State of Delaware Final Report: Ozone and $PM_{2.5}$ Observations and Forecasts in 2023

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Delaware Department of Natural Resources and Environmental Control
Wilmington, DE

April 2024

STi | Sonoma Technology

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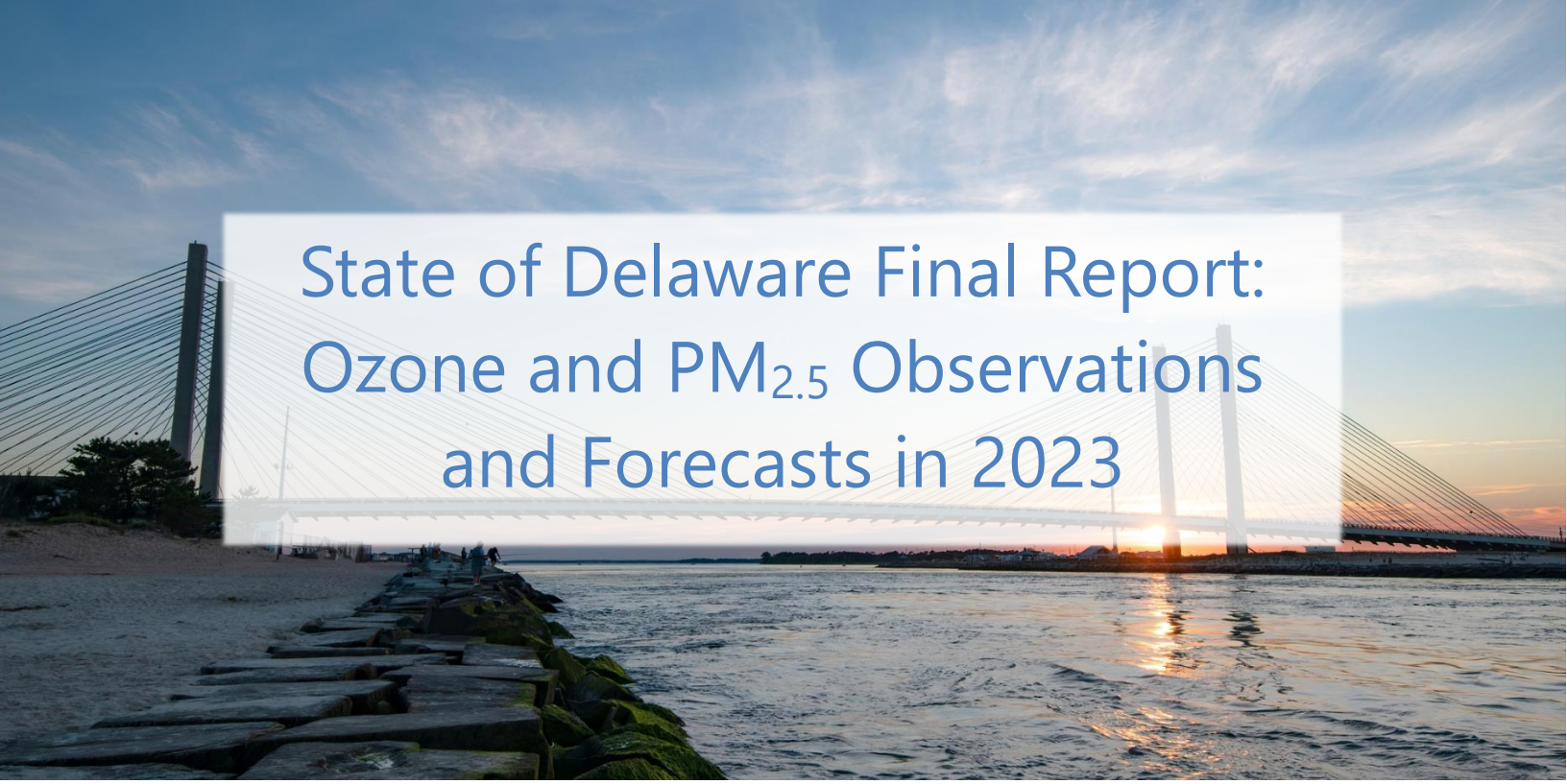

State of Delaware Final Report: Ozone and $PM_{2.5}$ Observations and Forecasts in 2023

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Final Report

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Executive Summary

Key Findings

- Air quality conditions in Delaware from May-September 2023 were worse than the previous three years, due primarily to the impact of smoke transport from unprecedented fire activity across Canada. The month of June featured significant smoke impacts on nearly every day of the month, as confirmed by both satellite-based smoke analysis and aerosol optical depth (AOD) observations.
- During the forecast season, Air Quality Index (AQI) levels in Delaware exceeded the Nation Ambient Air Quality Standard (NAAQS) on 11 days. The majority of those exceedances were for $PM_{2.5}$, but several days included ozone exceedances as well.
- In response to widespread, persistent smoke from record-setting fires in Canada, Sonoma Technology forecasters added $PM_{2.5}$ forecasts alongside the ozone forecasts beginning on June 1 and lasting through the end of September.
- Between May and September, ozone levels in Delaware were in the Good AQI category on 63% of days, the Moderate category on 35% of days, and the Unhealthy for Sensitive Groups (USG) category on 2% of days.
- Between May and September, $PM_{2.5}$ AQI levels in Delaware were in the Good category on 51% of days, the Moderate category on 43% of days, the USG category on 4% of days, the Unhealthy category on 1% of days, and the Very Unhealthy category on 1% of days.
- At the Good-to-Moderate threshold, next-day ozone forecasts were correct 71% of the time during summer 2023, with a probability of detection (POD) of 77% and a false alarm rate (FAR) of 45%. The average ozone forecast bias was +3.8 ppb.
- At the Good-to-Moderate threshold, next-day $PM_{2.5}$ forecasts were correct 83% of the time. At the Moderate-to-USG threshold, the POD was 80%, and the FAR was 11%. The average $PM_{2.5}$ forecast bias was -2.2 $\mu g/m^3$.
- Looking ahead to the 2024 ozone season, Sonoma Technology meteorologists predict slightly above-average temperatures and near- to slightly below-normal precipitation. The warmer, drier conditions are expected to enhance local ozone formation, likely leading to above-average AQI levels for ozone in Delaware for the season.
- Above-average temperatures and continued drought are predicted for much of Canada in summer 2024, which may lead to another year with significant wildfires; smoke transport from these fires could increase $PM_{2.5}$ concentrations and further enhance ozone formation in Delaware in 2024.

1. Air Quality Climatology 2018-2022

The summer air quality forecast season for the state of Delaware spans from May 1 – September 30. During this period, daily ozone forecasts are issued by Sonoma Technology, and, when conditions warrant, daily forecasts for $PM_{2.5}$ are periodically issued. Forecasts are provided seven days a week covering air quality conditions for the next-day and following two days.

Prior to the start of the air quality forecast season, Sonoma Technology meteorologists review the observed AQI values for ozone and $PM_{2.5}$ from regulatory monitoring sites across Delaware from the previous years (Figure 1). During this review process, an AQI climatology is developed from the past five years of observed ozone and $PM_{2.5}$ data. This AQI climatology helps Sonoma Technology meteorologists assess recent patterns and trends in air quality for the state of Delaware that will aid in forecast decision-making for the current air quality forecasting season.

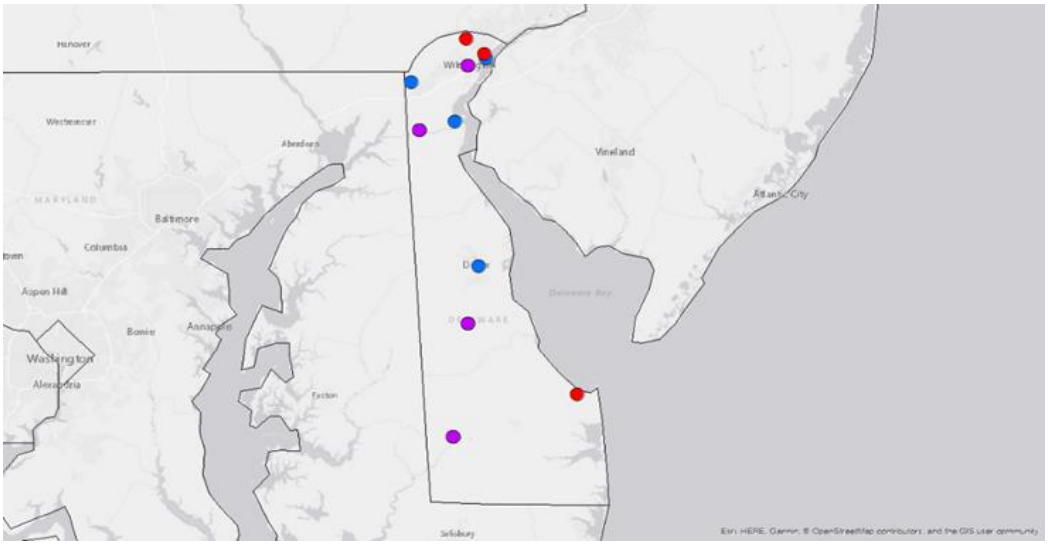

Figure 1. Active ozone and $PM_{2.5}$ monitoring sites in the state of Delaware. Red dots represent sites that monitor ozone, blue dots indicate sites that monitor $PM_{2.5}$, and purple dots depict sites that monitor both ozone and $PM_{2.5}$.

The following sections will review the AQI climatology for ozone and $PM_{2.5}$ for the 2018-2022 period. This climatology provides the monthly and daily distribution of past AQI values and highlight the frequency of multi-day high pollution events, defined by the AQI exceeding the NAAQS of 100.

1.1 Climatology of Ozone

Ground-level ozone formation depends on a variety of meteorological factors, with the primary catalysts being sunlight and surface air temperatures. In the spring, increasing daylight and warmer temperatures begin to enhance ozone production. This relationship is reflected in Figure 2, as days with Moderate-or-higher AQI levels increase in frequency from March through July. By August, gradually shorter days result in improved ozone levels, with Good AQI levels being recorded on most days.

Due to the long-term reductions in regional emissions, AQI levels for ozone in Delaware are generally in the Good category (≤ 50 AQI) for most days during the year. Based on the 2018-2022 data in Figure 2, Good ozone AQI levels were observed on 85% of days. During the summer air quality forecast period of May-September, nearly 70% of days featured Good AQI levels.

A clear pattern emerges for months when Moderate-or-higher AQI levels for ozone are recorded more frequently. Based on the 2018-2022 data, the occurrence of Moderate-or-higher ozone AQI values is most frequent in June and July, when surface temperatures are at their seasonal warmest and when days are longest. These meteorological conditions, combined with regional emissions, result in enhanced production of ground-level ozone in Delaware.

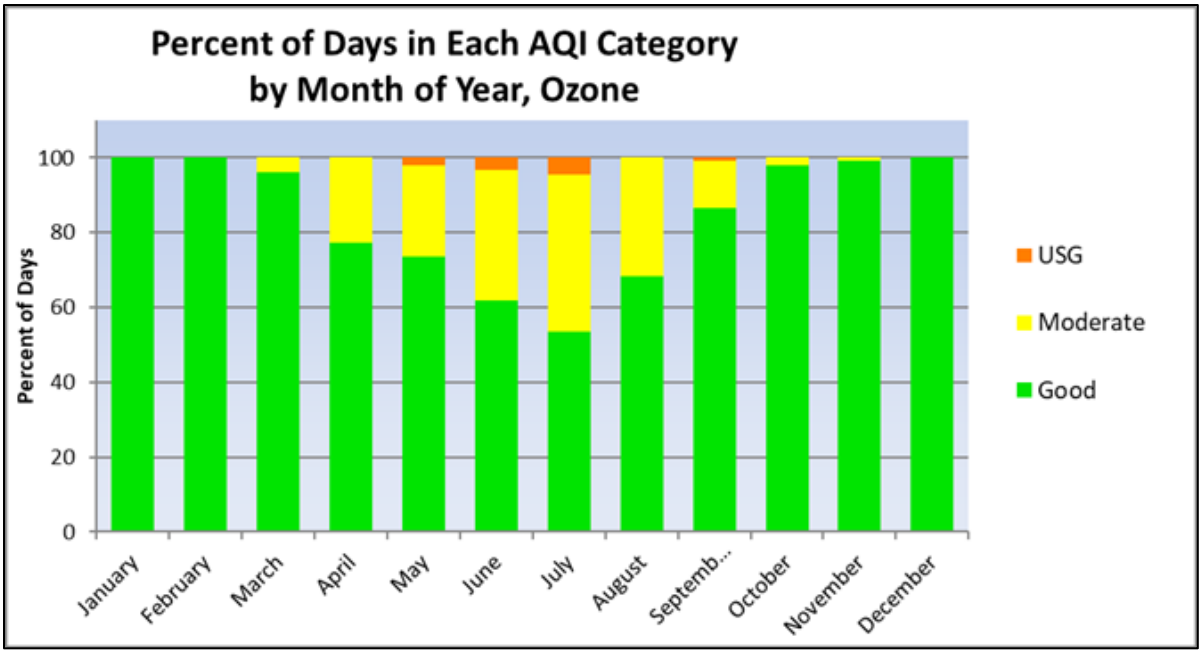

Figure 2. Monthly distribution of each AQI category based on 2018-2022 ozone data.

While infrequent, ozone AQI values in the USG category can occur in the First State. During the 5-yr period from 2018-2022, USG ozone AQI levels were most frequent in July, with other USG ozone days occurring in May, June, and September. Annually, USG ozone AQI levels account for less than 1% of all days.

To obtain information related to localized ozone patterns on a day-to-day basis, ozone AQI climatology based on the day of the week was also produced. From this, Sonoma Technology meteorologists can indicate which day(s) of the week may be more prone to Moderate-or-higher ozone AQI levels. Days with more frequent occurrences of Moderate-or-higher ozone AQI levels can be related to local emissions, such as industrial activity or rush hour driving patterns.

From 2018-2022, Moderate-or-higher ozone AQI levels were most prevalent on Wednesdays and Saturdays (Figure 3). While industrial and traffic patterns are lower on weekends versus weekdays, it is likely that pollutant carryover from the previous day led to a higher frequency of Moderate-or-higher ozone AQI levels on Saturdays in Delaware. Sundays featured the fewest occurrences of Moderate-or-higher ozone AQI levels, which can be related to the reduction in industrial emissions and traffic that occurs over the weekend. This pattern may also influence AQI levels on Mondays due to low pollutant carryover from the previous day.

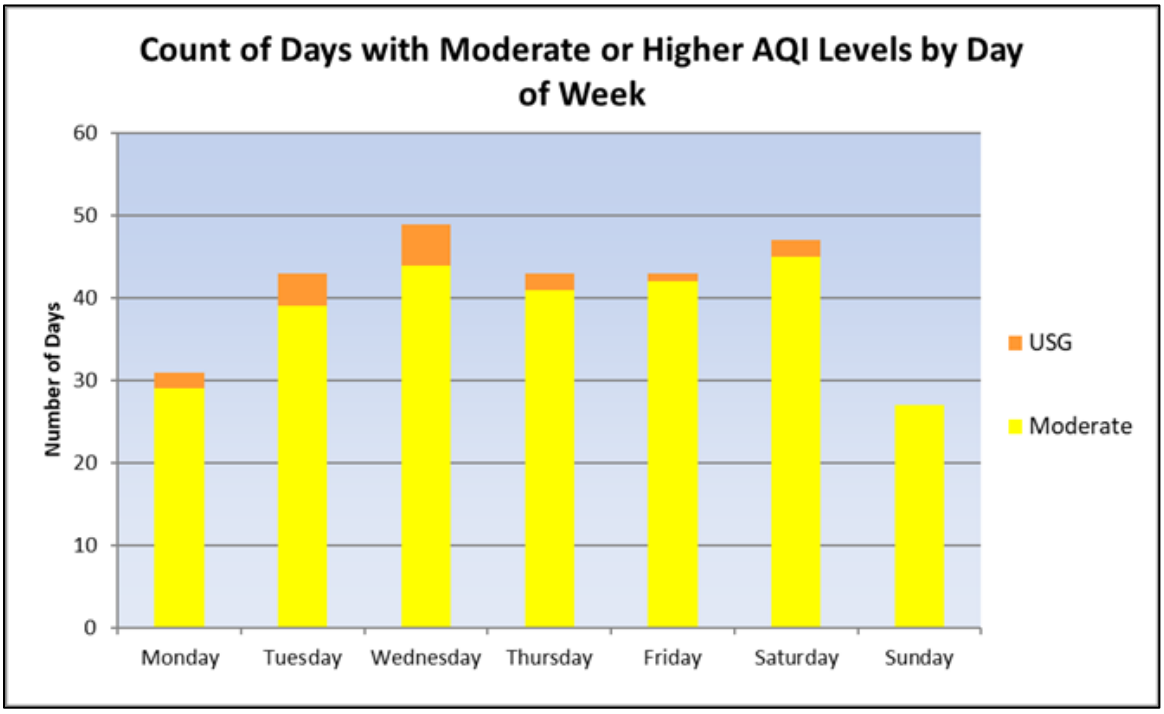

Figure 3. Number of Moderate-or-higher ozone AQI levels in Delaware by day of week from 2018-2022.

USG ozone events in Delaware are isolated occurrences. Even rarer are periods with multiple days of USG ozone AQI levels. Between 2018-2022, there were 16 days with USG ozone AQI levels recorded.

Of these, 9 occurred on a single-day basis (Figure 4). In addition, there were two occasions where USG ozone was recorded for two consecutive days. There was only one instance where USG ozone occurred on three consecutive days, which occurred between July 9-11, 2018.

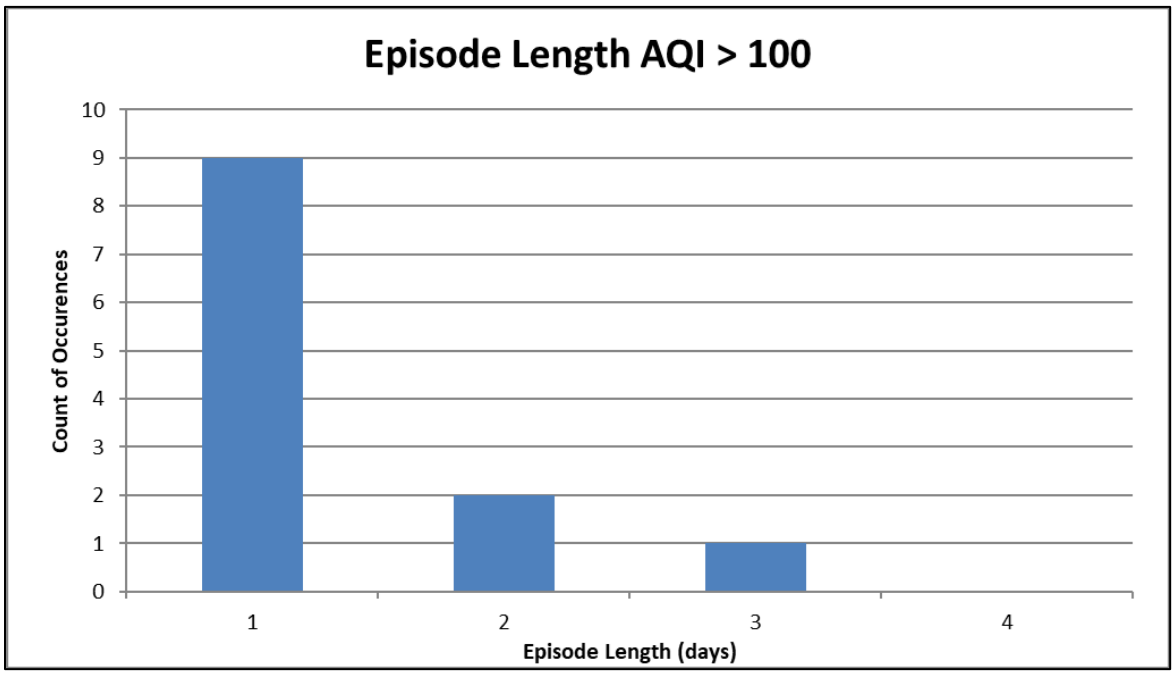

Figure 4. Count of occurrence for multi-day ozone AQI levels in the USG category or higher in Delaware, based on 2018-2022 data.

1.2 Climatology of $PM_{2.5}$

During the summer air quality forecasting season, long range transport of wildfire smoke can reach the state of Delaware. In these cases, daily forecasts for $PM_{2.5}$ are issued. To account for smoke events, and to give Sonoma Technology meteorologists perspective on potential $PM_{2.5}$ patterns, a monthly and seasonal $PM_{2.5}$ climatology was developed based on 2018-2022 observed $PM_{2.5}$ AQI data.

As shown by the historical $PM_{2.5}$ data, $PM_{2.5}$ AQI levels tend to be in the Good category on most days throughout the year (Figure 5). Based on the 5-yr period of $PM_{2.5}$ data obtained, Moderate-or-higher AQI is most frequent between November and February. This coincides with the time of year when temperatures are at their coolest, and temperature inversions that trap pollutants near the ground are more likely to occur than other months.

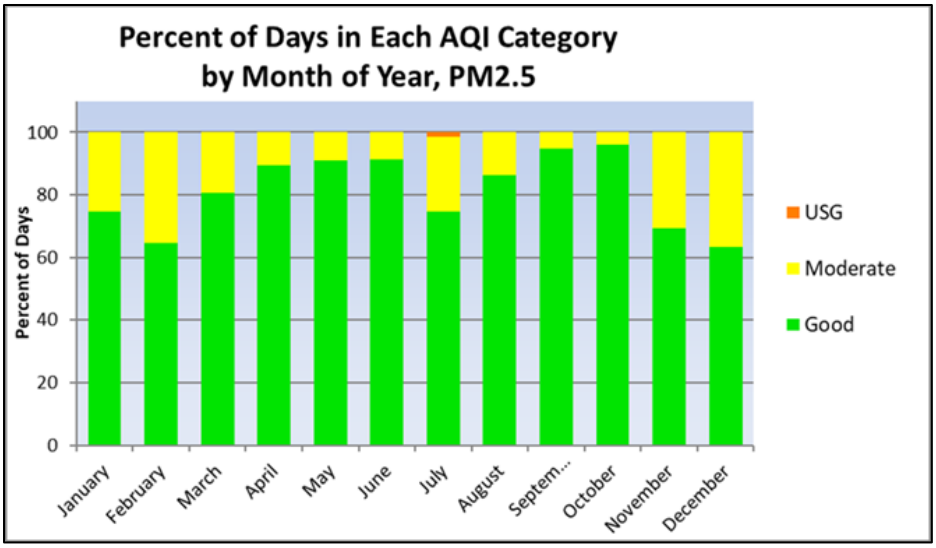

Figure 5. Monthly distribution of each AQI category based on 2018-2022 $PM_{2.5}$ data.

For the summer forecasting season, Moderate $PM_{2.5}$ AQI levels occurred on 12% of days, and USG $PM_{2.5}$ AQI levels were recorded on only 1% of days. July recorded the highest frequency of days with Moderate-or-higher AQI levels during the summer forecasting season, which occurred on 25% of July days between 2018-2022. Regarding daily $PM_{2.5}$ patterns, Wednesdays featured the highest count of Moderate or higher $PM_{2.5}$ days during the 2018-2022 period (**Figure 6**). The remainder of days throughout the week had a similar number of Moderate or higher $PM_{2.5}$ AQI levels.

USG $PM_{2.5}$ AQI levels occurred on only two days during the 2018-2022 period. These two days occurred consecutively on July 20-21, 2021 (**Figure 7**), when smoke from Canadian wildfires impacted the Mid-Atlantic region. Many summertime high-$PM_{2.5}$ events in recent years, especially during the month of July, were likely smoke-driven.

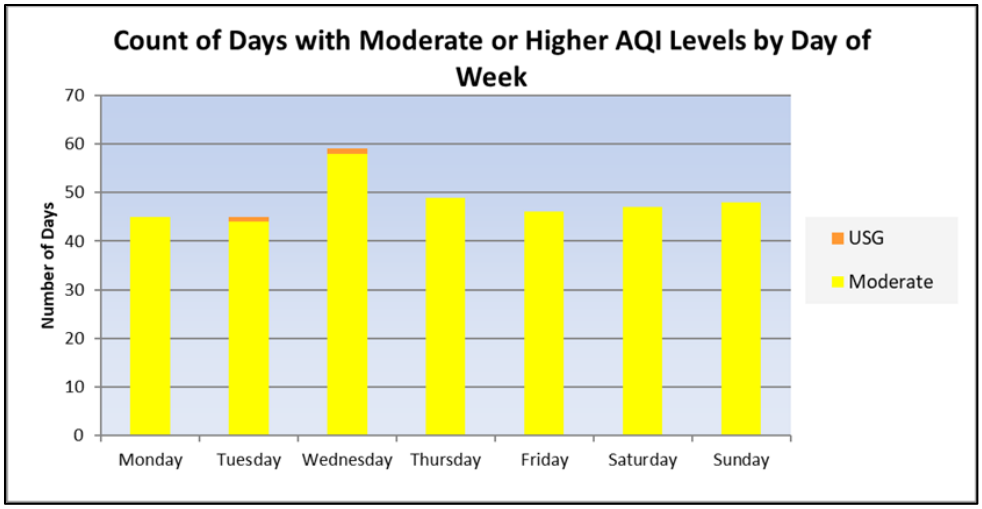

Figure 6. Number of Moderate-or-higher $PM_{2.5}$ AQI levels in Delaware by day of week based on 2018-2022 data.

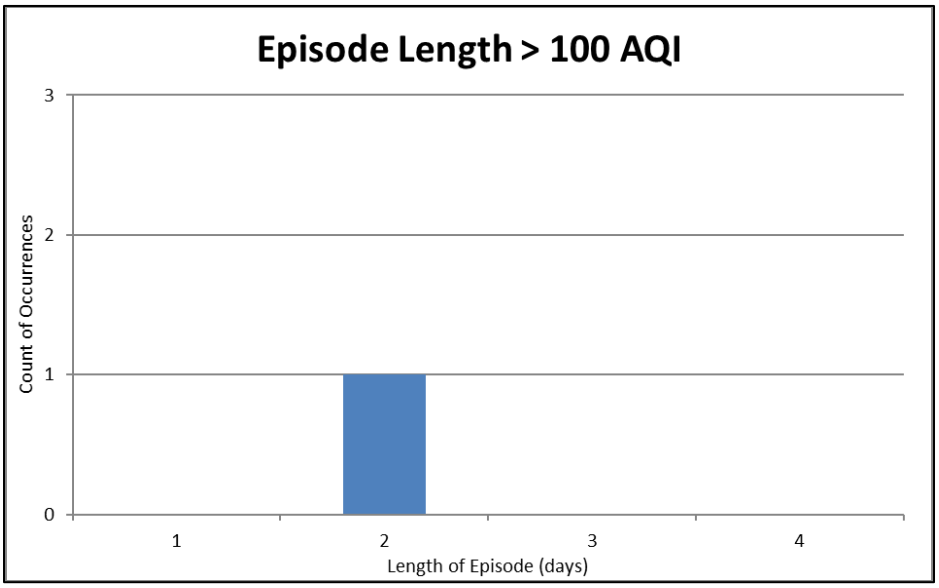

Figure 7. Count of occurrence for multi-day $PM_{2.5}$ AQI levels days in the USG category or higher in Delaware, based on 2018-2022 data.

2. Air Quality and Meteorological Observations in 2023

Weather plays a pivotal role in determining AQI levels in Delaware. On sunny and hot summer days, the prevailing weather conditions combine with regional and local emissions to enhance the production of ground-level ozone. Wind patterns and speeds can also dictate AQI values by either transporting smoke or other pollutants into the state, or by allowing pollutants to accumulate over time. On the other hand, days with cool, cloudy conditions tend to result in reduced ozone development, while strong winds can effectively disperse pollutants and lead to Good AQI levels.

The following section will provide a review of the meteorological conditions observed in Delaware during the 2023 summer air quality forecasting season, based on data from National Weather Service Automatic Surface Observation System (ASOS) climate sites. In addition, observed ozone and $PM_{2.5}$ AQI values from Delaware air quality monitoring sites will be summarized. This summary will include a comparison between AQI levels of this forecast season and previous ones, as well as an analysis of weather and pollutant transport impacts on Delaware's air quality throughout the 2023 summer forecast season.

2.1 May-September 2023 Meteorological Review

For the May-September 2023 period, the average temperatures around the Mid-Atlantic region were below-normal (**Figure 8**), while the state of Delaware recorded near-normal temperatures for the 5-month period. For the Wilmington ASOS site (KILG), the average temperature for the summer forecasting season was 0.4°F above normal, while the Georgetown ASOS site (KGED) recorded an average temperature that was nearly 1.0°F below normal.

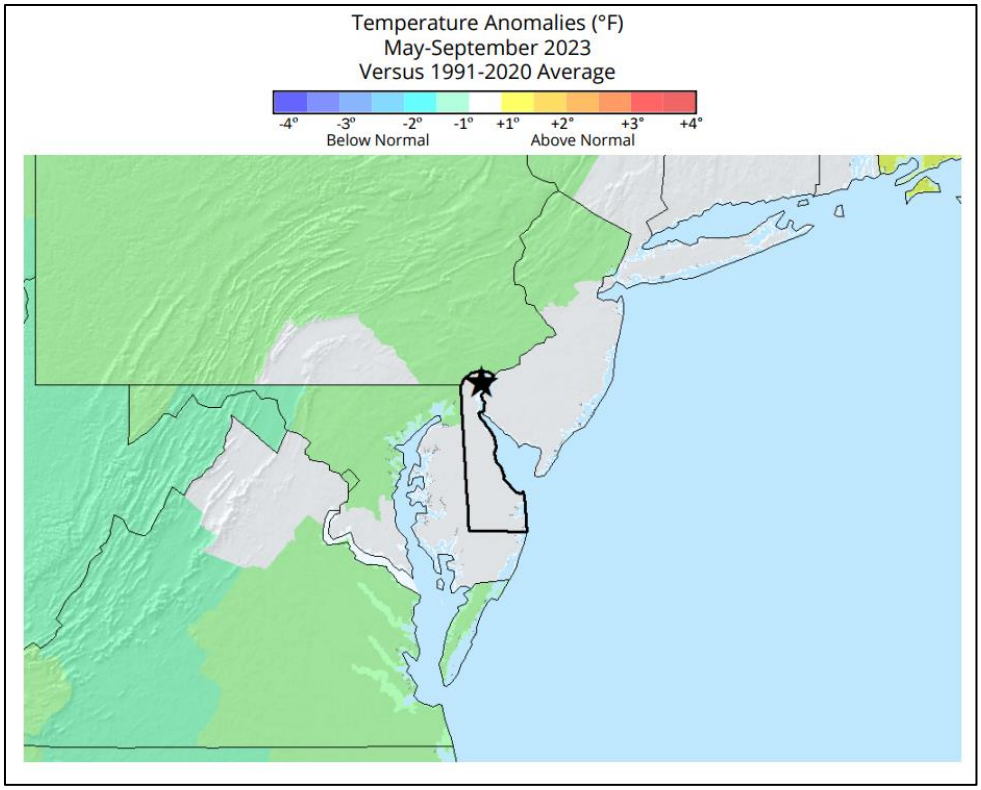

Figure 8. May-September 2023 average temperature anomaly map.

Based on average temperature values between 1991-2020, July is the climatological warmest month of the summer forecast season for both KILG and KGED. This remained true for the summer 2023, as both ASOS sites recorded their warmest average temperatures during the month of July. One reason why July was the warmest month of the 2023 summer forecast season was the frequency of maximum temperatures reaching or exceeding 90°F. In July 2023, KILG recorded 14 days of high temperatures at or above 90°F (Table 1), while KGED registered 12 days at or above 90°F (Table 2). For both ASOS sites, July 2023 had the highest occurrence of days at or above 90°F when compared to other months during the summer forecasting season.

Table 1. 2023 monthly meteorological summary for Wilmington-New Castle Airport (KILG).

Wilmington (KILG)	May	June	July	August	September
Average Temperature (°F)	62.7	71.3	80.0	76.8	69.4
Average Temperature Departure from Normal (°F)	-0.8	-1.3	+2.4	+1.0	+0.5
Total Precipitation (inches)	0.20	11.91	8.85	2.77	5.08
Precipitation Departure from Normal (inches)	-3.37	+7.24	+4.44	-1.21	+0.70
Number of Clear Days	23	13	18	16	17
Number of 90°F+ Days	0	2	14	7	6
Average Wind Speed (mph)	7.7	8.1	6.6	7.3	7.7
Average Wind Speed Departure from Normal (mph)	-0.6	+0.4	-0.6	+0.4	+0.2

Table 2. 2023 monthly meteorological summary for Georgetown (KGED).

Georgetown (KGED)	May	June	July	August	September
Average Temperature (°F)	62.5	72.1	78.7	75.8	70.6
Average Temperature Departure from Normal (°F)	-2.0	-1.5	+0.1	-0.9	+0.3
Total Precipitation (inches)	3.66	3.21	6.29	2.16	7.41
Precipitation Departure from Normal (inches)	+0.03	-0.86	+2.15	-1.83	+2.87
Number of Clear Days	16	14	22	16	17
Number of 90°F+ Days	0	3	12	6	6
Average Wind Speed (mph)	6.6	7.0	5.4	5.7	6.3
Average Wind Speed Departure from Normal (mph)	-0.8	+0.5	-0.7	+0.3	+0.2

Cumulative rainfall totals for May-September 2023 varied across the Mid-Atlantic region. Rainfall was below average across portions of Maryland and Virginia (Figure 9). Conversely, rainfall totals for the Tri-State area of New York, New Jersey, and Connecticut were well above normal. However, the state of Delaware recorded near-normal precipitation over the 5-month period.

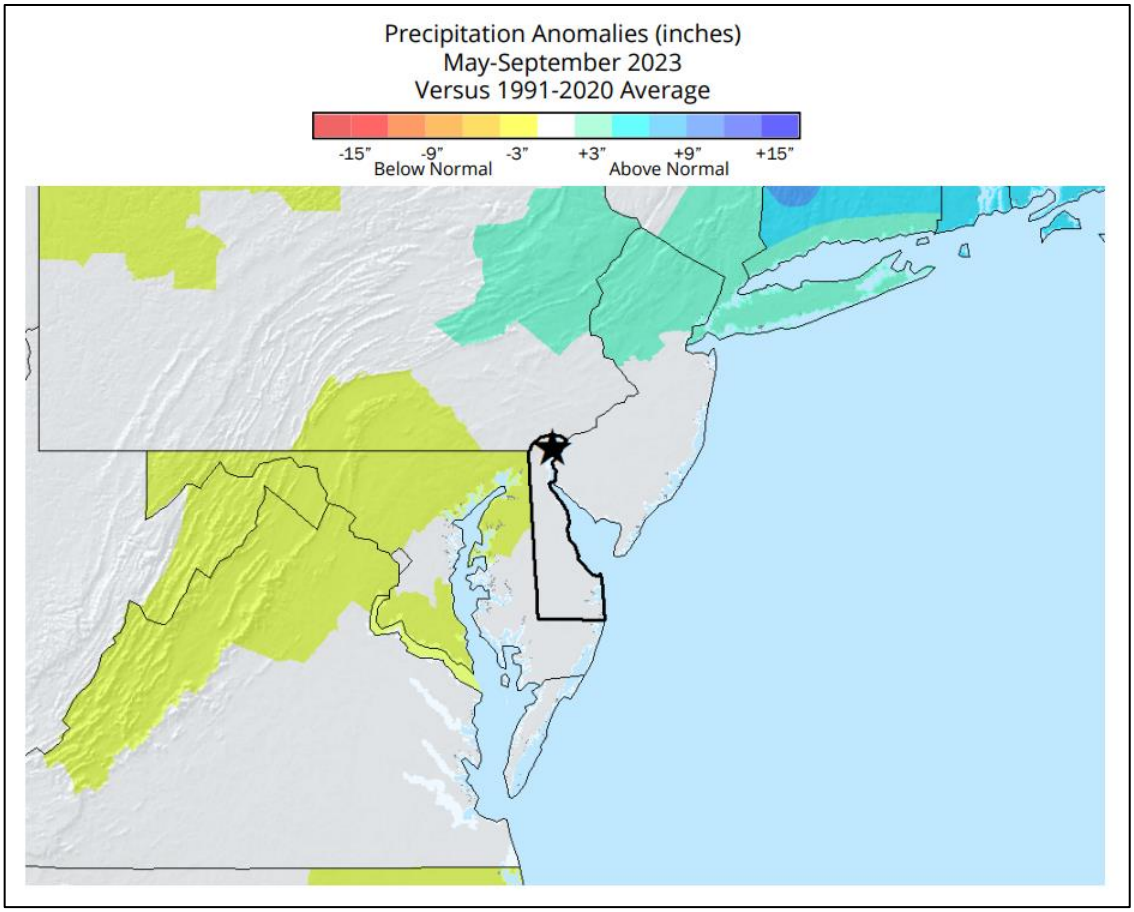

Figure 9. May-September 2023 precipitation anomaly map.

Seasonal rain totals for Delaware's individual climate ASOS sites between May and September were different when compared to the state-averaged total shown in Figure 9. At KILG, 28.81 inches of precipitation was measured during the 5-month period, which was nearly 8 inches above the May-September normal for that site. June was the wettest month of the summer forecasting season for KILG, with 11.91 inches of precipitation recorded. This total was the third highest ever recorded for June at KILG, with records dating back to 1894. June 2023 alone accounted for over 40% of the May-September 2023 rainfall total at KILG.

For the KGED ASOS site, 22.73 inches of rainfall was measured for the summer forecasting season, which was also above normal. Based on 1991-2020 climate data, September is considered the wettest month of the May-September period. This September was no different, as the 7.41 inches of rainfall measured during the month ended up being KGED's wettest month of the summer forecast season. Based on records going back to 1945, September 2023 was KGED's sixth wettest September on record.

2.2 Summer 2023 Daily Maximum AQI Observations

The summer air quality forecast season for the State of Delaware consists of 153 total days. Based on data from the ozone and $PM_{2.5}$ monitoring sites shown in Figure 1, daily maximum AQI levels for the May-September 2023 period were Good on 66 days, Moderate on 76 days, USG on 7 days, Unhealthy on 2 days, and Very Unhealthy on 2 days.

Figure 10 provides a time series of observed maximum AQI values during the 2023 summer forecast season, and Figure 11 shows the percentage of days for each AQI category. In all, 57% of the 2023 summer forecast days featured Moderate-or-higher AQI levels. Of the 87 days with Moderate-or-higher AQI levels during the 2023 summer forecast season, $PM_{2.5}$ was the primary pollutant 54 times, while ozone was the primary pollutant 33 times.

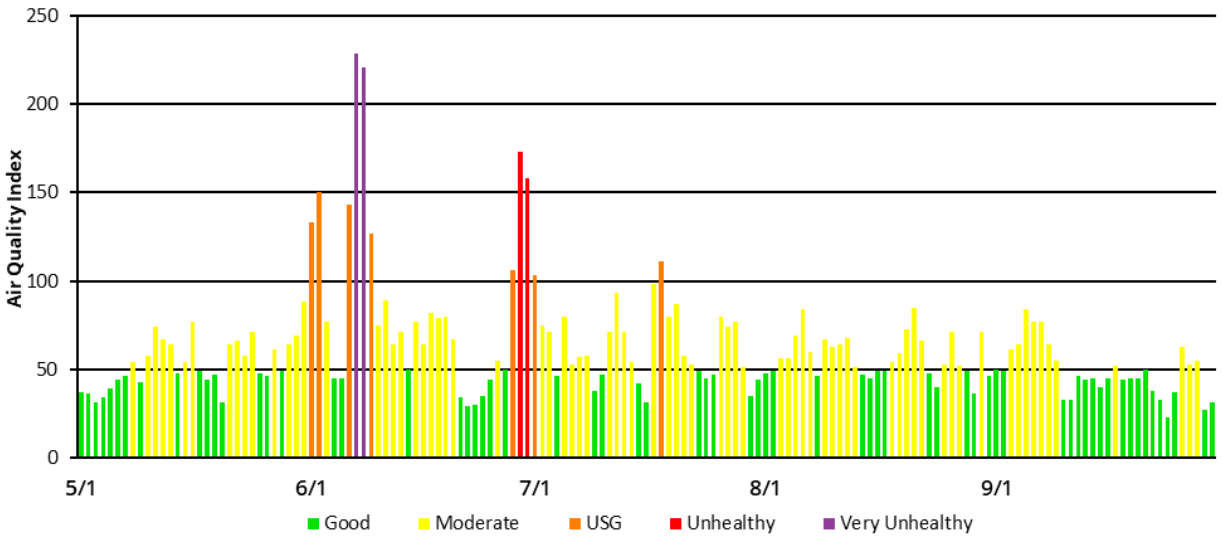

Figure 10. Delaware daily maximum observed AQI values observed during the summer 2023 forecast season.

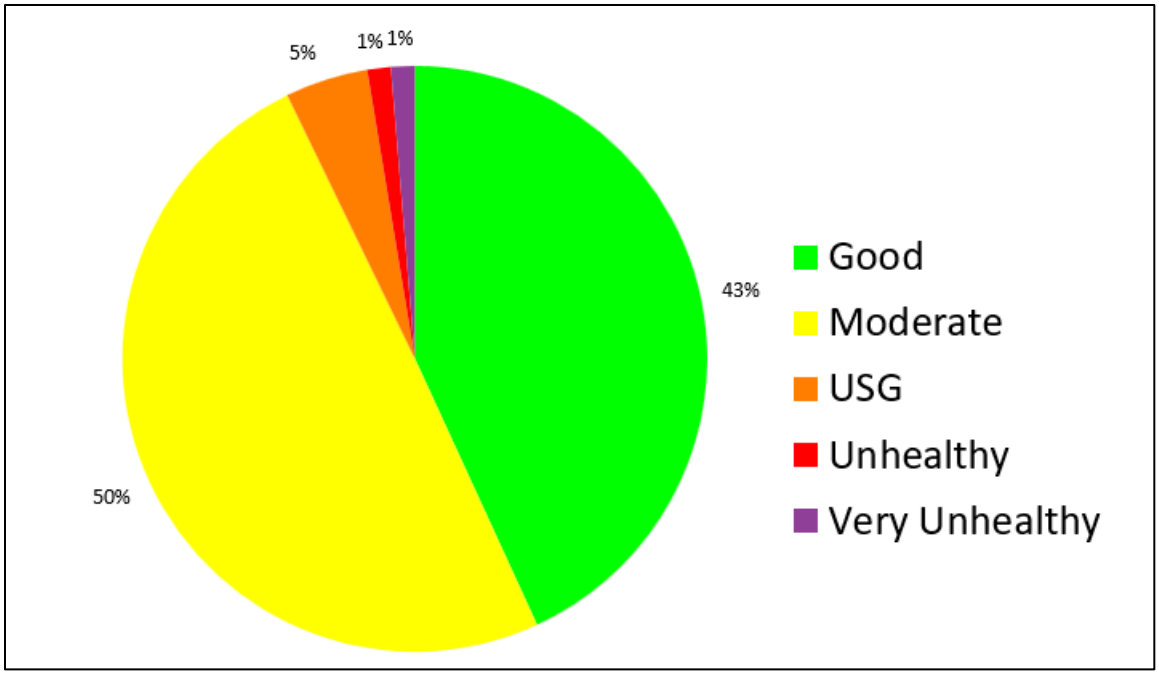

Figure 11. Percent of days with daily maximum AQI levels in each category during the summer 2023 forecast season in Delaware.

Table 3 displays the monthly breakdown of daily maximum AQI values for the state of Delaware. June and July each featured 21 days with Moderate-or-higher AQI levels, which were more than other months during the 2023 summer forecasting season. During June 2023, $PM_{2.5}$ was the primary pollutant on 16 days, compared to 5 days when ozone was the primary pollutant. Of the 9 June days when the AQI level exceeded the NAAQS, $PM_{2.5}$ was the primary pollutant 8 times.

Table 3. Percent of days with daily maximum AQI levels by month during the summer 2023 forecast season in Delaware

Month	Good	Moderate	USG	Unhealthy	Very Unhealthy
May	16	15	0	0	0
June	9	12	5	2	2
July	10	19	2	0	0
August	12	19	0	0	0
September	19	11	0	0	0

In July, on days with Moderate or higher AQI levels, ground level ozone was the primary pollutant on 12 occasions, while $PM_{2.5}$ was the primary pollutant 8 times. $PM_{2.5}$ was the primary pollutant on the 2 July days when AQI values exceeded the NAAQS.

2.3 Summer 2023 Daily Ozone AQI Observations

Ground-level ozone observations across the state of Delaware were in the Good AQI category on 63% of days from May-September 2023 (Figure 12). Moderate AQI levels were recorded 35% of the time, while USG AQI levels occurred on 2% of days. Compared to the 2018-2022 ozone climatology, the 2023 summer forecast season saw a 6% increase in days with Moderate-or-higher ozone AQI levels. Most months from May-September 2023 recorded a greater frequency of Moderate-or-higher ozone AQI levels when compared to historical climatology. The lone exception was August, when Moderate-or-higher ozone AQI levels were 5% lower than the 2018-2022 climatology.

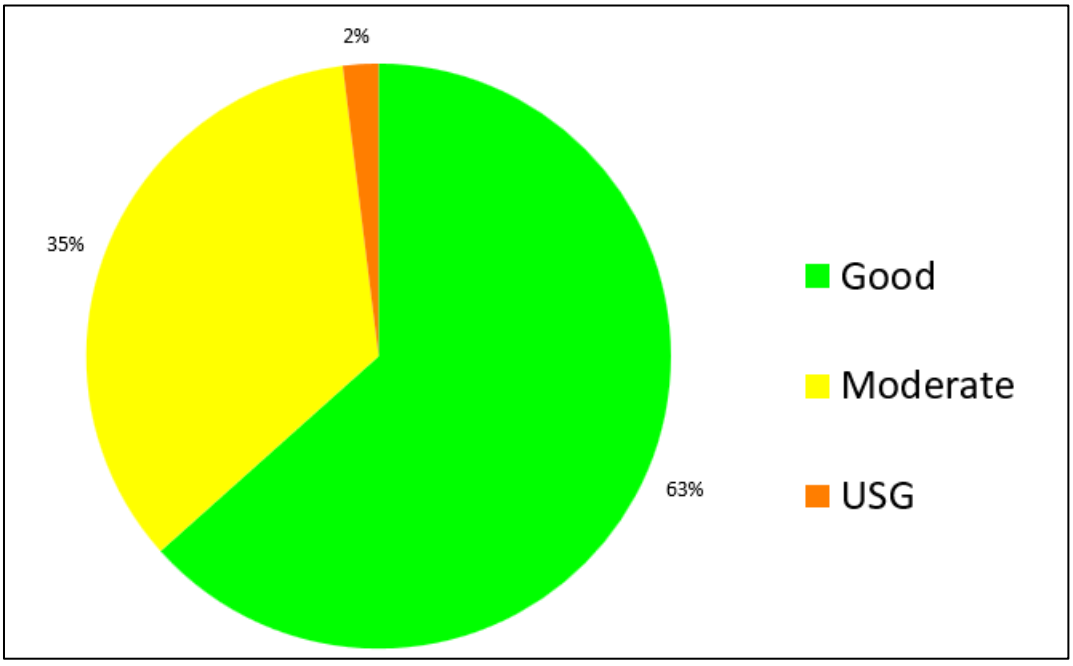

Figure 12. Percent of days with daily maximum AQI levels in each AQI category for the Delaware 2023 summer forecast season.

Figure 13 shows a site-by-site comparison of ozone AQI values for the 2023 summer forecast season, and Table 4 includes a percentage breakdown of AQI categories by each ozone monitoring site. Six of the seven ozone monitoring sites recorded at least one USG ozone day between May and September 2023. The MLK monitoring site registered 46 days with Moderate-or-higher ozone AQI levels over the 5-month period, which was the most of any ozone monitoring site across the state. One factor influencing ozone AQI levels at the MLK site is the proximity to industrial and vehicle

emissions, which lead to higher ozone precursors and enhance subsequent ozone production. Conversely, the Lewes monitoring site did not record a single day with USG ozone AQI levels during the summer 2023 forecasting season, as its close proximity to the Atlantic Ocean leads to cooler temperatures, stronger winds, and better air quality compared to other ozone sites.

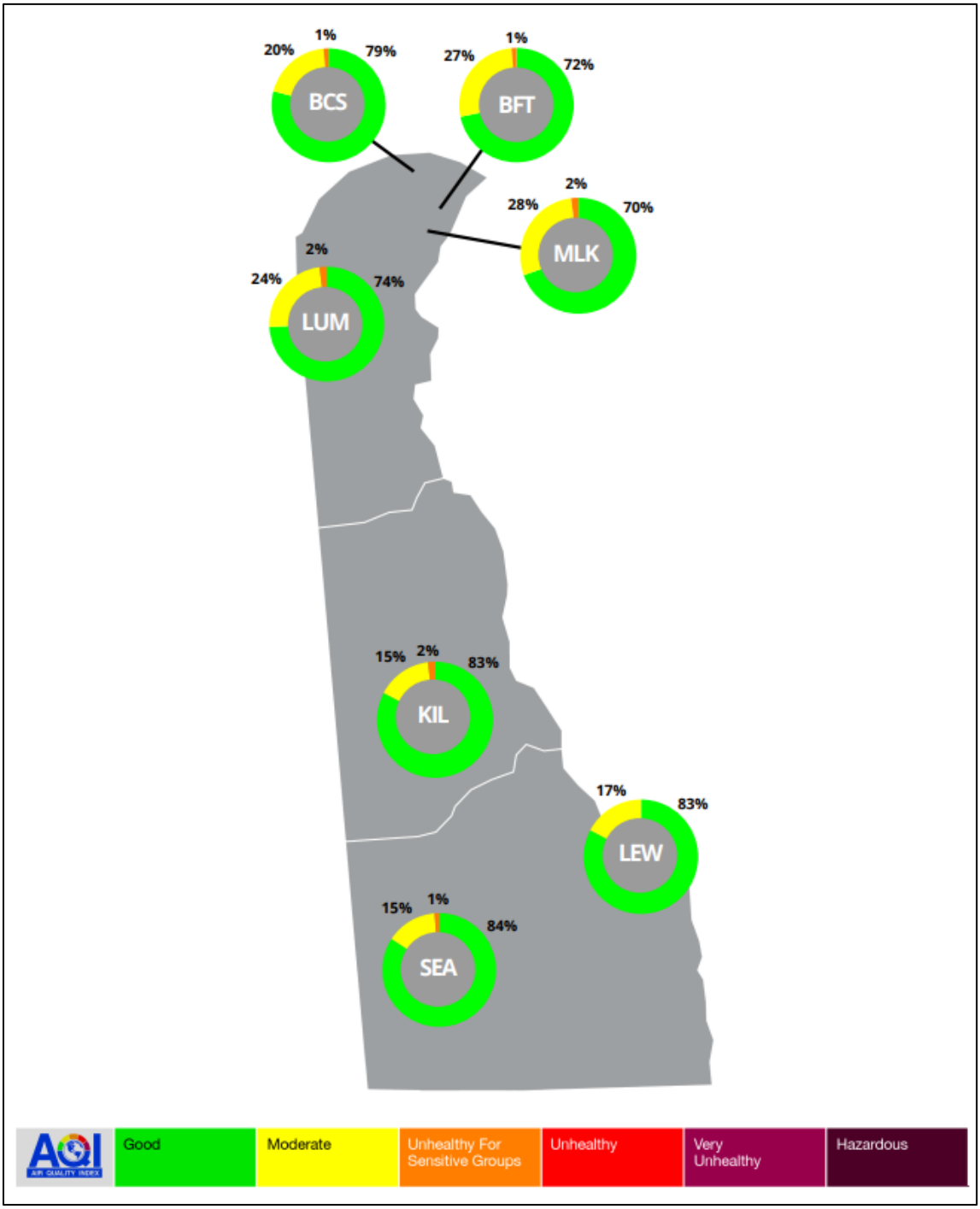

Figure 13. Daily maximum ozone AQI level percentage of days in each AQI category during the 2023 summer forecast season

Table 4. Percent of days at each AQI category for ozone by site for summer 2023. Station abbreviations from Figure 13 are in parentheses.

Monitoring Site	Good	Moderate	USG
MLK Boulevard (MLK)	70%	28%	2%
Bellevue State Park (BFT)	72%	27%	1%
BCSP (BCS)	79%	20%	1%
Lums (LUM)	74%	24%	2%
Killens (KIL)	83%	15%	2%
Seaford (SEA)	84%	15%	1%
Lewes (LEW)	83%	17%	0%

In all, 56 days with Moderate-or-higher ozone AQI levels occurred from May-September 2023. This marks the most days with Moderate-or-higher ozone AQI levels in Delaware during the May—September season since 2019. All three Delaware counties registered an increase in days with USG-or-higher ozone AQI levels in 2023 (Figure 14). Both New Castle and Sussex Counties recorded the highest number of USG ozone days since 2018. In Kent County, the three days with USG ozone AQI levels in 2023 were the most registered in the county since 2012. Despite the increase in frequency of high-ozone days compared to recent years, all three sites still maintained an overall downward trend in the number of days with ozone above the NAAQS over the past 24 years.

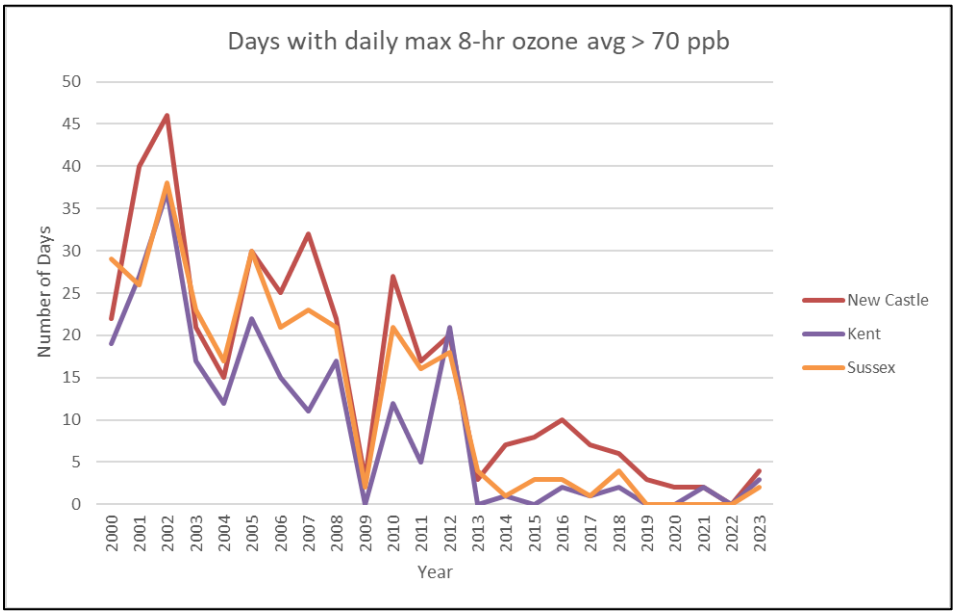

Figure 14. Year-to-year frequency of ozone exceedances between May and September by county. Source: U.S. EPA Air (https://www.epa.gov/outdoor-air-quality-data)

2.4 Summer 2023 Daily $PM_{2.5}$ AQI Observations

During the May-September 2023 period, daily $PM_{2.5}$ AQI levels across Delaware (Figure 15) were in the Good category 53% of the time. AQI levels were in the Moderate category on 43% of days, the USG category on 4% of days, the Unhealthy category on 1% of days, and the Very Unhealthy category on 1% of days.

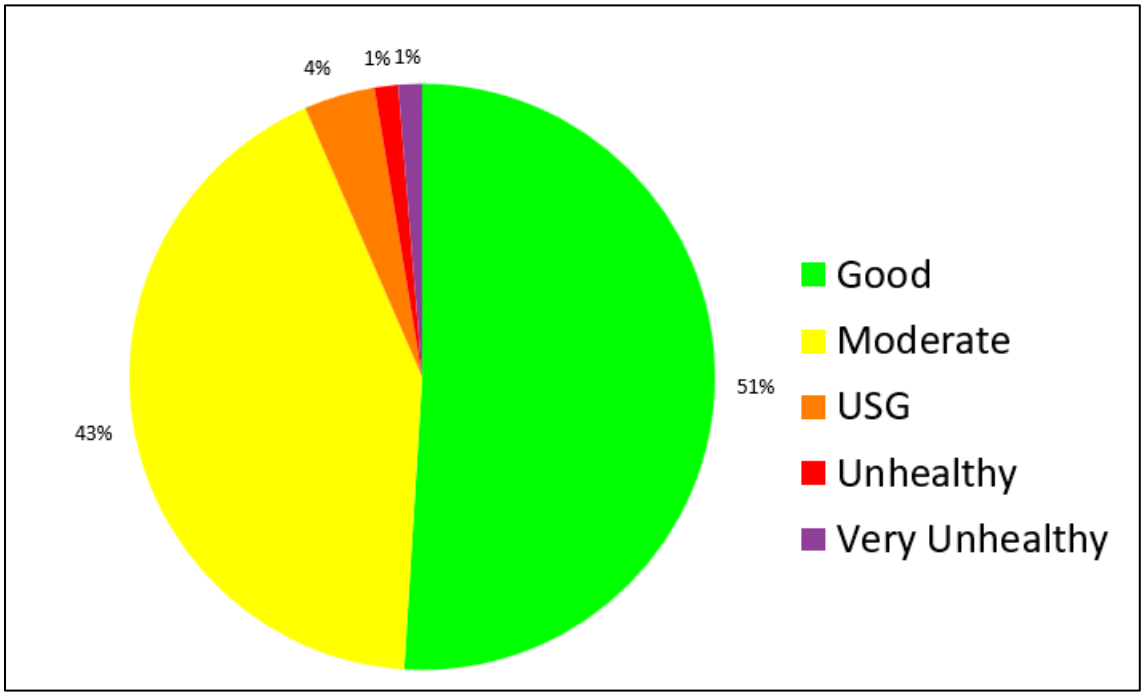

Figure 15. Percent of days with daily maximum AQI levels in each AQI category for the Delaware 2023 summer forecast season.

Figure 16 provides a site-by-site comparison of $PM_{2.5}$ AQI values in the First State, and Table 5 includes a percentage breakdown of AQI categories by each $PM_{2.5}$ monitoring site. All eight $PM_{2.5}$ monitoring sites in Delaware recorded USG and Unhealthy AQI levels during the May-September 2023 period. Moderate-or-higher $PM_{2.5}$ AQI levels occurred 74 times at the Newark monitoring site, which is the most of any $PM_{2.5}$ monitor during the summer 2023 forecast season. Of the 74 Moderate-or-higher AQI level occurrences at the Newark site, the NAAQS was exceeded 8 times. $PM_{2.5}$ AQI values reached the USG category on 4 occasions, while 2 instances of Unhealthy AQI levels and 2 instances of Very Unhealthy AQI levels were observed.

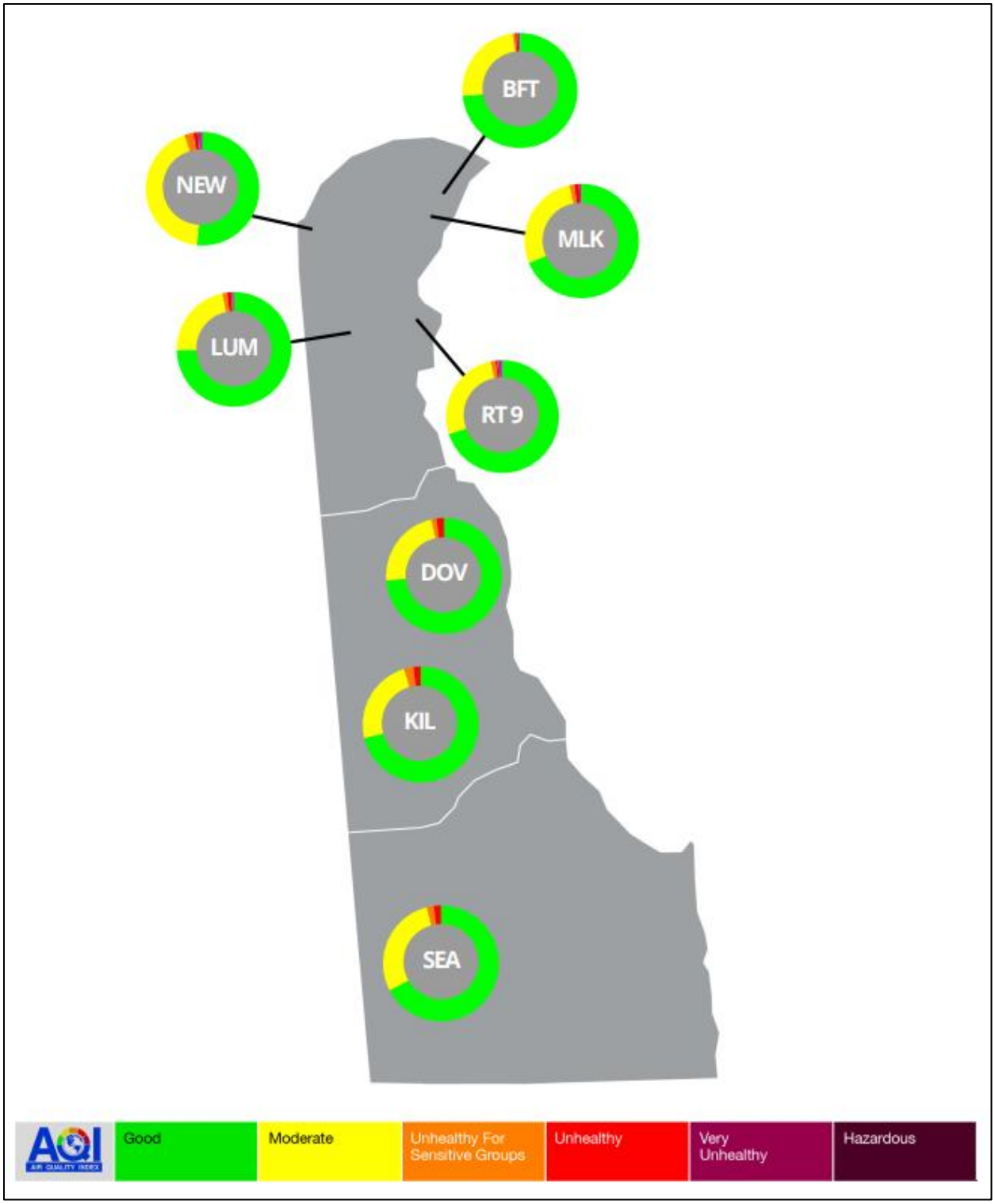

Figure 16. Daily maximum $PM_{2.5}$ AQI level percentage of days by site in each AQI category during the 2023 summer forecast season.

Table 5. Percent of days with daily maximum AQI levels in each category for $PM_{2.5}$ by site for summer 2023. Station abbreviations from Figure 16 are in parentheses.

Monitoring Site	Good	Moderate	USG	Unhealthy	Very Unhealthy
MLK Boulevard (MLK)	69%	28%	1%	1%	1%
Bellevue State Park (BFT)	73%	24%	1%	1%	1%
Delaware City (RT 9)	70%	27%	1%	1%	1%
Lums (LUM)	75%	22%	1%	1%	1%
Killens (KIL)	71%	24%	3%	2%	0%
Seaford (SEA)	67%	29%	2%	2%	0%
Dover (DOV)	74%	23%	1%	2%	0%
Newark (NEW)	52%	43%	3%	1%	1%

Based on the 2018-2022 air quality climatology, $PM_{2.5}$ AQI values in Delaware from May-September were Moderate or higher on just 10% of days. However, $PM_{2.5}$ AQI values during the summer 2023 forecast season were Moderate or higher on 49% of days. Combined with a greater occurrence of Moderate-or-higher ozone AQI discussed in Section 2.3, the observed air quality data suggests a potential impact from exceptional events on Delaware's air quality in 2023. The following section will discuss how the presence of long-range wildfire smoke transport impacted air quality in the First State during the summer 2023 forecast season.

2.5 Smoke Impacts on Delaware Air Quality during Summer 2023

Air quality across the contiguous United States (CONUS) was greatly diminished during summer 2023. The main influence on high AQI levels throughout central and eastern CONUS was smoke transport from numerous wildfires in Canada. Wildfires emit a variety of pollutants, including $PM_{2.5}$ and volatile organic compounds (VOCs). These pollutants not only increase $PM_{2.5}$ levels but can also interact with ozone chemistry and increase ozone production.

By acreage, the 2023 wildfire season in Canada was the worst ever recorded. With records dating back to 1982, the 2023 Canadian wildfire season saw 45.7 million acres of land burned, which broke the old record of 17.5 million acres burned in 1995. On average, 6.1 million acres of land burns annually in Canada.

Lightning or human-caused fires were most prevalent in the Canadian province of Quebec (Table 6), where 12.8 million acres burned during the late spring and summer months. According to the

National Aeronautics and Space Administration (NASA), nearly 400,000 acres in Quebec were burned by early June, outpacing the historical average of 610 acres for the first half of the year.

Table 6. Total hectares and acres burned during the 2023 Canadian wildfire season. Courtesy: Canadian Wildland Fire Information System

Province	2023 hectares burned	2023 acres burned	10-year average hectares	10-year average acres
QC	5,197,044	12,842,156	222,157	548,961
NT	4,163,426	10,288,034	662,888	1,638,029
YT	223,942	553,372	144,227	356,392
BC	2,830,808	6,995,068	432,013	1,067,526
SK	1,851,644	4,575,505	460,955	1,139,043
AB	2,624,083	6,484,240	234,039	578,322
Total	**16,890,947**	**41,738,375**	**2,156,279**	**5,328,273**

The Canadian fire season started early and continued late into the traditional season. Several million acres of land also burned in British Columbia, Alberta, Yukon, and the Northwest Territories, with many of these fires burning into early October (Figure 17).

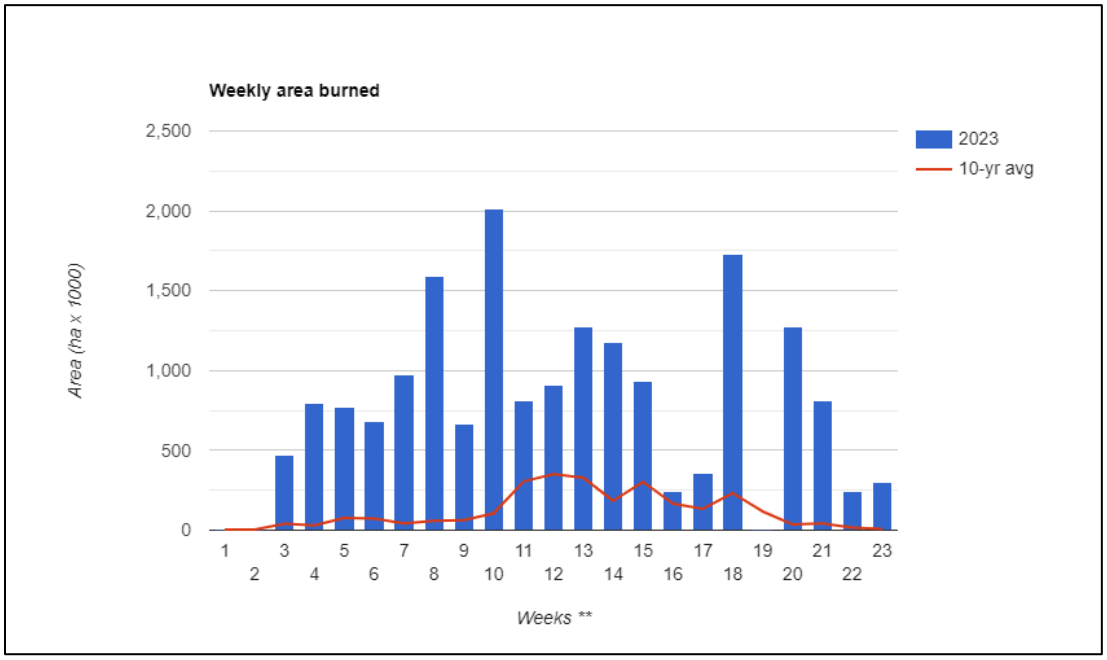

Figure 17. Weekly count of hectares (ha) burned during the 2023 Canadian fire season, with week one beginning April 26, 2023. Courtesy: Canadian Wildland Fire Information System

2.5.1 Prevailing Weather Conditions during the 2023 Canadian Wildfire Season

Throughout 2023, warm and dry conditions enhanced wildfire potential and growth across Canada. From April to June 2023, upper-level high pressure was persistent over western and central Canada. Observed 500-mb height anomalies were positive for a large portion of Canada, which indicated stronger-than-normal high pressure aloft (Figure 18). Due to strong high pressure in the upper levels of the atmosphere and the subsequent sinking and warming air aloft, mixing was reduced in the lower atmosphere.

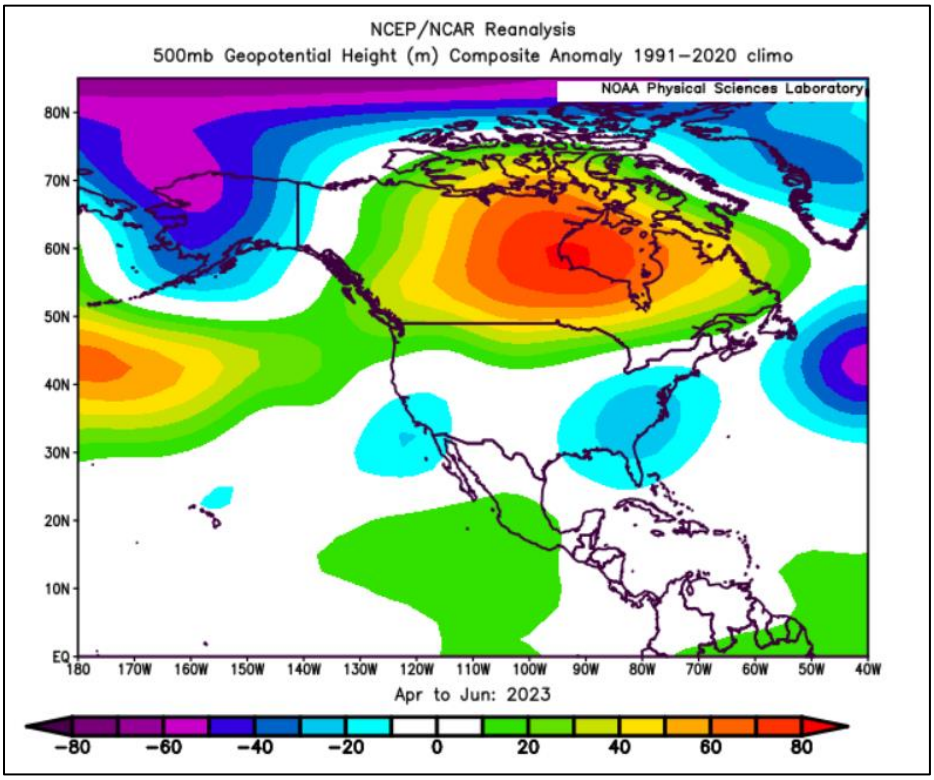

Figure 18. 500-mb height anomaly map for April-June 2023. Courtesy: the National Oceanic and Atmospheric Administration (NOAA).

As mixing decreased and sinking air hindered development of clouds and precipitation, warmer surface temperatures were recorded across the western and central portion of Canada. In addition, drought conditions worsened during this 3-month stretch. By June, abnormally dry to moderate drought conditions developed around Hudson Bay, while severe to extreme drought conditions were present in portions of British Columbia and Alberta (Figure 19).

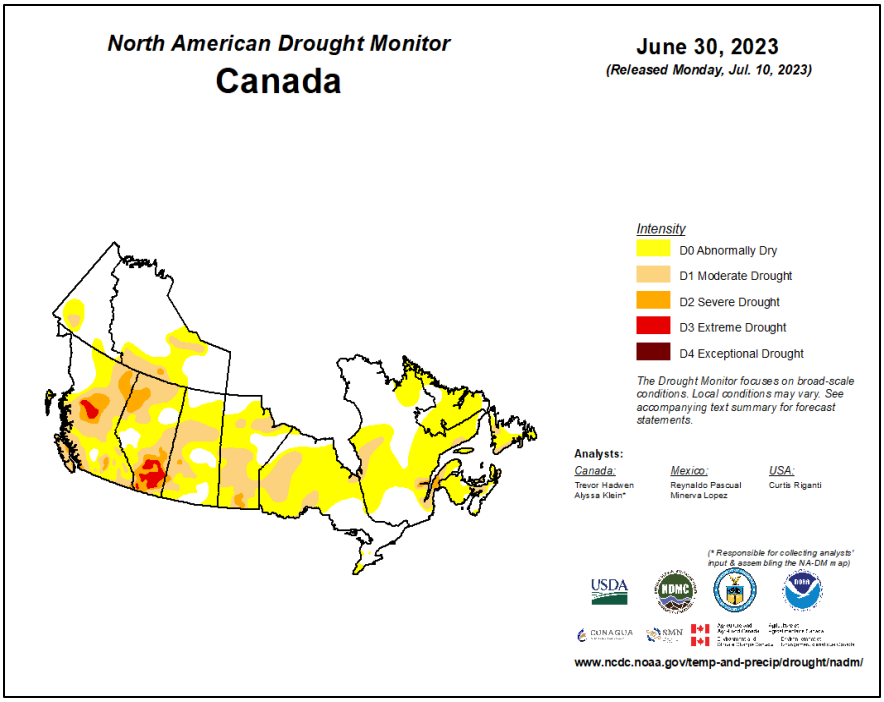

Figure 19. North American Drought Monitor for June 2023. Courtesy: https://droughtmonitor.unl.edu/NADM/

Between July and September, 500-mb height anomalies remained positive over much of Canada, as a ridge of upper-level high pressure was the dominant weather pattern over the western portion of the country (Figure 20). Upper-level ridging produces warmer, drier conditions at the surface, which are conducive to fire growth. Accordingly, the position of the upper-level ridge of high pressure coincided with the location of most Canadian wildfires during the second half of summer, with numerous fires detected by satellites in British Columbia, Alberta, Yukon, and the Northwest Territories.

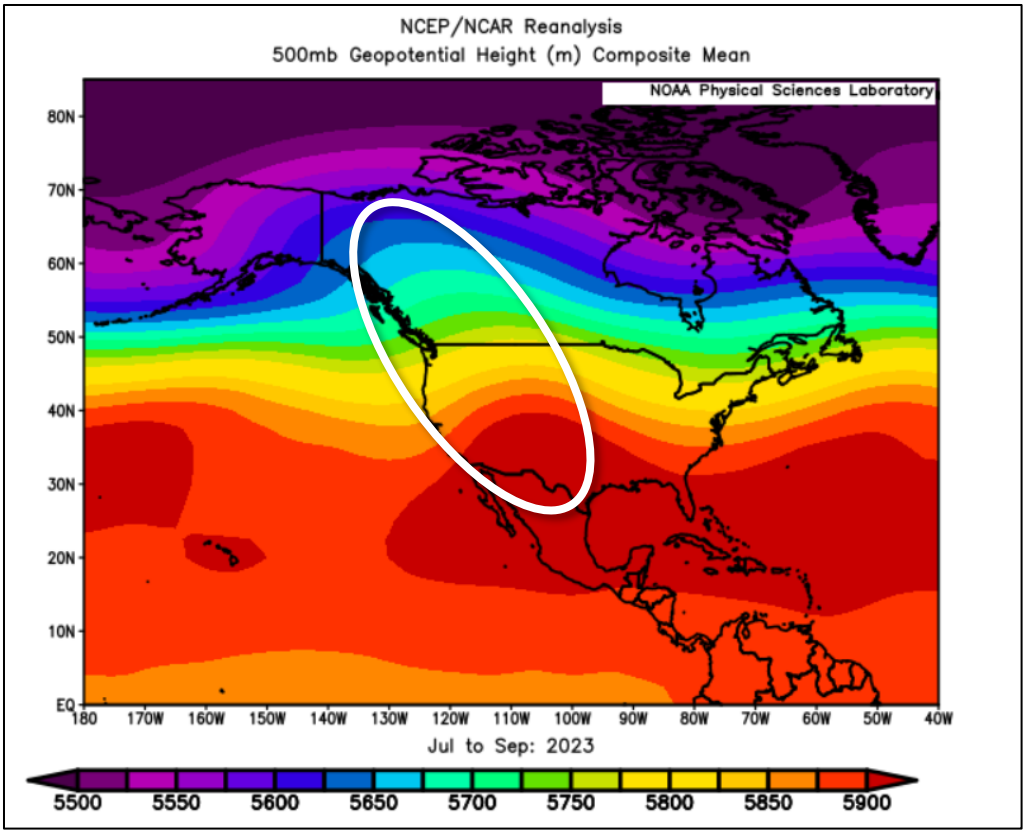

Figure 20. Mean 500-mb heights for July-September 2023. Circled is an upper-level ridge of high pressure over western Canada, which led to warm, dry conditions and high fire danger. Courtesy: NOAA

Along with persistent upper-level ridging, abnormally warm temperatures continued during this 3-month period. These conditions led to worsening drought conditions in portions of western Canada. By August, moderate-to-extreme drought conditions were recorded in Yukon and the Northwest Territories (Figure 21), while exceptional drought conditions developed in southern Alberta. These drought conditions continued into September. The combination of persistent drought, along with warm and dry weather, resulted in long-duration, large wildfires that produced high levels of smoke.

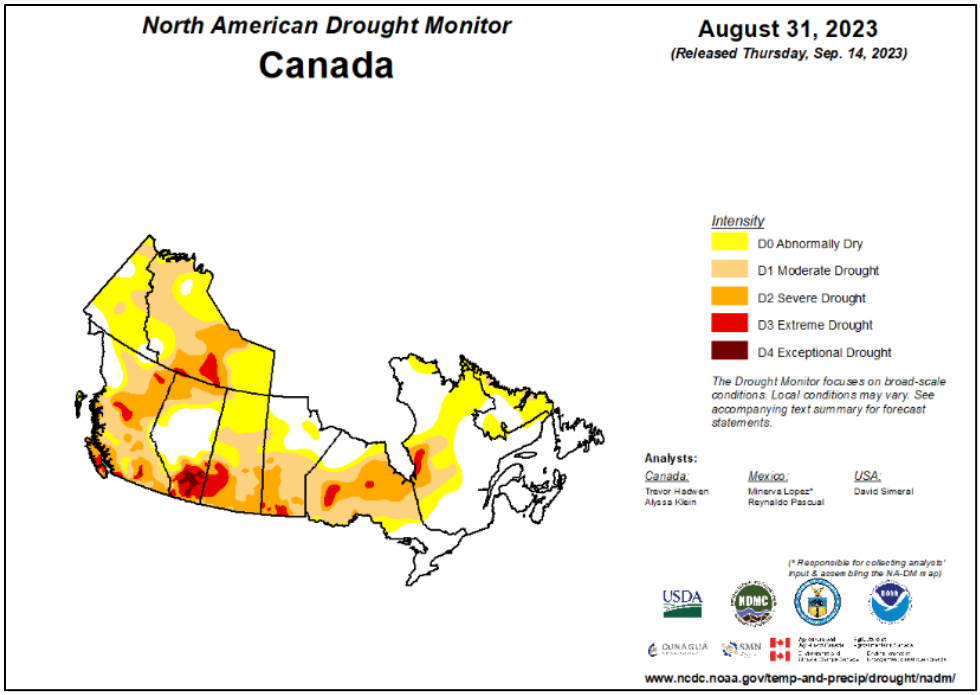

Figure 21. North American Drought Monitor for August 2023. Courtesy: https://droughtmonitor.unl.edu/NADM/

To capture the magnitude of smoke generated from these fires, Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data were analyzed. The MODIS aerosol optical depth (AOD) product can measure the density of particles, including smoke, within the atmosphere. Based on MODIS-Aqua data going back to 2002, summer 2023 featured 3 of the 5 highest monthly average AOD readings on record for Canada (Table 7), including the new all-time record monthly average AOD reading set in July 2023. All monthly average AOD readings between April and September 2023 were above the 2002-2022 average AOD (Table 8). These anomalously high AOD readings throughout the 2023 summer indicated the persistent presence of dense smoke over Canada.

Table 7. Ten highest MODIS-Aqua monthly average AOD values for Canada. Courtesy: **https://giovanni.gsfc.nasa.gov/**

Rank	Period	Mean AOD
1	July 2023	0.618
2	July 2004	0.517
3	June 2023	0.439
4	August 2023	0.421
5	August 2018	0.420
6	July 2021	0.390
7	May 2023	0.360
8	July 2014	0.355
9	August 2017	0.330
10	July 2015	0.317

Table 8. MODIS-Aqua monthly average AOD for Canada. Courtesy: **https://giovanni.gsfc.nasa.gov/**

Month	2002-2022 Mean AOD	2023 Mean AOD	2023 Departure from 2002-2022 Mean
April	0.182	0.224	+0.042
May	0.175	0.360	+0.185
June	0.202	0.439	+0.237
July	0.231	0.618	+0.387
August	0.187	0.421	+0.234
September	0.094	0.289	+0.195

2.5.2 June-August 2023 Weather Pattern Influence on Delaware Air Quality

Based on observed air quality data in Delaware, the worst smoke impacts from Canadian wildfires occurred between June and August. According to the 2018-2022 $PM_{2.5}$ climatology in Figure 5, Moderate-or-higher $PM_{2.5}$ AQI levels occurred on 9% of June days, 25% of July days, and 14% of August days. For 2023, however, Moderate-or-higher $PM_{2.5}$ AQI levels were recorded on 63% of June days, 55% of July days, and 58% of August days. Out of the 54 days during summer 2023 where $PM_{2.5}$ was the primary pollutant, 41 days occurred in the June-August period.

Ozone production was also impacted by persistent smoke. In the June-August 2023 period, ground-level ozone was the primary pollutant on 19 days with Moderate-or-higher AQI levels in Delaware. Based on NOAA smoke plume analysis, smoke was present over Delaware on all but 1 of the 19 days.

Weather conditions during the June-August period varied. The 500-mb mean height analysis for June 2023 (Figure 22) depicted an upper-level high pressure ridge over southern Canada and the central United States, with an upper-level trough of low pressure over eastern Canada and the northeastern United States. While this pattern led to cooler- and wetter-than-normal conditions in Delaware, it also resulted in persistent northerly winds aloft and enhanced vertical mixing. These winds carried dense smoke from fires in Quebec into the Mid-Atlantic region, and the increased mixing in the lower levels of the atmosphere allowed aloft smoke to reach the surface.

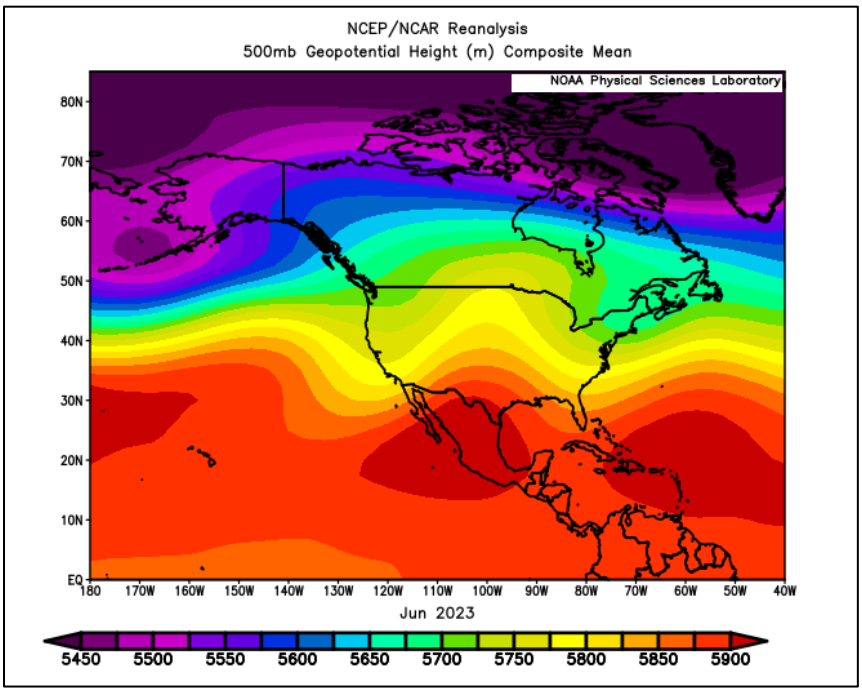

Figure 22. 500-mb mean heights in June 2023. Courtesy: NOAA

By July 2023, mean 500-mb heights showed an upper-level trough of low pressure from Hudson Bay to the southeastern United States (Figure 23), while an upper-level high pressure ridge was present across western Canada. This pattern led to westerly to northwesterly winds aloft, yielding smoke transport from fires in western Canada into the United States.

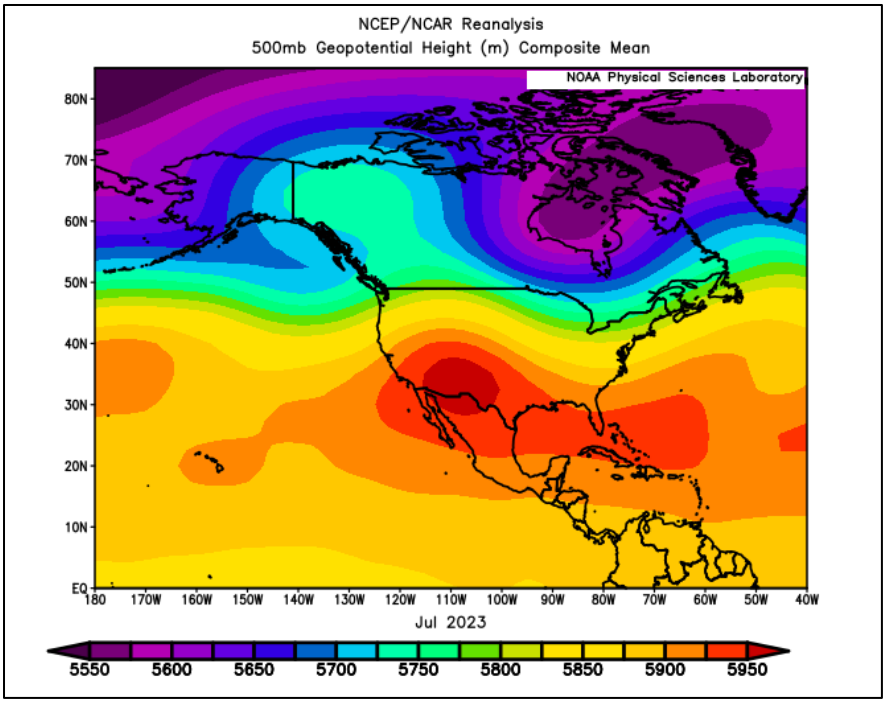

Figure 23. Mean 500-mb heights in July 2023. Courtesy: NOAA

As shown in Tables 1 and 2, surface temperatures in Delaware during July 2023 were warmer-than-normal, with a high frequency of days when the maximum high temperature was 90°F or higher. This surface heating promoted atmospheric mixing, which transferred aloft smoke to the surface. Once smoke reached ground level, lighter-than-normal surface winds during July 2023 (**Figure 24**) allowed smoke to accumulate, leading to high day-to-day pollutant carryover.

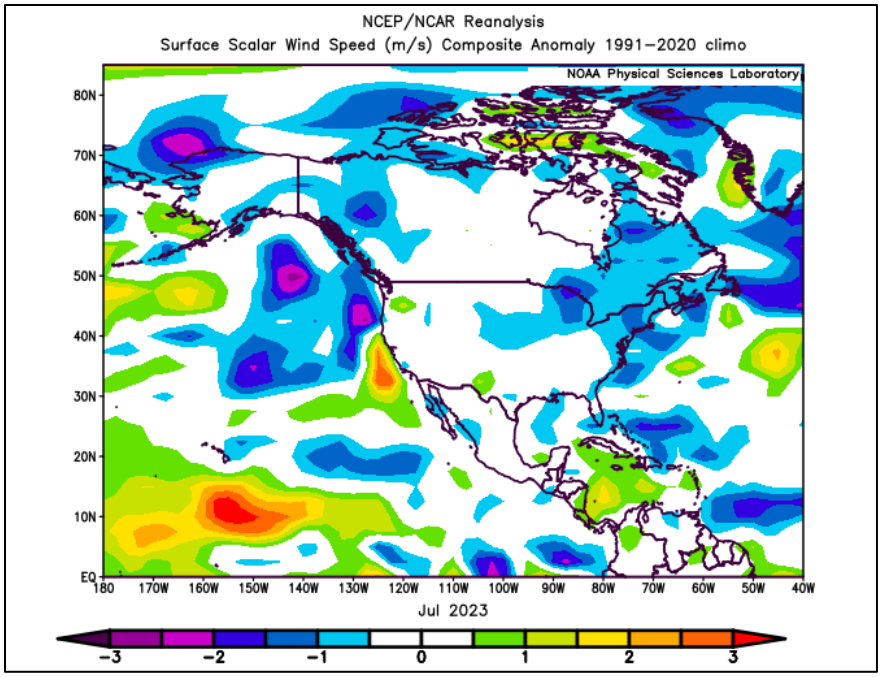

Figure 24. Surface scalar wind speed anomaly map for July 2023. Blue colors signify lighter than normal winds. Courtesy: NOAA

The mean 500-mb pattern in August 2023 (Figure 25) was similar to the previous month, with an upper-level ridge of high pressure remaining over western Canada. Meanwhile, a trough of upper-level low pressure was present from eastern Canada to the Mid-Atlantic coast. Due to this pattern, aloft winds remained westerly to northwesterly in the First State, maintaining transport of smoke from western Canadian fires into the region.

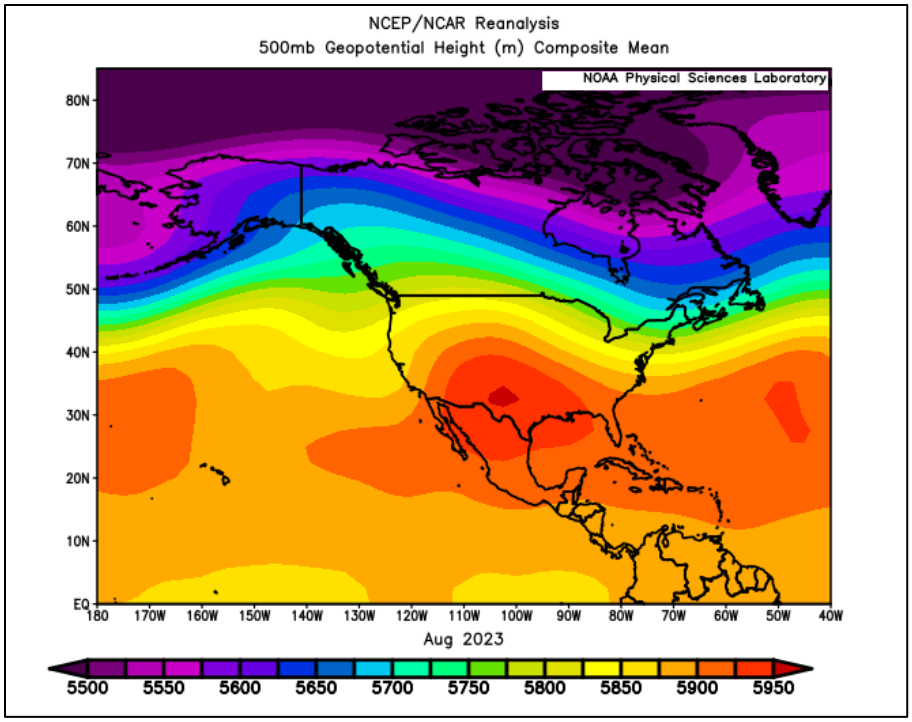

Figure 25. Mean-500 mb heights in August 2023. Courtesy: NOAA

In the lower atmosphere, the presence of persistent upper-level troughing over the Mid-Atlantic in August 2023 resulted in the passage of several dry cold fronts across Delaware. While frontal passages generally result in clean air and improving AQI levels, westerly to northerly winds behind these fronts transported surface smoke into the First State on nine occasions. Furthermore, this progressive weather pattern promoted atmospheric mixing, transporting additional smoke from high altitudes down to the surface.

Similar to the analysis shown in Section 2.5.1, smoke impacts in Delaware were also assessed with the MODIS-Aqua monthly average AOD values. Based on satellite records starting in 2002, the June 2023 monthly average AOD value for Delaware was the highest ever recorded (Table 9). Additionally, the monthly average AOD for the June-August 2023 period was higher than the 2002-2022 historical normal (Table 10). Both June and July registered above-normal monthly average AOD values, with the August 2023 average AOD value near the historical normal.

Table 9. Ten highest MODIS-Aqua monthly average AOD values for Delaware. Courtesy: https://giovanni.gsfc.nasa.gov/

Rank	Period	Mean AOD
1	June 2023	0.644
2	August 2002	0.488
3	July 2006	0.479
4	July 2002	0.469
5	July 2001	0.452
6	June 2003	0.447
7	June 2007	0.436
8	August 2003	0.435
9	August 2005	0.422
10	June 2008	0.413

Table 10. MODIS-Aqua monthly average AOD for Delaware. Courtesy: https://giovanni.gsfc.nasa.gov/

Month	2002-2022 Mean AOD	2023 Mean AOD	2023 Departure from 2002-2022 Mean
April	0.253	0.320	+0.067
May	0.305	0.644	+0.339
June	0.323	0.342	+0.019
July	0.294	0.277	-0.017
August	0.186	0.146	-0.040
September	0.253	0.320	0.067

Due in large part to the smoke transport described above, several days between May and September exceeded the NAAQS for ozone and $PM_{2.5}$. The following section will highlight the days with the highest AQI levels in summer 2023, including the weather and smoke transport conditions that contributed to poor air quality.

3. Meteorological Analysis of Days with High AQI Levels in Summer 2023

3.1 Introduction

The primary factor on high-AQI-level days (when observed AQI levels exceeded 100) for both ozone and $PM_{2.5}$ during summer 2023 was the influence of smoke, primarily from numerous large Canadian wildfires. There were several smoke-influenced episodes—some lasting multiple consecutive days — when NAAQS exceedances were observed in Delaware. Although $PM_{2.5}$ was the primary pollutant during most of the smoke-enhanced high-AQI-level days, several ozone NAAQS exceedances were observed as well. In all, there were 11 days when either ozone or $PM_{2.5}$ AQI levels exceeded 100.

- On 8 of the high-AQI-level days, only $PM_{2.5}$ AQI levels exceeded 100.
- On 1 of the high-AQI-level days, only ozone AQI levels exceeded 100.
- On 2 of the high-AQI-level days, both ozone and $PM_{2.5}$ AQI levels exceeded 100.

The high-AQI-level days were focused primarily during the month of June. As mentioned in Section 2, wildfire smoke led directly to June 2023 having the highest monthly average AOD on record for Delaware. Additionally, the NOAA's Hazard Mapping System (HMS) smoke product (https://www.ospo.noaa.gov/Products/land/hms.html) indicated a plume of smoke over at least part of the state of Delaware on 27 of 30 days in June 2023. On all high-AQI-level days observed in 2023, the HMS smoke product indicated smoke over Delaware.

Table 11 lists the 11 days from May through September 2023 with observed ozone and $PM_{2.5}$ AQI levels above 100, along with the next-day ozone and $PM_{2.5}$ forecast AQI levels predicted by Sonoma Technology. The high-AQI-level events in 2023 can be divided into four distinct episodes: June 1-2, June 6-9, June 28-July 1, and July 18. Sections 3.2-3.5 give a detailed review of the meteorological and air quality conditions during the first three of these episodes.

Table 11. Observed ozone and $PM_{2.5}$ AQI levels over 100 and next-day forecasts for the May-September 2023 period. **Bold** values indicate observed AQI levels exceeding the NAAQS.

Date	Observed Ozone AQI	Observed $PM_{2.5}$ AQI	Maximum AQI	Next-Day Forecast Ozone AQI	Next-Day Forecast $PM_{2.5}$ AQI
June 1	93	**133**	**133**	101	NA
June 2	**150**	82	**150**	143	112
June 6	90	**143**	**143**	51	112
June 7	100	**229**	**229**	71	158
June 8	80	**221**	**221**	64	177
June 9	47	**127**	**127**	80	151
June 28	64	**106**	**106**	50	107
June 29	**129**	**173**	**173**	90	161
June 30	**126**	**158**	**158**	97	124
July 1	71	**103**	**103**	90	102
July 18	84	**111**	**111**	93	99

3.2 June 1-2, 2023

In the days leading up to this high-AQI-level event, most of the eastern United States was blanketed by smoke originating from fires in western and central Canada. The statewide maximum 24-hr average $PM_{2.5}$ AQI levels in Delaware were 69 on May 30 and 88 on May 31, indicating the presence of smoke particles. In addition to the pre-existing smoke, weather conditions on June 1 and 2 were conducive to near-surface pollutant accumulation over Delaware. At the upper levels of the atmosphere, a ridge of high pressure extended from the Great Lakes to New England and the Mid-Atlantic, reducing mixing in the atmosphere. Furthermore, a broad area of surface high pressure over the region produced light winds, limiting dispersion. In addition to background smoke from previous days and limited mixing and dispersion, a local fire in New Jersey—the Allen Road Fire—produced significant smoke, which was then transported into central and southern Delaware by light northeasterly winds (Figure 26). On the afternoon of June 1, light southeasterly winds helped to disperse smoke from the Allen Road Fire and direct it away from Delaware. However, high $PM_{2.5}$ concentrations from the morning hours led to a daily $PM_{2.5}$ AQI level of 133 at the Killens site.

On June 2, winds near the Allen Road Fire became light and variable, limiting smoke impacts to areas immediately surrounding the fire. However, HMS smoke detections indicated a broad swath of regional smoke that remained over the Mid-Atlantic, keeping particle levels elevated and enhancing ozone formation. Furthermore, as the upper-level ridge of high pressure persisted, limited mixing,

sunny skies, and temperatures in the mid-90s enhanced ground-level ozone formation. Lastly, winds over Delaware remained light on this day, reducing dispersion and allowing pollutants to accumulate over the state. By the afternoon, light southeasterly winds developed, gradually transporting pollutants toward the northwest portion of Delaware. These conditions led to ozone AQI levels of 150 at the Lums 2 monitor in New Castle County. While smoke impacts on $PM_{2.5}$ were slightly reduced compared to the previous day, $PM_{2.5}$ AQI levels still reached 82 at the Newark monitor, which is in the high-Moderate AQI category.

In response to the widespread smoke, and the resulting impacts on both ozone and $PM_{2.5}$, Sonoma Technology added daily $PM_{2.5}$ forecasts beginning on June 1 (with the first valid next-day forecast for June 2); $PM_{2.5}$ forecasts continued along with ozone forecasts until the end of the 2023 forecast season.

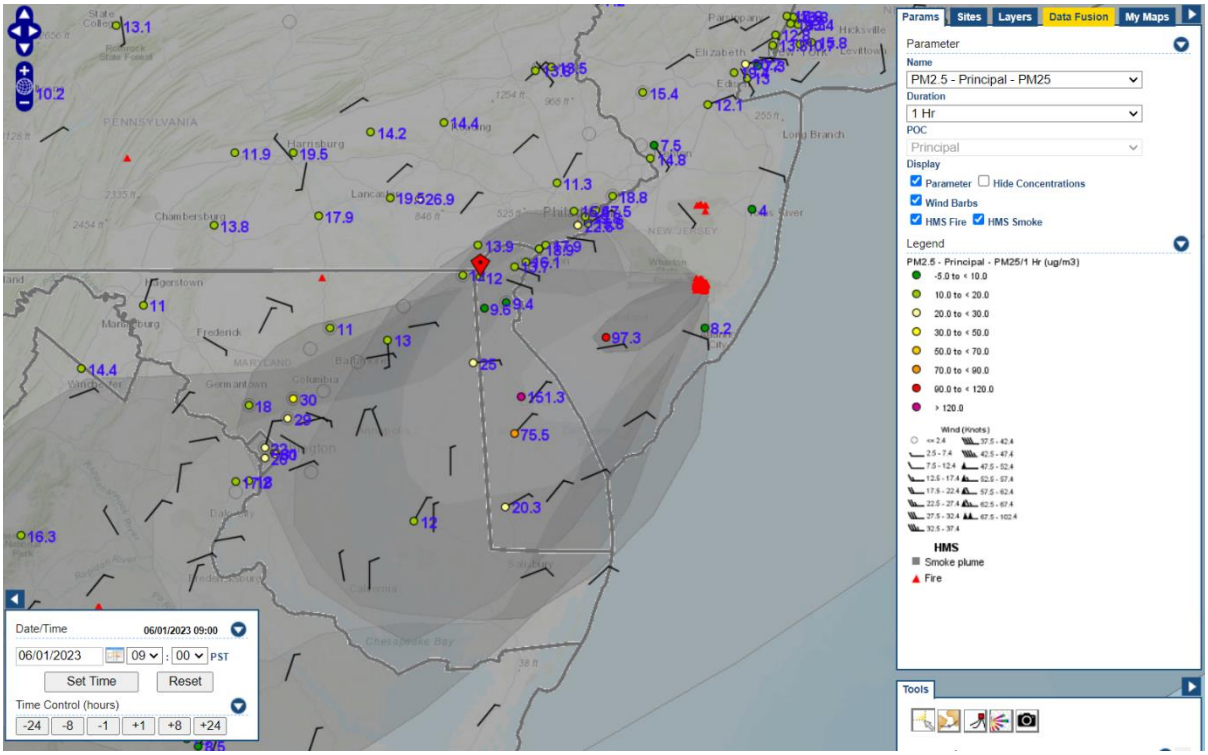

Figure 26. Hourly $PM_{2.5}$ concentrations, wind barbs, HMS fire detections (red triangles) and HMS smoke plumes (gray shading) at 1:00 p.m. EDT on June 1, 2023. Wind barbs indicate light northeasterly winds transporting smoke from the Allen Road Fire in New Jersey into central and southern Delaware, where a peak hourly $PM_{2.5}$ concentration of 151.3 µg/m^3 was observed at the Dover monitor. Courtesy: AirNow-Tech

3.3 June 6-9, 2023

Soon after the early-June high-AQI-level event, which was dominated by smoke production from a local fire, the season's highest AQI levels occurred between June 6 and 9, with a maximum daily $PM_{2.5}$ AQI level of 229 observed on June 7. This period was dominated by direct smoke transport from an unprecedented wildfire outbreak in Quebec, which was highlighted in Section 2.5. During much of this period, a deep surface low-pressure system hovered off the New England coast, producing moderate northerly to northwesterly winds. These winds typically disperse pollutants and bring clean air into Delaware; in this case, the winds transported smoke directly from the Quebec fires into the Mid-Atlantic region (**Figure 27**). Additionally, this period was characterized by an upper-level trough of low pressure at 500 mb, which would normally enhance mixing and aid dispersion. In this case, however, it is likely that enhanced mixing brought additional smoke from aloft down to the surface, increasing $PM_{2.5}$ concentrations near the ground.

Northerly to northwesterly winds persisted in Delaware from June 6 to 8, transporting dense smoke into the state each day. As a result of the extreme fire activity and smoke production in Quebec, as well as the persistent smoke transport directly into Delaware, AQI levels were USG on June 6 and Very Unhealthy on June 7 and 8. Although winds weakened slightly on June 9, northwesterly winds were strong enough to gradually push the densest portion of the smoke plume east of Delaware by the afternoon hours. However, high $PM_{2.5}$ concentrations from the early morning hours allowed 24-hr average $PM_{2.5}$ AQI levels to reach the USG category on this day.

Notably, the smoke over Delaware during this period was so dense that it effectively blocked sunlight from reaching the surface. As a result, although the smoke contained ozone precursors that would normally enhance ozone formation, it had the net effect of limiting ozone production throughout the episode. Slightly cooler temperatures during this multi-day period due to the northerly to northwesterly winds also served to reduce ozone production. These conditions led to Moderate AQI levels for ozone on all four days from June 6-9.

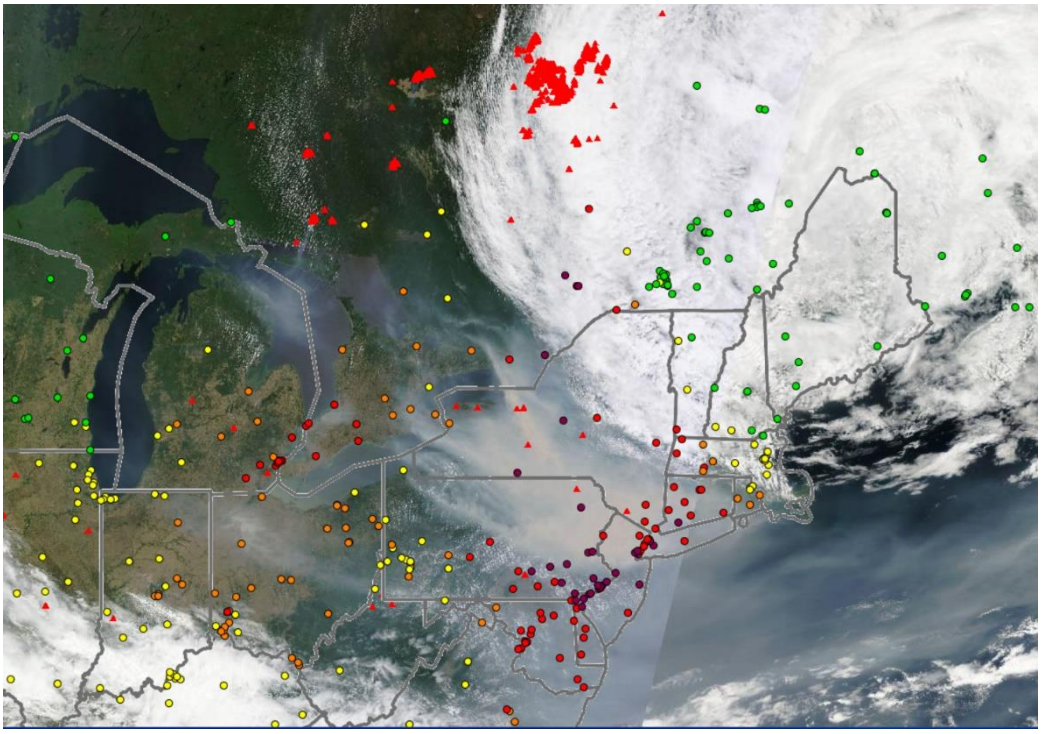

Figure 27. MODIS visible satellite imagery, HMS fire detections (red triangles) and $PM_{2.5}$ AQI levels (colored dots) on June 7, 2023. A dense smoke plume (light brown) is visible extending from Lake Huron across Ohio, southeastern Ontario, upstate New York, the Mid-Atlantic, and offshore. Cloud cover associated with a surface low pressure system – which drove smoke transport into Delaware – can be seen over eastern Quebec, Maine, Vermont, and New Hampshire. Red and maroon dots indicate Unhealthy to Very Unhealthy AQI levels throughout the Mid-Atlantic. Courtesy: AirNow-Tech

3.4 June 28-July 1, 2023

Similar to the June 6-9 smoke episode, the first two days of the June 28-July 1 smoke episode were characterized by smoke transport from fire complexes in eastern Canadian. In addition to the Quebec fires which continued to burn throughout most of June, by the latter portion of the month, additional fires were occurring in central Ontario. As a cold front departed Delaware on June 28, northwesterly winds developed, bringing dense smoke from Quebec – and to a lesser extent, Ontario – into Delaware on June 28 and 29 (Figure 28). This smoke transport resulted in USG $PM_{2.5}$ AQI levels on June 28 and Unhealthy $PM_{2.5}$ AQI levels on June 29.

On June 30 and July 1, light-to-moderate southeasterly winds developed in Delaware ahead of the next approaching low pressure system. These winds recirculated smoke over the Atlantic Ocean back into Delaware, keeping particle levels elevated. As a result, $PM_{2.5}$ AQI levels remained Unhealthy on June 30 and USG on July 1.

In contrast to the previous episode on June 6-9, the upper-level trough of low pressure was weaker during this event, and northwesterly surface winds on June 28-29 were lighter. These meteorological conditions led to slightly warmer temperatures at the surface, which aided ozone formation. Additionally, slightly lower $PM_{2.5}$ concentrations during the first portion of this event indicated a smoke plume that was less dense, allowing more sunlight to reach the surface compared to June 6-9. As a result, both ozone and $PM_{2.5}$ AQI levels exceeded 100 AQI value on June 29, with USG ozone AQI levels and Unhealthy $PM_{2.5}$ AQI levels on June 29 and 30. Continued warm temperatures, mostly sunny skies, and recirculated smoke allowed ozone AQI levels to remain USG on June 30. Ozone AQI levels lowered to Moderate on July 1, as increasing clouds reduced ozone formation.

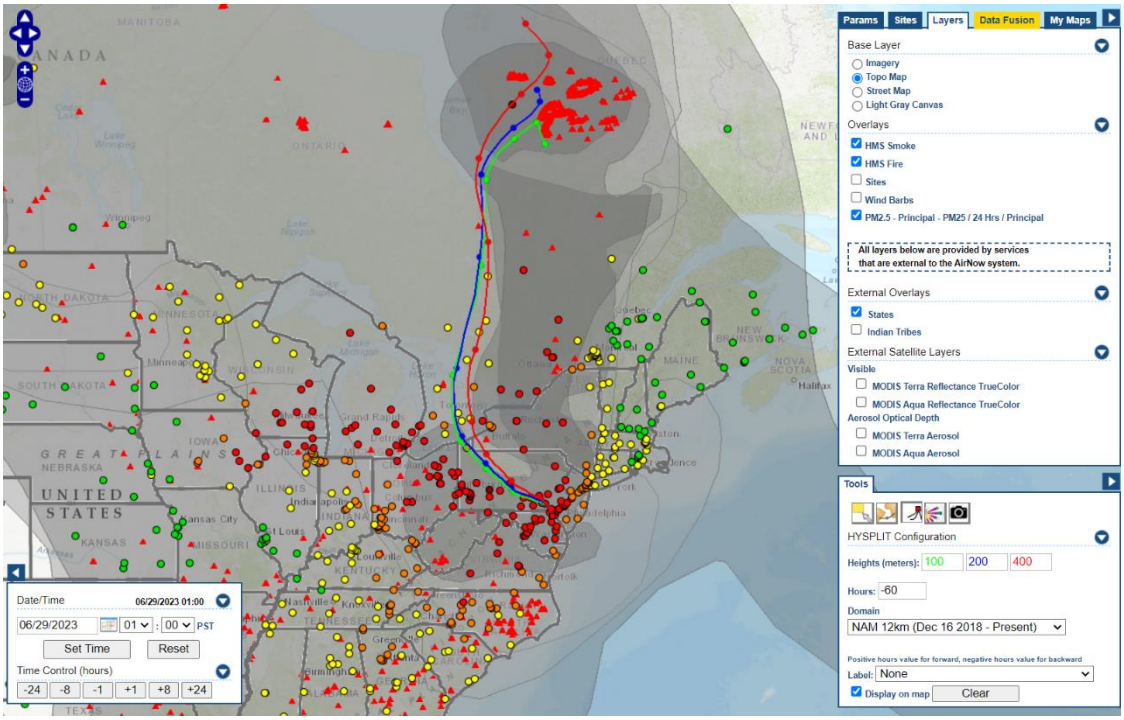

Figure 28. 24-hr average $PM_{2.5}$ AQI levels (dots), HMS fire locations (red triangles), HMS smoke plumes (gray shading), and HYSPLIT 60-hr back trajectory analysis (green 100 m above sea level [ASL], blue 200 m ASL, and red 400 m ASL) ending at 5:00 a.m. EDT on June 29, 2023. Red and maroon dots indicate widespread Unhealthy to Very Unhealthy AQI levels. Courtesy: AirNow-Tech

4. Skill of Air Quality Forecasts in 2023

4.1 Introduction to Sonoma Technology Forecasts

During the summer 2023 ozone season in Delaware, Sonoma Technology meteorologists issued ozone forecasts for the next-day and following two days during weekdays and weekends. During smoke events, $PM_{2.5}$ forecasts were also issued for the next-day and following two days. In the following pages, performance of Sonoma Technology next-day forecasts for ozone and $PM_{2.5}$ are analyzed. Additionally, performance of Sonoma Technology's next-day forecasts will be compared to previous years and the NOAA National Air Quality Forecast Capability (NAQFC) model.

4.2 2023 Ozone Forecast Statistics

A comparison between Sonoma Technology forecasts and observed ozone levels in Delaware during summer 2023 is shown in Figure 29. The forecasts generally track the observed AQI levels. Due to the low number of USG ozone forecasts issued, the Good-to-Moderate threshold was used to verify forecast accuracy. As a result, Sonoma Technology next-day ozone forecasts in Delaware were correct 71% of the time during summer 2023.

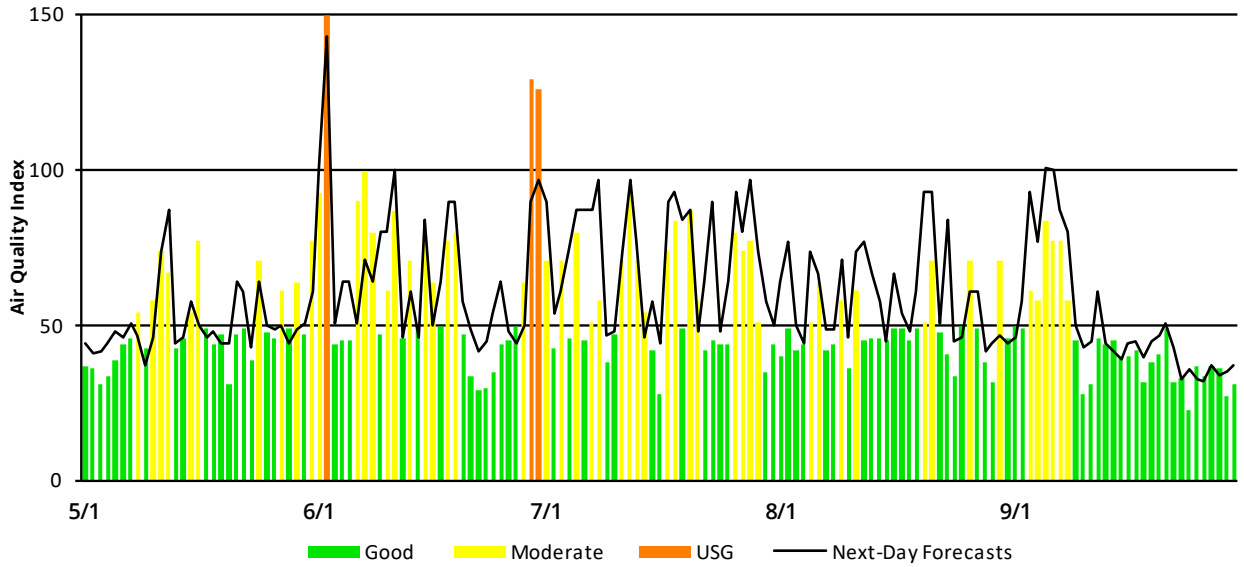

Figure 29. Daily observed 2023 ozone levels in Delaware versus Sonoma Technology next-day forecasts.

Moderate-or-higher ozone levels occurred on 56 out of the 153 forecast days in summer 2023, which was a 5% increase over summer 2022. Sonoma Technology forecasters issued Moderate AQI level forecasts on 41 of the 53 days with observed Moderate ozone AQI levels. This resulted in a probability of detection (POD) of 77% for days with Moderate ozone AQI levels, which is an improvement over the 71% POD from summer 2022. AQI values reached the USG category on 3 days during summer 2023 in Delaware, which follows 0 occurrences in summer 2022 and 3 in summer 2021.

Forecast false alarms occur when the forecast ozone AQI category is higher than the observed ozone AQI category. Of the 78 days during summer 2023 when Moderate ozone levels were forecast, there were 35 instances when observed ozone AQI levels were lower than the forecast levels (i.e., in the Good AQI category). As a result, the False Alarm Rate (FAR) for Moderate ozone forecasts during summer 2023 was 45%, which is better than the 48% FAR in summer 2022.

USG ozone levels were forecast on three days this summer: June 1, June 2, and September 5. One USG ozone forecast verified (June 2), while the remaining two USG ozone forecasts ended up as false alarms. On days with USG false alarms, the average observed ozone concentration came within 4.5 ppb of the USG category, with an average observed ozone concentration of 67 ppb. Figure 30 shows a comparison of percent correct, POD, and FAR for Sonoma Technology ozone forecasts over the last four years. The statistics for each year are comparable, with the highest overall accuracy so far occurring in summer 2021.

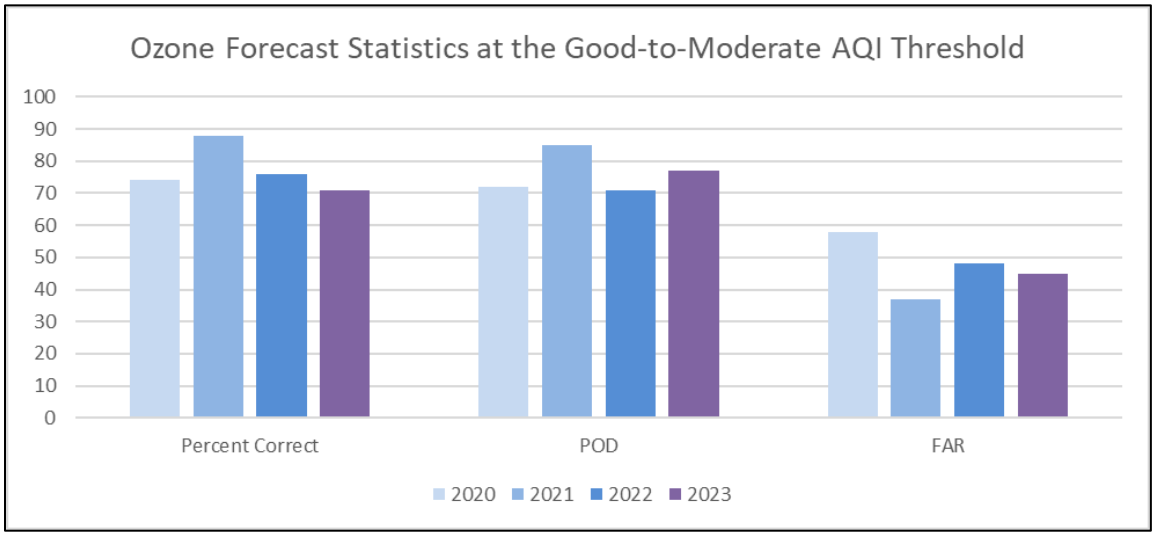

Figure 30. Percent Correct, Probability of Detection (POD), and False Alarm Rate (FAR) at the Good-to-Moderate AQI threshold for 2020-2023.

Forecast skill can also be assessed by calculating forecast bias and mean absolute error (MAE), which is done through comparing the forecast ozone concentrations to observed ozone concentrations. Bias is the average difference between forecast and observed concentrations. A positive bias

indicates that the forecast concentrations tended to be higher than observed concentrations. Conversely, a negative bias indicates that the forecast concentrations tended to be lower than observed. MAE indicates the average absolute difference between forecast and observed concentrations. A low MAE suggests that forecasts were fairly accurate.

Table 12 provides the forecast bias and MAE for all Sonoma Technology ozone forecasts during summer 2023 based on daily maximum 8-hr average ozone concentrations. For the May-September 2023 period, Sonoma Technology forecasts exhibited a bias of 3.8 ppb over observed ozone concentrations, with an MAE of 6.5 ppb. Both the bias and MAE for ozone forecasts in summer 2023 were improved versus summer 2022 (bias of +4.2 ppb, MAE of 7.1 ppb) and summer 2021 (bias of +4.7 ppb, MAE of 6.8 ppb).

Overall, next-day forecasts from Sonoma Technology strive to be protective of public health while maintaining forecast accuracy, which often results in a positive forecast bias. Sonoma Technology forecasts for ozone concentrations in summer 2023 were most biased in July (+6.4 ppb). However, this high bias was due in large part to the presence of smoke in Delaware throughout July. Sonoma Technology meteorologists aim to err on the side of caution when accounting for smoke enhancement in their ozone forecasts. The least-biased next-day ozone forecasts were in May, where the average forecast was bias 1.1 ppb over the observed ozone concentrations.

Table 12. Sonoma Technology bias and MAE for next-day ozone forecasts for summer 2023.

Month	Bias (ppb)	Mean Absolute Error (ppb)
May	+1.1	5.2
June	+2.2	7.3
July	+6.4	7.5
August	+5.3	6.8
September	+4.2	5.8
Average	+3.8	6.5

4.3 2023 $PM_{2.5}$ Forecast Statistics

Persistent smoke from Canadian wildfires led to the issuance of next-day $PM_{2.5}$ forecasts for Delaware starting on June 2. A comparison between Sonoma Technology next-day forecasts and observed $PM_{2.5}$ levels in Delaware during summer 2023 is shown in Figure 31. Using the Good-to-Moderate threshold, Sonoma Technology next-day $PM_{2.5}$ forecasts in Delaware were correct 83% of the time during summer 2023.

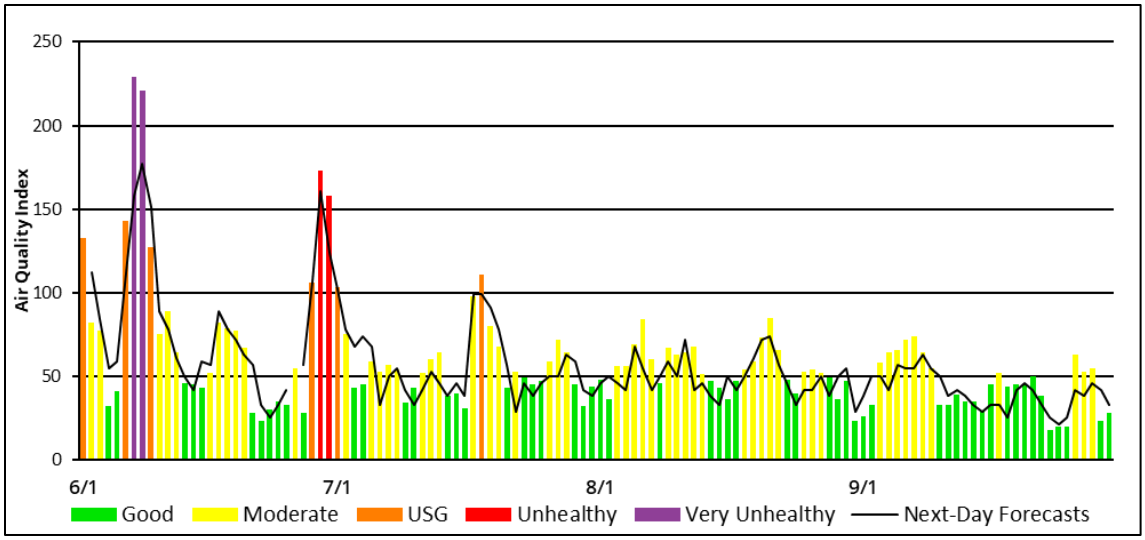

Figure 31. Daily observed June-September 2023 $PM_{2.5}$ levels in Delaware versus Sonoma Technology next-day forecasts.

Between June and September, Moderate-or-higher $PM_{2.5}$ AQI levels occurred 65 times. During this same period, Sonoma Technology issued Moderate $PM_{2.5}$ AQI level forecasts on 30 of the 55 observed Moderate $PM_{2.5}$ AQI days, resulting in a POD of 55%. Of the 41 Moderate AQI level forecasts issued for $PM_{2.5}$, there were 10 occurrences when the observed $PM_{2.5}$ AQI levels were lower than the forecast levels. This resulted in a FAR for Moderate $PM_{2.5}$ forecasts of 24%.

Observed $PM_{2.5}$ AQI levels at the USG or higher categories occurred 10 times in Delaware between June-September 2023, with 6 days in the USG category, and 2 days each in the Unhealthy and Very Unhealthy categories. Of the 10 days with USG-or-higher $PM_{2.5}$ AQI levels during this period, Sonoma Technology issued 8 USG-or-higher next-day $PM_{2.5}$ forecasts. Therefore, the POD of days with USG-or-higher $PM_{2.5}$ AQI levels was 80%. In total, Sonoma Technology forecasters issued 9 next-day $PM_{2.5}$ forecasts at the USG-or-higher AQI level, with only 1 occurrence of the observed $PM_{2.5}$ AQI level being lower than the USG threshold. As a result, the FAR for USG-or-higher next-day $PM_{2.5}$ forecasts was only 11%.

Table 13 provides the forecast bias and MAE for all Sonoma Technology next-day forecasts for $PM_{2.5}$ during summer 2023. For the June-September 2023 period, next-day forecasts exhibited a bias of 2.2 $\mu g/m^3$ below observed $PM_{2.5}$ concentrations, with an MAE of 5.2 $\mu g/m^3$.

Table 13. Sonoma Technology bias and MAE for next-day $PM_{2.5}$ forecasts for summer 2023.

Month	Bias (µg/m^3)	Mean Absolute Error (ppb)
June	-6.0	11.6
July	+0.1	3.5
August	-1.9	3.2
September	-1.4	2.9
Average	-2.2	5.2

June 2023 featured the largest $PM_{2.5}$ monthly bias of the summer, with next-day forecasts 6.0 µg/m3 below observed $PM_{2.5}$ concentrations on average. However, Sonoma Technology's $PM_{2.5}$ forecasts did perform well during the highest-AQI events in June. Out of the 8 next-day $PM_{2.5}$ forecasts issued at the USG-or-higher category in June 2023, 7 of those days verified with observed $PM_{2.5}$ AQI levels USG-or-higher. Starting with the first valid next-day forecast on June 2, there were 3 June days with observed USG $PM_{2.5}$ levels, 2 days with Unhealthy $PM_{2.5}$ levels, and 2 days with Very Unhealthy $PM_{2.5}$ levels. On all of these days, Sonoma Technology issued alerts predicting AQI levels over 100.

Figure 32 shows monthly average $PM_{2.5}$ concentration for Delaware for June-September 2023. While smoke continued to impact the state, $PM_{2.5}$ concentrations in July and September were lower than in June. Forecast bias and MAE improved as $PM_{2.5}$ concentrations decreased. The average bias for next-day $PM_{2.5}$ forecasts for July-September 2023 was 1.1 µg/m^3 below observed concentrations, with a MAE of 3.2 µg/m^3.

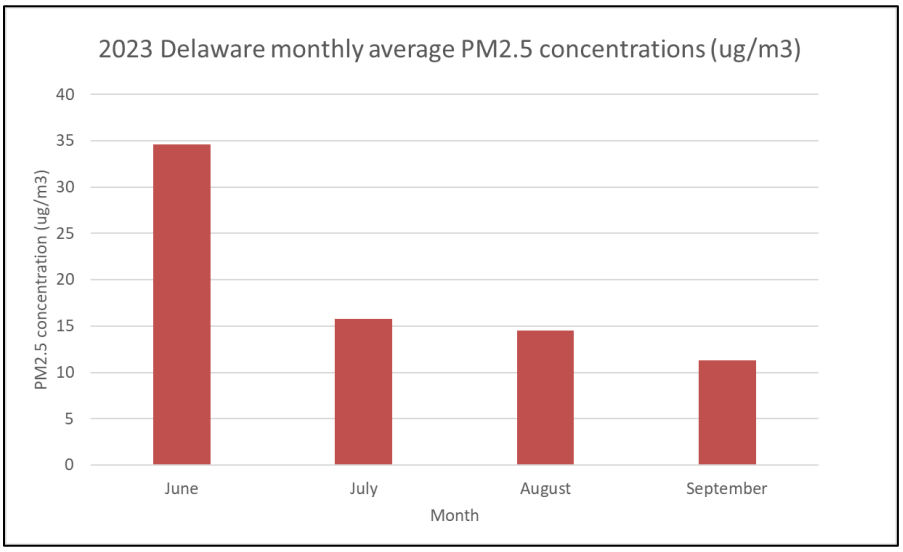

Figure 32. 2023 monthly average $PM_{2.5}$ concentrations for Delaware.

4.4 Introduction to Sonoma Technology Forecasts versus Model Forecasts

Sonoma Technology meteorologists use a variety of tools to issue ozone and $PM_{2.5}$ forecasts for the state of Delaware. One useful tool that Sonoma Technology applies to daily operations is air quality model guidance, which generally provides forecasts 1-3 days into the future. The primary air quality model used to aid in forecast decision-making is the NOAA NAQFC model, which updates twice daily (https://digital.mdl.nws.noaa.gov/airquality/). The NAQFC model suite provides the following products that Sonoma Technology meteorologists utilize during forecasting:

- Raw and bias-corrected ozone model
- Raw and bias-corrected $PM_{2.5}$ model

Each model is initialized twice daily, at 06Z and 12Z. The following sections analyze the skill of each model's next-day forecast output and compare model performance to Sonoma Technology next-day forecasts during summer 2023.

4.5 Comparison of Sonoma Technology Forecasts to 2023 NAQFC Ozone Forecasts

Table 14 provides the NAQFC next-day forecast bias and MAE for the raw and bias-corrected ozone product for Wilmington, Delaware. All NAQFC ozone products during the summer 2023 forecast season exhibited a negative bias, which indicates that ozone concentrations were underpredicted compared to actual ozone observations. However, the bias for the NAQFC bias-corrected products was better than the raw NAQFC product. The MAE for all NAQFC ozone products was >7 ppb.

Table 14. May-September 2023 next-day ozone forecast model statistics for Wilmington, Delaware.

Model	Bias (ppb)	MAE (ppb)
NAQFC 06Z Raw	-4.0	7.8
NAQFC 06Z Bias-Corrected	-2.5	7.4
NAQFC 12Z Raw	-4.2	7.6
NAQFC 12Z Bias-Corrected	-2.3	7.1

Figures 33 and 34 compare the next-day forecast bias and MAE for each month during the 2023 forecasting season. These figures include the modeled ozone predictions from NAQFC and Sonoma Technology's next-day ozone forecasts (blue bars at the left of each grouping) issued. The annual averages for bias and MAE during the May-September 2023 period are at the far right of each figure.

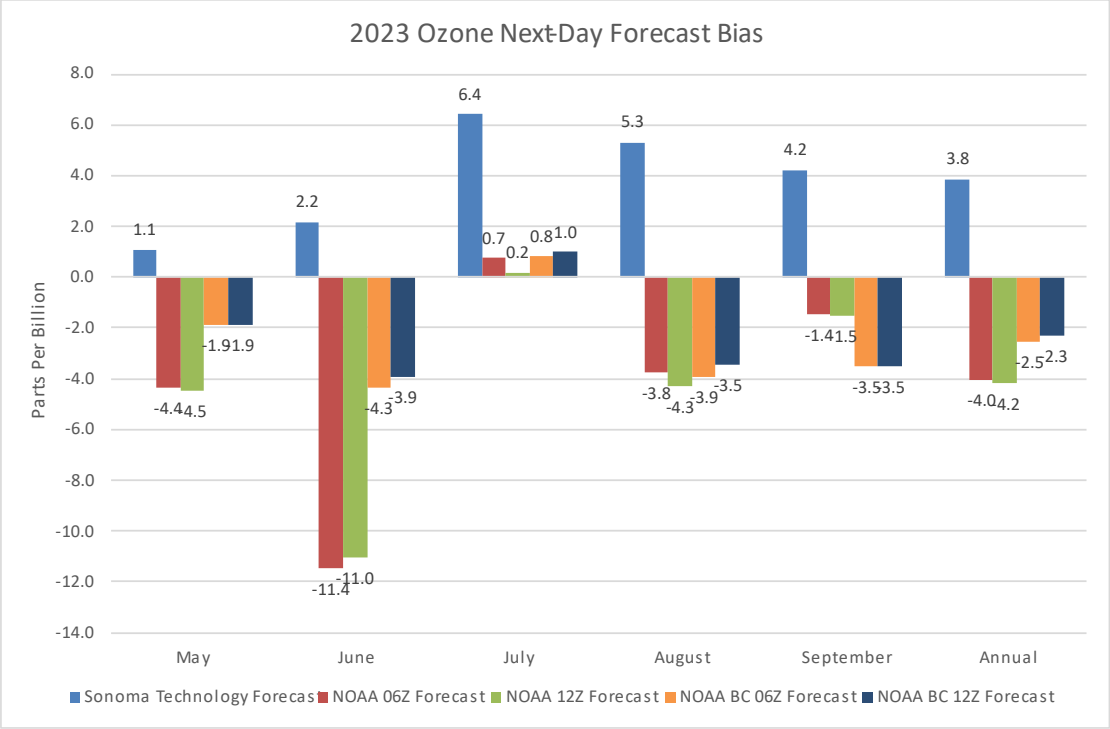

Figure 33. Monthly model ozone forecast and Sonoma Technology next-day ozone forecast bias during the 2023 summer ozone season in Wilmington, Delaware.

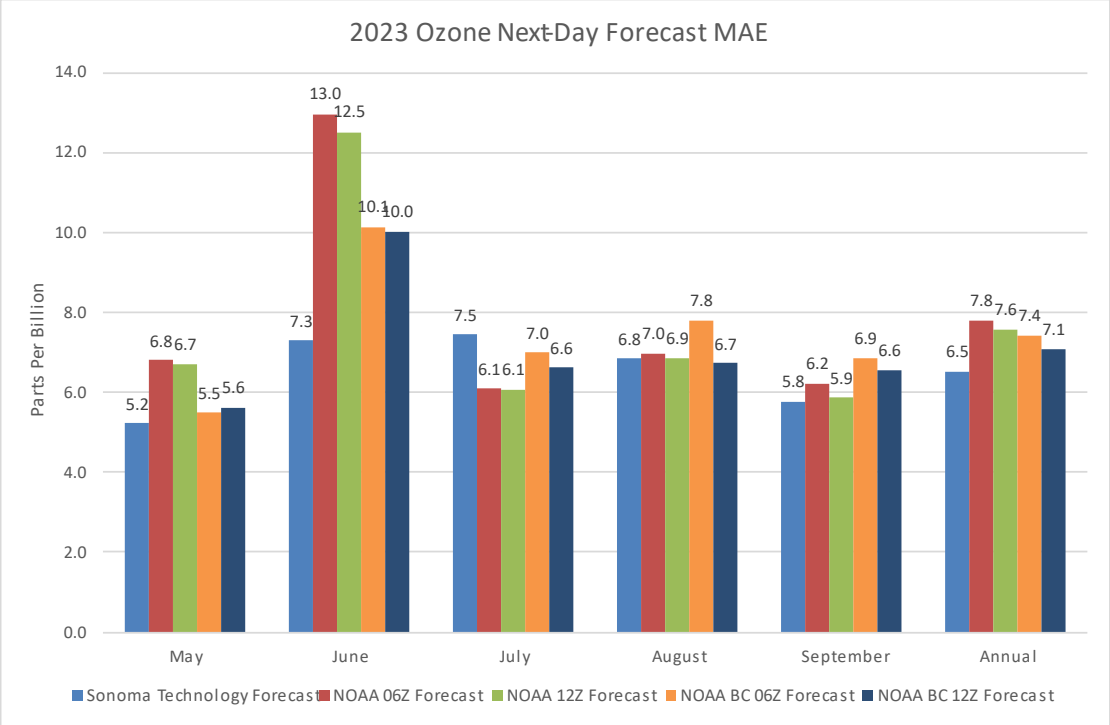

Figure 34. Monthly model ozone forecast and Sonoma Technology next-day ozone forecast MAE during the 2023 summer ozone season in Wilmington, Delaware.

Consistent with performance over the previous two summers, the NAQFC raw and bias-corrected ozone forecasts typically exhibited a negative bias each month during the 2023 ozone forecasting season. Ozone model performance was best in July, where the raw and bias-corrected NAQFC products exhibited a small positive bias versus observed ozone concentrations. By comparison, Sonoma Technology next-day ozone forecasts exhibited a positive bias throughout the May-September 2023 period. May 2023 featured the smallest positive bias for Sonoma Technology ozone next-day forecasts, outperforming the negative bias from the raw and bias-corrected NAQFC ozone forecasts. The largest bias for Sonoma Technology next-day ozone forecasts occurred in July, when the NAQFC raw and bias-corrected ozone products had improved forecast performance. However, as mentioned in Section 4.2, next-day forecasts from Sonoma Technology often result in a positive forecast bias, due to considerations made for protecting public health and aiding decision-making support for air quality outreach programs in Delaware.

The seasonal average MAE for Sonoma Technology next-day ozone forecasts was lower than the NAQFC MAE for raw and bias-corrected ozone products, which was true for most months during the 2023 summer ozone season. The lone exception was July, when the monthly average MAE for Sonoma Technology next-day ozone forecasts was 7.5 ppb. By comparison, all raw and bias-corrected NAQFC ozone forecasts in July displayed better accuracy with a lower MAE.

4.6 Comparison of Sonoma Technology Forecasts to 2023 NAQFC $PM_{2.5}$ Forecasts

Table 15 provides the NAQFC next-day forecast bias and MAE for the raw and bias-corrected $PM_{2.5}$ product for Wilmington, Delaware during the June-September 2023 period. All NAQFC $PM_{2.5}$ next-day forecasts during this 4-month period produced a negative bias, indicating the model underpredicted $PM_{2.5}$ concentrations. Both 06Z and 12Z initializations of the NAQFC bias-corrected $PM_{2.5}$ product showed forecast results that were closer to actual $PM_{2.5}$ concentrations than the raw models. However, the NAQFC bias-corrected $PM_{2.5}$ results were still 4.9 µg/m^3 lower than observations. All NAQFC $PM_{2.5}$ products contained an average MAE greater than 10 µg/m^3.

Table 15. May-September 2023 next-day $PM_{2.5}$ forecast model statistics for Wilmington, Delaware

Model	Bias (µg/m^3)	MAE (µg/m^3)
NAQFC 06Z Raw	-9.0	10.3
NAQFC 06Z Bias-Corrected	-4.9	11.1
NAQFC 12Z Raw	-9.1	10.3
NAQFC 12Z Bias-Corrected	-4.9	11.2

Figures 35 and 36 compare the $PM_{2.5}$ next-day forecast bias and MAE for the June-September 2023 period. These figures also include the Sonoma Technology $PM_{2.5}$ next-day forecasts issued (blue bars at the left of each grouping). The annual averages for bias and MAE during the June-September 2023 period are shown at the far right of each figure.

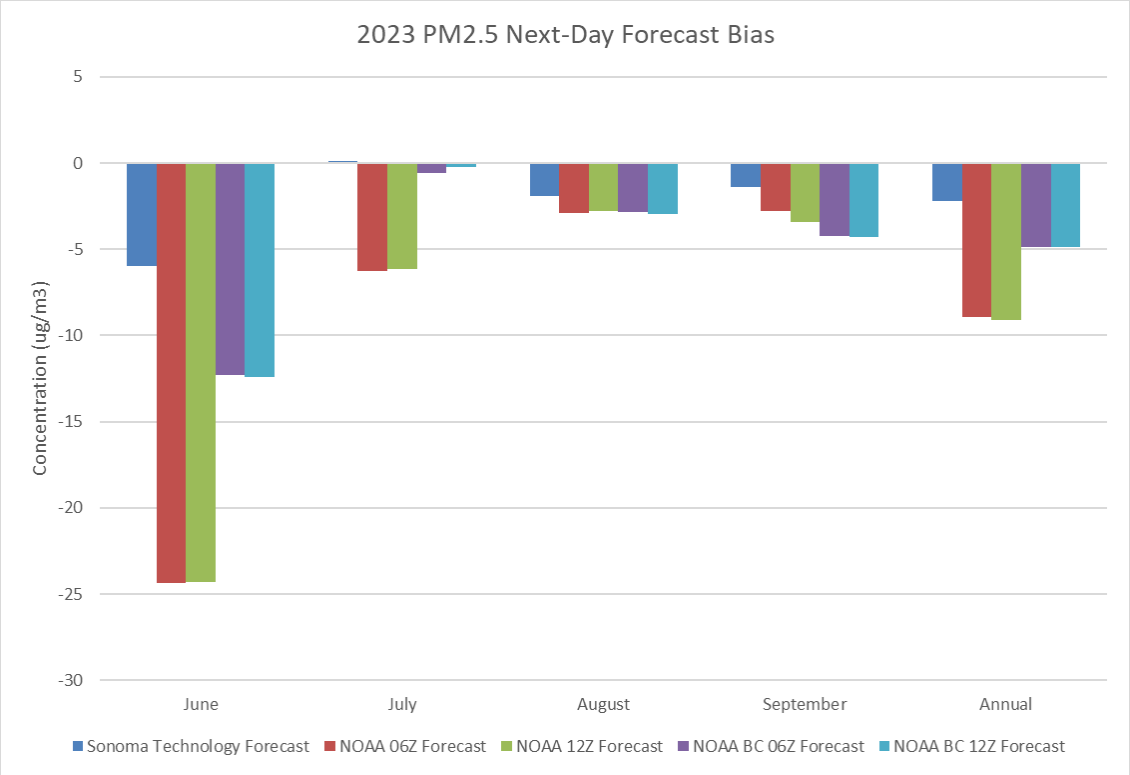

Figure 35. Monthly model $PM_{2.5}$ forecast and Sonoma Technology $PM_{2.5}$ next-day forecast bias during the June-September 2023 period in Wilmington, Delaware.

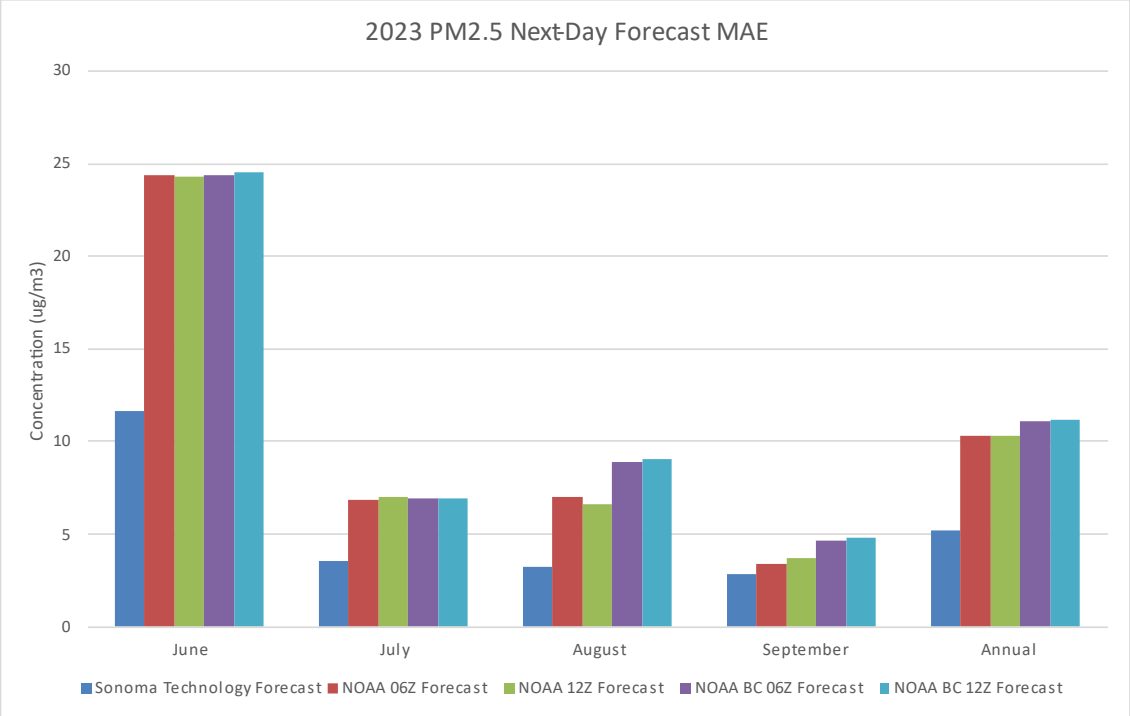

Figure 36. Monthly model $PM_{2.5}$ forecast and Sonoma Technology $PM_{2.5}$ next-day forecast MAE during the June-September 2023 period in Wilmington, Delaware.

Next-day $PM_{2.5}$ forecast biases for the NAQFC model and Sonoma Technology were generally negative throughout the June-September 2023 period. However, forecast biases in July from Sonoma Technology and the bias-corrected NAQFC model were close to 0, indicating next-day $PM_{2.5}$ forecasts were nearly identical to actual $PM_{2.5}$ observations. For the entire 4-month period, the Sonoma Technology next-day $PM_{2.5}$ forecast bias was 2.2 $\mu g/m^3$ lower than observed $PM_{2.5}$ levels. In contrast, the next-day $PM_{2.5}$ forecast bias for both raw NAQFC $PM_{2.5}$ products was around 9 $\mu g/m^3$ lower than observations, while the next-day $PM_{2.5}$ forecast bias for both bias-corrected NAQFC products was nearly 5 $\mu g/m^3$ lower than actual $PM_{2.5}$ observations.

Each month between June and September 2023, the MAE for Sonoma Technology next-day $PM_{2.5}$ forecasts was lower than all NAQFC $PM_{2.5}$ products. The greatest difference in MAE between Sonoma Technology and NAQFC $PM_{2.5}$ forecasts was in June 2023, where Sonoma Technology next-day $PM_{2.5}$ forecasts had an average MAE of 11.6 $\mu g/m^3$. This value showed improved accuracy over all NAQFC products, where the monthly average MAE was over 20 $\mu g/m^3$. For the entire 4-month period, the Sonoma Technology next-day $PM_{2.5}$ forecast average MAE was 5.2 $\mu g/m^3$, while both the raw and bias-corrected NAQFC $PM_{2.5}$ average MAE exceeded 10 $\mu g/m^3$.

5. Forecast Review and Outlook

5.1 Review of Sonoma Technology's Summer 2023 Outlook

In the 2022 end-of-season report for Delaware, Sonoma Technology meteorologists produced a temperature and precipitation outlook focusing on June, July, and August 2023. Several long-range forecast methods were discussed, including composite analog maps of seasons with similar El Niño-Southern Oscillation (ENSO) conditions, long-range model forecasts, and climatological trends in Delaware's summer temperature and precipitation patterns. The official seasonal climate forecast from NOAA's Climate Prediction Center (CPC) was also reviewed. Taking all those factors into consideration, meteorologists at Sonoma Technology forecasted the potential for above-average temperatures and rainfall in Delaware during summer 2023. The observed temperature and precipitation anomalies for the United States during summer 2023 are shown in **Figures 37 and 38**.

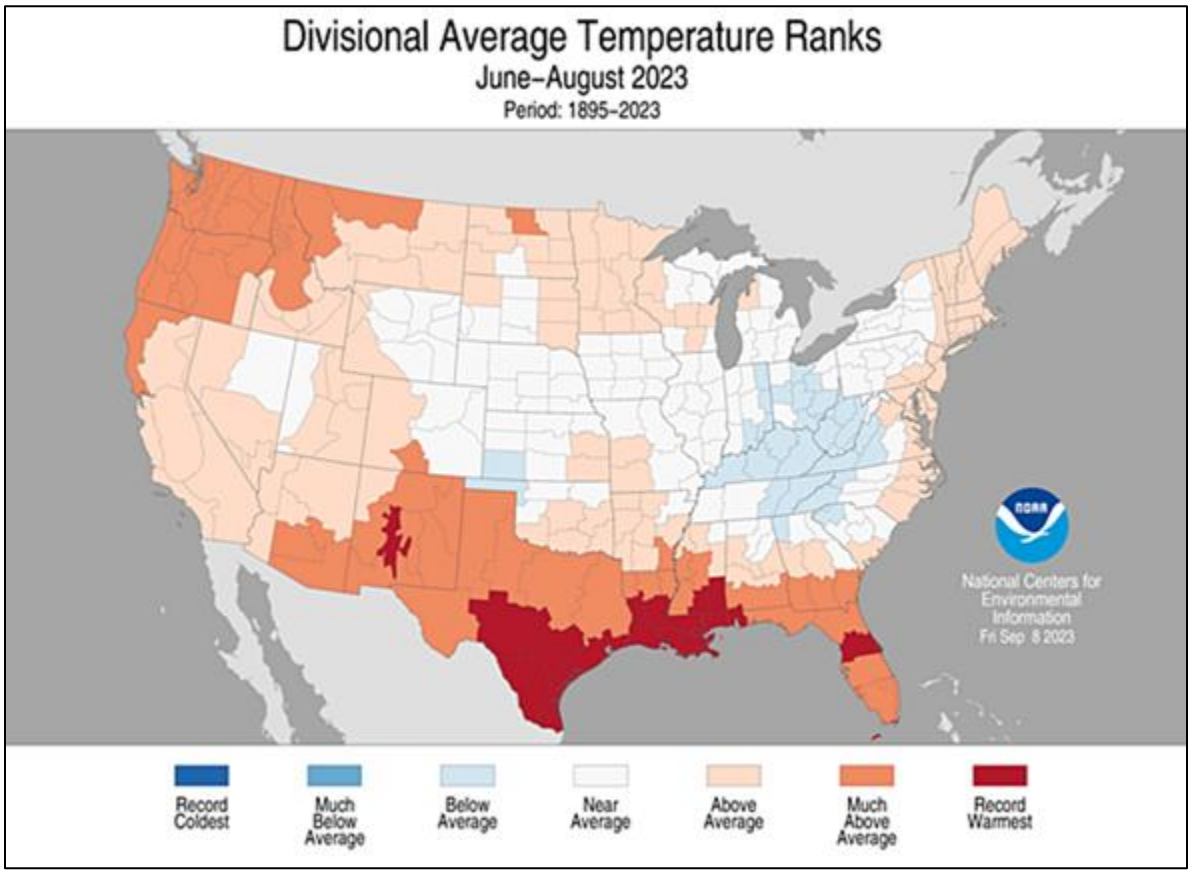

Figure 37. Temperature anomalies for summer 2023. Source: NOAA/NCEI

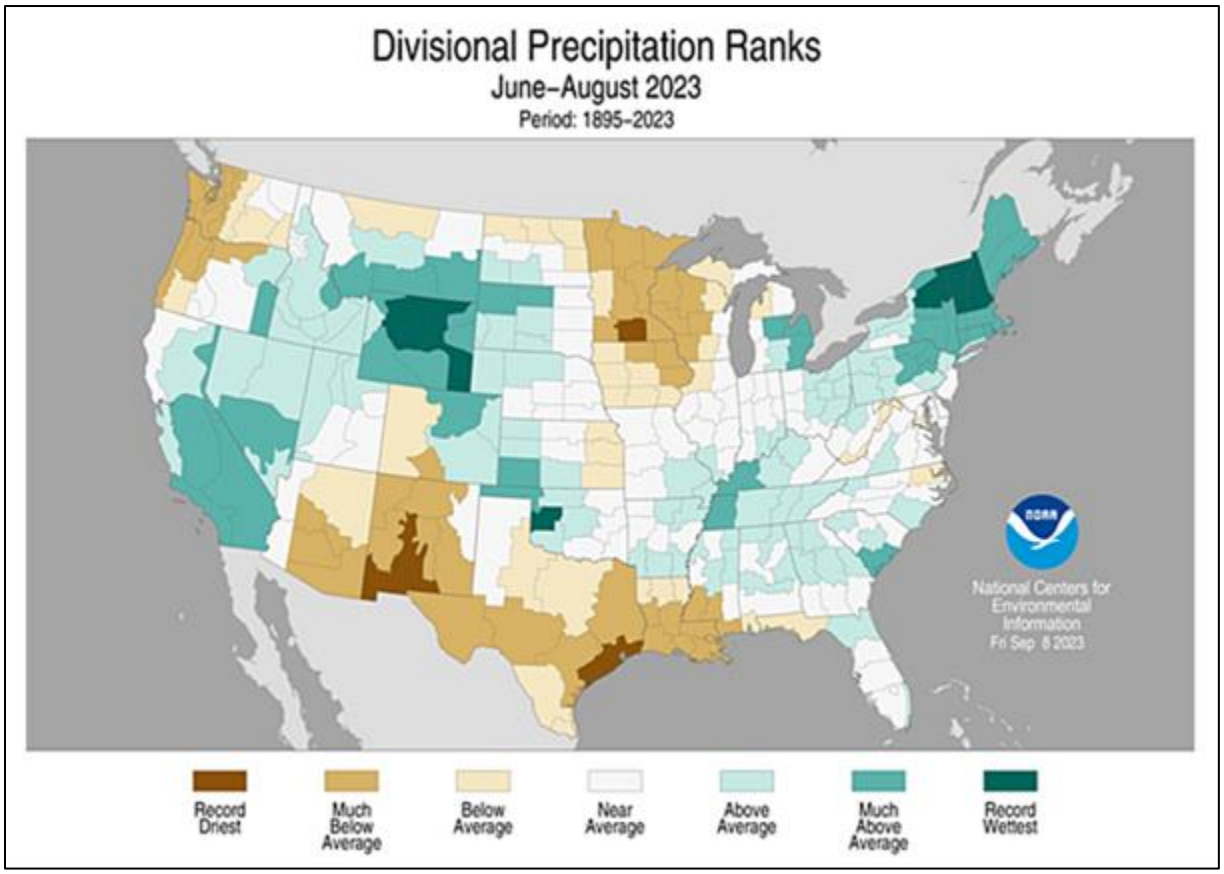

Figure 38. Precipitation anomalies for summer 2023. Source: NOAA/NCEI

Figure 37 shows that Delaware's average temperatures during summer 2023 were above-average, as predicted, while Figure 38 shows precipitation was near- to above-average. Figure 37 compares most favorably with the long-range forecast output from the CANSIPS model created in December 2022 (bottom-left of **Figure 39**), with the most significant warmth across southern and western portions of the U.S. The area of above-average rainfall observed during summer 2023 was focused slightly farther north than predicted. However, both the CPC's forecast and analog ENSO predictions did well at projecting above-average precipitation across the northeastern U.S. during summer 2023 (top-right and middle-right of Figure 39).

Ozone AQI levels were Moderate or higher on 43% of the days in June, July, and August, which is 5% greater than the average of the previous five summers. Some of this increase was possibly due to temperatures being above average in Delaware. However, ozone precursors from smoke also likely contributed to the increase. In fact, $PM_{2.5}$ was the primary pollutant on 68% of the days with Moderate-or-higher AQI levels in Delaware this summer, while on average $PM_{2.5}$ was primary on only 15% of days with Moderate-or-higher AQI levels during the previous five summers. $PM_{2.5}$ was also responsible for the four highest AQI values of the summer, including two days in the Very Unhealthy AQI category.

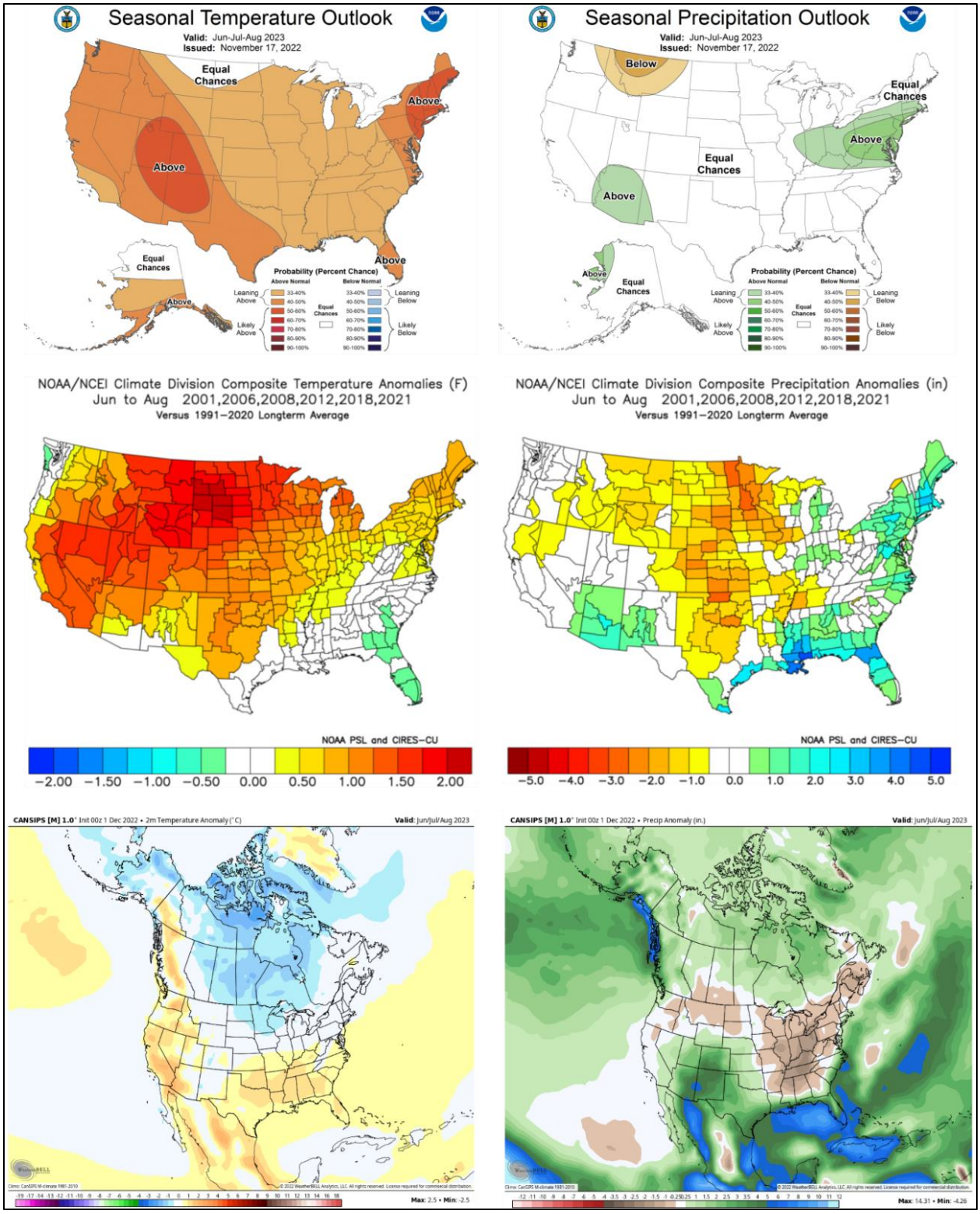

Figure 39. 2023 summer outlooks for temperature (left column) and precipitation (right column) from the CPC, ENSO analogs, and CanSIPS (top to bottom). Sources: NOAA and model data from WeatherBell.

The increase in $PM_{2.5}$ this summer was mainly due to extensive smoke produced by fires across Canada. The Canadian fire season started early in 2023 as hot and dry conditions across Canada allowed numerous fires to develop during the spring. In addition to widespread agricultural fire activity, Figure 40 shows the large number of wildfires that had already developed across Canada by the middle of May.

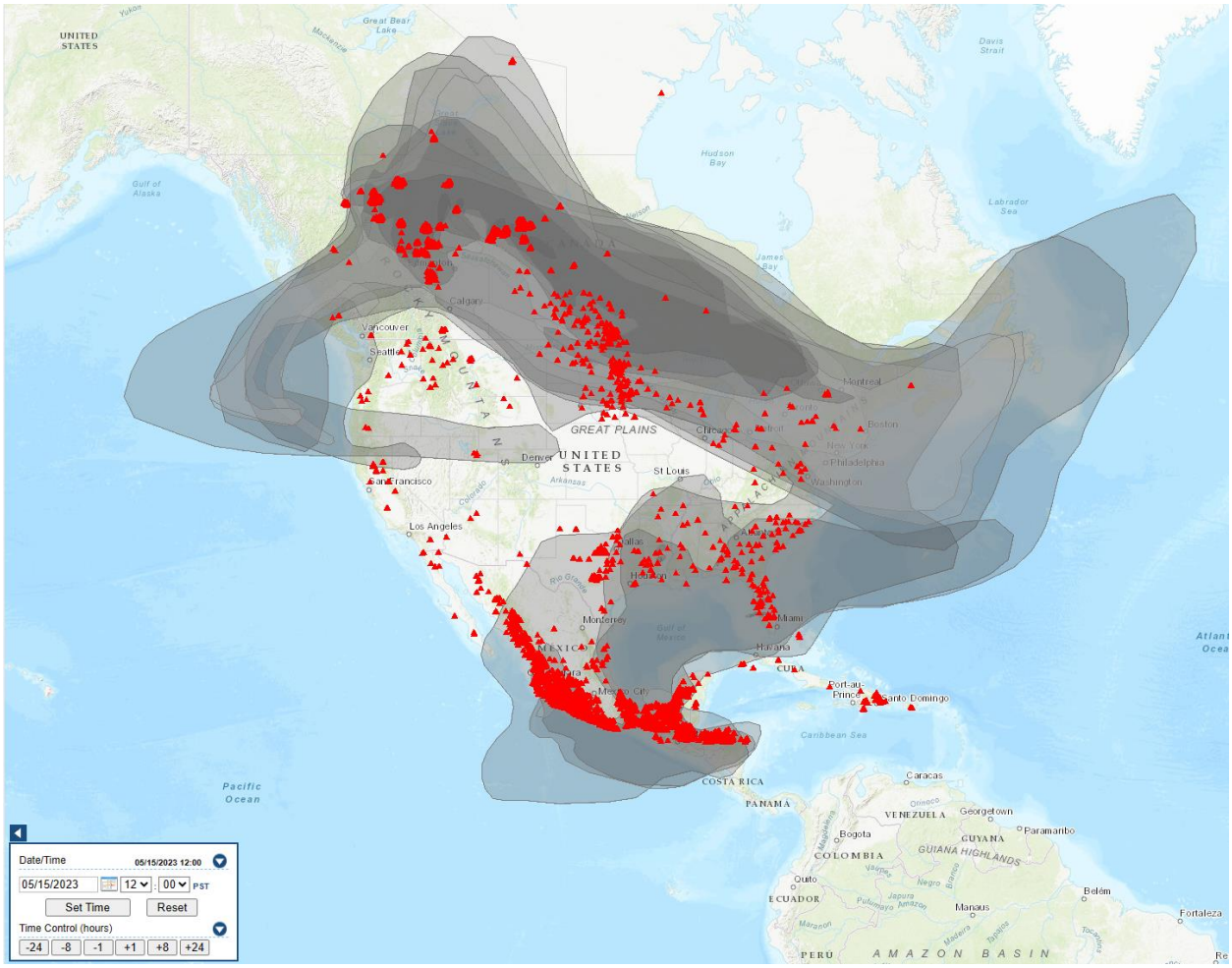

Figure 40. Satellite detected fire activity on May 15, 2023. Red triangles indicate fires, while gray shading indicates areas of smoke. Source: AirNow-Tech.

The coverage of fire activity increased throughout the summer, with several dense plumes of smoke impacting the Mid-Atlantic. The Canadian Interagency Forest Fire Centre (CIFFC) reported a record year for the number of hectares burned across Canada since records began in 1983. Nearly 18.5 million hectares (close to 46 million acres) burned in Canada in 2023, almost tripling the previous record of near 7 million hectares (approximately 17 million acres) set in 1995 (Figure 41).

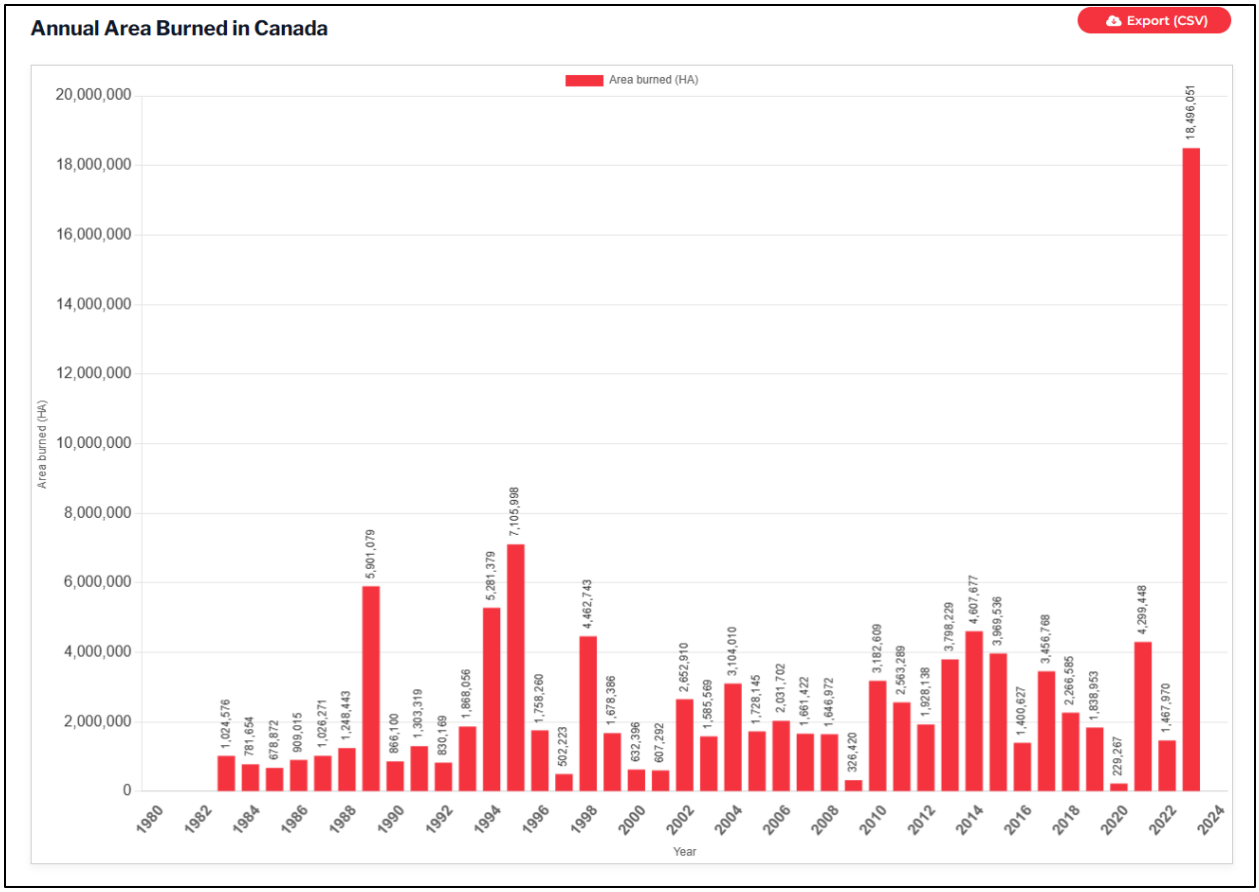

Figure 41. Annual area burned across Canada (hectares). Source: CIFFC.

Given the impact of Canadian wildfire smoke on air quality in Delaware last season, this year's summer outlook also includes a discussion of factors that could have an impact on Canadian wildfire activity during summer 2024.

5.2 Climate Prediction Center Summer Outlook

To gauge the potential for ozone development during the upcoming 2024 summer season, Sonoma Technology meteorologists reviewed seasonal forecasts by NOAA's Climate Prediction Center (CPC), composites of temperature and precipitation anomalies for years with similar ENSO conditions, and model output from seasonal weather models. Current trends in summer temperatures and precipitation were also considered. This analysis focuses on the forecast for June, July, and August 2024, as these months represent the peak of ozone season in Delaware.

CPC's forecast for temperature and precipitation anomalies for summer 2024 are shown below (Figures 42 and 43).

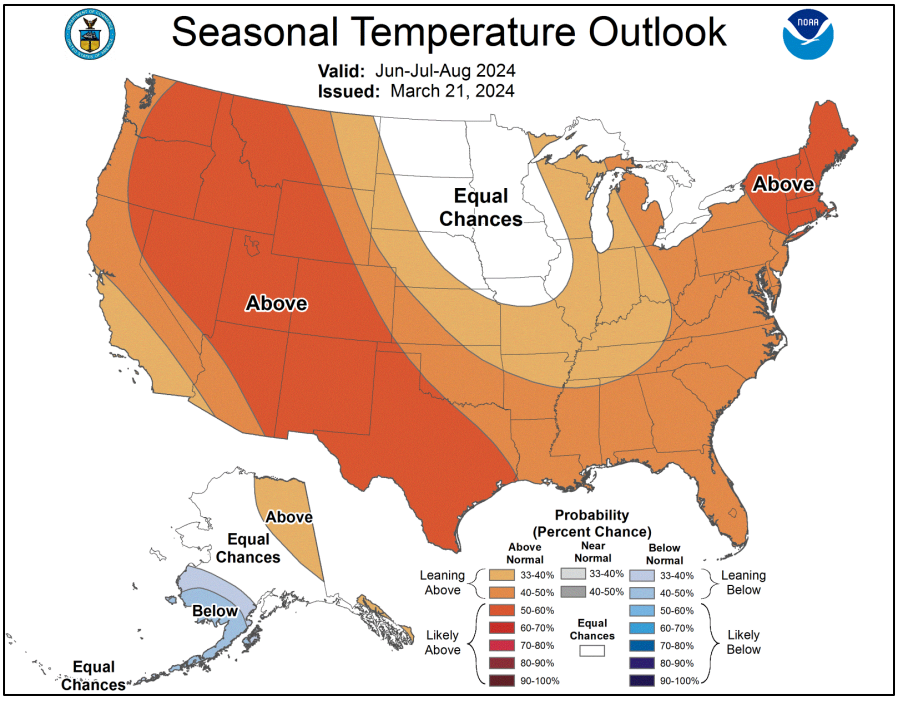

Figure 42. Forecast probability of surface temperature anomalies for June, July, and August 2024. Source: CPC

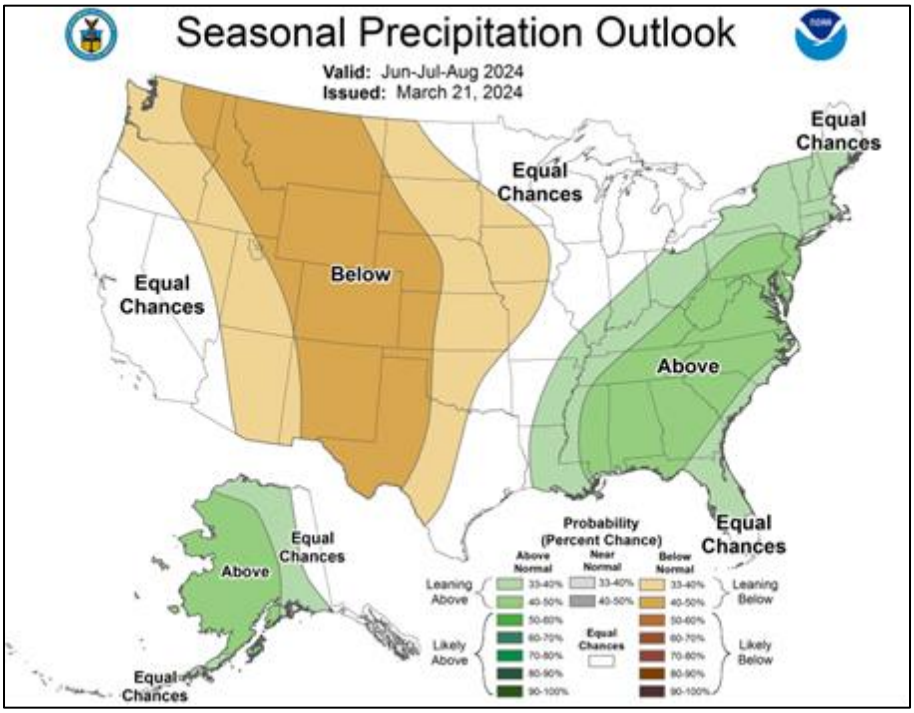

Figure 43. Forecast probability of precipitation anomalies for June, July, and August 2024. Source: CPC

Figures 42 and 43 indicate that the CPC is predicting a 40%-50% chance of above-average temperatures and a 40%-50% chance of above-average precipitation in Delaware for summer 2024. The following sections detail how other data sources compare to the official forecast, followed by a brief discussion on how meteorology could impact ozone and $PM_{2.5}$ in Delaware during the summer.

5.3 El Niño Southern Oscillation (ENSO)

CPC's ENSO outlook predicted a transition from the moderate El Niño conditions observed over winter 2023-2024, to ENSO neutral or La Niña conditions during summer 2024. Although ENSO is just one of many variables when it comes to global oceanic and atmospheric circulations, current ENSO conditions and forecasts can provide useful insight into how weather conditions may respond over the continental United States. Sonoma Technology meteorologists investigated how temperature and precipitation anomalies were impacted by recent occurrences of similar transitions from moderate or stronger El Niños to ENSO-Neutral or La Niña conditions. Since the year 1990, similar transitions occurred in 1992, 1995, 1998, 2010, and, most recently, 2016. **Figures 44 and 45** are composites of the temperature and precipitation anomalies that occurred during those analogous summers.

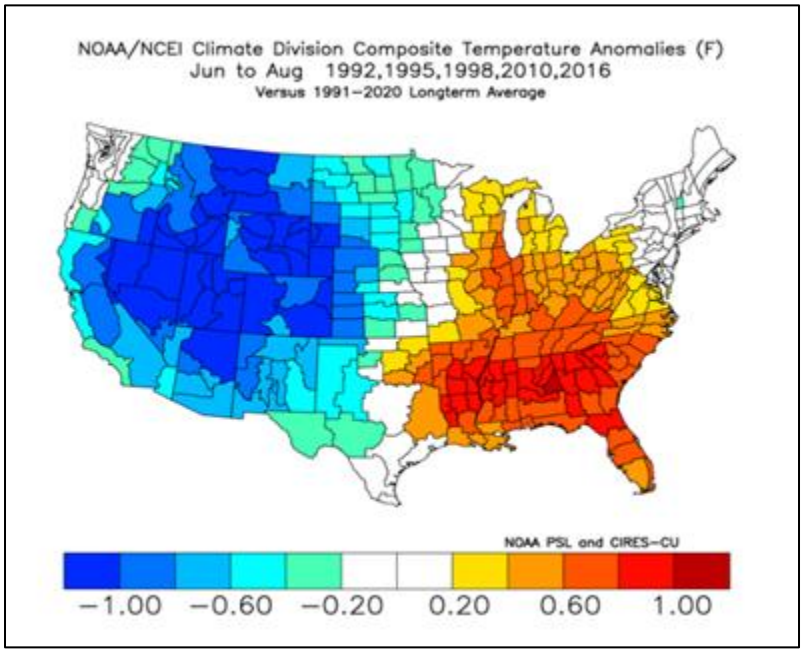

Figure 44. Temperature anomalies (°F) for La Niña and ENSO-Neutral summers after moderate or stronger El Niño winters. Source: NOAA PSL and CIRES-CU

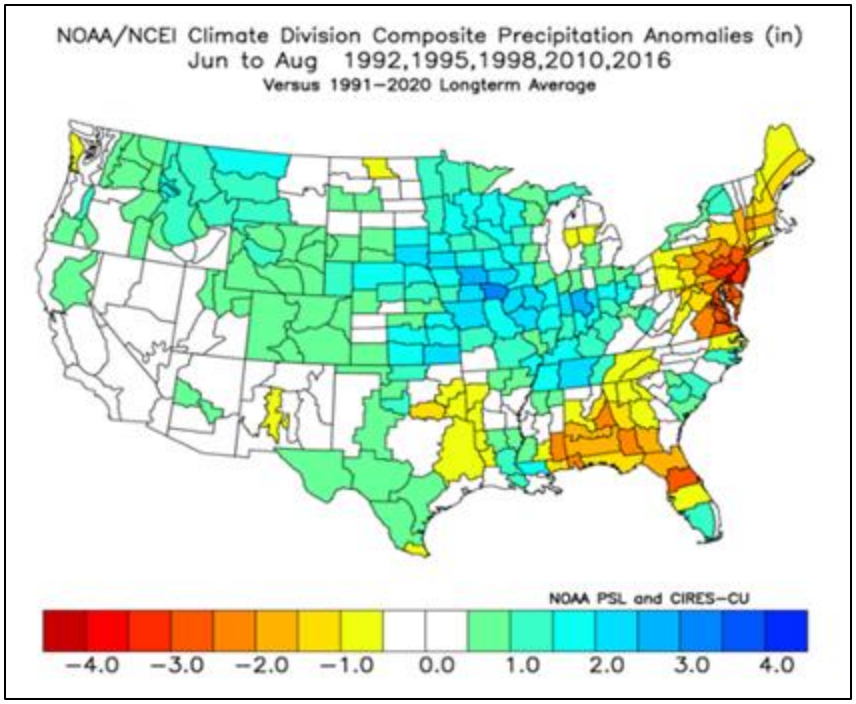

Figure 45. Precipitation anomalies (in.) for La Niña and ENSO-Neutral summers after moderate or stronger El Niño winters. Source: NOAA PSL and CIRES-CU

Comparing the CPC's temperature forecast in Figure 42 to historical temperature anomalies during La Niña and ENSO-neutral summers following moderate or stronger El Niño winters in Figure 44, there are some differences over Delaware. Whereas CPC's outlook has above-average temperatures over Delaware, the ENSO similar summers had temperatures near-average in the Mid-Atlantic. The precipitation forecast for Delaware from the CPC in Figure 43 also differs from the historical precipitation anomalies in Delaware in Figure 45, with the CPC forecasting above-average precipitation, while drier-than-average conditions occurred during ENSO-similar summers over the Mid-Atlantic. Sonoma Technology meteorologists also looked at La Niña summers since 1990 without regard to ENSO conditions the preceding winter (corresponding temperature and precipitation anomaly maps for analog years shown in **Figures 46 and 47**), as model predictions show good potential for La Niña conditions to develop by the summer.

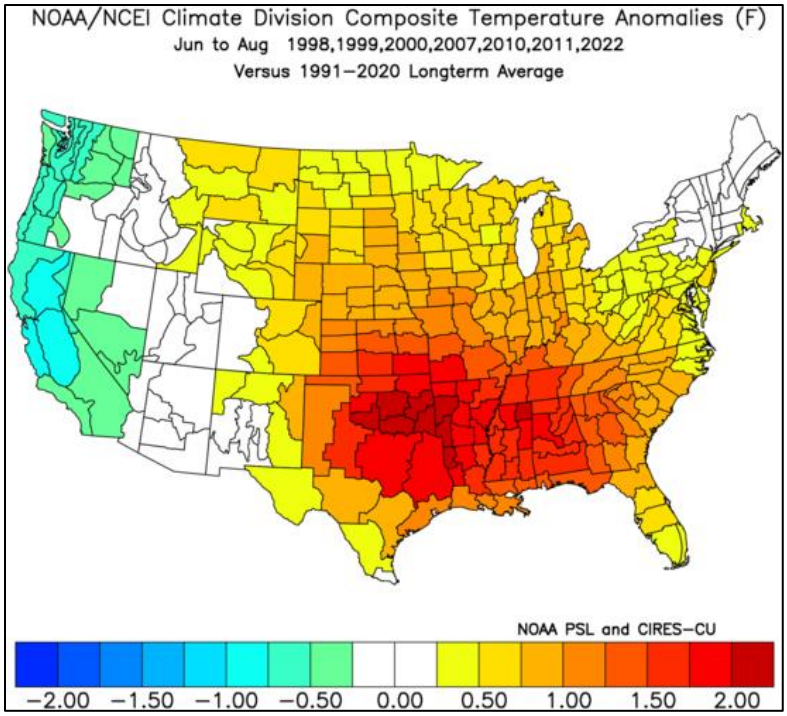

Figure 46. Temperature anomalies (°F) for summers with La Nina conditions since 1990. Source: NOAA PSL and Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder (CIRES-CU)

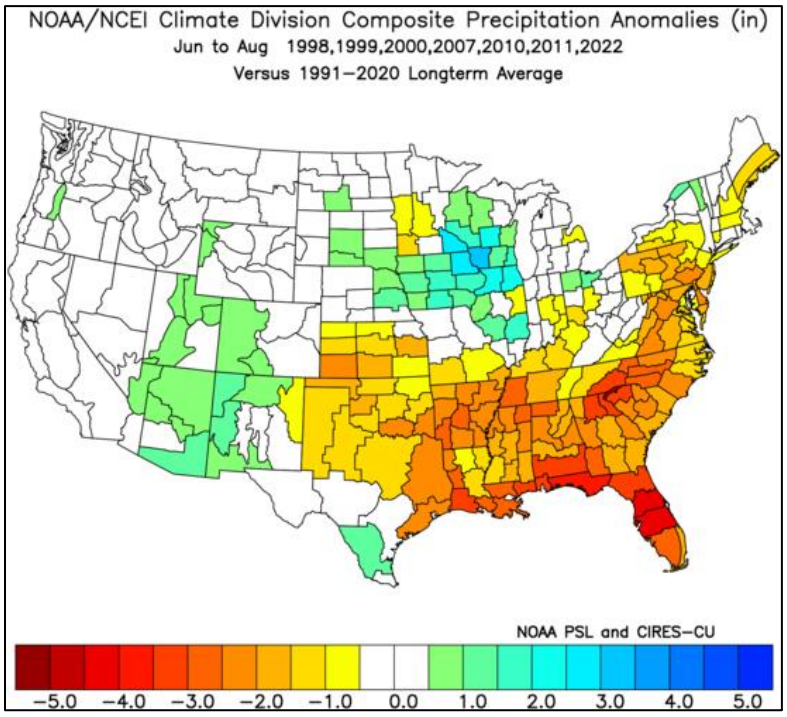

Figure 47. Precipitation anomalies (in.) for La Niña summers since 1990. Source: NOAA PSL and CIRES-CU

Figure 46 does expand above-average temperatures northward into Delaware, while Figure 47 maintains below-average precipitation for the Mid-Atlantic. Solely considering the ENSO analogs, near- to above-average temperatures and below-average precipitation could be expected this summer.

However, another consideration related to ENSO this summer is the combination of a developing La Niña and anomalously warm ocean water across the Tropical Atlantic (Figure 48). Sea surface temperatures (SSTs) in the Tropical Atlantic as of late March, 2024 were 1-2.5˚C above-average.

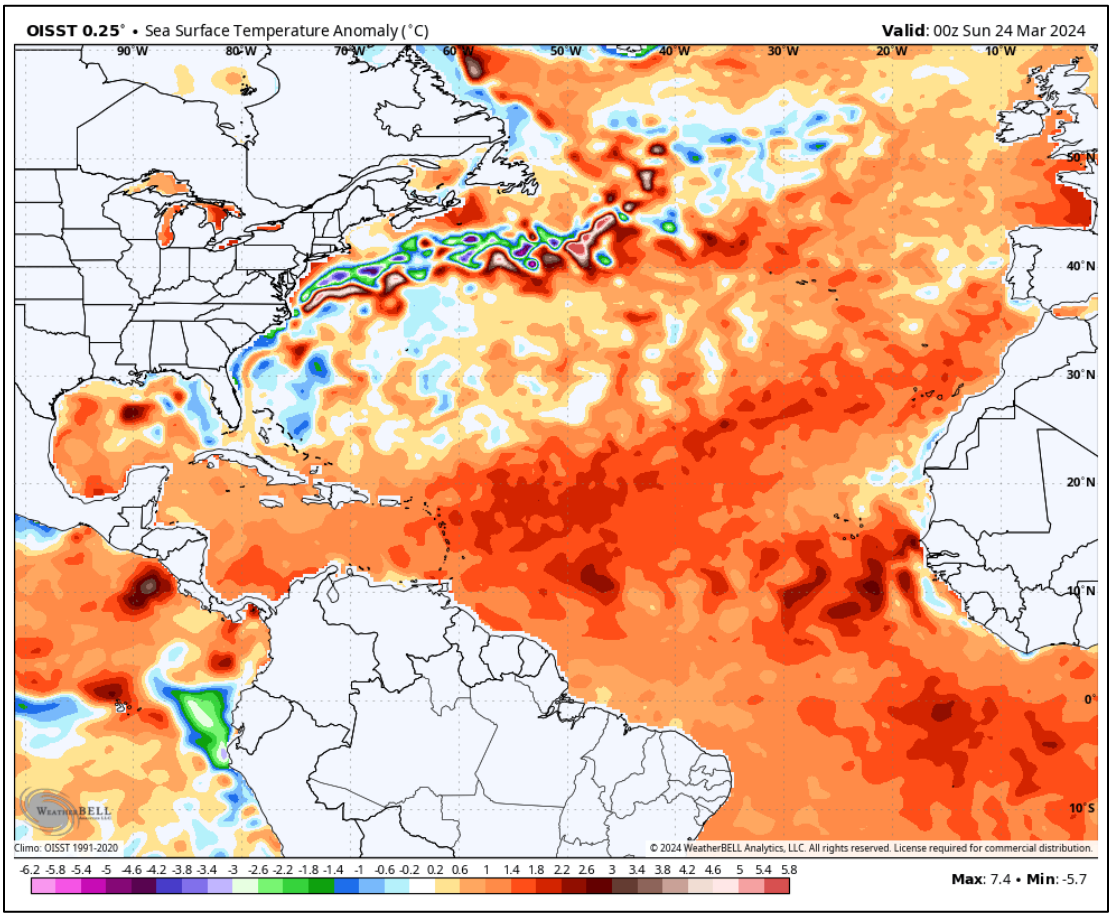

Figure 48. Sea surface temperature anomalies (˚C) as of March 24, 2024. Source: WeatherBell

These above-average SSTs, combined with a potential decrease in wind shear due to a developing La Niña, could lead to an increase in tropical cyclone activity this summer. While it is too early to predict if precipitation from that activity could impact Delaware, it is a significant variable to track heading into the summer.

Although ENSO conditions and forecasts are an important component of the summer outlook, forecast models can resolve additional complexity between the different atmospheric systems that

affect weather patterns around the globe. The following section examines the seasonal forecast from climate models to see how they compare with the overall forecast.

5.4 Model Forecasts

The seasonal temperature and precipitation forecasts from the Canadian Seasonal to Inter-annual Prediction System (CanSIPS) model are shown in Figures 49 and 50. The CanSIPS model is an ensemble of two climate models developed by the Canadian Centre for Climate Modelling and Analysis and the Canadian Meteorological Centre. The model considers some of the complex interactions among the atmosphere, oceans, ice, and land surfaces across the globe to produce seasonal long-range forecasts.

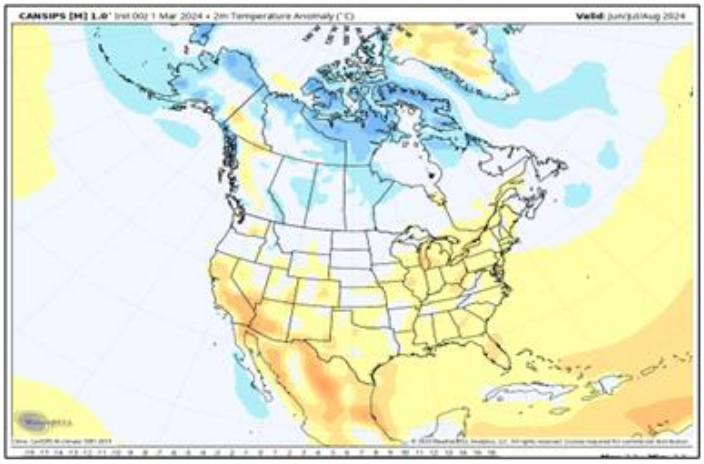

Figure 49. CanSIPS forecast temperature anomalies for June-August 2024.
Source: WeatherBell

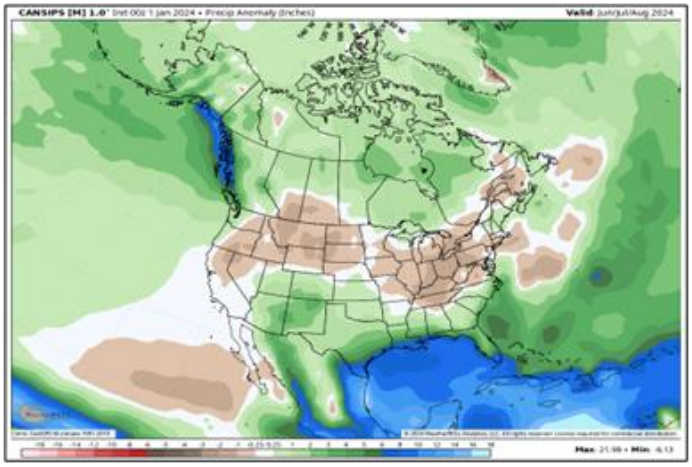

Figure 50. CanSIPS forecast precipitation anomalies for June-August 2024.
Source: WeatherBell

Similar to the CPC's forecast and the ENSO analogs, the CanSIPS model is forecasting slightly above-average temperatures for Delaware during summer 2024. Meanwhile, the precipitation forecast from CanSIPS for the Mid-Atlantic puts Delaware on the dividing line between increased precipitation to the south and drier conditions to the north. The area of above-average precipitation to the south is likely related to the potential increase in tropical cyclone activity discussed in Section 5.3.

Summer temperature and precipitation outlooks are also available from the European Centre for Medium Range Weather Forecasting (ECMWF) seasonal weather model. Similar to the CANSIPS model, the ECMWF seasonal model is forecasting slightly above-average temperatures for June, July, and August in Delaware (Figure 51).

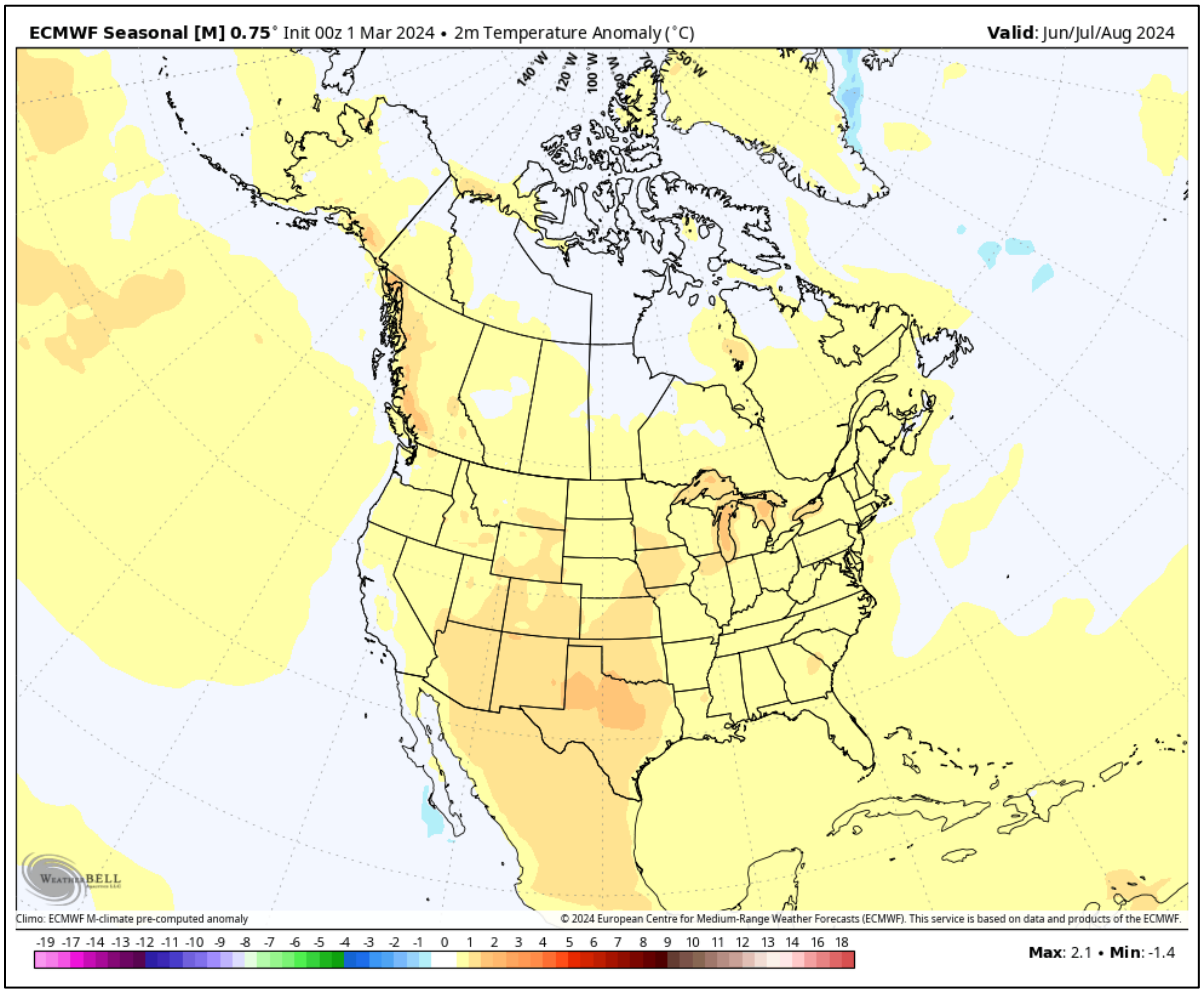

Figure 51. ECMWF temperature outlook for June, July, and August 2024. Source: WeatherBell

However, the summer precipitation forecast from the ECMWF differs from the CANSIPS model and ENSO analogs, as it is forecasting slightly above-average precipitation across much of the eastern United States, including the Mid-Atlantic (Figure 52).

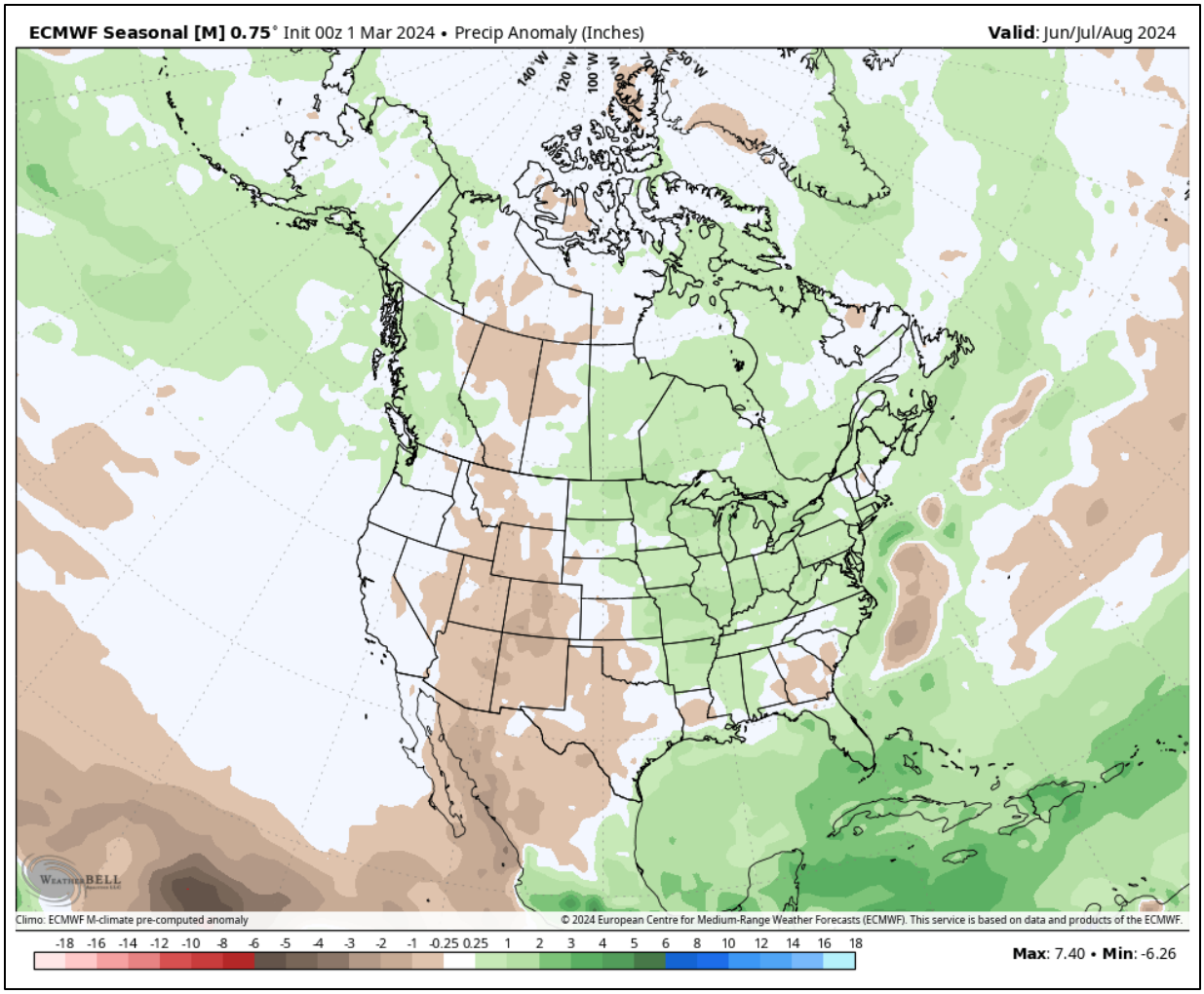

Figure 52. ECMWF precipitation outlook for June, July, and August 2024. Source: WeatherBell

5.5 Trends in Summer Temperatures and Precipitation

Another factor to consider in seasonal weather predictions is recent weather trends compared to climatological norms. The CPC produces maps of temperature and precipitation trends for 3-month periods throughout the year. Temperature trends reflect the difference between the average temperatures during a selected 3-month period over the last 10 years and the 30-year temperature climatology from 1981-2010. Precipitation trends reflect the difference between the average precipitation during a selected 3-month period over the last 15 years and the 30-year precipitation climatology from 1981-2010. The trend maps are shown in Figure 53.

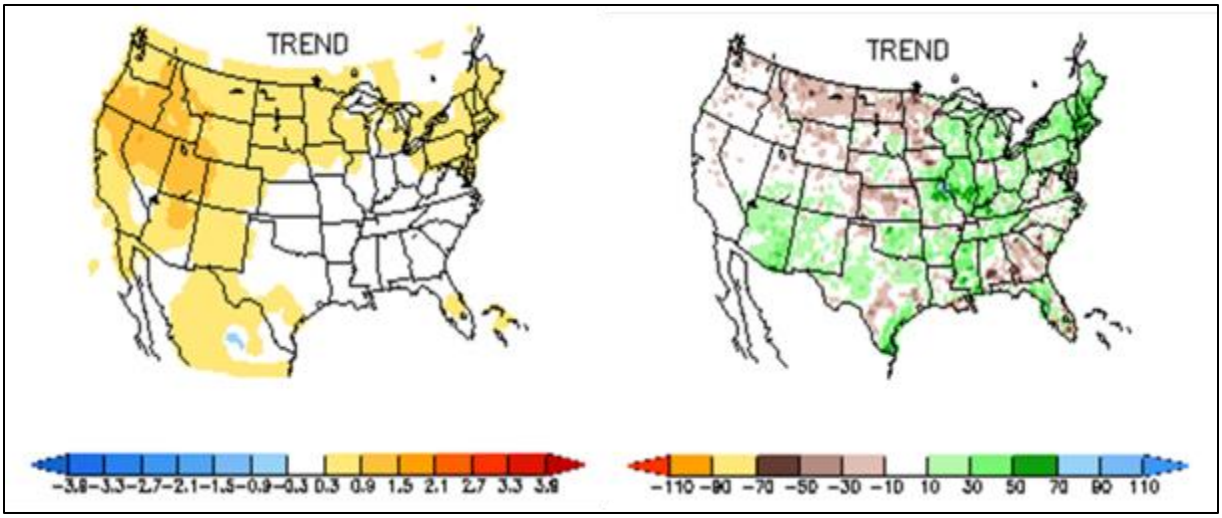

Figure 53. Recent trends in temperature in ˚C (left) and precipitation in millimeters (right) for June, July, and August. The recent trend is estimated by the Optimal Climate Normal (OCN) of Huang et al. (1996).[1]

Trends in summertime temperatures and precipitation show that, in general, temperatures are slowly warming and precipitation is increasing in the northeastern United States.

5.6 Canadian Smoke Factors

As mentioned in Section 5.1, smoke can also be an important factor in AQI levels in Delaware during the summer months; smoke can both enhance ozone production and increase concentrations of $PM_{2.5}$. A couple of the most important meteorological factors leading to last summer's prolific Canadian wildfire and smoke season were above-average spring temperatures, and abnormally dry antecedent conditions. **Figure 54** shows 500-mb geopotential height anomalies during April and May 2023. Warm colors indicate positive areas of high pressure aloft. This upper-level high pressure is associated with above-average temperatures throughout the lower levels of the troposphere.

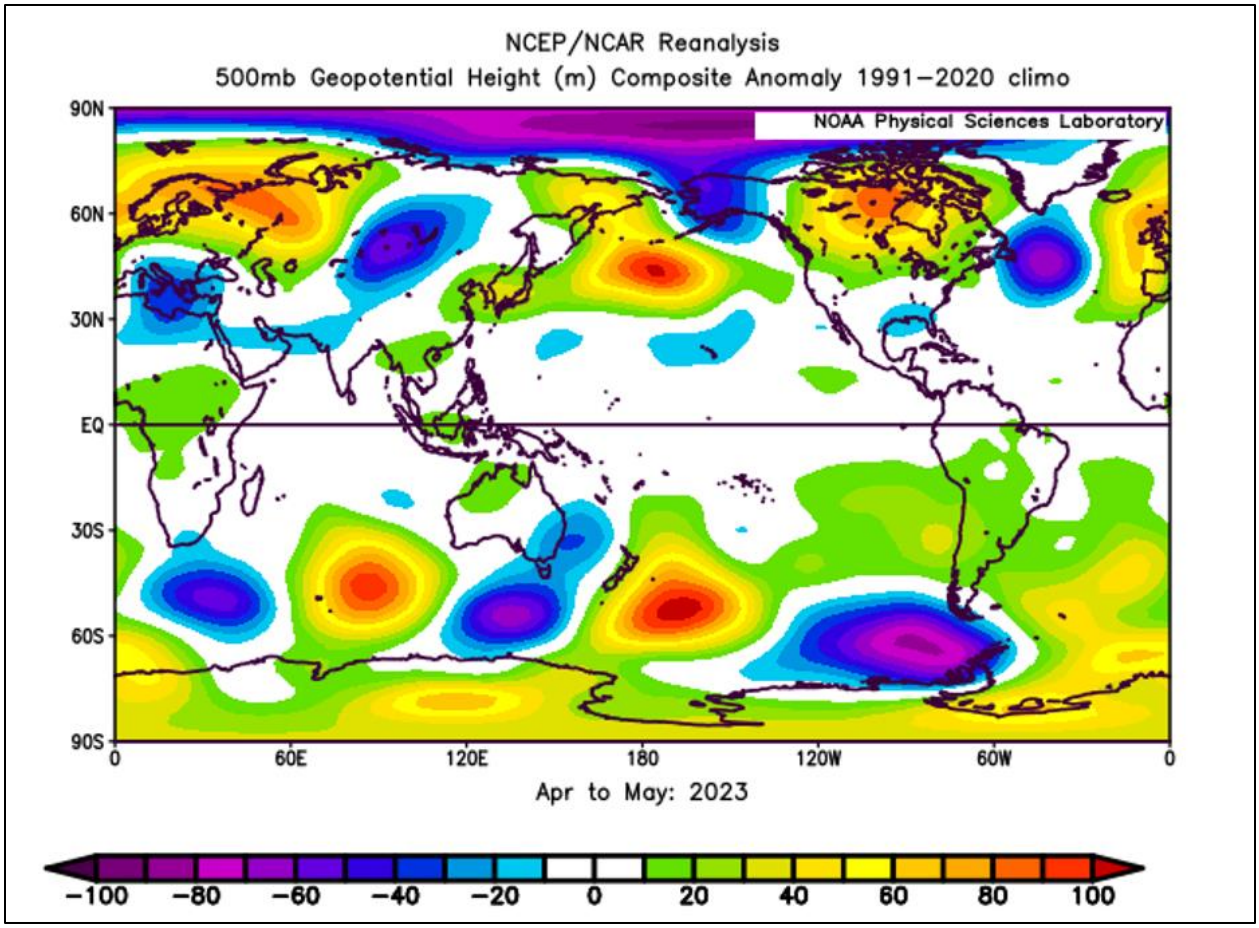

Figure 54. Global 500-mb height anomalies April to May 2023. Source: NCEP/NCAR

A large area of positive height anomalies stretched across most of Canada in the spring, indicating above-average lower troposphere temperatures during that time period. In addition, much of Canada was abnormally dry, with large areas of moderate to extreme drought from central into western Canada (**Figure 55**).

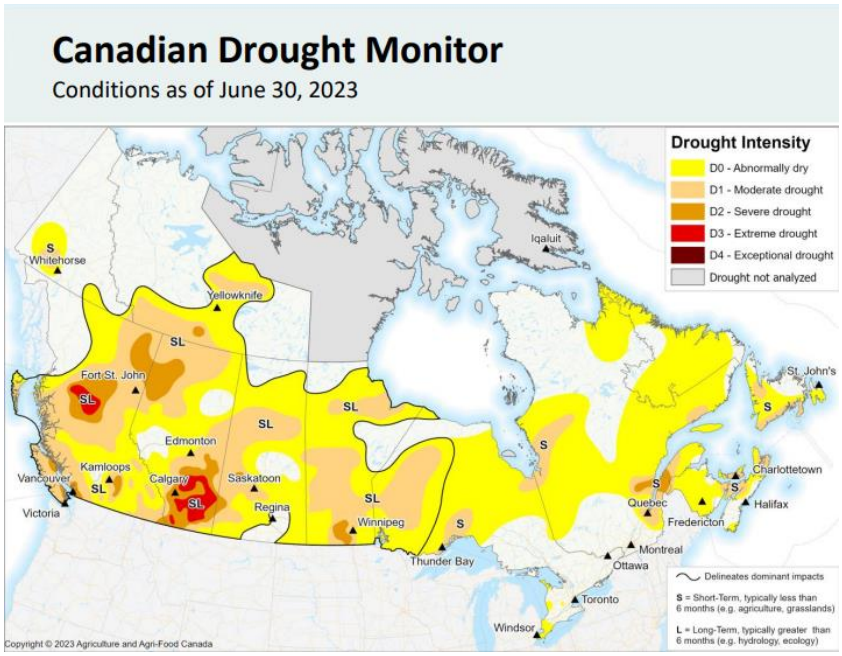

Figure 55. Drought conditions as of June 30, 2023. Source: Agriculture and Agri-Food Canada.

These conditions combined to produce an environment conducive to widespread fire activity throughout spring and summer 2023. Figure 56 shows that as of the end of February 2024, drought conditions have worsened since summer 2023 across Canada.

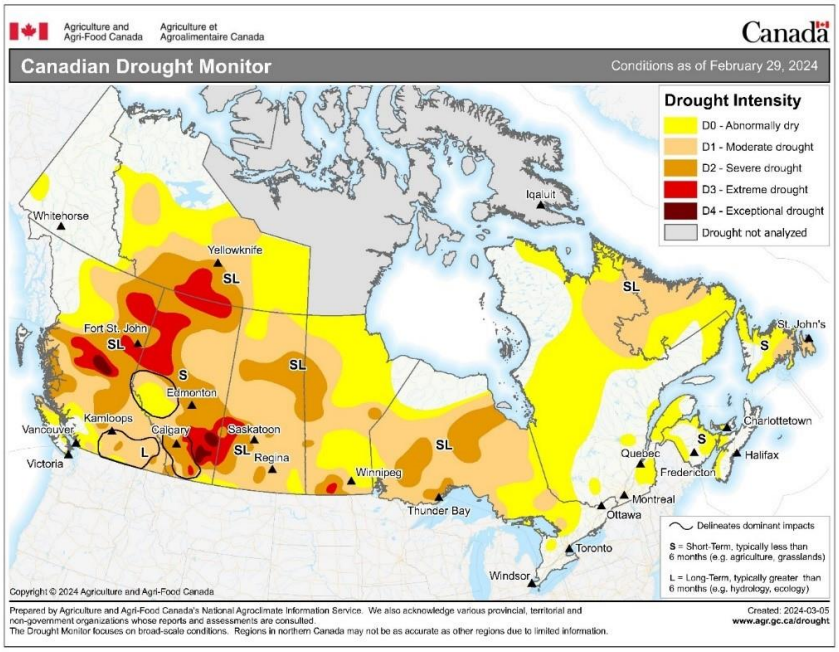

Figure 56. Canadian drought conditions as of February 29, 2024. Source: Agriculture and Agri-Food Canada.

In addition, snow cover is running below-average across much of Canada, with Quebec being the only province that has a significant portion of its region currently reporting above-average snowpack (Figure 57).

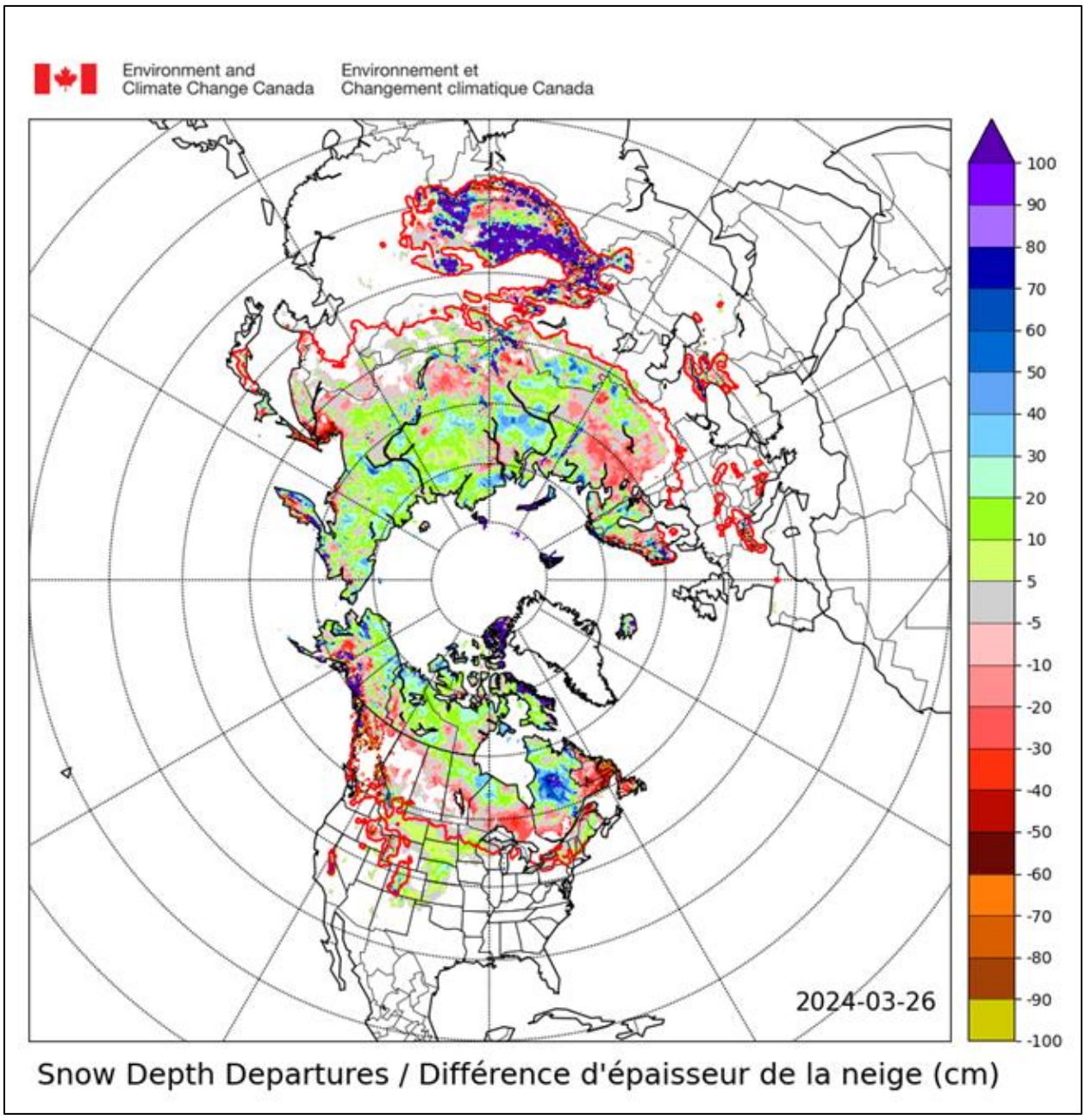

Figure 57. Snow depth departures (cm) for the northern hemisphere, as of March 26, 2024, compared to the period from 1998-1999 through 2011-2012. The thick red contour line indicates the historical location of the snowline (50% probability of snow depth of at least 2 cm). Source: Environment and Climate Change Canada.

Model forecasts from the ECMWF and CanSIPS heading into the spring and early summer agree on predicting near to slightly above-average temperatures across parts of Canada during the period from April through June 2024. However, the precipitation forecasts differ, with the CanSIPS model predicting above-average precipitation across much of the country, while the ECMWF is predicting near-average precipitation (Figure 58).

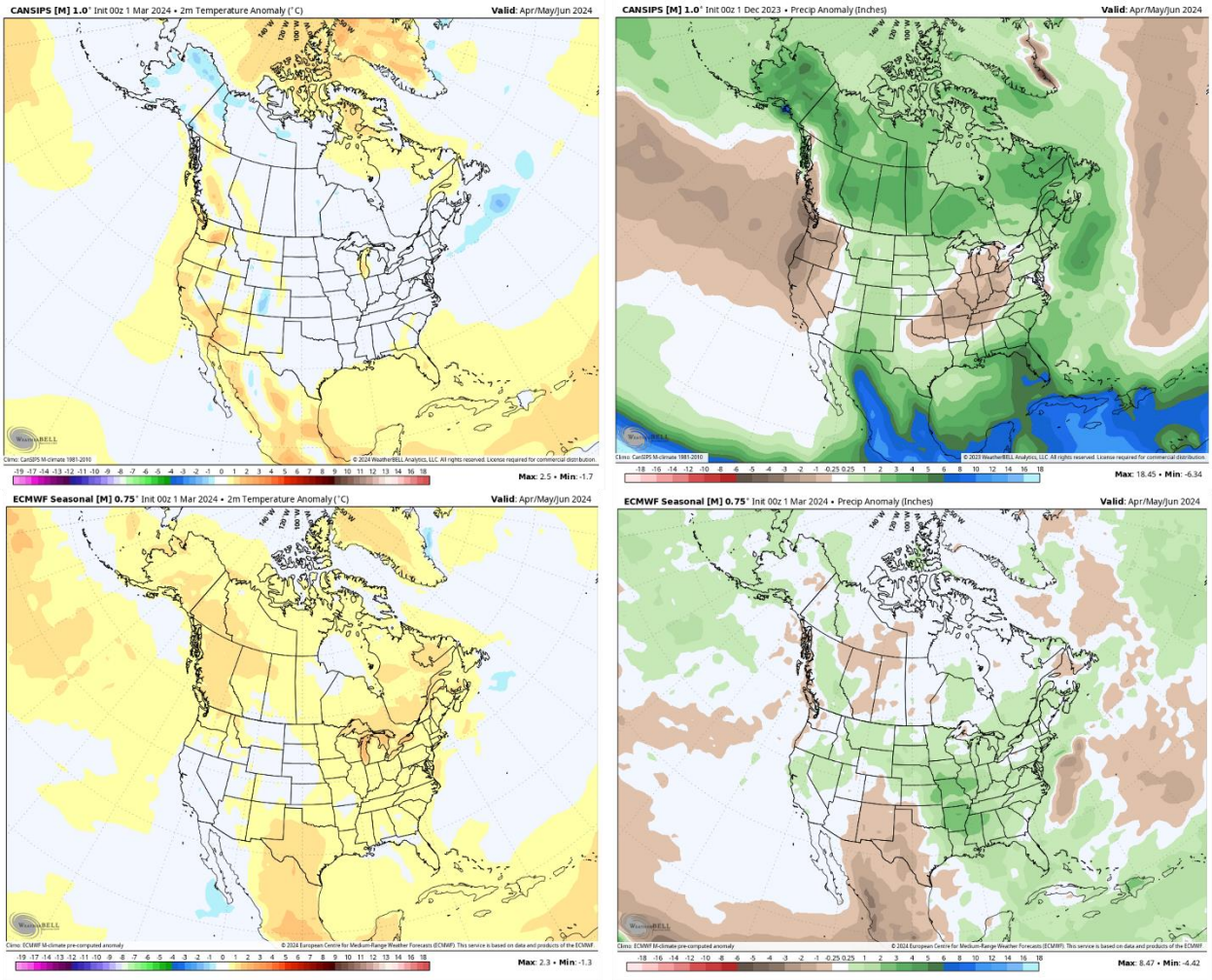

Figure 58. Temperature forecast (left), and precipitation forecast (right) for February through April 2024 from the CANSIPS model (top) and ECMWF model (bottom). Warm colors indicate a forecast for above-average temperatures, while cool colors indicate a forecast for below-average temperatures. Green colors indicate a forecast for above-average precipitation, while brown indicates a forecast for below-average precipitation. Source: WeatherBell

If the forecast from the CanSIPS model ends up verifying, above-average precipitation could improve the drought conditions in Canada, potentially reducing smoke production during summer 2024. However, increased storminess could also bring an increased threat of lightning-sparked fires if the above-average temperatures and lack of snow cover leave vegetation in a vulnerable state this

spring and summer. If the ECMWF forecast of near-average precipitation verifies and the above-average temperature forecasts verify, in light of the ongoing drought and snow cover deficit, above-average fire activity and smoke production would be expected for summer 2024.

5.7 Implications for the Summer 2024 Ozone Season in Delaware

Long-range air quality forecasting is inherently challenging due to the complexity of the interactions among the atmosphere, oceans, ice, and land. In addition, there are no linear relationships between certain climate regimes and air quality impacts. However, considering the outlooks and products discussed so far in Section 5, some general observations can be made to help inform a long-range air quality outlook.

Summarizing the methods discussed throughout Section 5, above-average temperatures are favored once again this summer in Delaware for several reasons. The first indication that temperatures will be above-average relates to the ENSO forecast. Model forecasts in NOAA's ENSO outlook favor a transition to La Niña conditions in the equatorial Pacific during summer 2024. On average over the last few decades, summers with La Niña conditions in the Pacific resulted in above-average temperatures in the Mid-Atlantic. In addition to the evidence from the ENSO forecast, the forecast from both the CanSIPS and seasonal ECMWF models is for above-average temperatures across much of the eastern United States this summer. Furthermore, long-term temperature trends indicate summers are trending warmer across the northeastern United States. Finally, CPC's forecast for the summer indicates a 40-50% chance for above-average temperatures in Delaware this summer. Due to the agreement amongst these various methods and products, Sonoma Technology meteorologists are forecasting above-average temperatures during summer 2024 in Delaware.

The precipitation forecast for summer 2024 is less certain, with ENSO analogs and forecast models predicting different outcomes for Delaware. It is likely that tropical cyclone development will be above-average this summer. However, the uncertainty in the tracks of these systems makes it challenging to predict if the tropical activity will have impacts on Delaware. Given that uncertainty, along with precipitation deficits in Delaware during previous ENSO similar years, as well as some model support for dry conditions in the region, Sonoma Technology forecasters are predicting near- to below-average precipitation in Delaware this summer.

With above-average temperatures, and near- to below-average precipitation in the forecast, Sonoma Technology meteorologists are forecasting the potential for above-average ozone production in Delaware this summer. In addition, with the potential for another active wildfire season across Canada due to the ongoing drought, forecasters at Sonoma Technology are also predicting above-average $PM_{2.5}$ AQI levels in Delaware during summer 2024, as well as further ozone enhancement from smoke. However, much of the influence of smoke will depend not only on Canadian wildfire activity, but also the long-range smoke transport patterns.