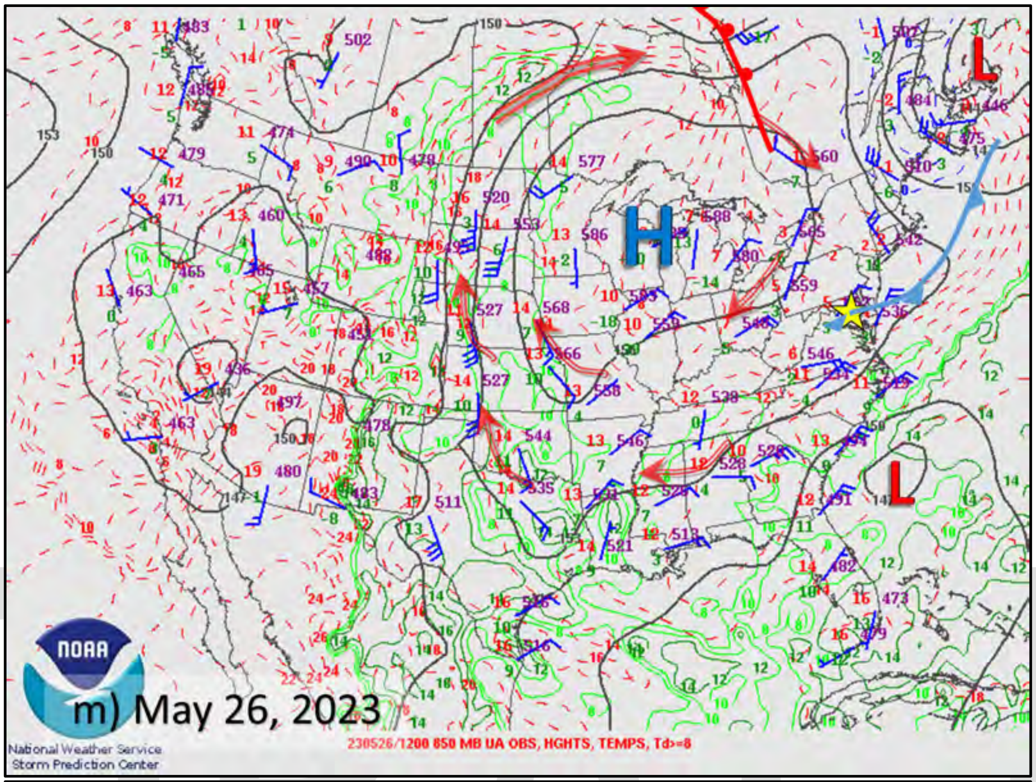
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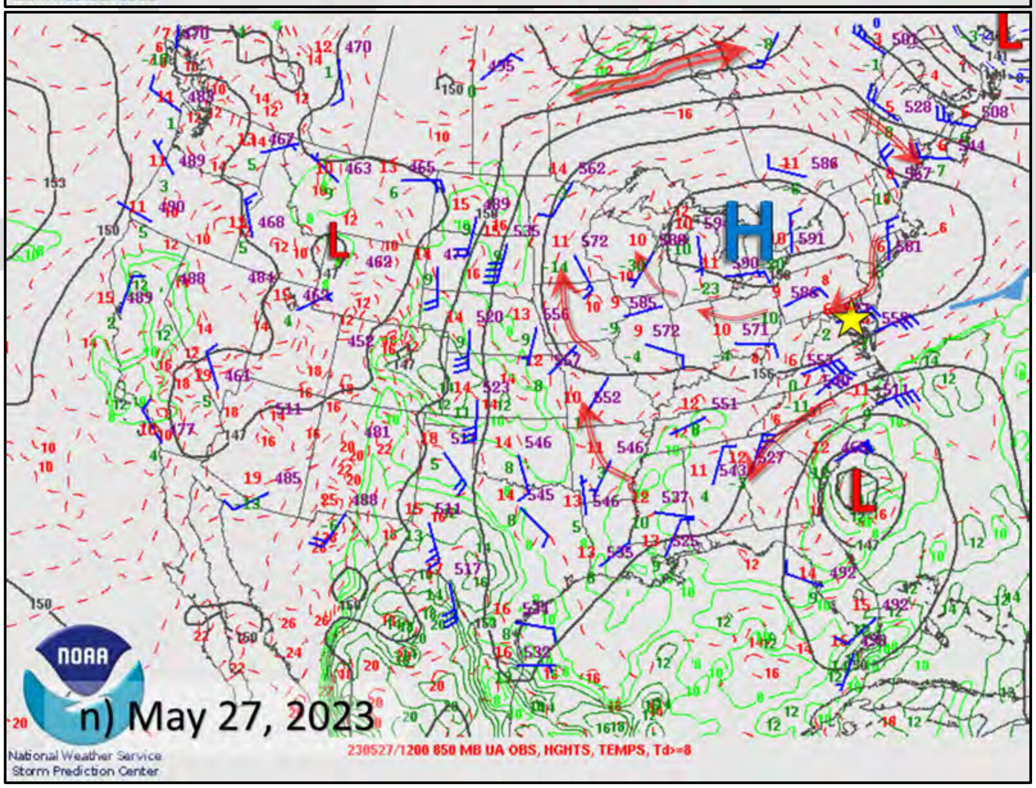
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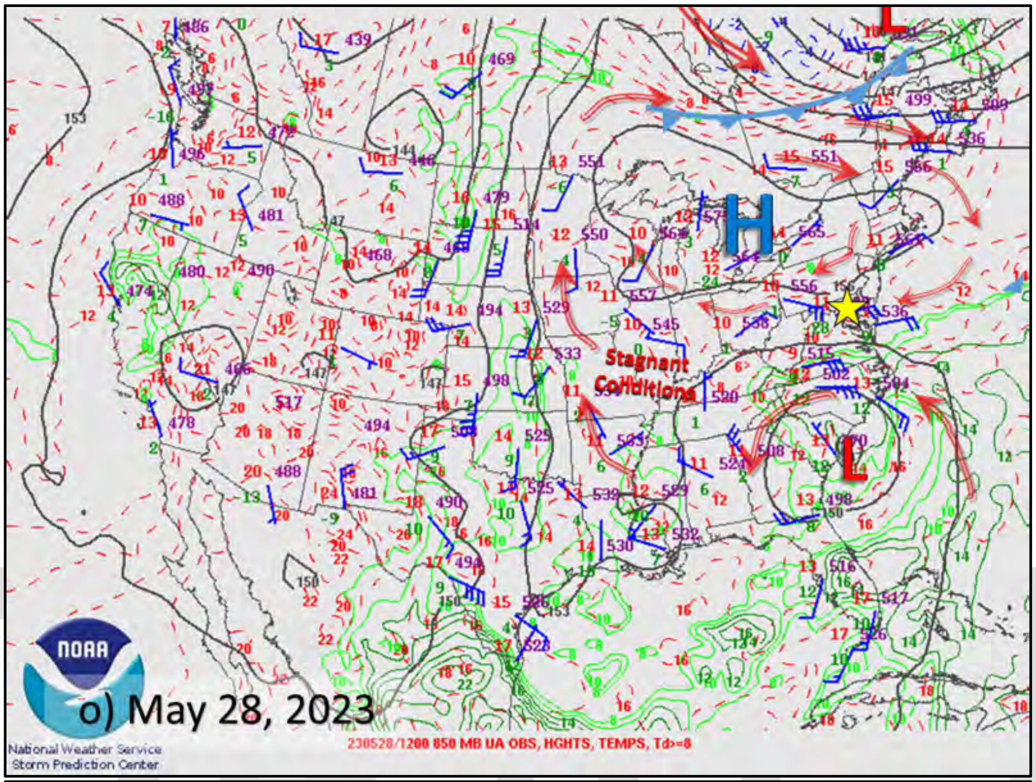
n) May 27, 2023
National Weather Service
Storm Prediction Center
230527/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8
H
L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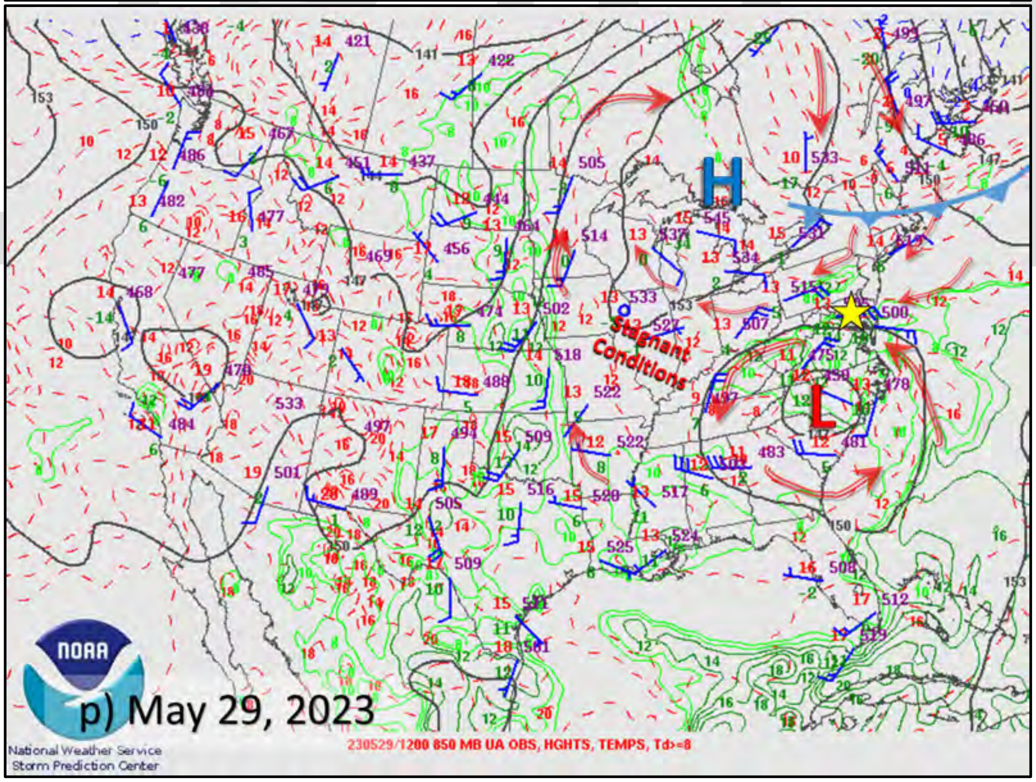
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p) May 29, 2023
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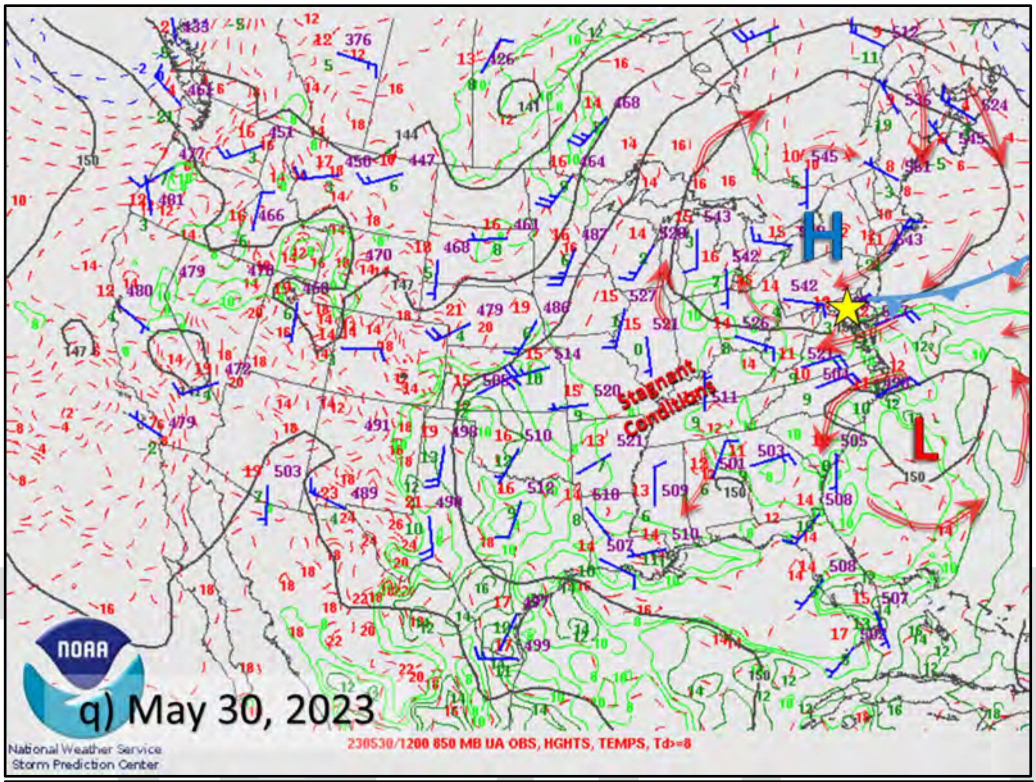
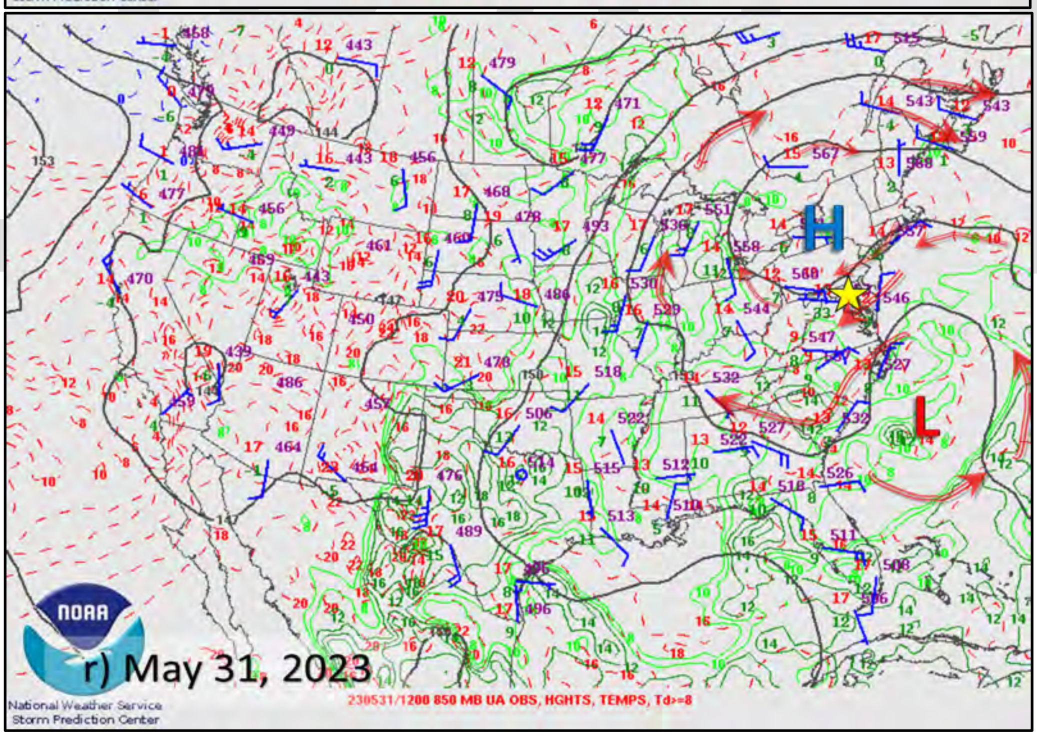
Storm Prediction Center
230529/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8


H
L
Stagnant Conditions
NOAA
q) May 30, 2023
National Weather Service
Storm Prediction Center
230530/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8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NOAA
r) May 31, 2023
National Weather Service
Storm Prediction Center
230531/1200 850 MB UA OBS, HGHTS, TEMPS, Td>=8

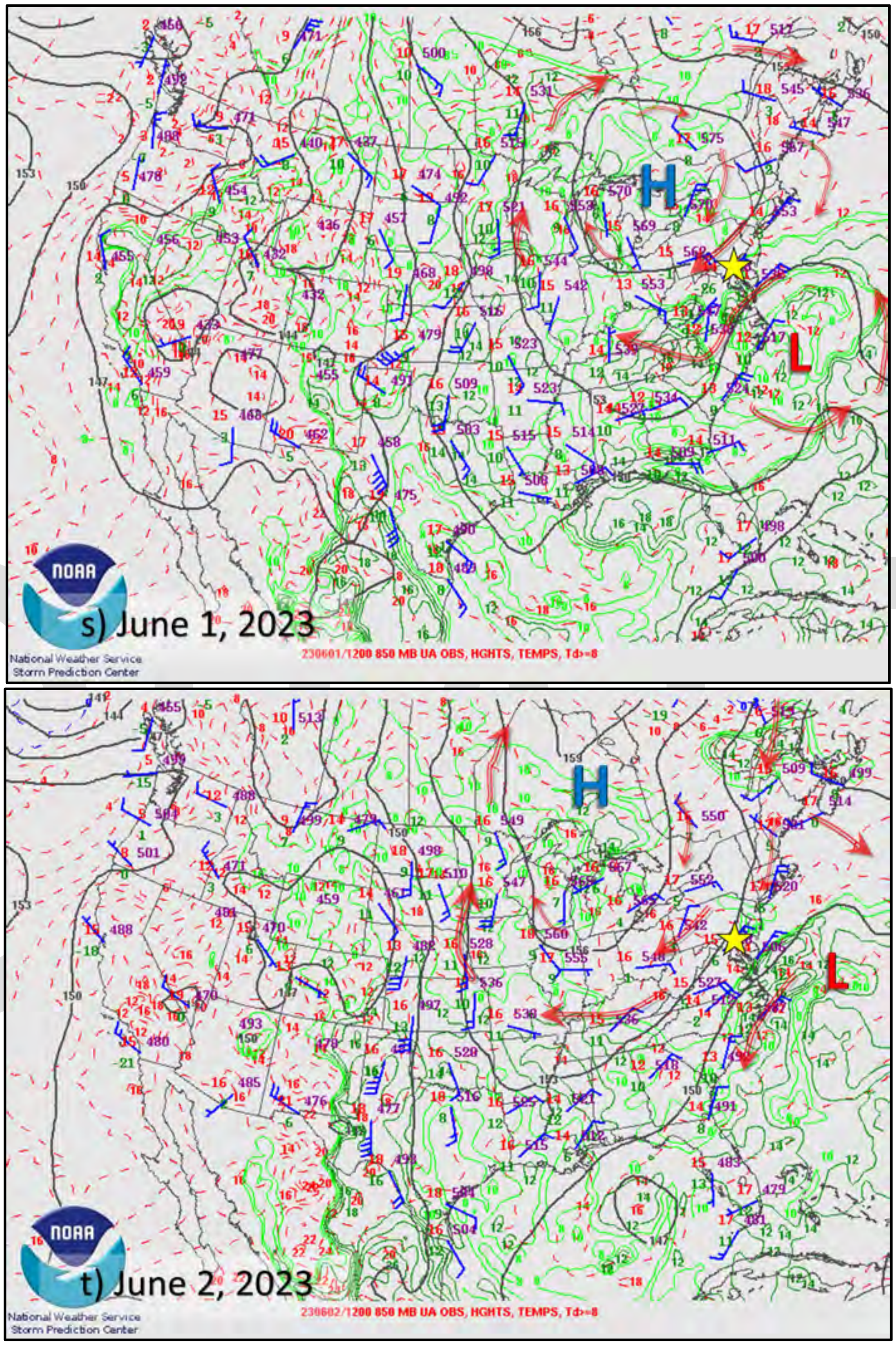



**Figure 19.** Upper-Level Weather Pattern, May 14 to June 2.
The 1200 UTC 850 mb pattern for CONUS, from May 14-June 2, 2023 (figures a-t). Red arrows show the general transport pattern and are generally sized by wind speed. Capital letter “H” is high-pressure and the letter “L” is low pressure. The base images switched sources on May 26 from the University of Wyoming to the Storm Prediction Center to better capture northern Canada and/or details of CONUS. In the North American figures (a-l), heights (m) (blue lines), temperature (°C) (green dashed lines) and station plots (red) which include temperature (°C), dewpoint depression (°C), height (+1000m), wind barb and station identifier, are all included. Similar features with slightly altered colors are presented in figures m-t. Yellow star identifies northern Delaware. Frontal boundaries are noted as cold fronts (blue lines with triangles) and warm fronts (red lines with semi-circles).

### 2.7.4 Surface Pattern Overview

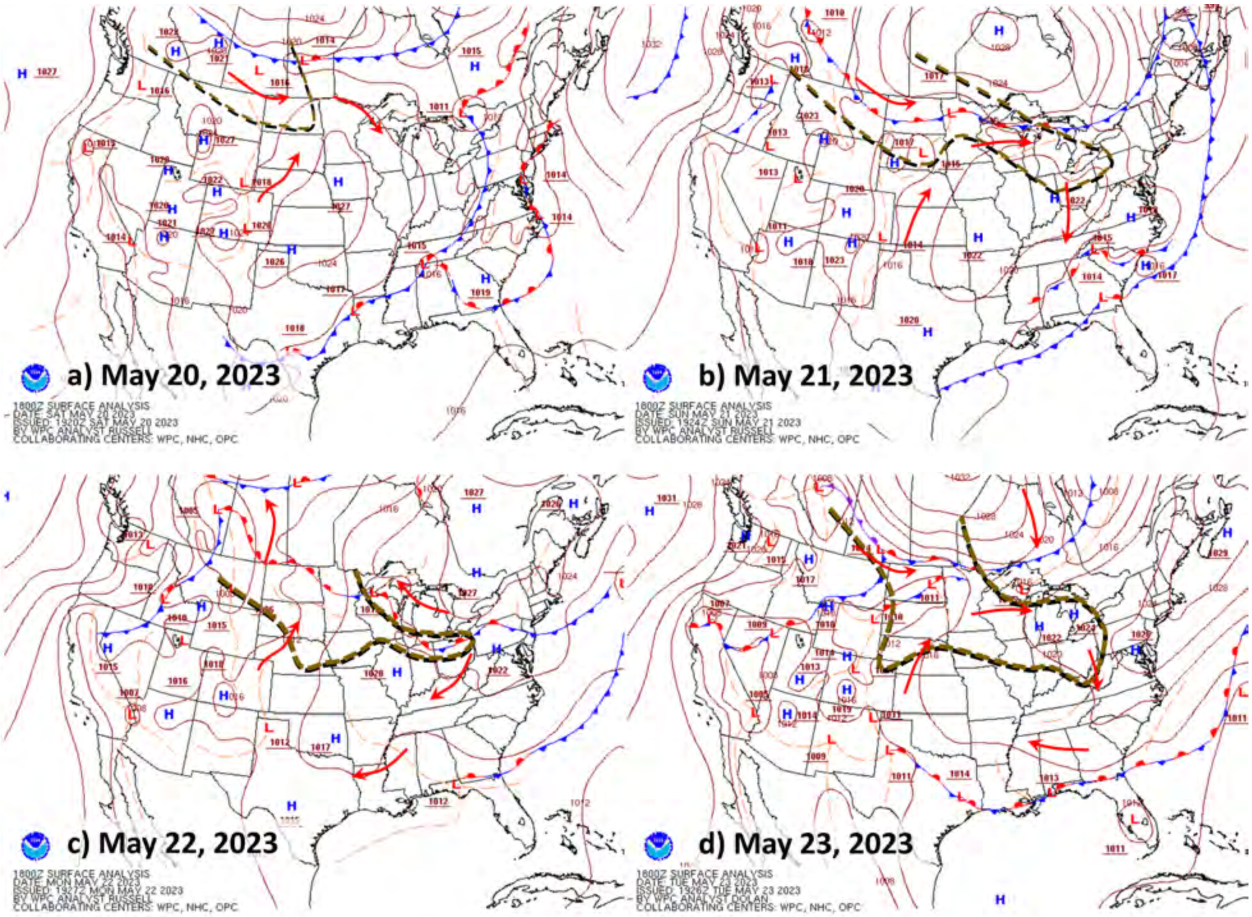
Gross transport in the atmosphere is generally representative at 850 mb, but lacks the detailed information of features such as surface fronts that provide insight to the evolution of events at specific locations and which impact the concentrations relevant to human health. Analysis of the surface pattern followed similar trends as those seen at 850 mb.

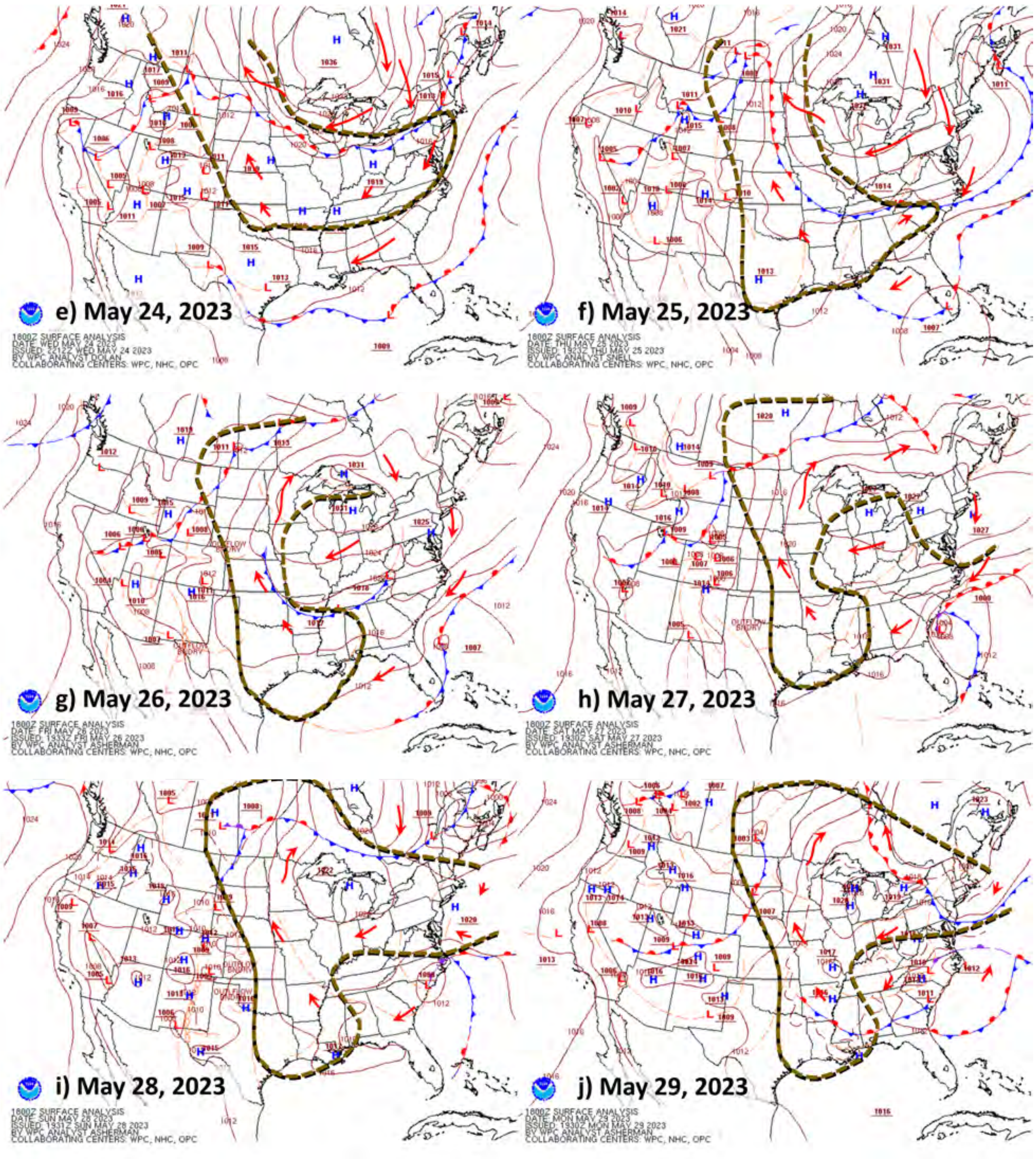
The smoke plume from the conglomeration of fires across west-central Canada entered CONUS on May 20, 2023 (Figure 20a). This was driven by transport level winds discussed above, and the associated surface cold front pushing across the region, as well as a weak low-pressure system over southern Saskatchewan. While this low pressure across southern Saskatchewan was weak, it had a noted influence in the smoke field, which had a spiral pattern consistent with counterclockwise flow associated with low pressure systems and was collocated with analyzed low pressure on Figure 21a. While this weak low may have helped to pull smoke into northern CONUS, the southward progress of the smoke was immediately met with southerly winds around the spatially massive area of high pressure dominating eastern CONUS on May 21 (Figure 20b). As a result, a narrow corridor of smoke existed by May 21 across north-central CONUS, into the Great Lakes pinched from the north by a cold front and pushed northward from the south by southerly winds around the west side of high pressure centered in over Missouri. At higher altitudes (even above the upper air analysis above) smoke drifted southward along the Rockies, underneath upper-level ridging.

The smoke plume was pulled into the ridge of high pressure centered over central CONUS on May 22 and May 23 (Figures 20c and 20d). By May 24, subsidence and surface divergence within the high had spread the regional extent of smoke eastward from the Colorado Rockies to the East Coast (Figure 20e). On May 25, a strong cold front moved through Delaware from the northeast (Figure 20f). The airmass behind the front was devoid of smoke, improving air quality in Delaware by removal of smoke and providing cooler temperatures. Under surface high pressure over the Great Lakes, clockwise circulation around the high, working with the cold front which moved through northeast CONUS placed clean air over areas east of the high, and put smoke on the western periphery of the surface high (still centered over the Great Lakes) from the Gulf Coast all the way into Canada. Cleaner air continued to push westward around the southern portion of surface high pressure across the lower Ohio River Valley on May 26 (Figure 20g). However, by this point, the surface front had essentially washed out, and the cleaner air was losing its character, mixing well with smoke still contained within the central high-pressure system. By May 27 (Figure 20h), smoke began to become visible again farther east in the central CONUS, with smoke noted to be wrapping around the high center over the northeast CONUS (aloft).

On May 28 (Figure 20i) another cold front pushed south out of northern Quebec. This removed much of the smoke initially evident via satellite. However, westerly winds aloft across southern Ontario brought additional smoke over the airmass behind the front; smoke that was recirculated several times around the high-pressure system. In a rare circumstance, a warm front / cold front pair developed under the high-pressure center located over southern Ontario on May 28. Fronts in this nature are typically associated with low pressure systems. However, in this instance, as a cold front moved southward out of northern Quebec and Ontario, it was acted on by surface high pressure, causing the north and western portion of the cold front to return north and eastward as a warm front while the south and eastward portion continued southward as a cold front. Furthermore, additional smoke continued to be locked immediately under the high-pressure center, and as the May 28 cold front swept southward (the eastern portion), subsidence and entrainment associated with high pressure caused smoke to fill in behind the front as it moved towards Delaware. Said another way, the smoke backfilled behind the front, evident by May 29 (Figure 20j). Acted on by high pressure increasingly northwest of the front’s progress, the cold front continued to push south but with greater southwestward inclination into May 29, arcing with an apex approaching Delaware by midday on May 29. By May 30, the front was well south of Delaware, and smoke was ushered in across the state (Figure 20k). Easterly flow due to slow moving low pressure off the Carolina coasts and high pressure centered over the eastern Great Lakes kept clouds and cooler temperatures in Delaware at the time, mitigating the smoke impact.

Light east to northeast flow persisted on May 31 (Figure 20l). While smoke had moved into Delaware, clouds continued to cover southern areas of the state due to easterly flow off low pressure off the coast of North Carolina. However, slightly more northeasterly than easterly flow allowed a return of sun to the northern half of the state. On June 1, cloud cover remained over central and southern Delaware (Figure 20m). Winds remained northeast, with the regional circulation now mainly dictated by the location of high pressure over the Great Lakes and the resulting clockwise flow around the high. A similar atmospheric state existed for June 2, with continued northeast flow dictated by the center of high pressure over the Great Lakes (Figure 20n). A weak trough of low pressure was analyzed from Maine to northeastern Maryland.  In Delaware, ozone exceedances occurred on June 2 for all ozone monitors in Kent and New Castle Counties (our central and northern counties).  Sussex County, Delaware's southern county, did not record ozone exceedances as local sea breezes shifted the wind direction in that area which reduced the amount of smoke present.




e) May 24, 2023
f) May 25, 2023
g) May 26, 2023
h) May 27, 2023
i) May 28, 2023
j) May 29, 2023

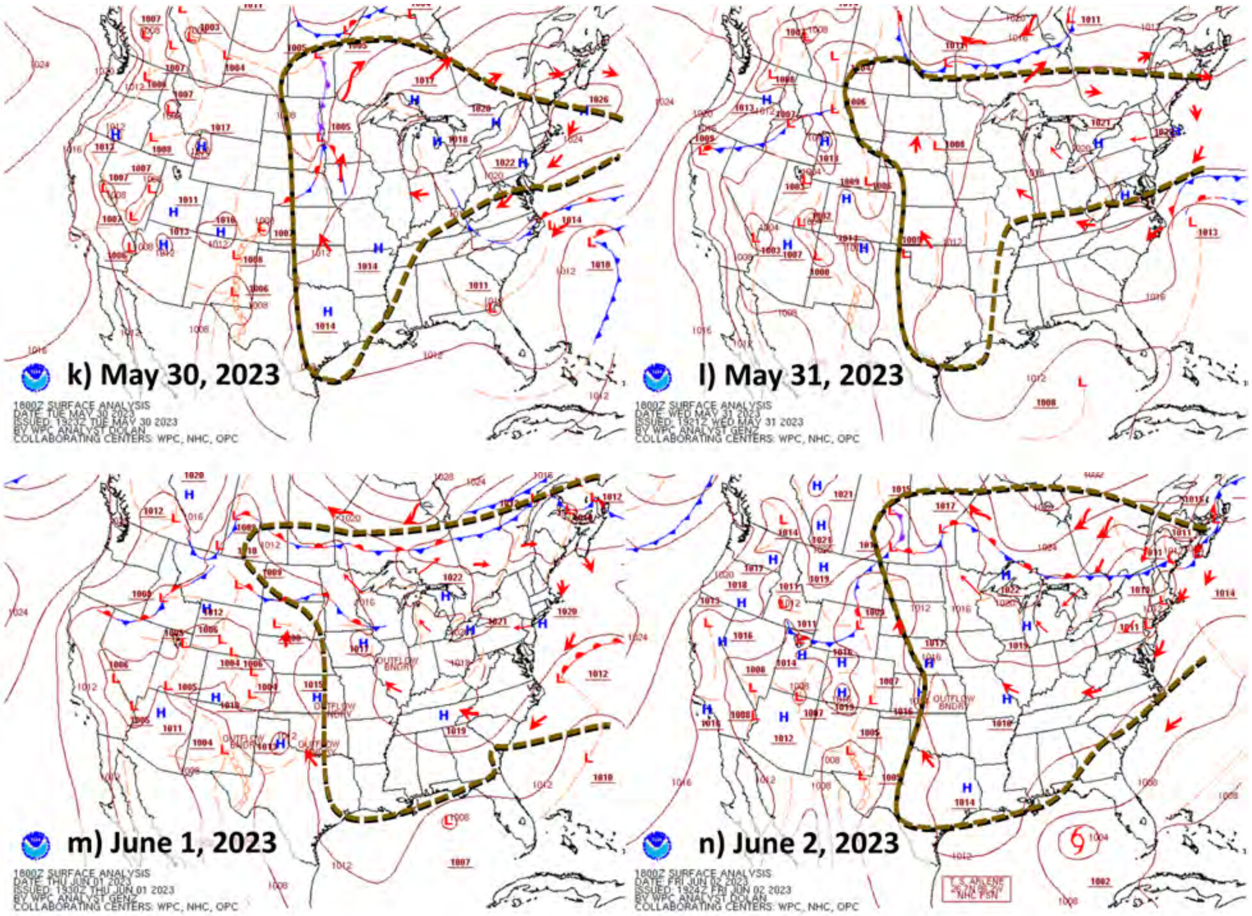



**Figure 20.** Surface Weather Pattern, May 20 to June 2.
Surface analysis at 1800 UTC (2pm local daylight time in Delaware) for May 20-June 2 (a-n), 2023. Red arrows show the general surface wind pattern/direction and are approximately scaled by wind strength. The letter "H" highlights high pressure, the letter "L" is low pressure. Heights (brown lines) and fronts are also analyzed. The thick, shadowed, dashed lines represent the visible smoke plume on satellite.

### 2.7.5 Temperature

Consistent with the theme of 2023, heightened ozone concentrations, specifically reaching near or beyond 70 ppb, were associated with periods of smoke. Smoke was initially observed across the Midwest beginning May 21, 2023. MD8AO greater than 70 ppb were first observed centered over the Minneapolis region. In the presence of smoke, MD8AO concentrations climbed from 51 to 74 ppb May 20 vs 21, a 23 ppb increase (Table 4). Temperatures did climb slightly, but only to 79°F on May 21 from 73°F on May 20. Though roughly 8°F above normal, the absolute temperature is not alone ozone conducive.

Smoke continued to be a presence across the Midwest, stretching to the Great Lakes region on May 22-23 and even a brief stint of diffuse smoke pushing to the East Coast May 24. Temperatures over this period were warmer than normal, but not ozone exceedance conducive. On May 23, Minneapolis, despite only reaching a high temperature of 84°F, saw an MD8AO of 82 ppb. A similar story occurred on this day at Chicago's O'Hare Airport, where MD8AO reached 80 ppb despite a high temperature of just 86°F (Table 4).

Beginning May 24, a cold front began to slowly push south and west through the Great Lakes and through the Ohio River Valley. Drops in temperature were first observed over Minneapolis, MN, and Chicago's O'Hare. A near 20°F drop in temperature was seen in Chicago, Illinois between May 23 and 24

(Table 4). Aside from temperatures, this front also helped to provide a reprieve from the smoke as clean air behind the front dropped ozone concentrations. Significant drops in ozone were observed on May 24 at both Minneapolis, Minnesota. and Chicago, Illinois, with a 21 and 26 ppb MD8AO drop at these two locations, respectively (Table 4). On May 25, this front was able to stretch all the way south through St. Louis, Missouri, where a similar drop in ozone was noted. Temperatures did not see as significant a drop at St. Louis however, due to the front washing out by this point.

High pressure became centered over the Great Lakes beginning May 25 and 26, persisting in that region for the remainder of this event. Clockwise flow began to wrap the smoke and warmer temperatures back over eastern CONUS. This warming trend and eventual onset of smoke was observed across all four Midwest and Great Lakes area cities (Minneapolis, Minn., Chicago, Ill., Cleveland, Ohio, and St. Louis, Mo.) between May 25 and 30, varying slightly on the exact days for each location given their orientation in reference to the high pressure (Table 4). Across the Mid-Atlantic over this period, temperatures remained at or slightly below seasonal norms, as smoke remained west of the region. Upper 70°F to low 80°F were observed during this time at from Philadelphia, Pennsylvania through Delaware and into Maryland, with MD8AO generally in the Good to low Moderate AQI range (Table 4).

By May 31, smoke had wrapped all the way around the Great Lakes high pressure system and was impacting Mid-Atlantic states. Surface temperatures on May 31 at through the Mid-Atlantic near seasonal norms at 80°F. An uptick of roughly 10 to 15 ppb ozone was observed versus May 30, despite temperatures only being a few degrees warmer (Table 4). At least part of the difference between May 30 and 31 was the availability of sunshine, with more available on May 31. Smoke continued to filter into the Mid-Atlantic on June 1 and 2 while slightly warmer air aloft wrapped around the high-pressure system. Temperatures saw an increase through the mid-Atlantic region, climbing from the upper 80s°F on June 1 to the 90s°F by June 2. By this point in time, smoke was covering a large stretch of eastern CONUS, with numerous locations and regions recording MD8AO greater than 70 ppb.

The temperature trends across these cities impacted by smoke indicated that, while warm temperatures support ozone production, they were not a primary deterministic factor of high values in this case. As asserted earlier and exemplified over this period of warm weather, temperatures no longer necessarily predict ozone production, and the most recent years of data have shown that warm temperatures are no longer sufficient for ozone exceedances in Delaware.

Temperatures cooled off June 3 and 4, from east to west as a steady onshore flow helped return temperatures to seasonal levels, but also brought in a non-smoke-filled air mass. Temperatures were comparable across the Mid-Atlantic on June 3 and 4 to the initial temperatures at the onset of the smoke in this region on May 30. Despite this, given a smoke-free air mass, a significant drop in ozone was observed (Table 4).

| Date | 20-May | 21-May | 22-May | 23-May | 24-May | 25-May | 26-May | 27-May | 28-May | 29-May | 30-May | 31-May | 1-Jun | 2-Jun | 3-Jun | 4-Jun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minneapolis, MN (°F)** | 73 | 79 | 82 | 84 | 86 | 77 | 81 | 84 | 84 | 88 | 90 | 90 | 91 | 87 | 90 | 92 |
| Normal (°F) | 70.7 | 71.1 | 71.4 | 71.7 | 72.1 | 72.4 | 72.7 | 73.1 | 73.4 | 73.7 | 74.1 | 74.4 | 74.7 | 75 | 75.4 | 75.7 |
| Departure (°F) | 2.3 | 7.9 | 10.6 | 12.3 | 13.9 | 4.6 | 8.3 | 10.9 | 10.6 | 14.3 | 15.9 | 15.6 | 16.3 | 12 | 14.6 | 16.3 |
| MD8AO | 51 | 74 | 74 | 82 | 51 | 59 | 68 | 74 | 75 | 73 | 65 | 69 | 62 | 67 | 77 | 68 |
| **Chicago, IL (°F)** | 73 | 81 | 83 | 86 | 97 | 92 | 70 | 74 | 80 | 86 | 91 | 91 | 91 | 91 | 87 | 77 |
| Normal (°F) | 71.9 | 72.3 | 72.6 | 73 | 73.3 | 73.7 | 74 | 74.3 | 74.7 | 75 | 75.4 | 75.7 | 76 | 76.4 | 76.7 | 77 |
| Departure (°F) | 1.1 | 8.7 | 10.4 | 13 | 23.7 | 18.3 | -4 | -0.3 | 5.3 | 11 | 15.6 | 15.3 | 15 | 14.6 | 10.3 | 0 |
| MD8AO | 44 | 63 | 69 | 80 | 54 | 43 | 56 | 65 | 66 | 74 | 78 | 65 | 79 | 85 | 78 | 55 |
| **Cleveland, OH (°F)** | 63 | 74 | 76 | 79 | 75 | 58 | 66 | 74 | 77 | 80 | 87 | 84 | 86 | 84 | 81 | 73 |
| Normal (°F) | 72.3 | 72.6 | 72.9 | 73.2 | 73.5 | 73.8 | 74 | 74.3 | 74.6 | 74.9 | 75.2 | 75.5 | 75.8 | 76.1 | 76.4 | 76.7 |
| Departure (°F) | -9.3 | 1.4 | 3.1 | 5.8 | 1.5 | -15.8 | -8 | -0.3 | 2.4 | 5.1 | 11.8 | 8.5 | 10.2 | 7.9 | 4.6 | -3.7 |
| MD8AO | 38 | 46 | 50 | 62 | 60 | 39 | 47 | 55 | 66 | 65 | 67 | 68 | 82 | 84 | 53 | 48 |
| **St. Louis, MO (°F)** | 73 | 78 | 81 | 85 | 88 | 81 | 77 | 81 | 82 | 87 | 90 | 91 | 92 | 93 | 94 | 93 |
| Normal (°F) | 78.2 | 78.5 | 78.8 | 79.1 | 79.4 | 79.7 | 80 | 80.4 | 80.7 | 81 | 81.3 | 81.6 | 81.9 | 82.3 | 82.6 | 82.9 |
| Departure (°F) | -5.2 | -0.5 | 2.2 | 5.9 | 8.6 | 1.3 | -3 | 0.6 | 1.3 | 6 | 8.7 | 9.4 | 10.1 | 10.7 | 11.4 | 10.1 |
| MD8AO | 41 | 60 | 68 | 65 | 82 | 61 | 62 | 68 | 71 | 76 | 82 | 77 | 69 | 75 | 88 | 69 |
| **Philadelphia, PA (°F)** | 71 | 77 | 79 | 75 | 81 | 71 | 75 | 80 | 79 | 82 | 76 | 80 | 88 | 95 | 76 | 77 |
| Normal (°F) | 75.4 | 75.7 | 75.9 | 76.2 | 76.5 | 76.8 | 77.1 | 77.3 | 77.6 | 77.9 | 78.2 | 78.5 | 78.8 | 79.1 | 79.4 | 79.7 |
| Departure (°F) | -4.4 | 1.3 | 3.1 | -1.2 | 4.5 | -5.8 | -2.1 | 2.7 | 1.4 | 4.1 | -2.2 | 1.5 | 9.2 | 15.9 | -3.4 | -2.7 |
| MD8AO | 37 | 51 | 50 | 43 | 65 | 49 | 50 | 60 | 53 | 63 | 49 | 63 | 72 | 105 | 40 | 44 |
| **Baltimore, MD (°F)** | 79 | 80 | 82 | 75 | 84 | 74 | 75 | 78 | 77 | 78 | 77 | 80 | 87 | 97 | 85 | 80 |
| Normal (°F) | 76.4 | 76.6 | 76.9 | 77.2 | 77.4 | 77.7 | 78 | 78.3 | 78.6 | 78.9 | 79.2 | 79.5 | 79.8 | 80.1 | 80.4 | 80.8 |
| Departure (°F) | 2.6 | 3.4 | 5.1 | -2.2 | 6.6 | -3.7 | -3 | -0.3 | -1.6 | -0.9 | -2.2 | 0.5 | 7.2 | 16.9 | 4.6 | -0.8 |
| MD8AO | 47 | 54 | 53 | 46 | 65 | 54 | 58 | 58 | 48 | 51 | 52 | 64 | 74 | 87 | 53 | 48 |
| **New Castle, DE (°F)** | 73 | 80 | 81 | 76 | 82 | 74 | 77 | 81 | 78 | 86 | 79 | 81 | 91 | 96 | 76 | 77 |
| Normal (°F) | 75 | 75 | 75 | 75 | 76 | 76 | 76 | 76 | 77 | 77 | 77 | 78 | 78 | 78 | 78 | 79 |
| Departure (°F) | -2 | 5 | 6 | 1 | 6 | -2 | 1 | 5 | 1 | 9 | 2 | 3 | 13 | 18 | -2 | -2 |
| MD8AO | 35 | 51 | 53 | 42 | 61 | 52 | 51 | 58 | 54 | 60 | 51 | 64 | 69 | 85 | 48 | 49 |

**Table 4.** Temperature and Ozone Data for Cities Affected by the Smoke Plume. Maximum daily temperature, average maximum daily temperature, departure from normal (observation minus normal/average) and MD8AO at various locations.

Smoke impacted an expansive region. Temperatures are given for a number of cities impacted by the smoke at various times and concentrations as smoke recirculated under the ridge (Table 4). Cities include Minneapolis, Chicago (O'Hare Airport), Cleveland, St. Louis, Philadelphia, Baltimore (BWI Airport) and New Castle, Delaware. MD8AO in proximity to these locations for May 20 through June 5, 2023 are included. Maximum daily temperature, average maximum daily temperature, departure from normal (observation minus normal/average) and MD8AO at various locations along the smoke trek to Delaware are taken from NWS NOWdata and Airnow sub-regional concentrations around each city. All temperatures are in degrees Fahrenheit. Yellow/Orange/Red shading corresponds to MD8AO AQI color.

### 2.7.6 Reduced Visibility in Delaware

Conditions in Delaware began to show visual evidence of smoke early in the week of May 29th through reduced visibility. Mid-morning on June 1, Sussex County Delaware was severely impacted by smoke transport and elevated PM through the southern part of the state resulted in relocating graduation ceremonies from outdoor to indoor locations and several local news reports. In New Castle County, PM was not as high, but visibility was impacted (Figures 21 and 22). These photographs of the Delaware Memorial Bridge, courtesy of the Delaware River and Bay Authority, show that visibility was reduced from normal visibility levels on June 1, 2023. Appendix B contains daily forecasts and air quality action day alerts for this week from Sonoma Tech. Inc, Delaware's forecaster as well as examples of social media posts and references to local news reports.

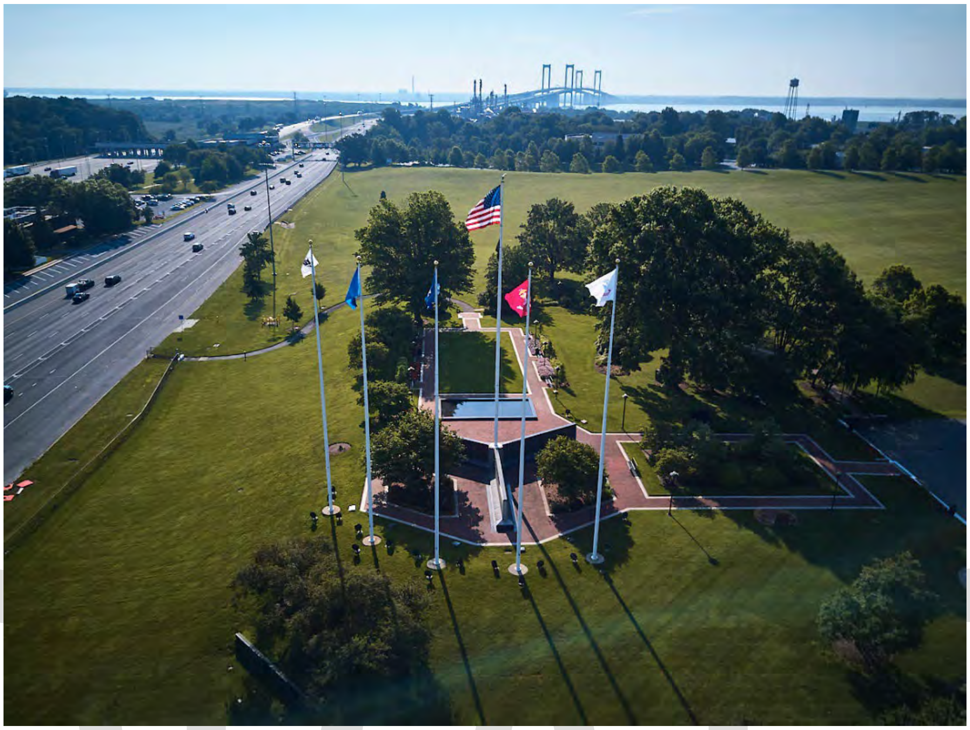


**Figure 21.** Normal Visibility in Delaware.
Photo of the Delaware Memorial Bridge, in New Castle County Delaware on June 29, 2019. This photo is provided as a reference to illustrate the reduced visibility in Figure 22.

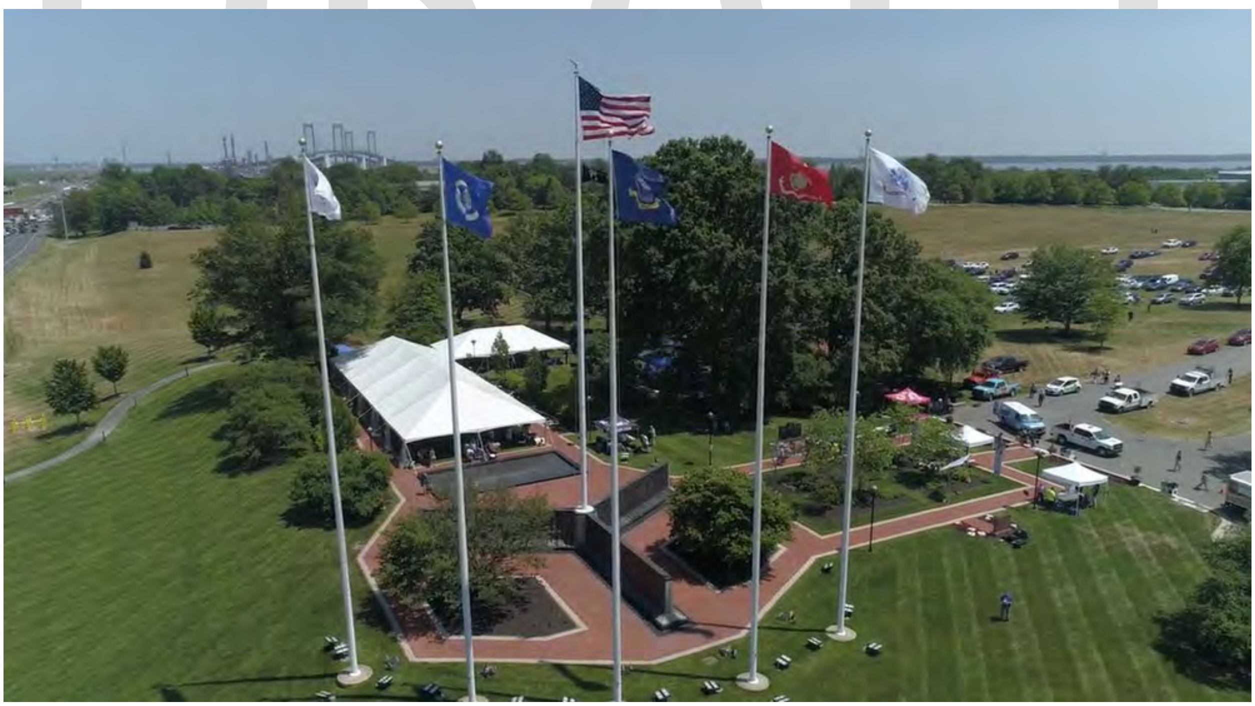


**Figure 22.** Reduced Visibility in Delaware.
Photo of the Delaware Memorial Bridge, in New Castle County Delaware on June 1, 2023. Reduced visibility is clear when Figure 22 is compared to Figure 21.

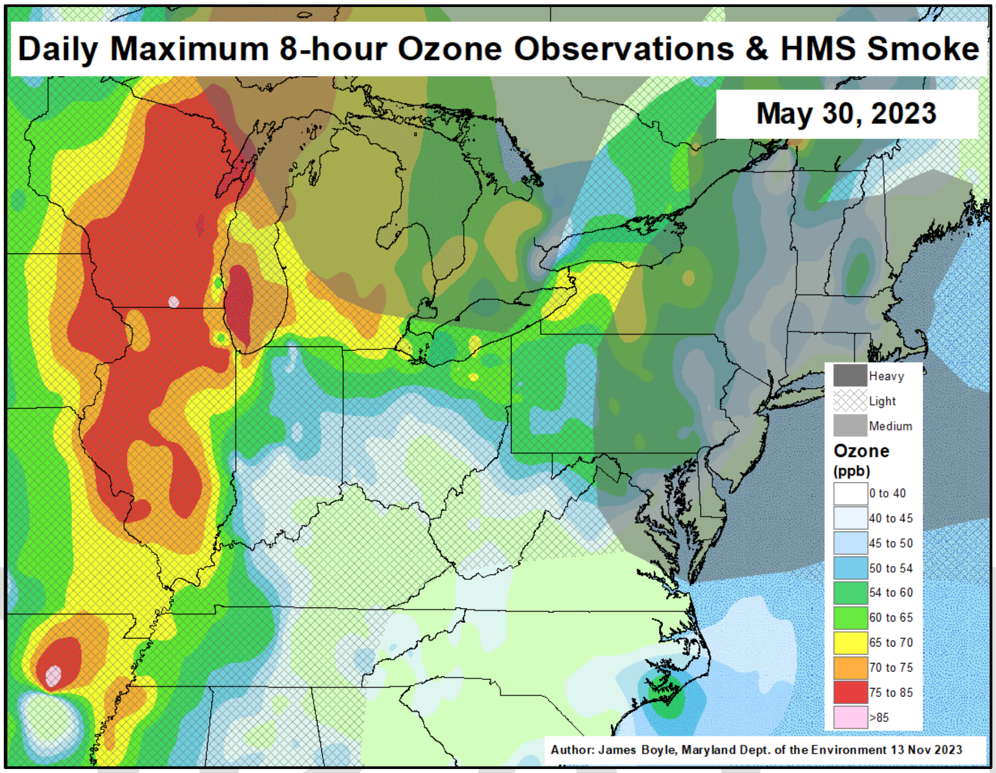
### 2.7.7 Smoke and Ozone Discussion and Analysis

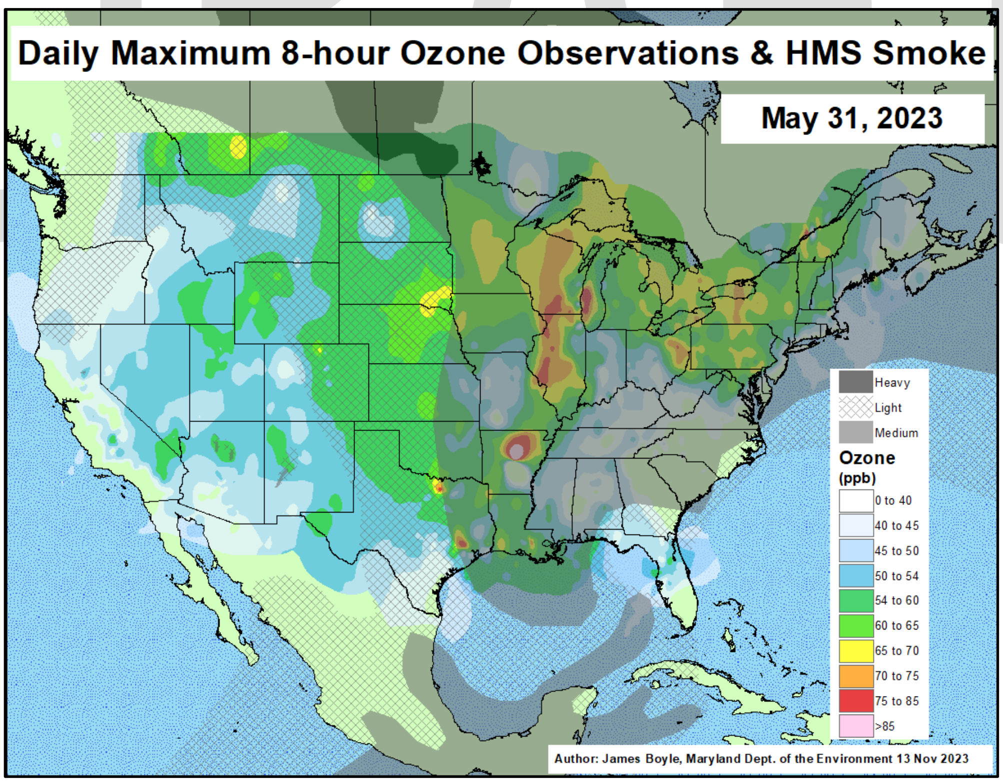
Spatial analysis of contoured MD8AO concentrations and HMS analyzed smoke was done for the period of May 30-June 4 (Figure 23). Thick smoke had already begun to make its way into the Mid-Atlantic and Great Lakes areas May 30. Temperatures along the East Coast were not ozone conducive, with high temperatures only reaching the mid-to-upper-70s°F on May 30, resulting in little ozone at this time (Table 4). Across the Southeast, widespread cloud coverage associated with a low-pressure disturbance also limited ozone production. By this point, the smoke plume was significantly aged. More favorable meteorology across the Midwest resulted in an anomalously large area of MD8AO above 70 ppb centered over Wisconsin and Illinois.

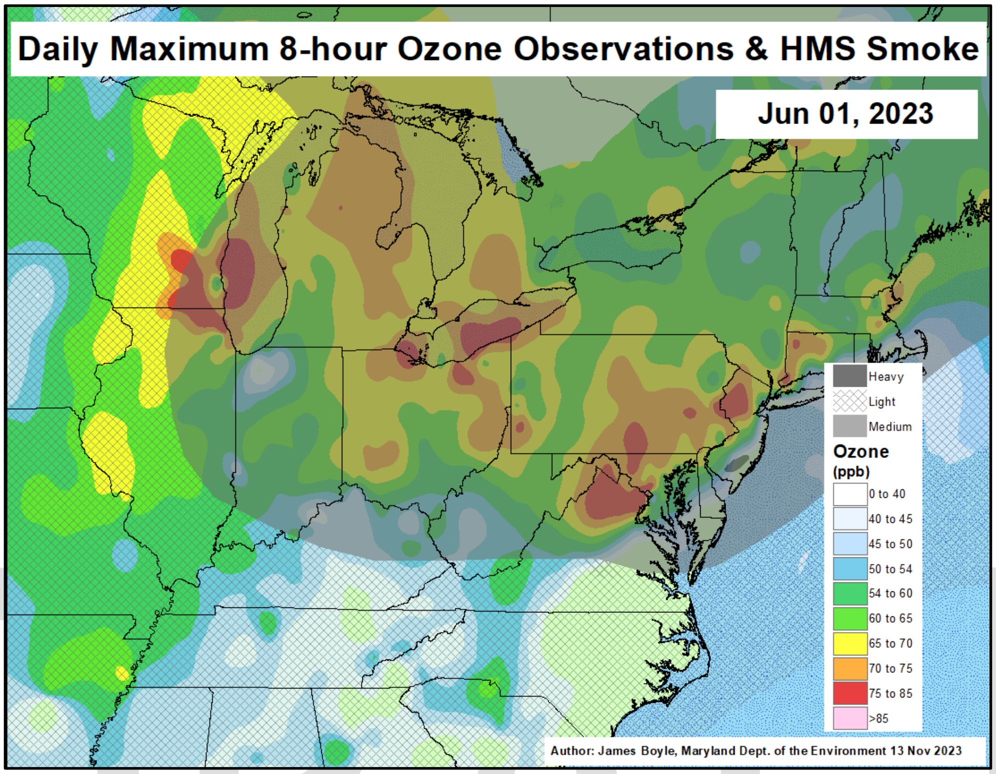
Ozone concentrations began to rise across the Mid-Atlantic states on May 31, as a result of slightly warmer temperatures, pushing into the low-80s°F. Widespread MD8AO above 70 ppb were again noted over Wisconsin and Illinois, with a few other pockets developing over Ohio and New York. Highest ozone concentrations across CONUS match up very well with HMS smoke of medium density with the exception of the southeastern states, where general cloud coverage lingered from the previous day.

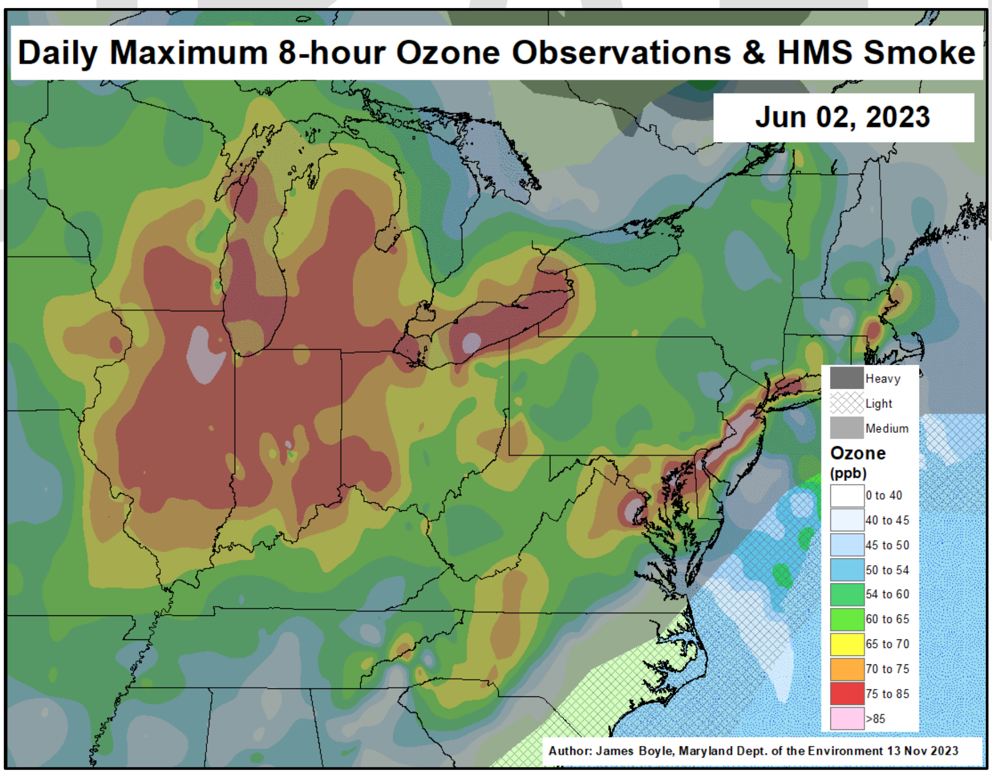
By June 1, surface temperatures climbed into the upper-80s°F for Delaware and the rest of the Mid-Atlantic states. Plentiful sunshine in the presence of aged smoke resulted in widespread MD8AO greater than 70 ppb for a large area, stretching from Virginia/Maryland northeastward to New England and northwestward to Wisconsin. Ozone concentrations were further compounded on June 2, with a further uptick in temperatures across the region. Apart from the Appalachian Mountain range region, MD8AO above 70 ppb were observed from Massachusetts south to North Carolina and extending westward to Iowa.

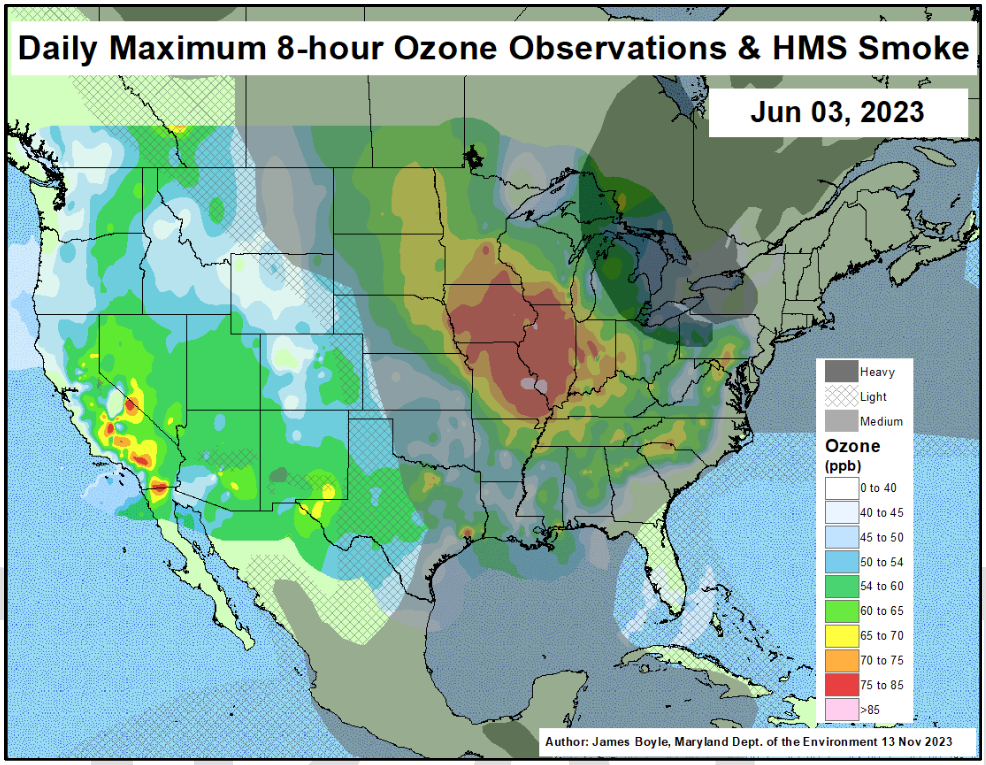
The aged smoke and associated ozone began to gradually shift westward June 3 and 4. As a result, the airmass associated with ozone exceedances also shifted mostly (though not entirely) away from the Mid-Atlantic, to the Midwest to the Northern Plains. Once again, there was a very close correlation of the aged smoke with surface ozone concentrations during this spatial evolution. The heavy smoke analyzed by HMS primarily over Quebec and Ontario on June 3 and 4, is tied to fresh wildfire emissions from central Quebec. Given the age of this secondary smoke plume, it had not yet had a chance to increase surface ozone concentrations over where it is located. The elevated ozone is strictly tied to the initial aged plume. By June 4, clearing of this aged smoke plume across the Mid-Atlantic brings the return of good air quality.


Daily Maximum 8-hour Ozone Observations & HMS Smoke
May 30, 2023
Heavy
Light
Medium
Ozone (ppb)
0 to 40
40 to 45
45 to 50
50 to 54
54 to 60
60 to 65
65 to 70
70 to 75
75 to 85
>85
Author: James Boyle, Maryland Dept. of the Environment 13 Nov 2023


Daily Maximum 8-hour Ozone Observations & HMS Smoke
May 31, 2023
Heavy
Light
Medium
Ozone (ppb)
0 to 40
40 to 45
45 to 50
50 to 54
54 to 60
60 to 65
65 to 70
70 to 75
75 to 85
>85
Author: James Boyle, Maryland Dept. of the Environment 13 Nov 2023


Daily Maximum 8-hour Ozone Observations & HMS Smoke
Jun 01, 2023
Heavy
Light
Medium
Ozone
(ppb)
0 to 40
40 to 45
45 to 50
50 to 54
54 to 60
60 to 65
65 to 70
70 to 75
75 to 85
>85
Author: James Boyle, Maryland Dept. of the Environment 13 Nov 2023


Daily Maximum 8-hour Ozone Observations & HMS Smoke
Jun 02, 2023
Heavy
Light
Medium
Ozone
(ppb)
0 to 40
40 to 45
45 to 50
50 to 54
54 to 60
60 to 65
65 to 70
70 to 75
75 to 85
>85
Author: James Boyle, Maryland Dept. of the Environment 13 Nov 2023



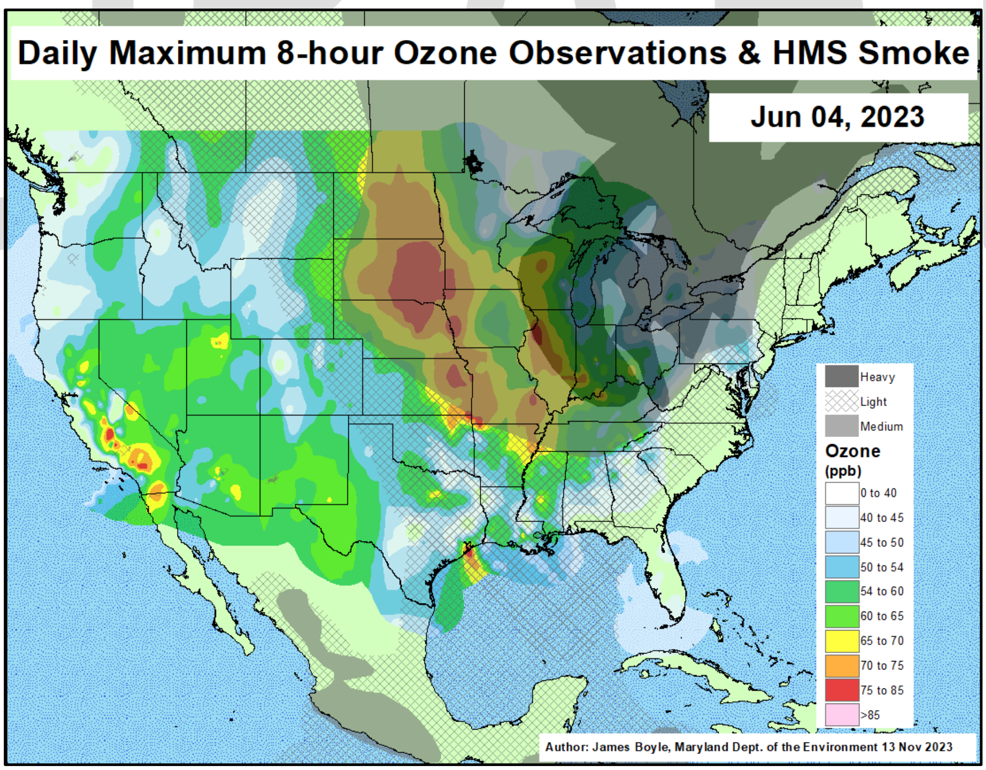




**Figure 23.** HMS and Ozone Maps, May 30 to June 4.
May 31-June 4 maximum 8-hour average ozone concentrations and HMS analyzed smoke (hatching and shading). Transported smoke was closely associated with ozone exceedances in Delaware June 2.

# 3. Clear Causal Relationship Between the Event and Monitored Ozone Concentrations

The event presented in this analysis illustrates a complex interaction between both aged and fresh wildfire smoke along with trans-continental and local smoke transport that impacted ozone concentrations in Delaware. The fires and related smoke generated ozone immediately near the fire source in Alberta but were also observed to continue to generate ozone as the plume aged. This was further exacerbated when interacting with urban emissions and when experiencing higher surface temperatures. Delaware presents the necessary evidence below, complimenting the conceptual model above, to show how the smoke affected air quality in Delaware. The smoke was clearly associated with ozone concentrations beyond what is otherwise expected in the absence of smoke, and that smoke caused the ozone exceedances on June 2. Comparison between ozone concentrations at the Lums monitor from June 2 to a 5-year look back, and a Q/d analysis (Tier 1 and 2 steps) are provided. While Delaware believes these analyses alone show a causal relationship between the ozone and smoke, they may not alone sufficiently 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 on June 2 in Delaware.

## 3.1 Historical Concentrations

A five year scatter plots of maximum daily 8-hour average ozone concentrations at the Lums monitor for the past 5 years, from 2019 through 2023 shows the exceptional nature of the event (Figure 24). All ozone data during the 2019-2023 ozone seasons (March 1 to September 30) were plotted for each monitor against that monitor’s multi-season 99th percentile. Significant and sustained reductions in ozone precursors across the eastern United States. have occurred in the past ten years. These reductions have been particularly evident in $NO_x$, leading to lower ozone concentrations. This has led to a noticeable decrease in ozone exceedance days (Figure 3), despite an increasing number of hot days. Delaware has seen reductions in the number of exceedance days over the past several years throughout the state. There were no exceedance days in 2022. Figure 4 clearly shows the downward trend in $NO_x$ emissions over recent years, with June 2023 having the lowest aggregate EGU emissions ever from these upwind states (62.9 tons). Mean $NO_x$ emissions were a bit higher at 84.5 tons in June 2022, but Delaware had no ozone exceedances in 2022. Average EGU emissions over June 1-3 (78.6 tons) were lower than the June 2022 average. The 2023 average daily output for June of 62.9 tons per day is around 53% lower than the 2019-2021 average (134.7 daily tons). Review of the ozone concentrations over the past 5 ozone seasons show 2023 data as not consistent with recent previous years. Further, June 2 stands out as an extreme outlier point. Although Lums is the only site that has current regulatory significance for the June 2 event, four additional ozone monitors in Delaware also exceeded on this date.

Regarding the Lums data from June 2, 2023:

- The Lums monitor met or exceeded the 99th percentile of the data when comparing the 99th percentile metric of the ozone season (March-September) from 2019-2023.
- The Lums monitor exceeded the $99^{th}$ percentile of the data when compared to the 99th percentile metric of the month of June from 2023.
- The Lums monitor met or exceeded the 99th percentile from 2019- 2022.
- The Lums monitor met or exceeded the 99th percentile of 2022 data.

On June 2, the Lums monitor, which Delaware is seeking concurrence for exclusion due to influence by an exceptional event, exceeded all 99th percentile thresholds. Elevated ozone was already being observed in Delaware on June 1, despite lower temperatures. All ozone monitors in New Castle County experienced the highest 8-hour ozone concentrations of the year on June 2 (Figure 24).

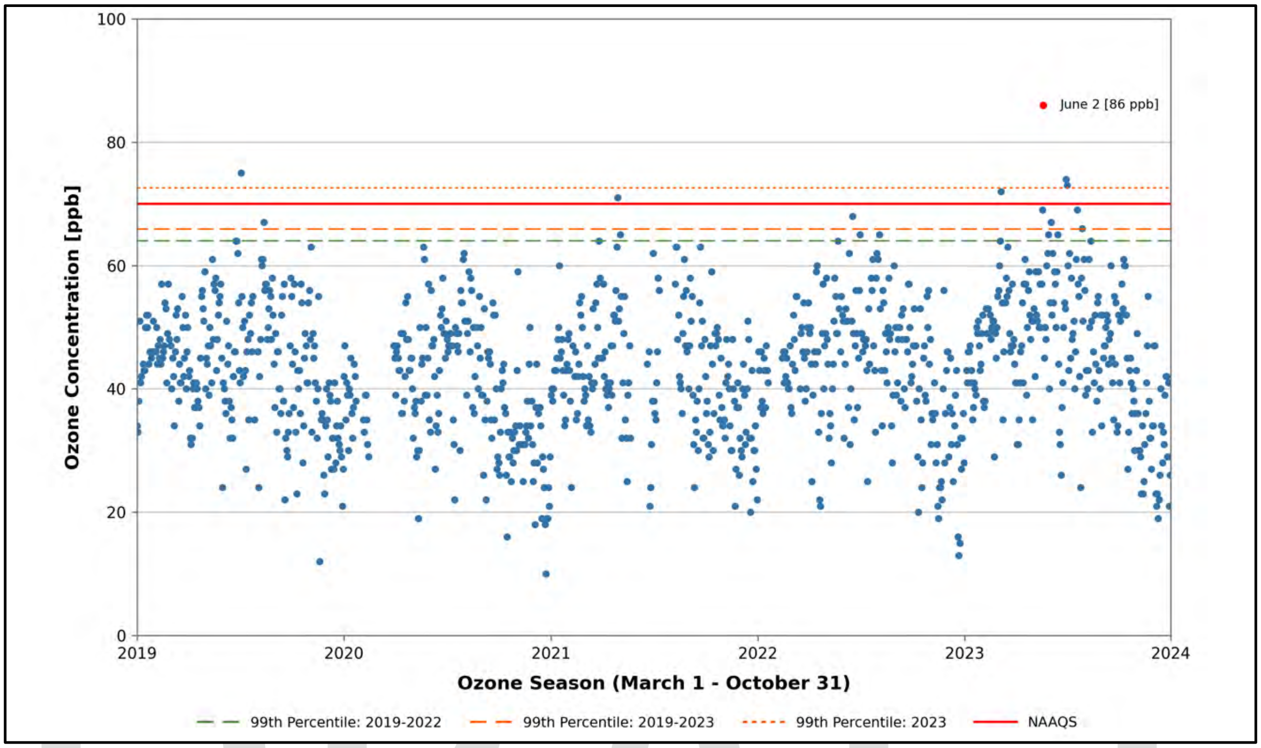



**Figure 24.** Historic Ozone Concentrations at Lums.
Scatterplot of Maximum Daily 8-hour Average Ozone (MD8AO) concentrations Lums, March 1 through September 30, 2019-2023.

This data shows that the June 2 event should be considered exceptional in nature. The uncharacteristically high ozone concentrations, particularly considering the huge anthropogenic precursor reductions over the past five years, suggest the monitors were influenced by wildfire smoke. Delaware believes the evidence presented thus far indicates a clear causal relationship. Additional supportive analysis is presented below.

As part of demonstrating a clear causal relationship between ozone concentrations and the fire event, monitored concentrations were put in the context of historical observations. Observations at monitors falling at or above the 99th percentile in the past five years establish statistical evidence that the event was likely influenced by an exceptional event and are a "Key Factor" used to determine whether a Tier 2 application is appropriate. Following the Exceptional Events Guidance documents, the 99th percentile was calculated for the Lums monitor for all days of the ozone season (March-September) from 2019-2023 as 2019 to 2022 and 2023 alone (Figure 24). The ozone concentration at Lums on June 2 is an outlier to all these values.

## 3.2 Tracking Smoke and Wildfire Emissions Transport to Delaware

Section 2 of this demonstration contains an exhaustive description concerning the transport of smoke from west-central Canada to the Mid-Atlantic. Instead of repeating such a narrative, the story of how background smoke from Canada existed in Delaware complimented by local fires is considered sufficient. Here, the focus will be observations of the smoke locally.

Ceilometer data provided the highest multi-dimensional temporal resolution of the arrival of smoke. Delaware operates one ceilometer in the state, at our NCore site, MLK, in Wilmington, Delaware (Figure 2). This site is located in New Castle County. Ceilometer plots from May 29 through June 2 are presented here (Figures 25-26, note that the time is presented as Eastern Standard Time). A ceilometer sends out short, powerful laser pulses in a vertical or near-vertical direction. The light reflection caused by haze, fog, mist, virga, precipitation, aerosols, and clouds, known as backscatter, is measured as the laser pulses traverse the sky. The backscatter profile, that is, the signal strength versus the height, is stored and processed, and the data is used to calculate the cloud bases and the planetary boundary layer structure.[23]

The cold front came to Wilmington at approximately 19:00 Eastern Standard Time (EST) on May 29. The ceilometer at Delaware's MLK monitoring stations noted a deeper layer of faint aerosol, after the arrival of the cold front (Figure 25A). Darker colors and smoke layers are visible throughout the night of May 29 and into the morning on May 30 (Figure 25A and B). These layers are seen during times of nocturnal stability, and this trend repeats over the coming days. Reviewing the ceilometer data from this event, smoke layers and dense aerosols are present to varying degrees throughout. On May 31dense aerosols were present consistently throughout the day (Figure 25C). On June 1, Delaware experienced high levels of smoke transport, especially in Sussex County (the southern part of the state). In New Castle County, winds remained predominantly from the north to northeast in origin (Figure 25D). On June 2, light wind continued from the north in New Castle County and a dense layer of smoke is present at the surface throughout the morning (Figure 25E). A brief rain event occurred late in the day on June 2 as shown by the vertical lines on the plot (Figure 25E).



[23] Vaisala User Guide, March 16, 2024. https://docs.vaisala.com/r/M211185EN-E/en-US/GUID-49BAC3E3-3E94-4C02-94A6-33A683235899/GUID-B8A80745-EC0B-40AE-852F-F9C55D86A49C

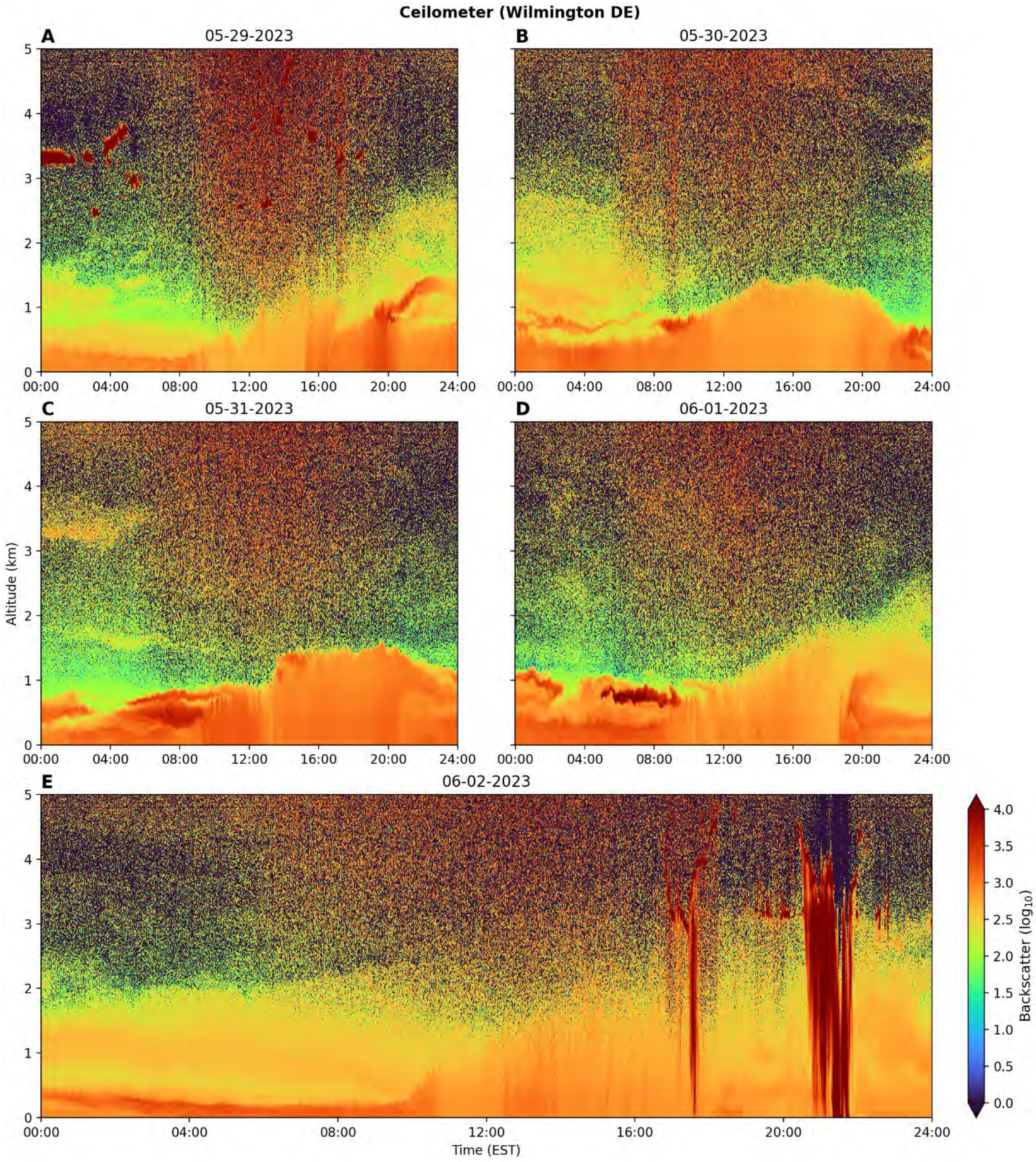



**Figure 25. Ceilometer Plots, May 29 to June 2.**

Ceilometer backscatter (colors) from the MLK monitor in New Castle County Delaware from May 29 through June 2, 2023. Darker oranges and reds identify areas of thicker aerosol returns. Plots are labeled with the date above the plot. The time on the x-axis presented as Eastern Daylight Time.

The ceilometer data can be further processed to develop extinction coefficient plots (Figure 26). The extinction coefficient is calculated by the ceilometer as part of its “level 3” post-processing routine. The extinction coefficient (Ec) measures the degree of light attenuation, so a higher Ec coincides with a higher density of light-absorbing particles in the air. The greyed-out portion of the figures represent areas with negligible light attenuation. This is due to an absence of light attenuating particles. This view of the information provides a striking indication of the particle (smoke) present on June 2 when contrasted with a known day that did not have smoke influence (Figure 26).

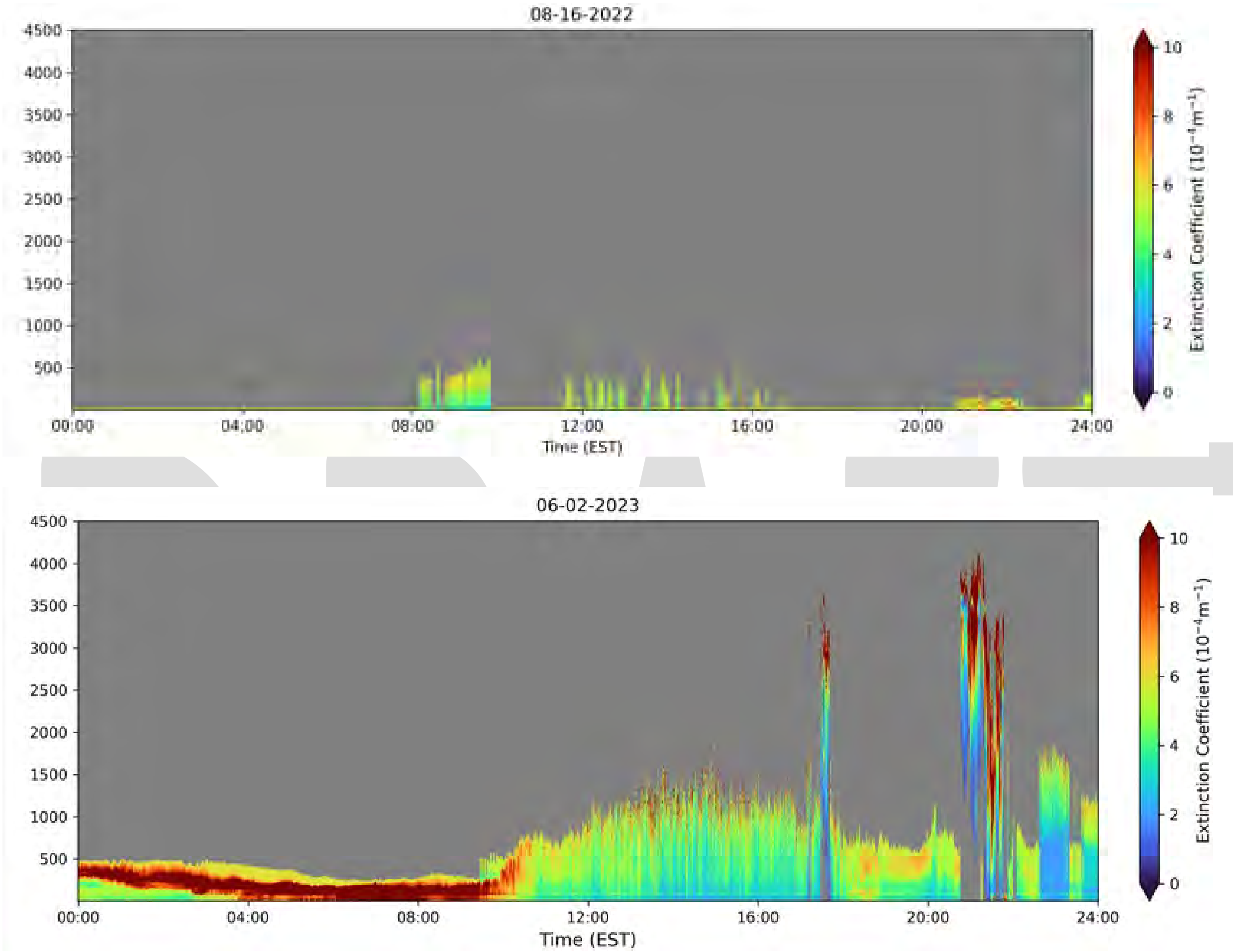



**Figure 26.** Ceilometer Plot Extinction Coefficient
Ceilometer Extinction Coefficient plots from August 16, 2022 and June 2, 2023. Smoke was not present on August 15, 2022 resulting in a nearly clear plot. This contrasts sharply with the data from June 2, 2023, which shows dense smoke especially throughout the morning and a short rain event in the evening.

## 3.3 Evidence that Fire Emissions were Transported to Delaware Using HYSPLIT

While we have already demonstrated that smoke from west-central Canada, New Jersey, and Nova Scotia fires reached Delaware, trajectory modeling is presented here to lend additional support. Note that weakly forced meteorological conditions (e.g., winds), such as occur under high pressure, tend to be associated with relatively poor meteorological transport modeling performance due to weak winds. The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT; Rolph, 2017; Stein et al., 2015) model was used to calculate backward trajectories originating from within Delaware on June 2, 2023. Meteorological data driving these trajectories was from the Global Forecast System (GFS) model (0.25 degree) dataset.

Backward trajectories from Delaware starting at 2:00 pm EDT on June 2, 2023 were run at three heights: 2000 m, 1250 m, and 750 m (Figure 27). The trajectories were allowed to run backwards for 13 days, which would be 2:00 pm on May 20, or approximately when smoke was seen entering the CONUS. While the evolution of this smoke has already been conveyed extensively above, these trajectories support the same conclusions. Symbols on the trajectories provide 12-hour intervals of the trajectory path.

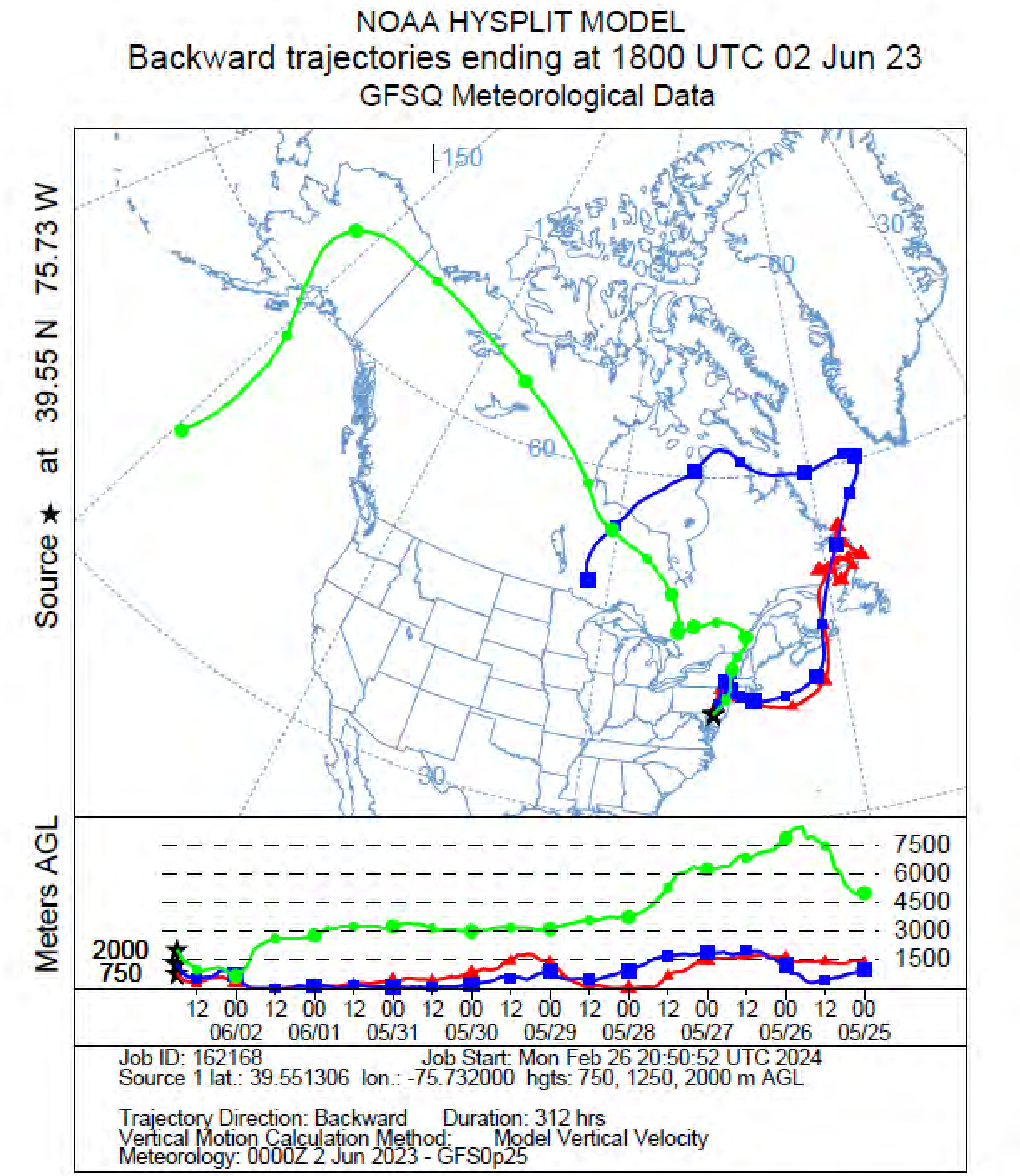



**Figure 27. HYSPLIT Model for Delaware.**

Three-height Backward 312-hour (13 days) GFS (0.25 degree) Transport Trajectories. GFS back trajectories at three heights (2000 m green, 1250 m blue, 750 m red) from Lums Pond, Delaware beginning on June 2 at 2:00 pm EDT.

The backward trajectory from Delaware at 2000 m collects smoke from above the Great Lakes on May 29-30. On May 31 to June 2, it continues to collect smoke from the New Jersey and Nova Scotia smoke plumes along east coast. The 1250m and 750m trajectories begin at a northeast path collecting smoke along the east coast from New Jersey fire plumes during the first 48 hours of the run (June 1-2). Then continue directly to the Nova Scotia fire area during the next 72 to 96 hours of the trajectory run (May 29-30), in line with the burn period of that fire (May 27-June 4), again supporting the importance of the New Jersey and Nova Scotia fires for the June 2 event. Together these trajectories confirm the narrative model and also highlight the complexity of the event.

## 3.4 University of Maryland Aircraft Data

On June 2, the Maryland Department of the Environment (MDE) requested a research flight by the University of Maryland (UMD) in their Cessna aircraft. The UMD plane is outfitted to take copious measurements of atmospheric composition at various heights in the atmosphere to identify, diagnose, and speciate atmospheric pollution. The aircraft flight took place between 4:00 pm and 7:30 pm EDT and sampled a smoky atmosphere. The aircraft flew a broad pattern across the Maryland, but also crossed into Delaware, and sampled along a vertical atmospheric profile. The flight time over Delaware took place from approximately 4:30 pm to 4:50 pm local time. The location of the Delaware sampling was approximately 28 km south of the Lums Monitor.

While over Delaware, the plane detected ozone concentrations up to 87 ppb (Figure 28a). Moderately elevated carbon monoxide (CO) concentrations were also measured (Figure 28b). The median CO concentration over Delaware was 200 ppb, this is elevated above normal CO readings in Delaware (based on 2022 data from the MLK station). Heightened CO concentrations throughout the atmospheric profile suggest regionally influenced CO concentrations (i.e., a smoky background).

The aircraft is equipped with an aethalometer, which can measure black carbon (BC) concentrations, a pollutant which may be associated with diesel and/or biomass burning, among a few other sources relevant to the region (Figure 28d). Black carbon concentrations in the ambient, clean, free atmosphere (elevated observations in the aircraft), should generally reside near zero. The flight elevation ranged from 0.4 to 2.5 km above the surface. BC concentrations should not be measured several thousand meters from the surface. Some of the greatest concentrations of ozone measured by the plane over the Eastern Shore of Maryland and in Delaware were collocated with elevated BC. While BC can have more than one source, the collocation of elevated CO and BC suggested an efficient combustion.

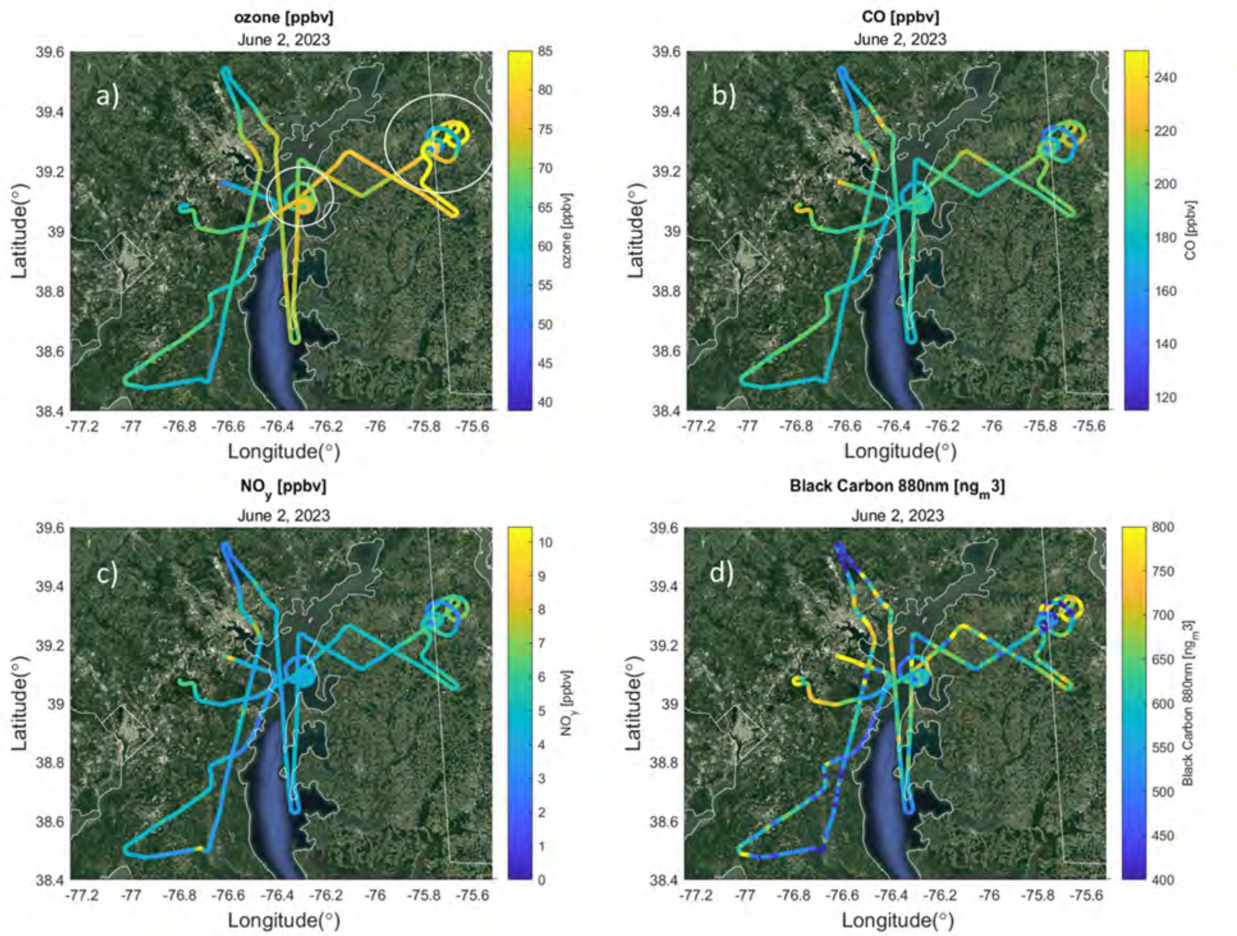



**Figure 28.** Aircraft Flight Path Data.

University of Maryland Cessna research aircraft flight path and concentrations of a) ozone, b) carbon monoxide (CO), c) total reactive nitrogen ($NO_y$), and d) Black Carbon (BC). The circles in a) highlight the vertical spirals when the plane varies altitude to measure a vertical profile of the atmosphere.

Time series of some of these same pollutants revealed periods indicative of wildfire smoke. The aethalometer on the aircraft measures aerosols in multiple wavelengths. BC concentrations are measured with the infrared wavelength or channel. Because black objects absorb at all frequencies, including lower frequencies such as infrared, which is not readily absorbed by non-black objects. Non-black objects such as lighter colored aerosols will instead, still attenuate higher frequencies of light but not as readily absorb the infrared. In this sense, when there is a signal strength separation between the UV (370 nm) and infrared (880 nm) channels, the aethalometer is likely picking up on aerosols that are not "black". These aerosols are generally referred to as "brown" carbon and are indicative of combustion of natural materials. In the present case, the presence of brown carbon, seen as the channel separation in the UMD flight time series, supports the assertion of diffuse wildfire smoke in the region (Figure 29, top). As noted earlier, CO concentrations were generally around 200 ppb for the duration of the flight, which is elevated above a clean ambient background value of around 100-120 ppb (Figure 29, middle).

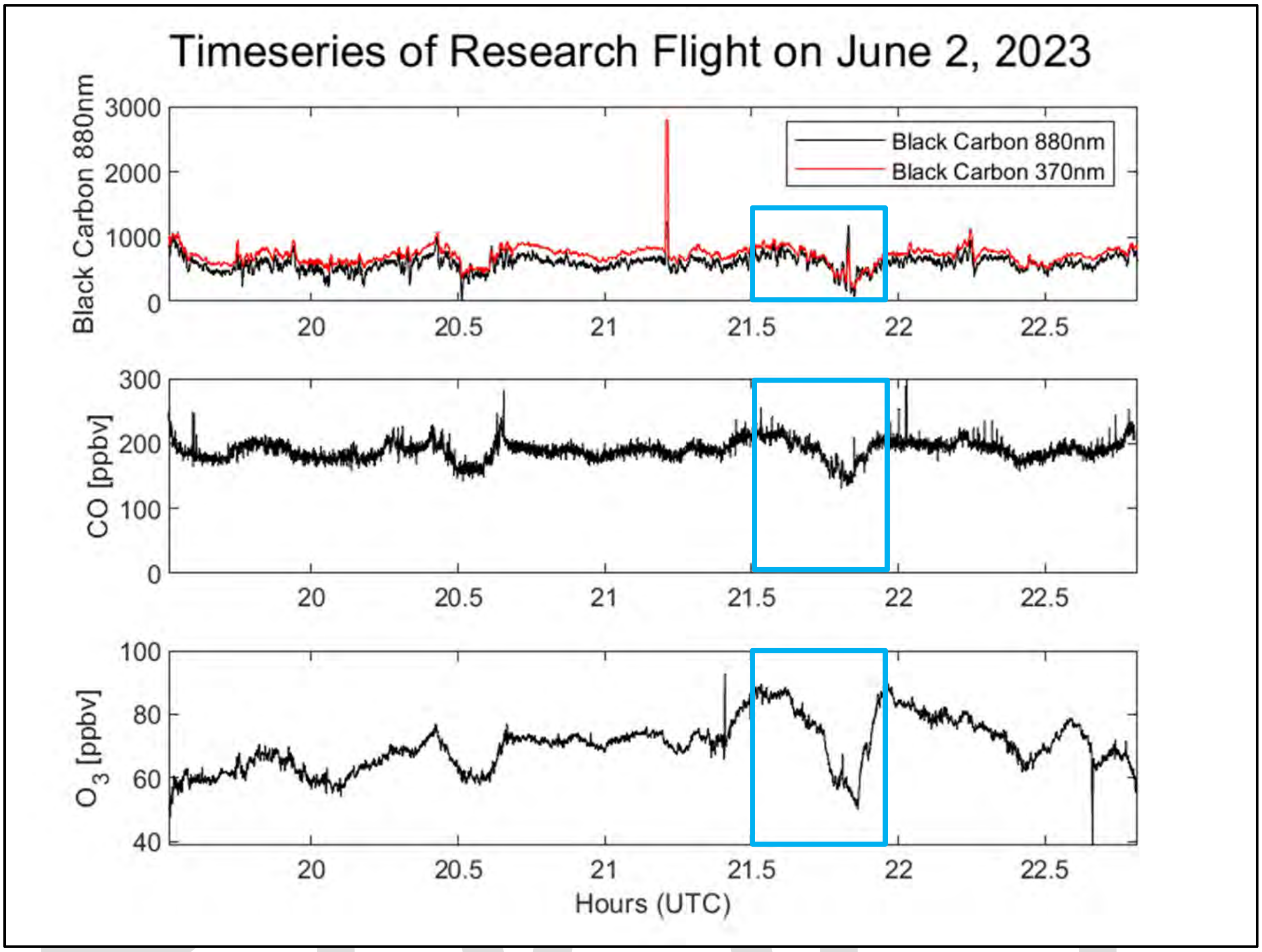


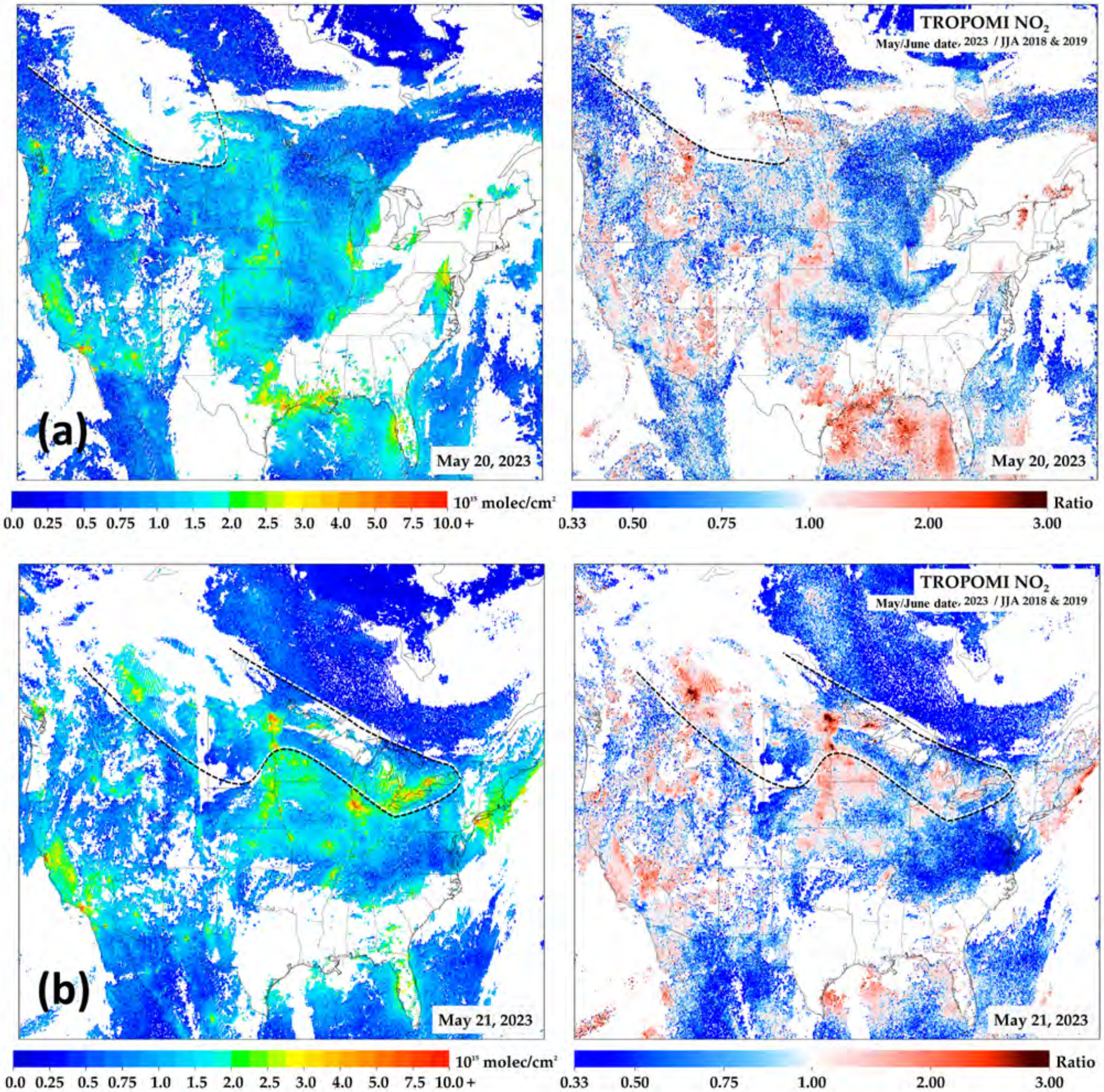

**Figure 29.** Aircraft Data Plots.
University of Maryland Cessna research aircraft flight time series of concentrations of black carbon (top panel), carbon monoxide (middle panel) and ozone (bottom panel). The black carbon time series includes both the UV (370 nm) and infrared (IR, 880 nm) channels of the aethalometer to investigate the degree of "brown carbon" in the air. Periods with separation of the UV channel from the IR indicate the presence of brown carbon in the air, suggestive of wildfire smoke. Figure used with permission from Hannah Daley, University of Maryland, College Park. Blue boxes indicate the portion of the flight that took place over Delaware.

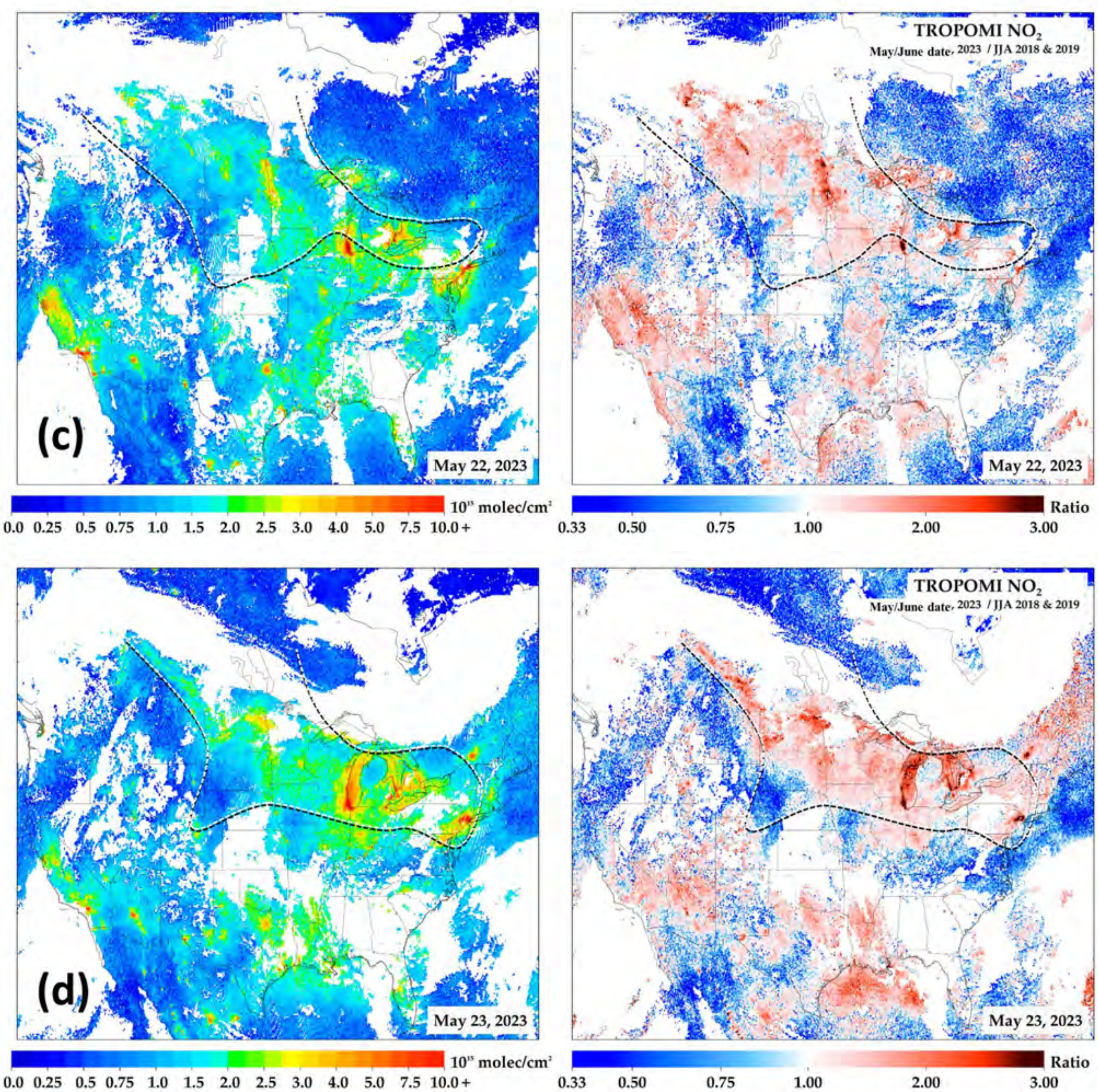
## 3.5 Satellite Data

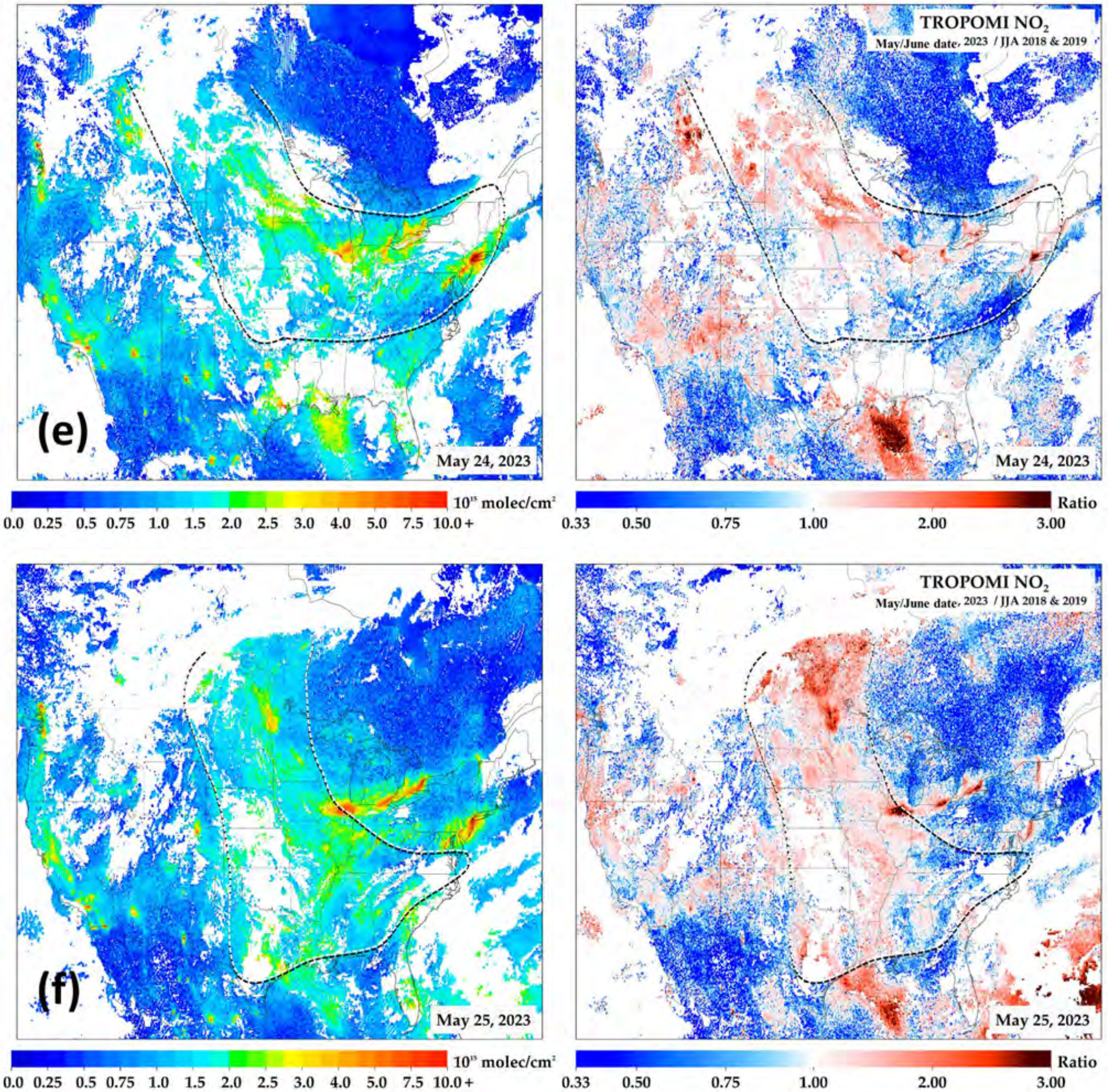
The Tropomi instrument on the Copernicus Sentinel-5 satellite was able to track higher $NO_2$ and/or positive anomalies associated with the smoke of this event. As a critical first note, diffusion of a prior smoke intrusion event over CONUS was ongoing at the time of the major smoke intrusion on May 20, and was observed as an enhancement of $NO_2$ ahead of the smoke entering the CONUS in Montana and North Dakota. Note the higher band of $NO_2$ from central Texas, through the panhandle, and southeastern Colorado, into Kansas, Nebraska, and South Dakota (Figure 30a). This area of higher $NO_2$ corresponds to smoke from the prior intrusion event on May 17-19. Otherwise at this point, smoke entering CONUS over Montana and western North Dakota was so thick on May 20, that algorithms interpreted it as a cloud, and thus initially returned no $NO_2$ (Figure 30a).

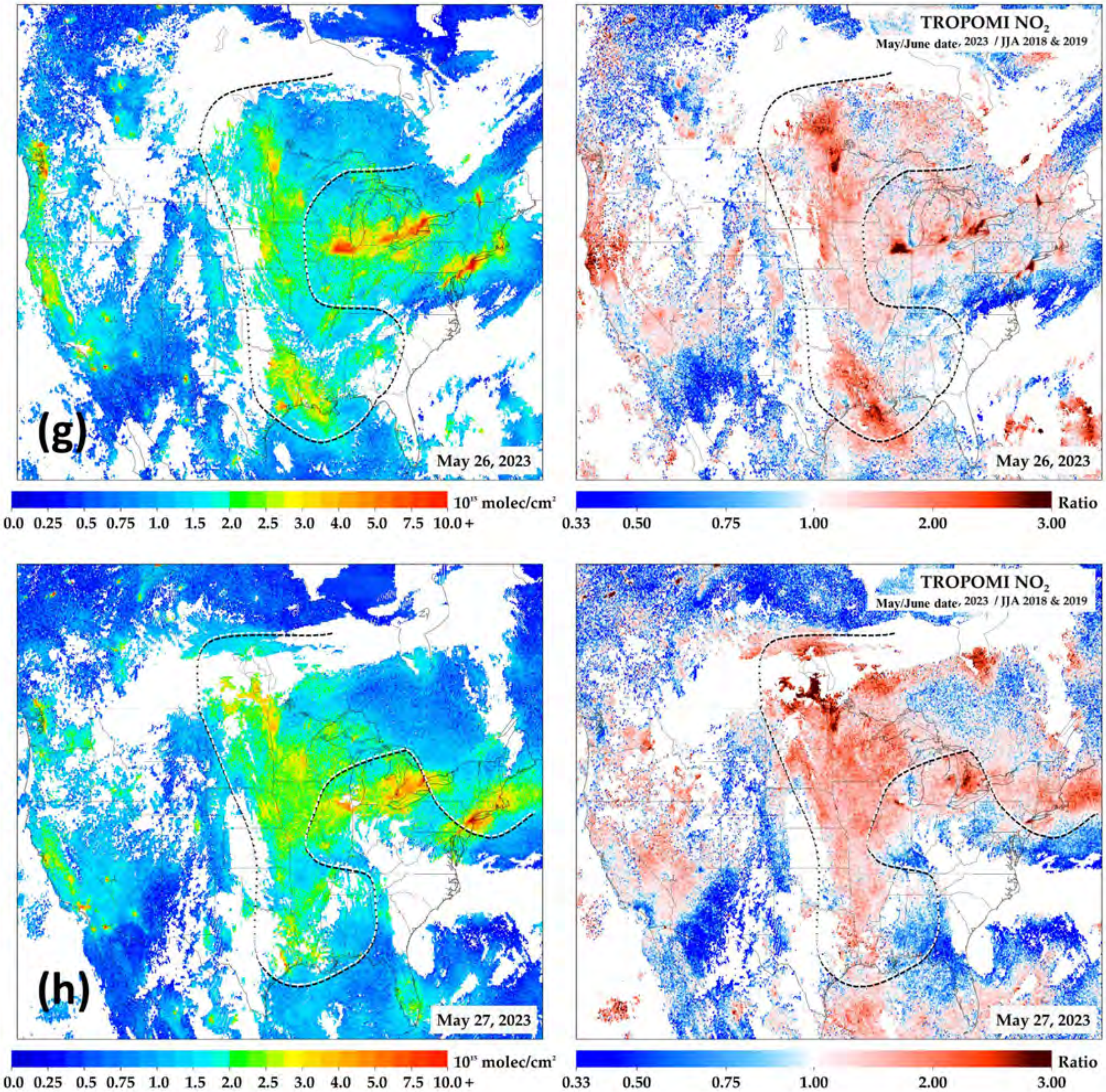
The primary smoke plume of interest began to be analyzed with $NO_2$ by May 21, even as it blended with residual $NO_2$ from the previous plume (Figure 30b). For example, note again the area of anomalously higher $NO_2$ over southern Minnesota; this was either associated with the new plume of smoke as asserted earlier or was a continuation of smoke seen moving northward from the Central Plains on May 20. By May 22, much of the anomalous high area of $NO_2$ very closely matched with the extent of the visual smoke plume (Figure 30c). As the plume became optically thinner, analysis on the smoke was also more complete, with $NO_2$ column retrievals available across the extent of the smoke plume. The pattern of anomalously high $NO_2$ continued to match the general shape of the smoke plume from May 23 through May 25 (Figures 30d-30f).

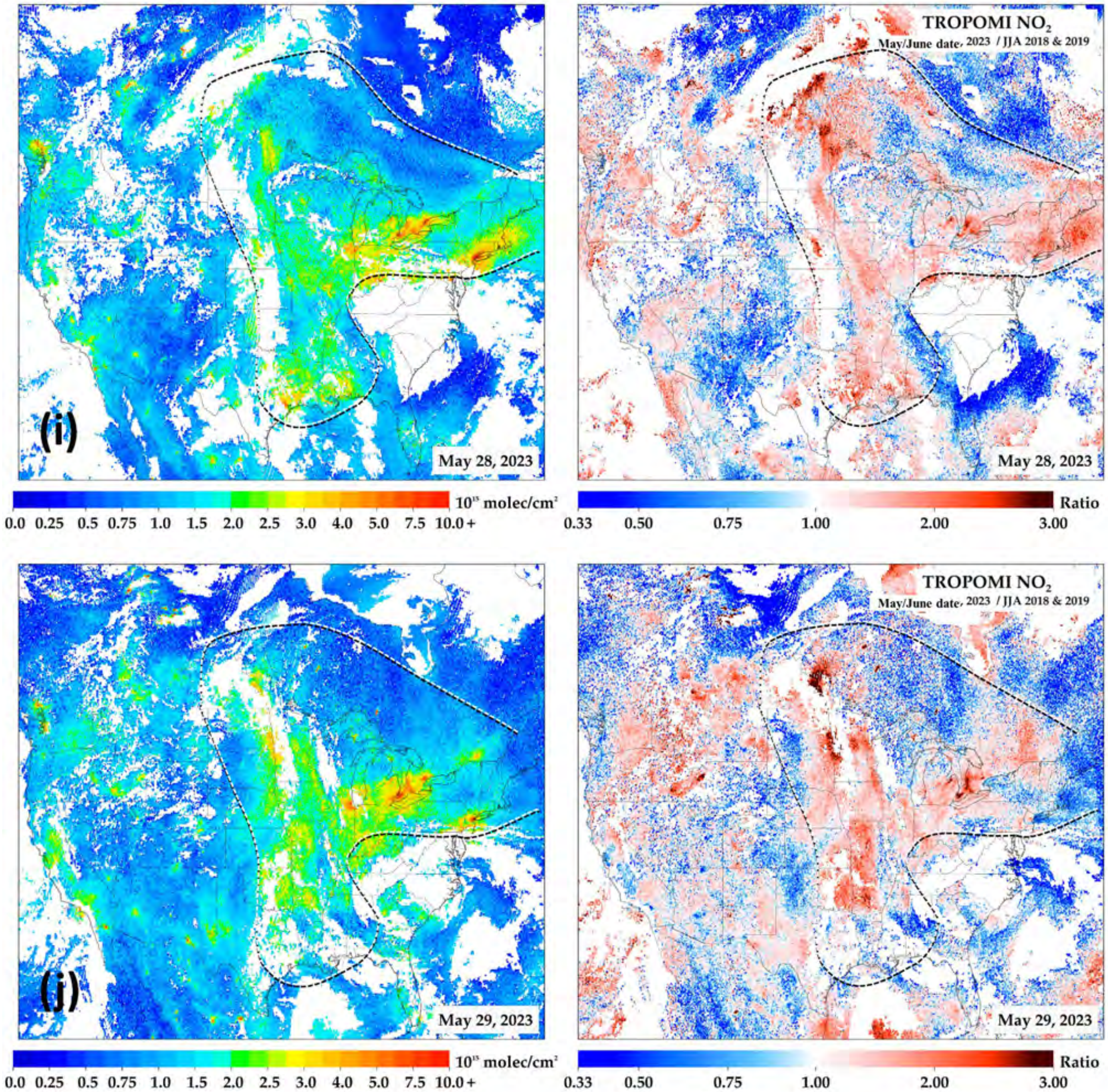
On May 26, the continued progress of a cold front through the Ohio River Valley pushed visible smoke into an elongated “C” type pattern, with an absence noted where the front had moved across areas of Michigan, Illinois, Indiana, and surrounding states (Figure 30g). A discrepancy between the analyzed plume of smoke (white dashed line) and anomalously high $NO_2$ developed. Anthropogenic $NO_2$ concentrations are an important part of the atmospheric column, and evidence of this was at least partially seen in many of the previous day’s analyses where urban areas have greater $NO_2$ concentrations and anomalies than other areas. What is also true is that the column retrieval algorithms for Tropomi are more sensitive to $NO_2$ in the upper portions of the column than near the surface. Smoke was optically thin so that it was not readily apparent on visible satellite imagery at that altitude or concentration. As such, the $NO_2$ column retrievals compared to the white dashed lines are highlighting the weakness of using visible satellite imagery only when delineating the spatial extent of smoke species impacts. The high $NO_2$ anomaly outside of the dashed smoke outline is partly due to urban areas in Indiana, Michigan, Illinois, and surrounding areas, but also due to the sensitivity of $NO_2$ higher in the column, which the AIRS instrument has shown is present by inference of CO due to diffuse smoke at higher altitudes.
The discrepancy seems to be rectified by May 27, and the visible outline of smoke starts to generally agree with $NO_2$ positive anomalies again (Figure 30h). Spatially, the anomalously high $NO_2$ generally agrees with the visual outline and progression of smoke through the remainder of the event, suggesting that $NO_2$ remained present within the smoke to contribute to ozone formation (Figures 30i-30n). The Allen Road fire was also observed as an $NO_2$ hotspot in southern New Jersey, influenced $NO_2$ retrievals in the area (Figure 30m). Other fires or smoke plumes were in the NYC to Washington DC corridor at this time, including Nova Scotia smoke and possible contributions from the Box Turtle and Fort Dix fires, increasing the total $NO_2$ column retrieval in the region. The amount of $NO_2$ across western Pennsylvania was also instructive. Both absolute and relative concentrations of the $NO_2$ column were low, and yet MD8AO in this area was 60-65 ppb. This highlights the regional burden the smoke placed on background ozone concentrations. At the same time, active photochemistry due to aged smoke in the airmass could readily act on $NO_2$. Available additional $NO_2$ was thus manifest as exceptional ozone concentrations beyond what is typical in similar conditions without smoke.

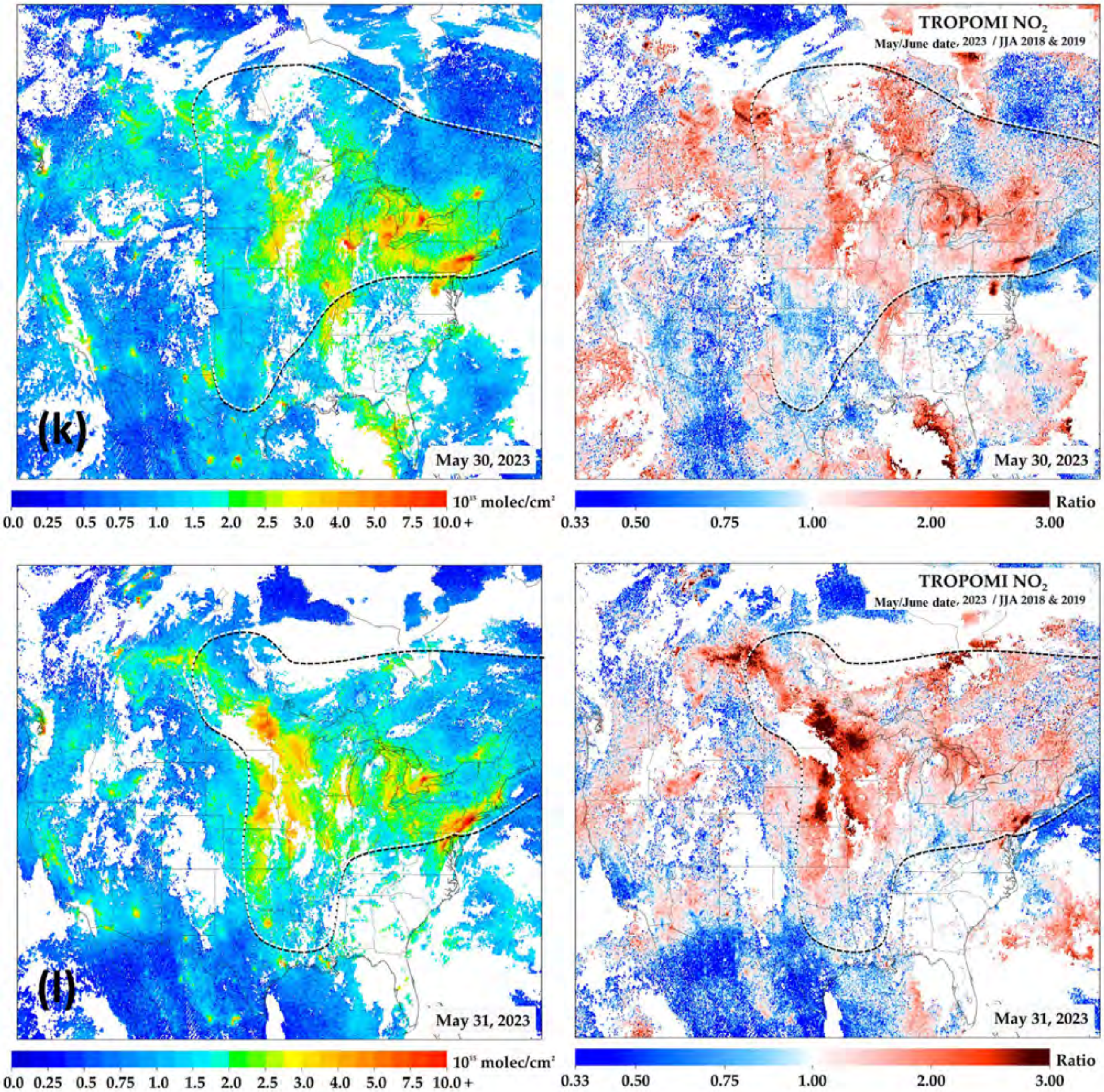

TROPOMI $NO_2$
May/June date, 2023 / JJA 2018 & 2019
(a)
May 20, 2023
May 20, 2023
$10^{15}$ molec/cm$^2$
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0+
Ratio
0.33 0.50 0.75 1.00 2.00 3.00
TROPOMI $NO_2$
May/June date, 2023 / JJA 2018 & 2019
(b)
May 21, 2023
May 21, 2023
$10^{15}$ molec/cm$^2$
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0+
Ratio
0.33 0.50 0.75 1.00 2.00 3.00


(c)
May 22, 2023
10[15] molec/cm²
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0 +
TROPOMI $NO_2$
May/June date, 2023 / JJA 2018 & 2019
May 22, 2023
Ratio
0.33 0.50 0.75 1.00 2.00 3.00
(d)
May 23, 2023
10[15] molec/cm²
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0 +
TROPOMI $NO_2$
May/June date, 2023 / JJA 2018 & 2019
May 23, 2023
Ratio
0.33 0.50 0.75 1.00 2.00 3.00


(e)
May 24, 2023
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
May 24, 2023
10^15 molec/cm²
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0 +
Ratio
0.33 0.50 0.75 1.00 2.00 3.00
(f)
May 25, 2023
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
May 25, 2023
10^15 molec/cm²
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0 +
Ratio
0.33 0.50 0.75 1.00 2.00 3.00


(g)
May 26, 2023
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
May 26, 2023
10^15 molec/cm^2
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0 +
Ratio
0.33 0.50 0.75 1.00 2.00 3.00
(h)
May 27, 2023
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
May 27, 2023
10^15 molec/cm^2
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0 +
Ratio
0.33 0.50 0.75 1.00 2.00 3.00


TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
(i)
May 28, 2023
May 28, 2023
10^15 molec/cm^2
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0+
Ratio
0.33 0.50 0.75 1.00 2.00 3.00
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
(j)
May 29, 2023
May 29, 2023
10^15 molec/cm^2
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0+
Ratio
0.33 0.50 0.75 1.00 2.00 3.00


(k)
May 30, 2023
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
May 30, 2023
10^15 molec/cm^2
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0+
Ratio
0.33 0.50 0.75 1.00 2.00 3.00
(l)
May 31, 2023
TROPOMI NO2
May/June date, 2023 / JJA 2018 & 2019
May 31, 2023
10^15 molec/cm^2
0.0 0.25 0.5 0.75 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10.0+
Ratio
0.33 0.50 0.75 1.00 2.00 3.00

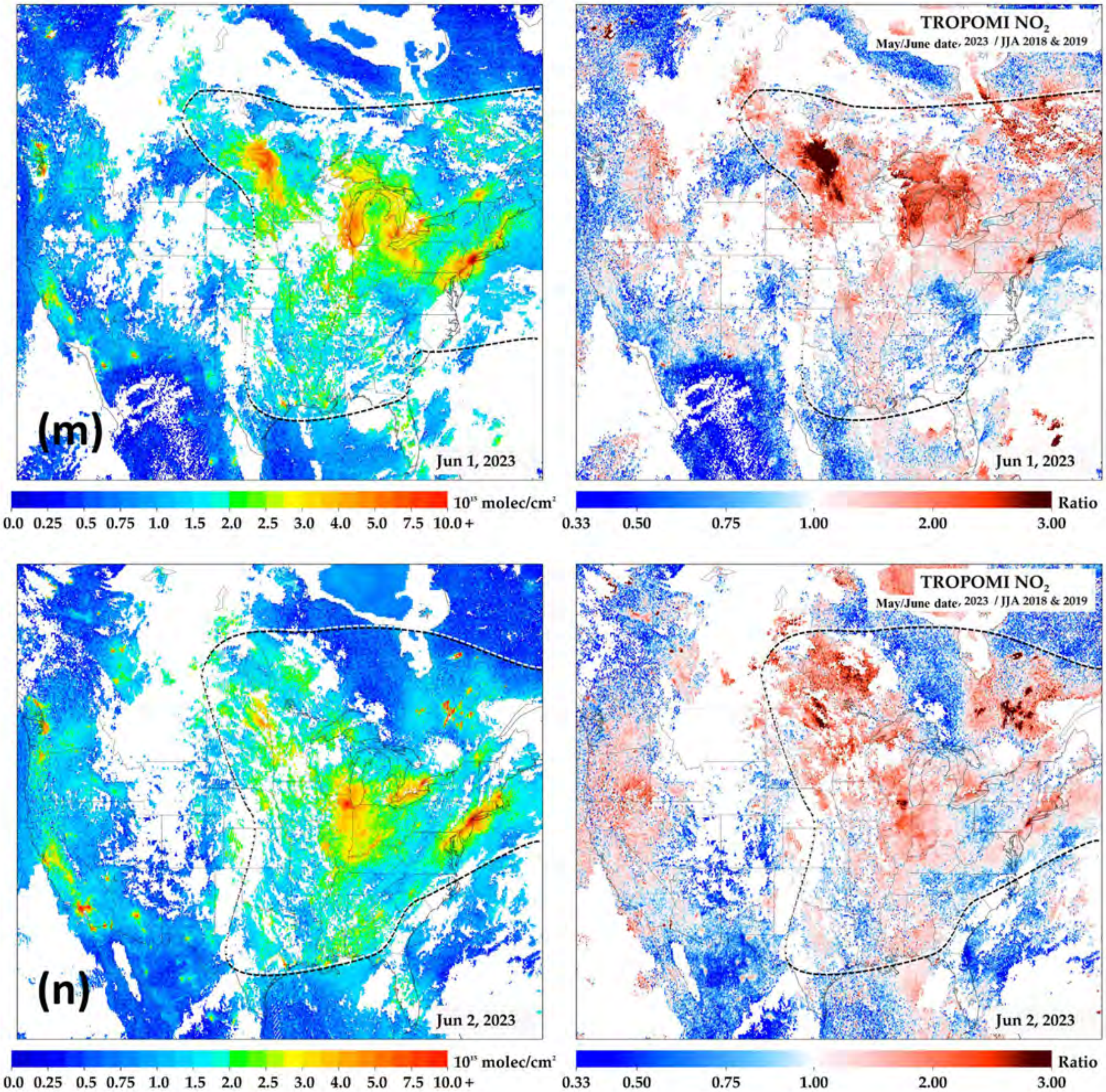



**Figure 30. TROPOMI Imagery, May 20 to June 2.**

TROPOMI column $NO_2$ satellite retrievals in molecules per square centimeter (left) and departure from June, July, August (JJA) average concentration from 2018 and 2019 (right) for May 20 through June 2 (a-n). The dashed line outlines the smoke, both seen in visible imagery and as heightened $NO_2$ concentrations. Retrieval of these products is available through https://tropomino2.us/. The $NO_2$ retrieval algorithm is described in Goldberg et al. (2021). Special North American domain provided courtesy Dr. Goldberg.

## 3.6 Q/d Analysis

EPA guidance recommends conducting a Q/d analysis as a rough assessment of the ability of a wildfire to cause increased ozone concentrations.[24] The Q/d analysis is simply a 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 indicates that a fire should have a Q/d in excess of 100 tons per day (tpd) per kilometer (km) in order to be considered to have a clear causal impact on ozone. EPA developed this value based on analyses of four fires that occurred in 2011. Due to the large distances which Canadian wildfire plumes must travel to Delaware, the Q/d analysis will regularly fail to achieve the 100 tpd/km deemed acceptable by the same EPA guidance. Therefore, Delaware feels the 100 tpd/km value is not representative for long-range east-coast smoke events. Delaware instead presents several alternatives based on this analysis.

### 3.6.1 Estimating 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.[25] The equations given are as follows:

$$F_i = P_i \times L$$
$$E_i = F_i \times A = P_i \times L \times A$$

Where:

$F_i$ = emission factor (mass of pollutant/unit area of forest consumed)
$P_i$ = 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
$E_i$ = total emissions of pollutant "i" (mass pollutant)

The value of $P_i$ given above is 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 associated with Central Canadian forests. Note that our results could increase by a factor of 6 were we to expect the high end of emissions.

Information provided by CWFIS reported that between May 13 and May 20, 2023, fires across northwestern Canada consumed 1,400,000 hectares (3,459,475 acres), with a slight lull around May 17 amid an otherwise extremely intense eight-day period (Figure 31). On May 16 alone, 311,360 hectares (769,387 acres) were consumed by fire. For reference, the total land area of Rhode Island is approximately 314,000 hectares.[26] It appeared that smoke lingered and built up over parts of that region during this period, before a passing low-pressure system "released" a thick plume of smoke into the Central United States. This appears to be the primary plume which meandered around central CONUS under the stout Omega-block ridge, before moving around the Great Lakes to approach the Mid-Atlantic from the north and northeast. There may be some additional contribution from additional enhanced

[24] 42 U.S.C. 7619(b)(1)(iii), *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
[25] https://www.epa.gov/sites/default/files/2020-10/documents/13.1_wildfires_and_prescribed_burning.pdf
[26] A contextual comparison to the State of Rhode Island makes the fires' size more comprehensible. [https://www.ri.gov/facts/trivia.php]

burning near the end of the month, however, initial analyses seemed to indicate that this may have drifted northward. Smoke at this latitude is harder to track due to limited satellite overpasses (latitude is too far north for geostationary retrievals) and cloud cover during polar orbiting overpasses. To that end, we focus on the recirculated smoke emanating from the burning period between May 13-20, 2023, in Delaware prior to the June 2 event.

As complicated as the smoke transport from the west-central makes the event on its own, several additional fires occurred closer to the Mid-Atlantic. These fires were smaller in scale, but due to increasing proximity to Delaware, provided further amplification of airborne precursors (Figure 32). The first fires of note and chronology were the Nova Scotia fires. These occurred on the southernmost tip of the province between May 28 and June 2. Fires burned 24,840 hectares (61,381 acres) over this time period. The majority of the burning took place on May 29 when 9,154 hectares (22,620 acres) burned. Smoke from these fires appeared to move towards the Mid-Atlantic on north-northeasterly flow from May 29-31, burning a total of 19,670 hectares (48,605 acres) over that period, resulting in residual smoke across the Mid-Atlantic region for the June 2 event.

Several fires also occurred in New Jersey leading up to the June 2 ozone exceedance in Delaware. Note that these fires were also upstream of Delaware, further contributing to precursor concentrations in the atmosphere from the “background” smoke from west-central Canada and Nova Scotia (Figure 32). The first fire chronologically and by size was the Allen Road fire in southern New Jersey. This fire burned a total of 2,215 acres between May 31 and June 2. Most of the burn occurred on June 1, when 1,772 acres burned. This smoke came thickly through central and southern Delaware on June 1, leaving another source of residual smoke for June 2. In this analysis, we consider only emissions from May 31 (332 acres; relatively inconsequential, but happening very late and thus considered June 1 as well) and June 1. Two other known smaller fires were also reported or observed across New Jersey. The first occurred on the Fort Dix military installation in central New Jersey on June 1, directly east of Philadelphia. Little information is available from military burns, however, estimation done by satellite area-of-detection put the magnitude of the fire around 77 acres. While small, a copious, visible plume was apparent from the fire heading towards the eastern Greater Philadelphia area on June 1 (Figure 33). There was an additional fire on June 2, called the Flatiron fire in Medford Township, New Jersey. This fire was reported at 86 acres and burned only on June 2. It is unclear if this fire was influential to Delaware on June 2, but may have played a role. There was a third fire reported on May 29 called the Box Turtle Wildfire, which occurred in Monroe Township, of Gloucester County, southeast of Philadelphia. This fire consumed 158 acres. The timing of this fire would have allowed smoke to push into Delaware behind the cold front. Unfortunately, due to cloud cover, little visible evidence can be extracted from this burn, and thus, it has been left out of further analysis here. Still, collectively, despite the smaller fire sizes, the close proximity to the ozone exceedance region suggests an additional contributing direct causal relationship.

Understanding the above, Q/d analyses may be applied to each individual fire. Due to the transport pattern from the north-northeast, each fire may have had a compounding contribution to smoke on June 2, with ozone formation already apparent on June 1 amidst many of these fires/smoke sources. Each fire is presented individually below, though each may also be additively considered.

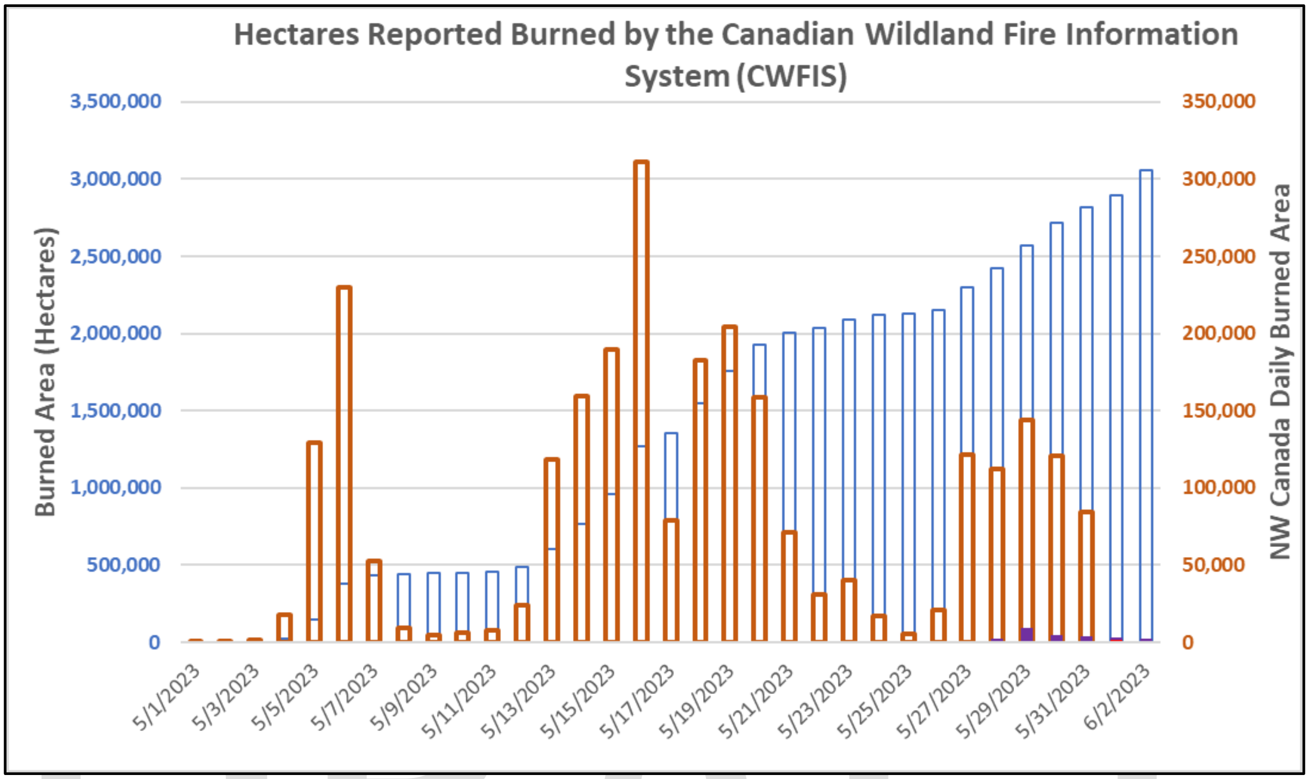



**Figure 31. Daily Hectares Burned, Canada**

Daily hectares of land burned across Canada May 1-June 2, 2023. Data provided by CWFIS. Blue bars indicate the total area over the course of the 2023 season. Orange bars indicate the daily area burned over west-central Canada, pertinent to this demonstration with values given on the right axis. Purple bars in late May and early June are fires in Nova Scotia and/or New Jersey.

From the west-central Canada fires, the total hydrocarbon (HC) emissions over the entire period from May 13 through May 20) is estimated to be:

$$E_{HC} = \frac{24\ lb\ of\ HC}{ton\ of\ forest\ consumed} \times \frac{10\ ton\ fuel}{acre\ of\ forest} \times 3{,}466{,}255\ acres$$

$$E_{HC} = 831{,}901{,}200\ lb\ of\ HC = 415{,}951\ ton\ of HC$$

Similarly for $NO_x$:

$$E_{NOx} = \frac{4\ lb\ of\ NO_x}{ton\ of\ forest\ consumed} \times \frac{10\ ton\ fuel}{acre\ of\ forest} \times 3{,}466{,}255\ acres$$

$$E_{NOx} = 138{,}650{,}200\ lb\ of\ NO_x = 69{,}325\ ton\ of NO_x$$

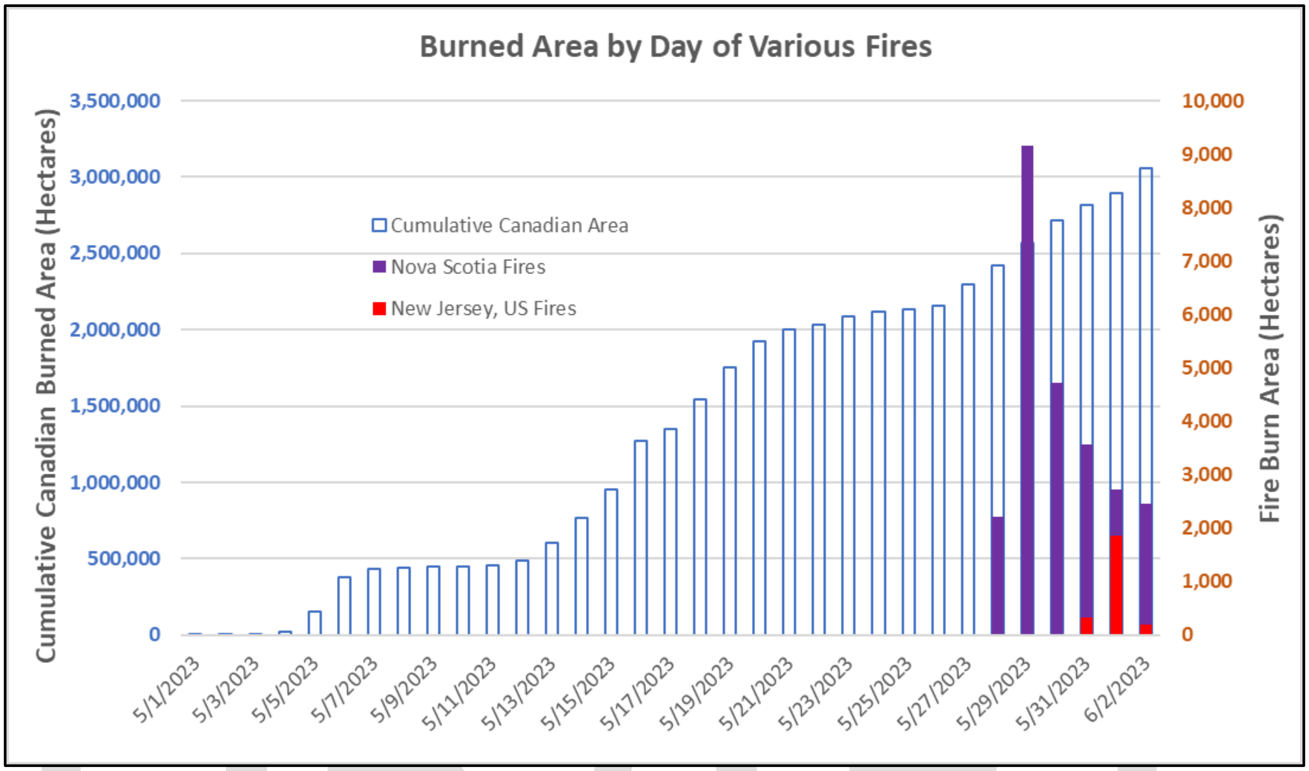



**Figure 32. Daily Hectares Burned, Canada and New Jersey.**
Like Figure 31 but with emphasis on Nova Scotia and New Jersey fires. Daily hectares of land burned across Canada May 1-June 2, 2023. Data provided by CWFIS. Blue bars indicate the total area over the course of the 2023 season. Purple bars give the area burned in Nova Scotia, Canada, while red bars indicate the daily area burned in New Jersey, United States, pertinent to this demonstration with values given on the right axis. Partial fire information for New Jersey fires is available at: https://www.nj.gov/dep/newsrel/2023/23_0050.htm

Q is the total daily emission rate in tons per day of reactive hydrocarbons and nitrogen oxides. EPA recommends in the exceptional events guidance[27] that only 60% of the hydrocarbons should be considered reactive. Therefore, the reactive hydrocarbon emissions become:

$$reactive\ HC = rHC = 0.6 \times E_{HC} = 0.6 \times 415{,}915\ ton\ HC = 249{,}571\ ton\ rHC$$

No adjustments are suggested for the $NO_x$ emissions. Therefore:

$$Q = \frac{249{,}571\ ton\ rHC + 69{,}325\ ton\ NO_x}{8\ days} = 39{,}862\,\frac{ton}{day}$$

Similar procedures are followed for each successive fire to calculate the emission rate.

### 3.6.2 Estimate of d

Based on the large distance and the widely dispersed nature of the fires across west central Canada, Delaware calculated the distance from the centroid of the fire region along the border between Alberta and Saskatchewan (roughly 55.8835°N, 110.1683°W) to the Lums monitor. The travel path was complicated due to residence time across the central CONUS for several days, however for this analysis

[27] 42 U.S.C. 7619(b)(1)(iii), *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

Delaware used a straight distance calculation. This yielded a distance of 3,101 km. This process was repeated for the other fires.

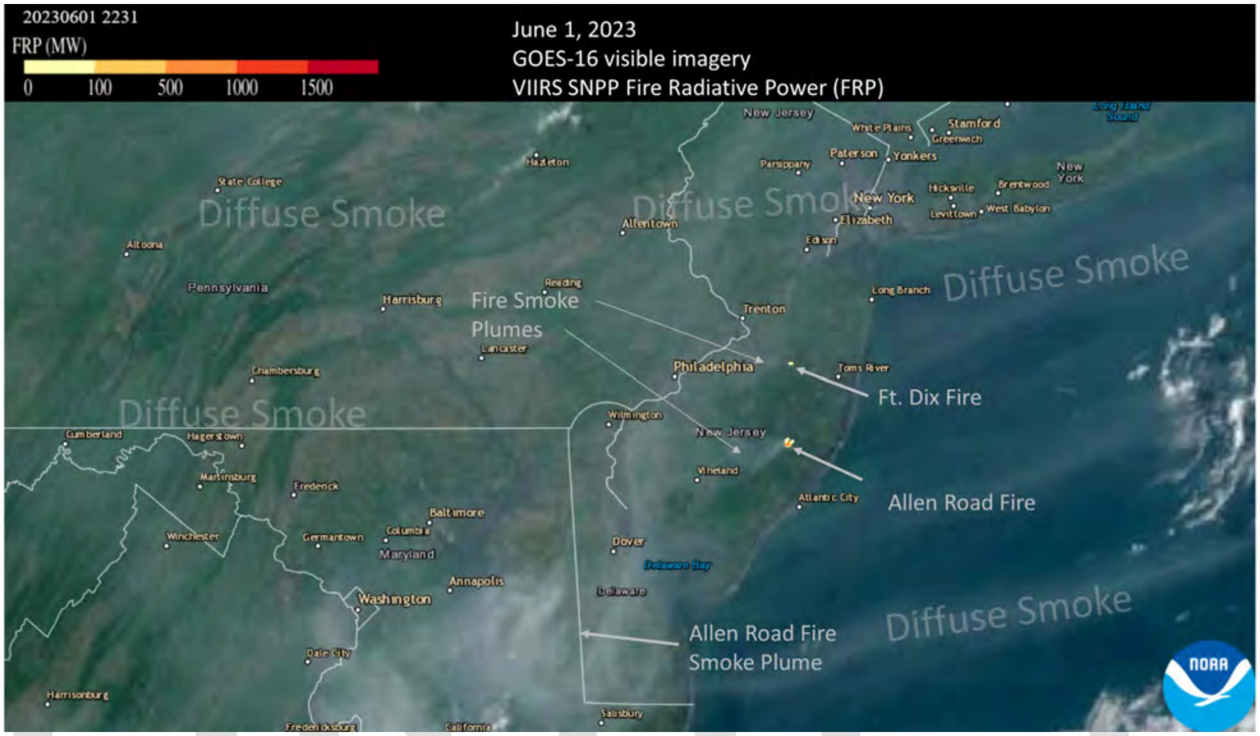



**Figure 33. Satellite Imagery Showing New Jersey Fires, June 1.**

June 1, 2023 GOES-16 visible satellite imagery at 2231 UTC (6:31 pm EDT) over the northern Mid-Atlantic. Diffuse smoke covers the entire region. Thicker plumes of smoke associated with the Allen Road Fire over southern New Jersey, Delaware and Maryland and the Fort Dix fires in Central New Jersey are visibly distinct amidst the background smoke. Fire radiative power (FRP) is measured by satellite and is a reliable measure of fire intensity and location. Hot spots of FRP are collated with the origins of plumes of smoke, which are blowing towards the west/southwest.

### 3.6.3 Q/d Estimate

Using the values and days burned determined above for the west-central Canada fires, Q/d becomes:

$$\frac{318{,}895\ tons}{3{,}101\ km \times 8\ days} = 12.9\,\frac{ton\ per\ day}{km}$$

This value is well below the EPA recommended level of 100 tpd/km indicating clear causality. However, this is higher than the concurred Exceptional Event Demonstration submitted by the state of Maryland to EPA's Mid-Atlantic Regional Office for May and July of 2016. Several other calculation strategies are presented below in Tables 5 through 9 for each of the fire locations.

| ACRES | Ehc (tons) | Enox | Q | No. days burning | d | Q/d | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 3,466,255 | 415,951 | 69,325 | 318,895 | 8 | 3101 | 12.9 | Standard Q/d |
| 311,360 | 92,326 | 15,388 | 70,784 | 1 | 3101 | 22.8 | May 16 only |
| 1,347,522 | 161,703 | 26,950 | 123,972 | 3 | 3101 | 13.3 | May 18-20 only |
| 1,347,522 | 970,216 | 161,703 | 743,832 | 3 | 3101 | 80.0 | Fuel loading at maximum of 60 tons/arce instead of 10, May 18-20 |

**Table 5.** Q/d analysis, Western Canada, May 13 through 20.

| ACRES | Ehc (tons) | Enox | Q | No. days burning | d | Q/d | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 43,127 | 5,175 | 863 | 3,968 | 3 | 965 | 1.4 | Standard Q/d |
| 22,620 | 2,714 | 452 | 2,081 | 1 | 965 | 2.2 | May 29 only |
| | | | 0 | 1 | 965 | 0.0 | Comparing to Appendix A2 fires |
| 22,620 | 16,286 | 2,714 | 12,486 | 1 | 965 | 12.9 | Fuel loading at a maximum of 60 tons/arce instead of 10 |

**Table 6.** Q/d analysis, Nova Scotia, May 29 through 31.

| ACRES | Ehc (tons) | Enox | Q | No. days burning | d | Q/d | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 2,104 | 252 | 42 | 194 | 2 | 112 | 0.9 | Standard Q/d |
| 1,772 | 213 | 35 | 163 | 1 | 112 | 1.5 | June 1 only |
| | | | 0 | 1 | 112 | 0.0 | Comparing to Appendix A2 fires |
| 1,772 | 1,276 | 213 | 978 | 1 | 112 | 8.7 | Fuel loading at a maximum of 60 tons/arce instead of 10, May 31 |

**Table 7.** Q/d analysis, Allen Rd fire, New Jersey, May 29 through June 1.

| ACRES | Ehc (tons) | Enox | Q | No. days burning | d | Q/d | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 77 | 9 | 2 | 7 | 1 | 105 | 0.1 | Standard Q/d |
| | | | 0 | 1 | 105 | 0.0 | June 22 emissions only |
| | | | 0 | 1 | 105 | 0.0 | Comparing to Appendix A2 fires |
| 77 | 55 | 9 | 43 | 1 | 105 | 0.4 | Fuel loading at a maximum of 60 tons/arce instead of 10 |

**Table 8.** Q/d analysis, Fort Dix fire, New Jersey, June 1.

| ACRES | Ehc (tons) | Enox | Q | No. days burning | d | Q/d | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 86 | 10 | 2 | 8 | 1 | 112 | 0.1 | Standard Q/d |
| | | | 0 | 1 | 112 | 0.0 | June 22 emissions only |
| | | | 0 | 1 | 112 | 0.0 | Comparing to Appendix A2 fires |
| 86 | 62 | 10 | 47 | 1 | 112 | 0.4 | Fuel loading at a maximum of 60 tons/arce instead of 10 |

**Table 9.** Q/d analysis, Flat Iron fire, New Jersey, June 2.

The calculations above show various estimates for Q/d for each fire that contributed to the smoke in the air in Delaware leading up to and on June 2. Even the largest estimates fall below the 100 ton/day/km value, however using the higher emission factor from AP-42 results in a Q/d = 80 for the western Canada fires, which is approaching closer to 100.

### 3.6.4 Cumulative Q/d

EPA's 2016 guidance recommends a weighted average distance for combining Q/d for multiple sources as would be appropriate for the June 2 ozone event, when several different fires all contributed to smoke in a location.[28] In a maximum scenario, where we assume 60 tons/acre of fuel loading, the summation of all the fire events, starting with May 18-20 from west-central Canada, yields the following result:

$$d_{weighted\ avg} = \frac{(3101 \times \frac{743{,}832}{3}) + (965 \times 12{,}486) + (112 \times 978) + (105 \times 43) + (112 \times 47)}{\frac{743{,}832}{3} + 12{,}486 + 978 + 43 + 47} = 2{,}987km$$

Recalculating Q/d using the sum of Q and the weighted average of d yields:

$$Cumulative\ Q/d = \frac{\frac{743{,}832}{3} + 12{,}486 + 978 + 43 + 47}{2{,}987km} = 88\frac{ton\ per\ day}{km}$$

This cumulative Q/d using maximum emission factors and the weighted average d value, yields a result that is still less than 100 but is approaching that value.

### 3.6.5 Evidence that the Fire Emissions Affected the Monitors

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 follow their transport, they do not necessarily confirm the existence of smoke at the surface by themselves or quantify the concentration at the surface. The ceilometer readings at Wilmington have already been discussed. Thus, as smoke impacted surface air chemistry by providing ozone precursors within the smoke, these would likely be subtly observable in some parameters, such as $PM_{2.5}$, compared to other parameters in the surface monitor network in Delaware.

It also shows consistently higher than normal PM readings, not only rarely dipping below the annual NAAQS (green AQI) but even exceeding the daily NAAQS throughout the period. Prior to May 29, throughout Delaware, the daily concentration of PM at each monitoring station was less than 10 μg/m$^3$. As smoke arrives on May 31 and persists through June 2, we observed increasing daily concentrations of PM along with much wider variability of concentration throughout the state (Table 10). Hourly ozone and PM data are plotted together from May 30 to June 2 (Figure 34). The PM data shows is from the continuous federal equivalent method (FEM) instrument at the site. This data shows ozone increasing daily leading up to the exceedance on June 2.

| Date (2023) | Daily $PM_{2.5}$ Concentration (μg/m$^3$) in Delaware, low | Daily $PM_{2.5}$ Concentration (μg/m$^3$) in Delaware, high |
|---|---|---|
| May 28 | <5 | <10 |
| May 29 | 10 | 15 |
| May 30 | 10 | 20 |
| May 31 | 15 | 30 |
| June 1 | 15 | 50 |
| June 2 | 10 | 27 |
| June 3 | <10 | 25 |

**Table 10.** Daily PM Concentration Range in Delaware, from AirNow archive.

[28] 42 U.S.C. 7619(b)(1)(iii), *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

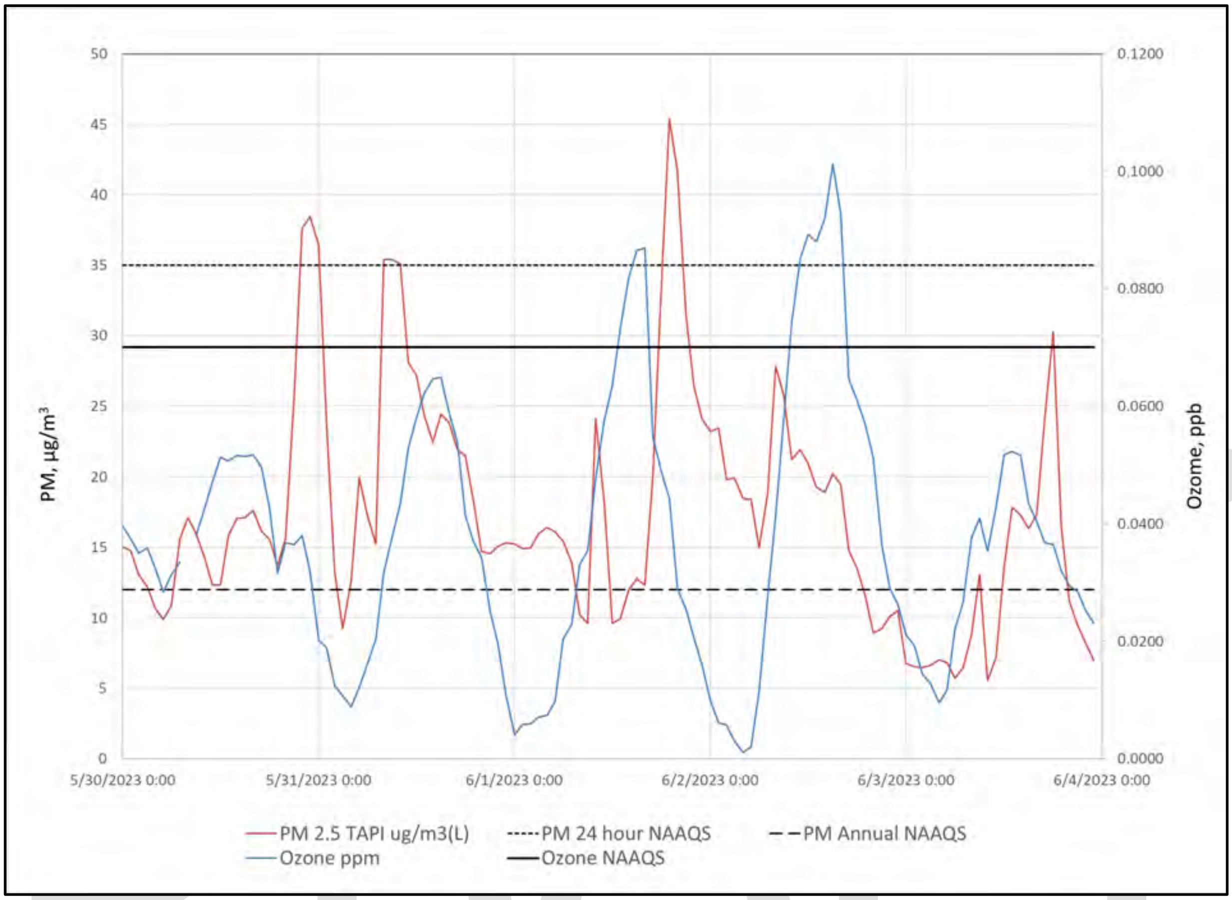



**Figure 34.** PM and Ozone data at the Lums Monitor, May 30 through June 2.

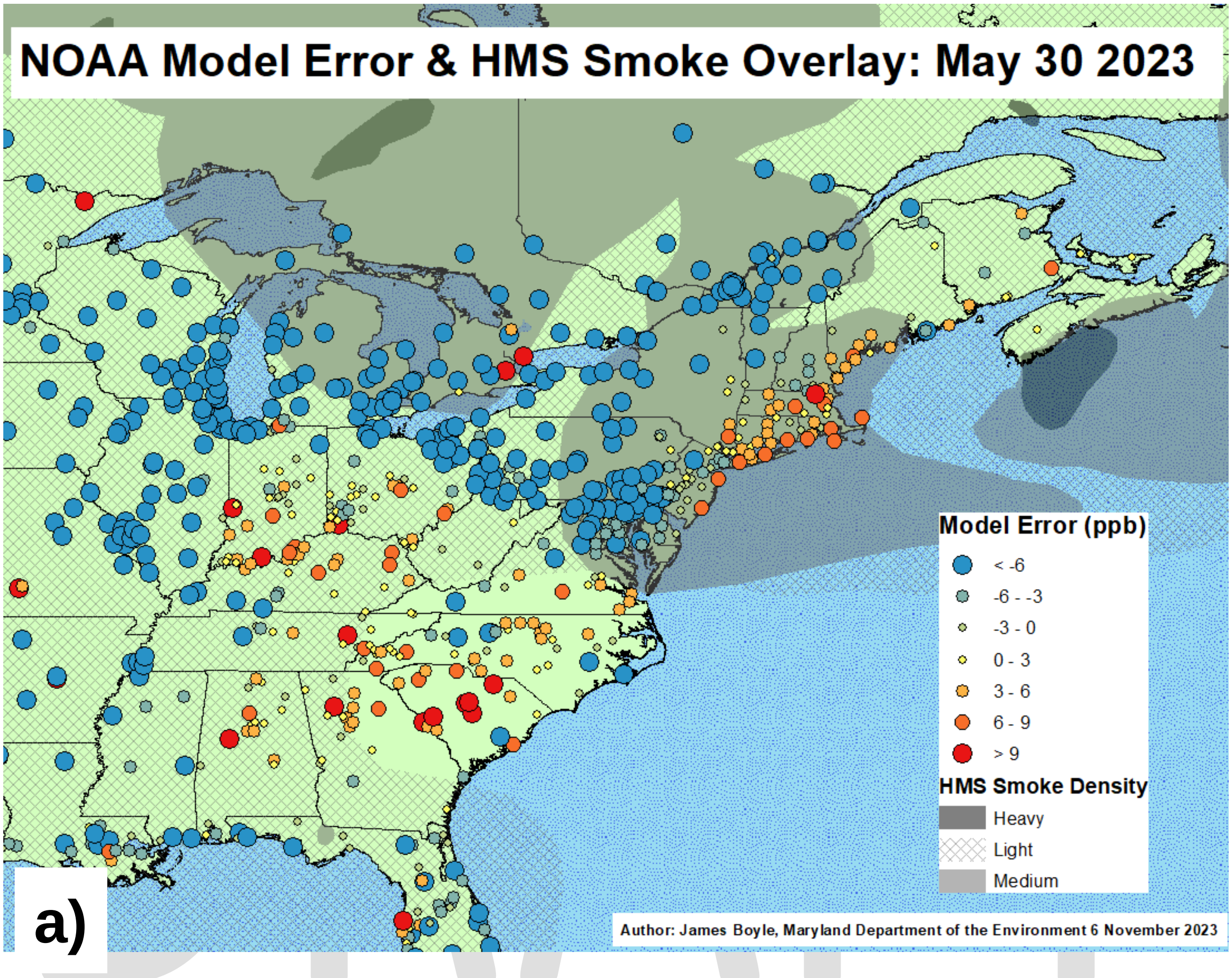
## 3.7 Model Data, CMAQ Underestimation of Ozone

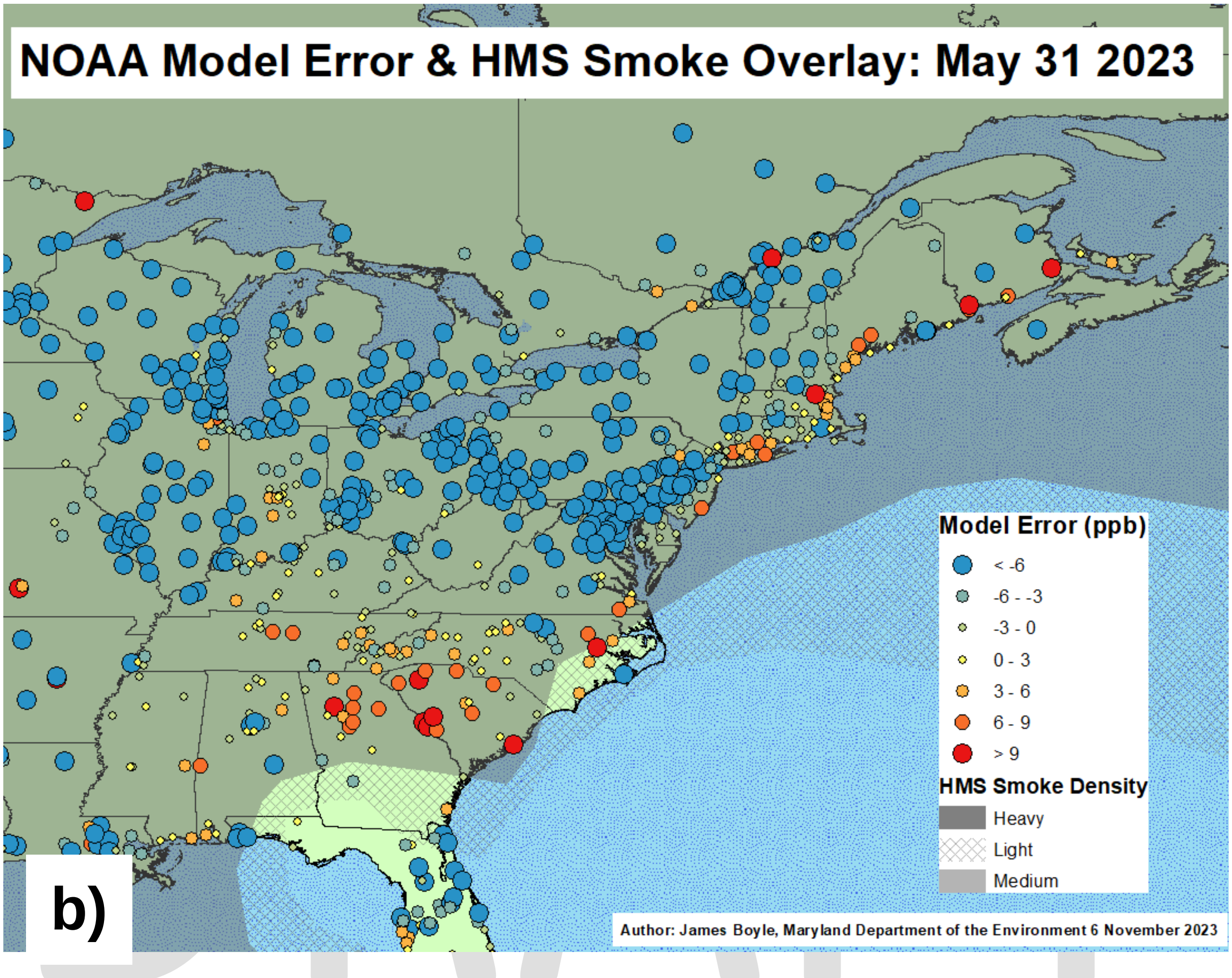
The presence of smoke leading up to and through the June 2 ozone exceedance event and its associated tracers (such as VOCs and $PM_{2.5}$) provides clear causal evidence that significant portions of ozone production were attributable to smoke. Given the presence of increased smoke tracers at the surface and ozone values climbing above the 99th percentile levels of the past 5 years of data, the impact of smoke constituents on ozone is incontestable. To quantify the contribution, however, MD8AO concentrations forecast with the operational NOAA CMAQ ozone model were compared to observed concentrations. VOCs found in wildfire smoke were not included in the NOAA operational CMAQ model during 2023 (personal communication Joel Dreessen, NOAA air quality forecaster workshop).[29] The gas phase chemical interactions from VOCs and their interactions in the formation of ozone were therefore not in the model. Therefore, the NOAA operational CMAQ model prediction of ozone was not inclusive of smoke related ozone chemistry of the atmosphere and provides a proxy for the impact of wildfire smoke on atmospheric concentrations for trace gasses such as ozone when compared to measured concentrations. The difference in the model forecast of ozone to actual observations over the June 2 event period provided an estimate of the increase in ozone due to smoke and the spatial extent of the influence.

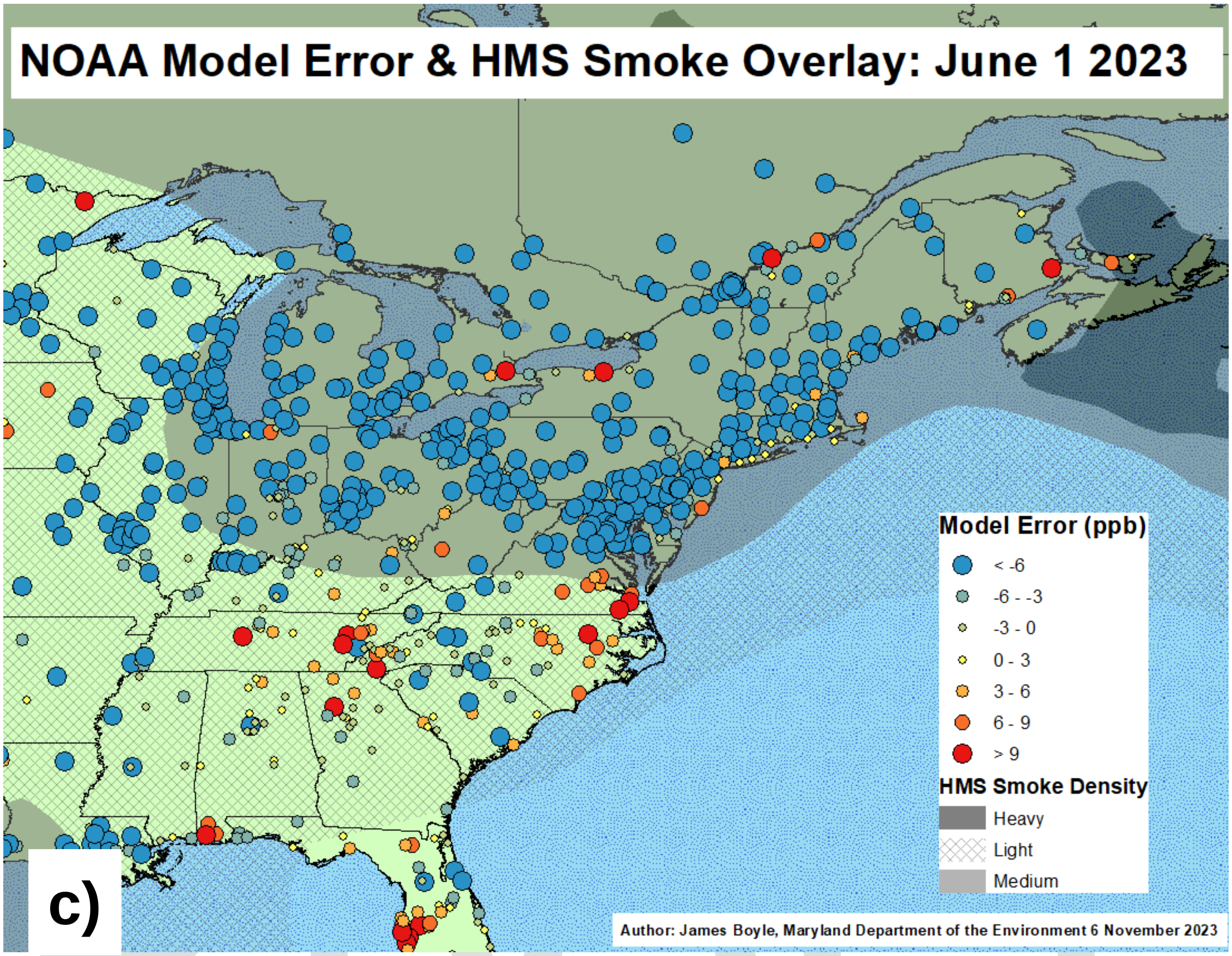
[29] Maryland, State of (2023, Dec). State of Maryland Exceptional Event Demonstration and Analysis of the West-Central and Nova Scotia, Canada and New Jersey Wildfires' Impact on Maryland's Ozone Air Quality on June 2, 2023. MDE.Maryland.Gov.
https://mde.maryland.gov/programs/air/AirQualityMonitoring/Documents/ExceptionalEvents/MDE_Ozone_EE_Demo_2023_June_2.pdf

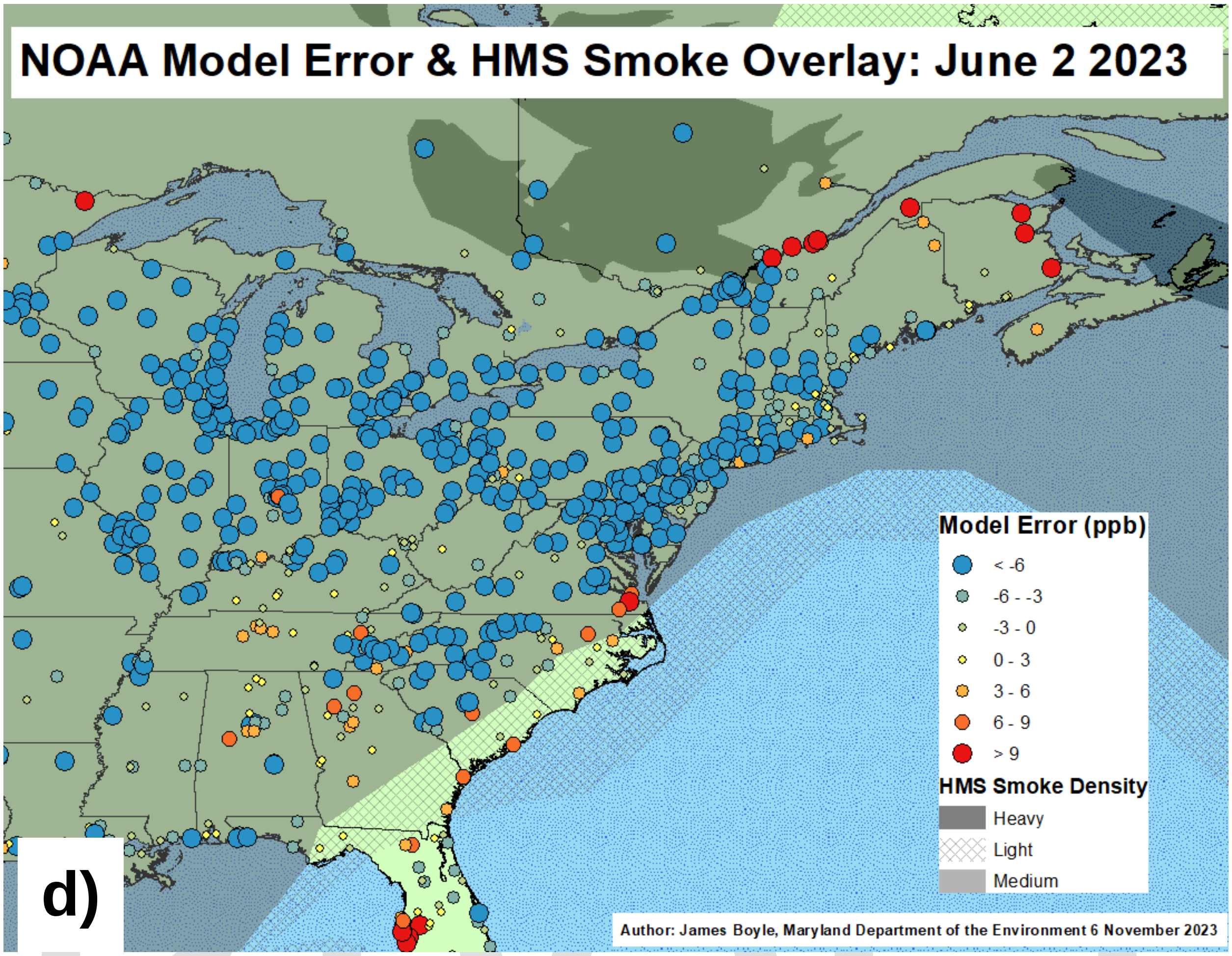
Gridded model data was extracted at observation points throughout eastern CONUS for May 30-June 4, 2023 (Figure 35). The difference between the predicted and observed 8-hour maximums along with HMS smoke density were mapped across the region daily. Significant underpredictions were seen across most of the eastern CONUS over this period. Note HMS analyses provided below were representative of the entire atmospheric column, and do not differentiate between layers of the atmosphere. As such, spatial inconsistencies between the 'thickest' smoke should not be confused with lack of lower-level smoke impacting surface chemistry. Instead, the HMS analyses are quite adept at tracking the plume, and mimicking the horizontal transport pattern, in close agreement with surface ozone discrepancies. Sequential examination of the images revealed an area of modeled under prediction that developed across the Great Lakes and Mid-Atlantic on May 30 linked to medium smoke density analyzed by HMS (Figure 35a). Model underpredictions in Maryland, Delaware and southeastern Pennsylvania were largely on the order of 6 ppb. A near net zero error bias is noted across the Southeastern US in an area where smoke is either very diffuse or not analyzed by HMS. Light to medium smoke density persisted across most of the region from May 31 into June 1 (Figure 35b and c). A very close correlation is seen on June 1 between HMS medium smoke density and NOAA model under predictions across the Northeast, Mid-Atlantic and Great Lakes regions. Ozone underprediction, a possible sign of missing smoke influences in the model, persisted with MD8AO prediction 6 ppb too low across the whole region. Continued presence of smoke, making progress south and west into June 2 (Figure 35d), NOAA model under predictions were now across most of the eastern CONUS showing significant model underprediction greater than 6ppb. Meanwhile, across central Quebec, heavy smoke began to develop linked to a new wave of wildfires which ignited the previous day.

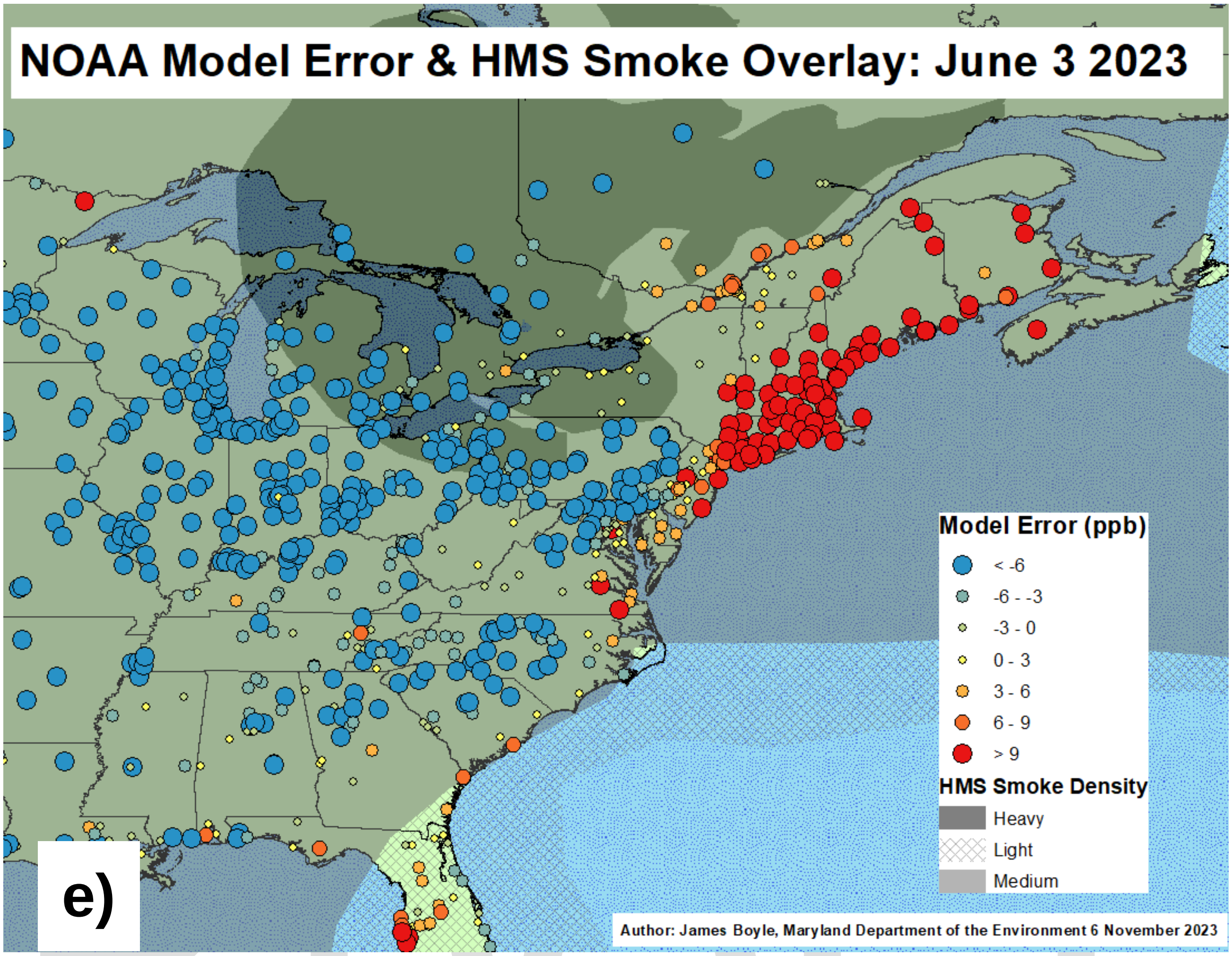
Smoke conditions improved throughout the day along the East Coast on June 3 as onshore flow brought in cleaner air from the Atlantic (Figure 35e). Although HMS analyzed smoke over the open waters of the Atlantic this day, it should be noted that the HMS smoke product is a vertical integration and is not always representative of what is going on at the surface. Model bias completely switched to strongly positive across the New England states. This could be an indication that the model was not capturing cleaner air off the Atlantic. Locations further west experienced continued negative bias associated with persistent smoke. Easterly flow persisted into June 4 (Figure 35f) allowing for continued clearing out of smoke along the entire Eastern Seaboard. HMS smoke of medium to heavy density matches quite well with NOAA model underprediction centered over the Great Lakes. A net zero or positive bias is noted elsewhere across eastern CONUS. In conclusion, during the peak days of smoke influenced ozone concentrations in Maryland on June 1 and 2, ozone underprediction by the CMAQ operational model, a quantitative proxy for the concentration influence of smoke on ozone, averaged -14.4 ppb and -11.3 ppb across the state of Maryland on June 1 and June 2, respectively, implying a 10-15 ppb ozone added to the MD8AO due to smoke in the region.


NOAA Model Error & HMS Smoke Overlay: May 30 2023
Model Error (ppb)
< -6
-6 - -3
-3 - 0
0 - 3
3 - 6
6 - 9
> 9
HMS Smoke Density
Heavy
Light
Medium
a)
Author: James Boyle, Maryland Department of the Environment 6 November 2023


NOAA Model Error & HMS Smoke Overlay: May 31 2023
Model Error (ppb)
< -6
-6 - -3
-3 - 0
0 - 3
3 - 6
6 - 9
> 9
HMS Smoke Density
Heavy
Light
Medium
Author: James Boyle, Maryland Department of the Environment 6 November 2023
b)


NOAA Model Error & HMS Smoke Overlay: June 1 2023
Model Error (ppb)
< -6
-6 - -3
-3 - 0
0 - 3
3 - 6
6 - 9
> 9
HMS Smoke Density
Heavy
Light
Medium
c)
Author: James Boyle, Maryland Department of the Environment 6 November 2023


NOAA Model Error & HMS Smoke Overlay: June 2 2023
Model Error (ppb)
< -6
-6 - -3
-3 - 0
0 - 3
3 - 6
6 - 9
> 9
HMS Smoke Density
Heavy
Light
Medium
d)
Author: James Boyle, Maryland Department of the Environment 6 November 2023


NOAA Model Error & HMS Smoke Overlay: June 3 2023
Model Error (ppb)
< -6
-6 - -3
-3 - 0
0 - 3
3 - 6
6 - 9
> 9
HMS Smoke Density
Heavy
Light
Medium
e)
Author: James Boyle, Maryland Department of the Environment 6 November 2023

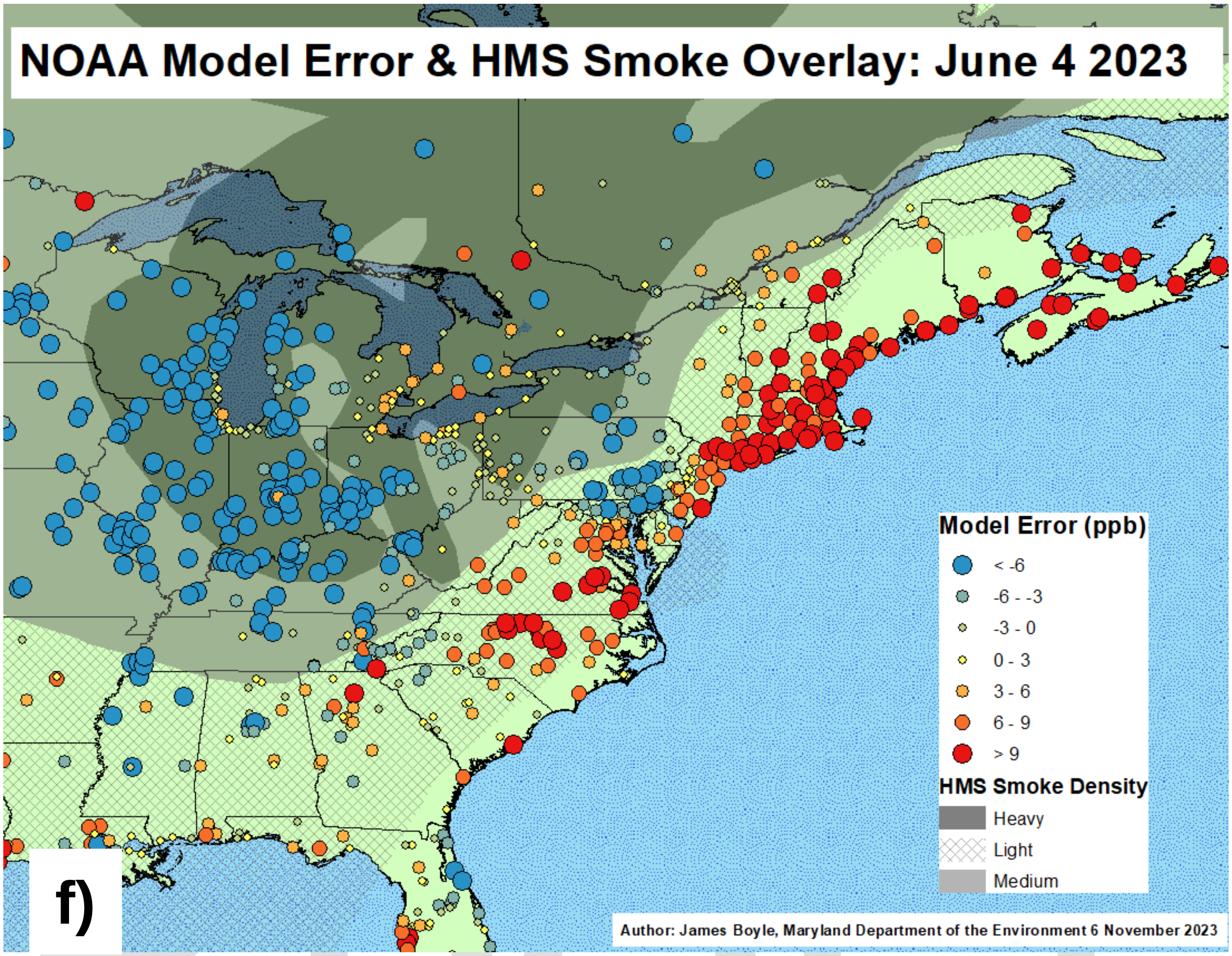



**Figure 35. CMAQ Ozone Predictions, May 30 to June 4.**
NOAA operational CMAQ ozone prediction errors at monitors across eastern CONUS for a) May 30, b) 31, c) June 1, d) 2, e) 3, and f) 4, 2023. HMS Smoke density is overlaid on top to showcase NOAA model underprediction where thicker smoke is prevalent.

## 3.8 Similar Day Analysis

Similar meteorology in the absence of smoke should not produce ozone exceedances of the same magnitude in Delaware as was observed on June 2, 2023. A similar day analysis attempts to identify days which are similar in weather pattern and characteristics (temperatures, winds, transport regime) but without the burden of smoke on ozone production. A comparison of such days should yield substantially less ozone if the ozone concentrations of the current event were impacted by smoke.

To better establish the transport pattern for the onset of the event for a similar day analysis, a meteorological overview of the event day (June 2, 2023) was first done using surface analysis maps, HYSPLIT backward trajectories, and meteorological data. Delaware selected similar days to June 2, 2023 using the following methodology:

1. Metrological data (average wind direction and maximum temperature) was analyzed from 2019, 2021, 2022, and 2023 from meteorological stations at the Wilmington, Dover and Georgetown airports. Data from 2020 was excluded because the COVID pandemic affected typical emissions/activities. The goal of this review was to identify approximately 30-40 days for further

analysis. Delaware identified 31 days that met the criteria using the sort parameters for each individual weather station (Table 11).

| Station | 6/2/23 Average Wind Direction (degrees) | Sort Criteria Average Wind Direction (degrees) | 6/2/23 Max. Temp. (degrees) | Sort Criteria Max. Temp. (degrees) |
|---|---|---|---|---|
| Wilmington | 167 | 150-190 | 97 | Over 92 |
| Dover | 103 | 80-120 | 85.6 | Over 84 |
| Georgetown | 93 | 70-110 | 89 | Over 87 |

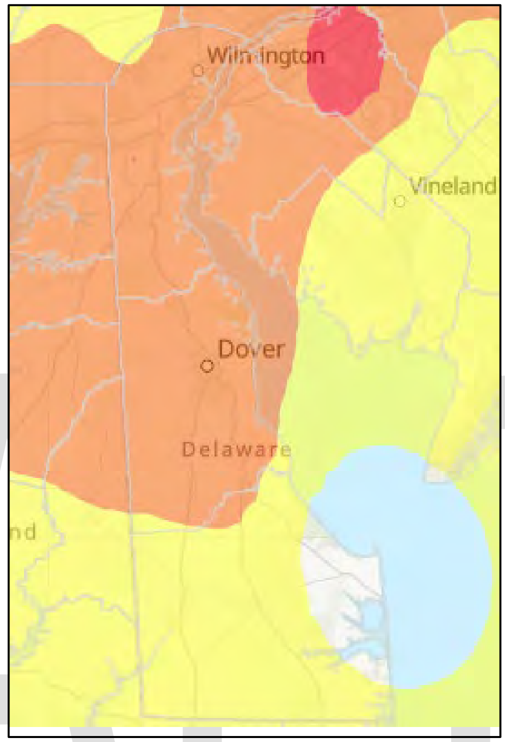
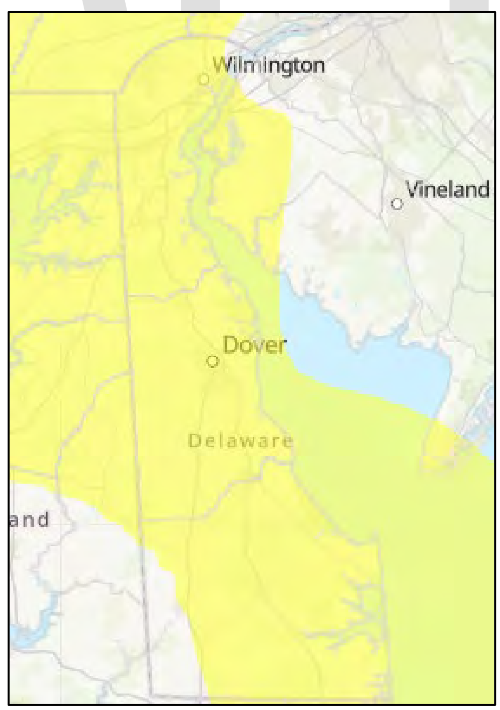
**Table 11.** Weather data from June 2, 2023 Throughout Delaware.

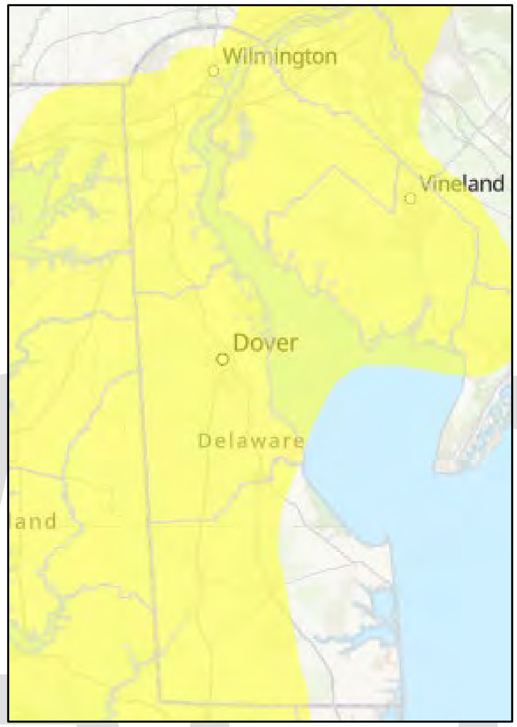
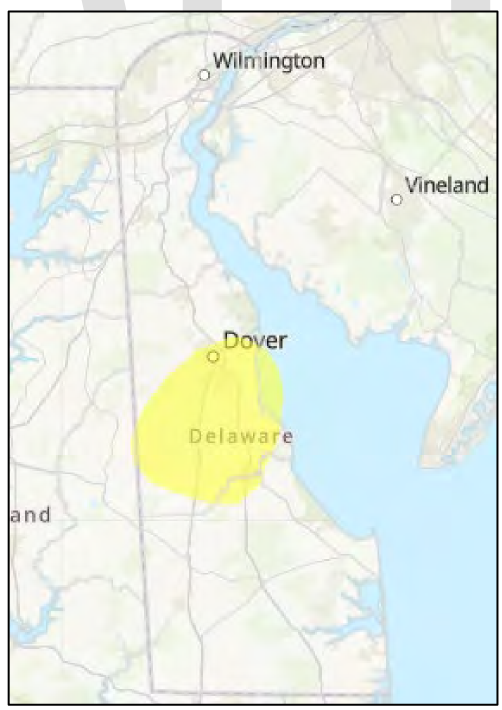
2. Surface maps were examined for the 31 days to identify comparable surface features. In addition, Delaware also analyzed days that were selected by Maryland and Pennsylvania for their June 2, 2023 Exceptional Events Demonstrations because of their close proximity to Delaware. From the surface maps ten days were identified as being similar to conditions on June 2, 2023.

3. HYSPLIT back trajectories were modeled for the resulting 10 days to identify comparable aloft winds. From the trajectory analyses, five days were found to have conditions similar to June 2, 2023:

    - 7/15/22
    - 7/26/19
    - 7/25/19
    - 7/12/18
    - 8/30/16

4. Finally, the ozone concentrations, maximum temperatures, and AQI levels for the five days were compared to those at the Lums Pond monitor on June 2, 2023 (Table 12).

| Date | Maximum Daily 8-hour Average Ozone (ppb)* | Maximum Temperature (°F) | Mapped AQI |
|---|---|---|---|
| **6/2/23** | **85** | **97** |  |
| 7/15/2022 | 61 | 94 |  |

| Date | Maximum Daily 8-hour Average Ozone (ppb)* | Maximum Temperature (°F) | Mapped AQI |
|---|---|---|---|
| 7/26/2019 | 62 | 97 |  |
| 7/25/2019 | 55 | 97 |  |

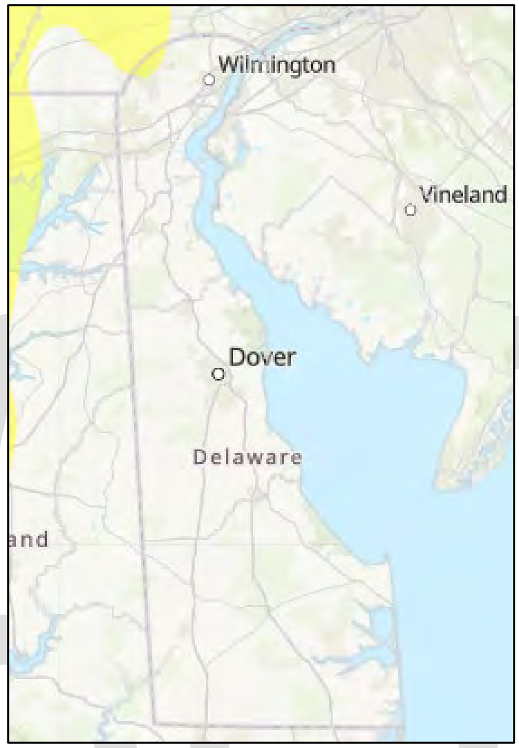
| Date | Maximum Daily 8-hour Average Ozone (ppb)* | Maximum Temperature (°F) | Mapped AQI |
|---|---|---|---|
| 7/12/2018 | 48 | 91 |   |
| 8/30/2016 | 61 | 90 | AirNow map not available. |

**Table 12.** Similar Day Analysis for June 2, 2023.
The similar day analysis includes five dates compared to the June 2, 2023 ozone event. Ozone is the maximum daily 8-hour average ozone concentration for the Lums Pond monitor. *"Daily Concentration" level from EPA's AirNow archive map.[30]

The MD8AO on June 2, 2023 was 85 ppb, which qualified as an "unhealthy for sensitive groups" AQI day based on the 2015 standard. The next highest ozone concentration on a similar day was on July 15, 2022 and July 26, 2019, when similarly warm temperatures at 94°F and 97°F, respectively, produced ozone which was 24 ppb lower (Table 12).

None of the days included in this analysis were comparable to June 2 in respect to mapped AQI (Table 12). Roughly half of the state was under at least code orange AQI conditions on June 2, 2023. In contrast, for July 15, 2022 and July 26, 2019 there were no areas in Delaware above 70 ppb (Table 12). In the remainder of the similar days, there were no exceedances in the state. This analysis reveals that similar meteorological conditions in previous years did not produce as much ozone as on June 2, 2023. In fact, this shows that the ozone production when no smoke is present is between 23-37 ppb less than the



[30] https://gispub.epa.gov/airnow/index.html?tab=3&xmin=-8947667.932515707&xmax=-7802946.996916966&ymin=4516416.76169967&ymax=4999498.7804619605&archivedates=07%2F03%2F2018&monitors=ozone&contours=ozone

MD8AO on June 2. This further supports Delaware's position that the June 2, 2023 ozone exceedance was due to influences from wildfire smoke and meets the definition of an exceptional event.

## 3.9 Conclusion Regarding Clear Causal Relationship

In late May 2023 wildfires erupted across Western Canada. As the smoke from these fires traveled across the United States, additional wildfires began burning in Nova Scotia (Eastern Canada) and New Jersey. These wildfires generated ozone precursors resulting in elevated concentrations throughout the Mid-Atlantic Region of the United States, and specifically at the Lums monitor in New Castle County Delaware. The monitored ozone concentrations of 0.085 ppm (85 ppb) exceeded all 8-hour average measurements over the past 5 years. Although temperatures were high on June 2, this remains inconsistent with historically high ozone concentrations. The comparisons and analyses, provided in sections 2 and 3 of this demonstration support Delaware's position that the wildfire events affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance on June 2 and thus satisfies the clear causal relationship criterion.

# 4. The Occurrence was a Natural Event or Unlikely to Recur

According to the CAA and the Exceptional Events Rule, an exceptional event must be "an event caused by human activity that is unlikely to recur at a particular location or a natural event". [31] [32,33] The west central Canada wildfires were a "natural event." Fires in Nova Scotia and New Jersey currently have an unknown cause. 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."[34] Based on the documentation provided in section 2 of this submittal which discusses the origin and evolution of the wildfire events, the Canadian fires and New Jersey wildfires all qualify as a "natural event" because they were unplanned fires on wildland ignited by lightning or were unplanned with unknown cause. 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.[35] Accordingly, Delaware has shown that the event is a natural event and may be considered for treatment as an exceptional event.



[31] 42 U.S.C. 7401 et seq.
[32] 40 CFR 50.14
[33] 42 U.S.C. 7619(b)(1)(iii), *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 30: https://www.epa.gov/sites/default/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf
[34] 40 CFR 50.1(n)
[35] 40 CFR 50.1(k)

# 5. The Occurrence was not Reasonable Controllable or Preventable

Based on the documentation provided in section 2, the fires relevant in this demonstration were primarily due to lightning (in Canada) or an unknown human-caused event unlikely to recur (New Jersey fires) that caused wildfire events on wildland. These fires were considered natural wildfire events by the EPA, the CWFIS.[36] Many of the fires were outside of the United States and were therefore neither reasonably controllable or preventable by the state of Delaware. No policy that Delaware enacted could have prevented the fires, or the smoke which they caused, to enter the United States or the state of Delaware. Delaware is 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.



[36] National Wildland Fire Situation Report. March 15, 2023. https://cwfis.cfs.nrcan.gc.ca/report

# 6. Public Comment

This draft document was public noticed from March 31 to April 30, for 31 days.

This draft is for public comment. Information and response to comments will be included in the final document.

# 7. Conclusion

The demonstration presented in this document has shown the nature of the event that brought wildfire smoke to Delaware and has shown the clear causal relationship between the smoke transport and the elevated ozone levels that were recorded on June 2, 2023. It has also shown that one monitor in Delaware, located at Lums Pond (10-003-1007) that currently has regulatory significance associated with this event. Exclusion of the June 2, 2023 MD8AO from Lums will bring this site into attainment for 2023, and will result in all Delaware data being eligible for a 1-year extension to demonstrate attainment of the 2015 ozone NAAQS for the Philadelphia- NAA.

An extended, multi-day event associated with arrival, persistence, and aging of smoke impacted Delaware ozone concentrations between May 30 and June 3, 2023. This report focused on the regulatory significance of June 2 during that event. It was evident that a clear causal relationship between wildfire smoke and ozone was established prior to the impacts on June 2.

The June 2 event surpassed the 99th percentile for all statistical thresholds at the monitor where Delaware is requesting concurrence of an exceptional event. The magnitude of the concentrations that were reached on June 2 are extremely rare. Tracking of smoke from hundreds of fires across west-central Canada, fires in Nova Scotia, and fires locally in New Jersey provided cumulative precursors in Delaware to push ozone to the highest level recorded in years. The monitored 8-hour ozone concentrations were elevated region-wide, reaching as high as 85 ppb on June 2 in Delaware where all monitoring sites in New Castle County had MD8AO concentrations above the NAAQS. The analyses provided in sections 2 and 3 of this demonstration support Delaware's position that the May 30-June 3 wildfire smoke event in Delaware, culminating in the regulatorily significant exceedances on June 2 affected air quality in such a way that there exists a clear causal relationship between the events discussed and the monitored concentrations on June 2, 2023 and thus satisfies the clear causal relationship criterion for exclusion.

Exclusion of the MD8AO concentration at the Lums station on June 2, 2023 directly impacts the annual DV and brings that site into attainment of 70 ppb when considering this event in isolation. Based on these facts, Delaware requests that EPA concur that the MD8AO concentration at the Lums station (10-003-1007) on June 2, 2023, which exceeded the 70 ppb NAAQS, was impacted by an exceptional event. As such, Delaware requests that the data from this monitor on June 2, be flagged as such and be excluded from use for regulatory determinations.

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# Appendix A Initial Notification Documentation

STATE OF DELAWARE
DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL
DIVISION OF AIR QUALITY
STATE STREET COMMONS
100 W. WATER STREET, SUITE 6A
DOVER, DELAWARE 19904

DIRECTOR'S OFFICE

PHONE (302) 739-9402

February 12, 2024

Ms. Cristina Fernandez
Division Director
U.S. Environmental Protection Agency, Region 3
Air & Radiation Division (3AD00)
1600 John F Kennedy Blvd
Philadelphia, PA 19103

RE: Exceptional Event Initial Notification

Dear Ms. Fernandez:

In accordance with 40 Code of Federal Regulations (CFR) Part 50.14 – Treatment of air quality monitoring data influenced by exceptional events, Delaware is submitting the attached initial notification of an exceptional event. The exceptional event demonstration to follow will address conditions that led to an exceedance of the National Ambient Air Quality Standard (NAAQS) for ozone (70 ppb) at Delaware's Lums monitoring station (AQS ID 100031007) on June 2, 2023.

If you have any questions or need additional information, please feel free to call me at (302) 739-9402.

Sincerely,

ADMarconi

Angela D. Marconi, P.E.
Air Director

cc: Alice Chow, U.S. EPA Mid-Atlantic Region
Verena Joerger, U.S. EPA Mid-Atlantic Region
Valerie Gray, Division of Air Quality, DNREC
Tristan Bostock, Division of Air Quality, DNREC
James Roberts, Division of Air Quality, DNREC
Kevin Kahover, Division of Air Quality, DNREC

## EPA Region 3 Exceptional Events Initial Notification (IN) Summary Information

**Directions**: For Initial Notifications for attainment date extensions, please fill out A, D, and E. For all other requests, please fill out A, B, C, F.

**Submitting Agency:** Delaware Department of Natural Resources and Environmental Control

**Agency Contact: Angela Marconi, angela.marconi@delaware.gov**

**Date Submitted: 2/12/2024**

**Applicable NAAQS (e.g. 2015 8-Hour Ozone): 2015 8-Hour Ozone Standard (70 ppb)**

**Affected Regulatory Decision[1]: Attainment date extension**
*(for classification decisions, specify level of the classification with/without EE concurrence)*

**Area Name/Designation Status:** Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE – Delaware only / Only Moderate Nonattainment

**Design Value Period (list three year period):** (2023 DV year) 2021, 2022, 2023
*(where there are multiple relevant design value periods, summarize separately)*

[1] designation, classification, attainment determination, attainment date extension, or finding of SIP inadequacy leading to SIP call
[2] Provide additional information for types of event described as "other"

**A) Information Specific to Each Flagged Monitor Day** (*or attach separate spreadsheet)*

| Date of Event | Type of Event (high wind, intrusion, wildfires/prescribed fire, other[2]) | AQS Flag | Monitor AQS ID (and POC) | Site Name | Exceedance Concentration | Units | Event Name | Notes (e.g. links to other events) |
|---|---|---|---|---|---|---|---|---|
| June 2, 2023 | wildfire | Y | 100031007 | Lums Pond - DE | 85 | ppb | NW Canada, Nova Scotia Canada, & NJ Wildfires | This is based on preliminary data. |

**B) Violating Sites Information**

**(listing of all violating sites in the planning area, regardless of operating agency, and regardless of whether or not they are impacted by EEs)**

| Site/monitor | AQS ID | Design Value (without EPA concurrence on any of the events listed in Section A) | Design Value (with EPA concurrence on all events listed in Section A) |
|---|---|---|---|
| * Lums Pond - DE | 100031007 | DV 2021-2023 = 61<br>2023 4th highest = 72 | 2023 4th highest = 70 |

***No sites are violating the standard for the three year period from 2021 through 2023. Lums is violating the standard for 2023 only. This is based on preliminary data.**

[1] designation, classification, attainment determination, attainment date extension, or finding of SIP inadequacy leading to SIP call

[2] Provide additional information for types of event described as "other"

**C) Summary of Maximum Design Value (DV) Site Information (Effect of EPA Concurrence on Maximum Design Value Site Determination)**

**(Two highest values from Table B)**

| | | | |
|---|---|---|---|
| Maximum DV site (AQS ID) without EPA concurrence on any of the events listed in attached spreadsheet | Design Value 0.063 | Design Value Site Brandywine | Comment Delaware's preliminary data is in compliance for the three year period but not for 2023 alone. |
| Maximum DV site (AQS ID) with EPA concurrence on all events listed in attached spreadsheet | Design Value 0.063 | Design Value Site Brandywine | Comment The change for Lums for 2023 will not affect overall DV for the period. |

**D) Highest 4th High Monitors that Exceed the Standard** *(or attach separate spreadsheet)*

**(listing of all "highest 4th high" exceeding sites in the planning area, regardless of operating agency, and regardless of whether or not they are impacted by EEs)**

| Site/monitor | AQS ID | 4th High (4th high without EPA concurrence on any events listed in section A) | 4th High (4th high with EPA concurrence on all events listed in section A) |
|---|---|---|---|
| | | | |
| Camden – NJ | 340070002 | 71 | 67 |
| Colliers Mills – NJ | 340290006 | 73 | 68 |
| Clarksboro – NJ | 340150002 | 74 | 68 |
| Washington Crossing – NJ | 34029991 | 71 | 68 |
| Lums Pond - DE | 100031007 | 72 | 70 |
| Bristol – PA | 420170012 | 79 | N/A |
| Chester – PA | 420450002 | 74 | N/A |
| North East Airport (NEA) – PA | 421010024 | 72 | N/A |
| North East Waste (NEW) – PA | 421010048 | 71 | N/A |

[1] designation, classification, attainment determination, attainment date extension, or finding of SIP inadequacy leading to SIP call
[2] Provide additional information for types of event described as "other"

**E) Summary of Highest 4th High Site Information (Effect of EPA Concurrence on Highest 4th High Site Determination)**
**(Two highest values from Table D)**

| | | | |
|---|---|---|---|
| Maximum 4th high site (AQS ID) without EPA concurrence on any of the events listed in section A | 4th High 72 ppb | 4th High Site Lums | Comment Lums is the only DE monitor that exceeds on the 4th highest without concurrence. |
| Maximum 4th high site (AQS ID) with EPA concurrence on all events listed in section A | 4th High 70 ppb | 4th High Site Brandywine | Comment With concurrence at Lums, and Brandywine's 4th highest for 2023 will be the highest reading. |

**F) List of any sites (AQS ID) within planning area with invalid design values (e.g., due to data incompleteness)**

Lums may have invalid design values due to issues with data completeness. Delaware is in the process of data validation at present but there were data completeness issues in recent years.

[1] designation, classification, attainment determination, attainment date extension, or finding of SIP inadequacy leading to SIP call
[2] Provide additional information for types of event described as "other"

REGION 3
PHILADELPHIA, PA 19103

February 14, 2024

Ms. Angela D. Marconi, P.E.
Air Director
Division of Air Quality
State of Delaware Department of Natural
Resources and Environmental Control
W. Water Street, Suite 6A
Dover, Delaware 19904

Dear Ms. Marconi:

This letter provides a response to the Department of Natural Resources and Environmental Control (DNREC) exceptional event (EE) initial notification (IN) submittal, dated February 12, 2024, regarding ozone (O3) data affected by an EE. The IN stated that emissions from wildfires based in north-west and Novia Scotia, Canada and New Jersey, USA caused an exceedance of the 2015 O3 National Ambient Air Quality Standards (NAAQS) on June 2, 2023 at the following monitoring site within the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE Nonattainment Area: Lums Pond (AQS ID: 10-003-1007). The IN indicated that the (preliminary) 4th high for the Lums Pond monitor would change from having an exceedance of the standard to not having any exceedances based on exclusion of the data for the date indicated in the IN.

Based on the information provided in DNREC's IN submittal, the U.S. Environmental Protection Agency (EPA) has determined that O3 data from June 2, 2023 at the Lums Pond site may affect a future regulatory decision and the exceedance could be considered for exclusion under the Exceptional Events Rule.

EPA has been in communication with DNREC regarding this request. Based on the nature of the event and the anticipated timing of EPA's determination of whether the Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE area attained by the applicable attainment date of August 3, 2024, EPA requests that the demonstration be formally submitted to EPA no later than April 15, 2024. Please be sure to certify data relating to this EE request prior to submittal to EPA.

EPA encourages continued communication throughout the development and submittal of this EE demonstration. If you have any questions regarding this response, please feel free to contact me or have your staff contact Verena Joerger, Exceptional Events Lead, Air & Radiation Division, at 1600 John F. Kennedy Boulevard, Philadelphia, PA 19103, or 215-814-2218. We appreciate your partnership in working through implementation of the Exceptional Events Rule.

Sincerely,

CRISTINA FERNANDEZ
Digitally signed by CRISTINA FERNANDEZ
Date: 2024.02.14 13:50:51 -05'00'

Cristina Fernández
Division Director

cc: Valerie Gray
Tristan Bostock
James Roberts
Kevin Kahover
Alice Chow
Verena Joerger

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# Appendix B Supporting Information

This appendix contains reference and support materials that document the smoke transport that took place leading up to the June 2, 2023, ozone exceedances in Delaware.

## 1. Air Quality Forecasts

Delaware does not have in house staff who perform ozone or PM forecasting. For several years Delaware has contracted with Sonoma Technology, Inc. to perform forecasting statewide. Weekday forecasts are provided for ozone on weekdays from May 1 through September 30 annually. STI has provided “as needed” PM forecasting when the situation warrants this information in addition to ozone. All forecasts are posted on our website located at de.gov/aqi. When the forecast predicts ozone or PM with an AQI of Unhealthy for Sensitive Groups (USG) or higher, in addition to posting on our website, Delaware also issues an email to an opt-in list and posts the forecast on the Delaware.gov landing page (Figures B1 and B2).

In late May/early June 2023 STI had begun to watch smoke transport but had not yet added PM forecasting, so PM forecasts are not available for these dates. Delaware has since added this service because of the impact of PM throughout the summer of 2023.

**From:** DNREC Ozone Alerts List <dnreclist@state.de.us>
**Sent:** Thursday, June 1, 2023 3:00 PM
**To:** DNREC Ozone Alerts List <dnreclist@state.de.us>
**Subject:** Code Orange Air Quality Action Day for Ozone for Delaware – June 2

**Friday, June 2, will be a Ozone Code Orange Air Quality Action Day for Delaware!**

**Tomorrow’s Forecast:**
A ridge of high pressure aloft will build southward across Delaware, hindering atmospheric mixing. In addition, light northeasterly to southwesterly winds will limit dispersion and transport regional pollutants into the First State. Furthermore, lingering smoke from wildfires in Nova Scotia will contribute to ozone precursors, while mostly sunny skies and high temperatures in the upper-80s to low-90s enhance ozone formation. As a result, AQI levels will be Unhealthy for Sensitive Groups.

**Extended Forecast:**
Saturday, moderate and gusty easterly winds will enhance dispersion and transport cleaner air into the region as a cold front moves across Delaware. In addition, increasing clouds will hinder ozone formation, leading to low-Moderate AQI levels.

**Forecast Graphic:**
**Extended Forecast**

| | | | | |
|---|---|---|---|---|
| Friday, Jun 2: | 126 AQI | Unhealthy for Sensitive Groups | Orange | Ozone |
| Saturday, Jun 3: | 51 AQI | Moderate | Yellow | Ozone |

For more information about the air quality alerts and what you can do to reduce air pollution, check out the following website:
https://dnrec.alpha.delaware.gov/air/quality/forecast/
A Code Orange air quality forecast for ozone is a level of pollution that can be unhealthy for sensitive groups, such as young children, the elderly, and those with heart and/or respiratory conditions. Such persons should limit outdoor activities, especially those that require a high level of exertion. Any health-related questions should be directed to the Division of Public Health at 302-744-4700. All other questions should be directed to the Division of Air Quality at 302-739-9402.

**Figure B1.** Air Quality Action Day email sent for June 2, 2023.

**A(n) Action Day has been declared for Delaware, on Thursday, Jun 1**

**Tomorrow's Forecast**

| | | | | |
|---|---|---|---|---|
| Thursday, Jun 1: | 101 AQI | Unhealthy for Sensitive Groups | Orange | Ozone |

**Extended Forecast**

| | | | | |
|---|---|---|---|---|
| Friday, Jun 2: | 126 AQI | Unhealthy for Sensitive Groups | Orange | Ozone |
| Saturday, Jun 3: | 51 AQI | Moderate | Yellow | Ozone |

Thursday, June 1 and Friday, June 2: A ridge of high pressure aloft will build southward across Delaware, hindering atmospheric mixing. In addition, light northeasterly to southwesterly winds will limit dispersion and transport regional pollutants into the First State. Furthermore, lingering smoke from wildfires in Nova Scotia will contribute to ozone precursors, while mostly sunny skies and high temperatures in the upper-80s to low-90s enhance ozone formation. As a result, AQI levels will be Unhealthy for Sensitive Groups on both days. Saturday, moderate and gusty easterly winds will enhance dispersion and transport cleaner air into the region as a cold front moves across Delaware. In addition, increasing clouds will hinder ozone formation, leading to low-Moderate AQI levels.

For more information, contact the State of Delaware Department of Natural Resources and Environmental Control at 302-739-9402.

**Figure B2.** Air Quality Action Day email sent for June 1, 2023.

## 2. Social Media Posts

The Department of Natural Resources and Natural Resources (DNREC) posted several messages about this incident as it was taking place. The posts are provided to show that the effects of the smoke were notable and affecting the Delaware population (Figures B3 through B7).

**Delaware DNREC** @DelawareDNREC · 6/1/23

🟠 A Code Orange Air Quality Action Day 🟠 has been declared for #Delaware for June 1 and 2. These conditions will cause air quality index (AQI) levels to be unhealthy for sensitive groups. Check out the full forecast de.gov/aqi

**June 01, 2023**
Ozone: 101
Unhealthy for Sensitive Groups

**June 02, 2023**
Ozone: 126
Unhealthy for Sensitive Groups

3 1 473

**Figure B3. Air Quality Action Day Social Media Post, June 1.**


Figure B4. Air Quality and Health Social Media Post, June 1.


Figure B5. Delaware State News Social Media Post, June 1.


Figure B6. WBOC Social Media Post, June 1.


**Figure B7. AirNow Social Media Post, June 2.**

## 3. Local News Coverage

Local news reported on the poor air quality and visibility in the area during this week (May 28-June 3). Several links to this coverage are provided below. Additional examples are available but may require subscriber status to access.

WHYY, June 1, 2023. Delaware poor air quality alert until midnight Friday linked to Canadian wildfires. https://whyy.org/articles/delaware-poor-air-quality-alert-midnight-friday-canadian-wildfires/ (accessed 3/17/24).

NASA Earth Observatory, May 31, 2023. Raging Fires in Nova Scotia. https://earthobservatory.nasa.gov/images/151407/raging-fires-in-nova-scotia (accessed 3/17/24).

WDRE, June 2, 2023 (Updated June 2, 2023). DNREC Declares Code Orange Air Quality Alert for June 1 and 2. https://www.wrde.com/news/dnrec-declares-code-orange-air-quality-alert-for-june-1-and-2/video_ba17b2b6-ff8a-556e-a961-52d67c9ed2bc.html (accessed 3/17/24).

WDRE, June 1, 2023 (Updated June 29, 2023). DNREC Declares Code Orange Air Quality Alert for June 1 and 2. https://www.wrde.com/news/dnrec-declares-code-orange-air-quality-alert-for-june-1-and-2/article_7504be5c-0085-11ee-883f-a7218fb337cd.html (accessed 3/17/24).

Delaware Public Media, June 1, 2023. DNREC issues Ozone Action Days, advises residents to stay indoors. https://www.delawarepublic.org/delaware-headlines/2023-06-01/dnrec-issues-ozone-action-days-advises-residents-to-stay-indoors (accessed 3/17/24).