State of Delaware Final Report: Ozone and $PM_{2.5}$ Observations and Forecasts in 2024

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and Environmental Control
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Executive Summary

Key Findings

- Air quality in Delaware during summer 2024 was much improved compared with summer 2023, due in large part to the reduced influence of long-range smoke transport in 2024.
- Between May and September, ozone levels in Delaware were in the Good Air Quality Index (AQI) category on 71% of days, the Moderate category on 26% of days, and the Unhealthy for Sensitive Groups (USG) category on 3% of days.
- In February 2024, the U.S. Environmental Protection Agency (EPA) made changes to the 2012 rule on $PM_{2.5}$ concentration thresholds. The $PM_{2.5}$ concentration threshold for the Moderate AQI category was lowered from 12 $\mu g/m^3$ to 9 $\mu g/m^3$. This change resulted in the percentage of days with Moderate $PM_{2.5}$ AQI levels more than doubling in 2024, with an increase from 14% to 37% when compared with the old standard.
- Between May and September, $PM_{2.5}$ AQI levels in Delaware were in the Good category on 63% of days and the Moderate category on 37% of days. The lowering of the Moderate $PM_{2.5}$ AQI threshold partially contributed to the increase in the number of days with Moderate $PM_{2.5}$ AQI levels. All historical $PM_{2.5}$ AQI comparisons in this document are based on the updated threshold.
- However, smoke continued to be a contributing factor to poor air quality. During July and August 2024, smoke was observed over Delaware on 30 of the 31 days with Moderate $PM_{2.5}$ AQI levels. Since 2021, at least 80% of days with Moderate or higher $PM_{2.5}$ AQI levels each summer have been associated with smoke observed over Delaware.
- The most polluted month of the summer forecast season was June, when 17 days recorded Moderate-or-higher AQI levels. Ozone was the primary pollutant 11 times in June, including the lone day with USG AQI levels for the month on June 26. Above-normal temperatures and below-normal precipitation likely contributed to the increase in ozone AQI levels in June.
- Two of the four days with USG AQI levels occurred in May, when ozone AQI levels exceeded 100 on May 22 and 23. USG ozone AQI levels in May are historically very rare.
- In response to the persistent threat of smoke and its influence on both ozone and $PM_{2.5}$ in Delaware, Sonoma Technology forecasters added $PM_{2.5}$ forecasts alongside the ozone forecasts throughout the entire 2024 forecasting season.
- At the Good-to-Moderate threshold, next-day ozone forecasts were correct 69% of the time during summer 2024, with a probability of detection (POD) of 89% and a false alarm rate (FAR) of 51%. The average ozone forecast bias was +4.8 ppb, with a mean absolute error (MAE) of 7.7 ppb.

- At the Good-to-Moderate threshold, next-day $PM_{2.5}$ forecasts were correct 76% of the time, with a POD of 68% and an FAR of 33%. The average $PM_{2.5}$ forecast bias was +0.8 µg/m^3, with an MAE of 2.4 µg/m^3.
- Looking ahead to the 2025 ozone season, Sonoma Technology meteorologists predict above-normal temperatures and above-normal precipitation in Delaware during the peak of ozone season from June through August.
- While the forecast for above-normal temperatures could result in increased ozone formation in Delaware this summer, this effect is expected to be balanced by increased precipitation and the associated cloud cover.
- Canadian smoke impacts are expected to stay close to average this summer. As a result, ozone and $PM_{2.5}$ concentrations are forecast to be near-average across the Mid-Atlantic during summer 2025.

1. Air Quality Climatology 2019-2023

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

Prior to the start of Delaware's summer air quality forecast season, Sonoma Technology meteorologists review the observed AQI values for ozone and $PM_{2.5}$ from regulatory monitoring sites (**Figure 1**) across the state from past years. During this review process, climatologies of AQI levels are created using the past five years of observed ozone and $PM_{2.5}$ data. These climatologies assist Sonoma Technology meteorologists in identifying new patterns and trends in Delaware's air quality that will aid in forecast decision-making for the current air quality forecasting season.

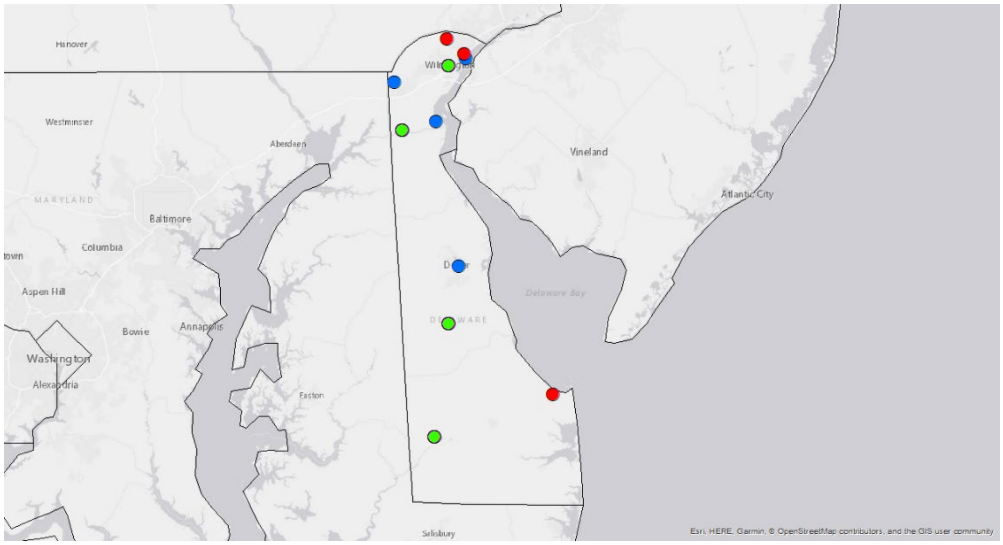

Figure 1. Active ozone and $PM_{2.5}$ monitoring sites in the state of Delaware. Red dots indicate sites that monitor ozone, blue dots indicate sites that monitor $PM_{2.5}$, and green dots indicate sites that monitor both ozone and $PM_{2.5}$.

The following sections recap the climatologies of AQI levels for ozone and $PM_{2.5}$ for the 2019-2023 period. Sonoma Technology meteorologists provide the monthly and daily distributions of past AQI values and highlight the frequency of multiday high pollution events, as defined by the AQI exceeding the National Ambient Air Quality Standards (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, longer days and warming temperatures increase ozone production. This relationship is reflected in Figure 2: days with Moderate-or-higher AQI levels become more frequent from March through July. By August and September, gradually decreasing sunlight and the gradual, seasonal reduction in temperatures result in 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 historical data shown in Figure 2, Good ozone AQI levels were observed on 84% of days. During the summer air quality forecast period, nearly 69% of days between May and September were characterized by Good AQI levels.

While Moderate-or-higher ozone AQI values have occurred as early as March and as late as November, these days are most frequent in June and July, when surface temperatures and sunlight reach their seasonal maxima. These meteorological conditions, combined with local and regional emissions, result in enhanced ground-level ozone development in Delaware.

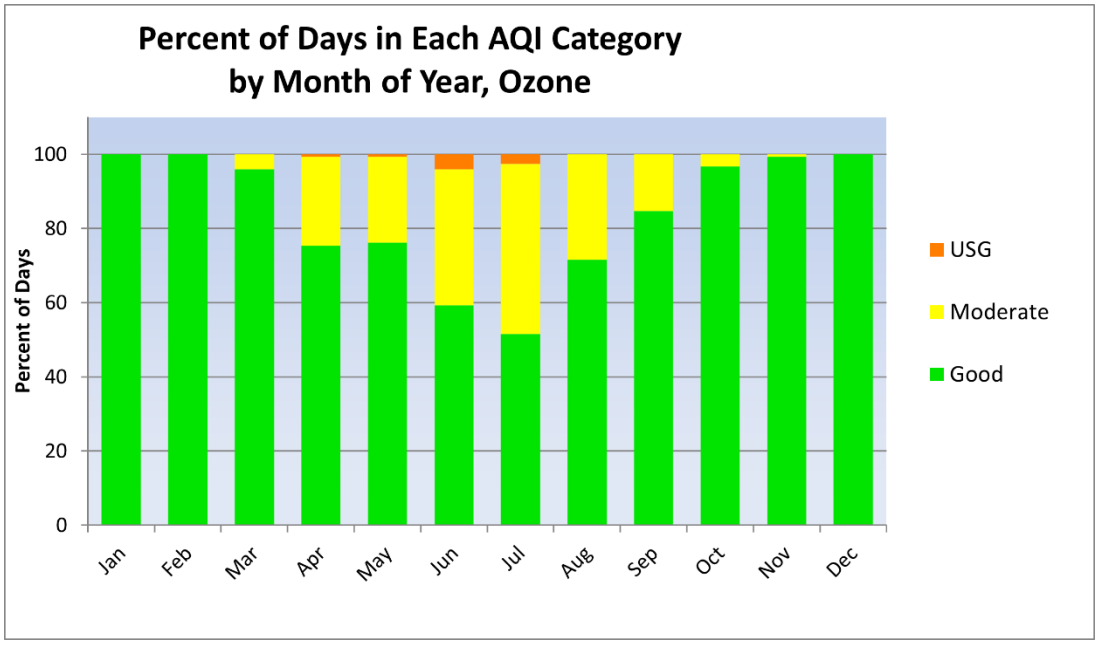

Figure 2. Percentage of days falling in each AQI category each month for ozone for 2019-2023.

While infrequent, ozone AQI values in the USG category can occur in the First State. During the five-year period from 2019-2023, USG ozone AQI levels were most frequent in June and July, with other

USG ozone days occurring in April and May. Overall, USG ozone AQI levels account for only 1% of all days during the summer air quality forecasting season.

To detect localized ozone patterns on a day-to-day basis, a climatology of ozone AQI levels based on the day of the week was also produced. Based on this climatology, Sonoma Technology meteorologists can identify which day(s) of the week may be more prone to Moderate-or-higher ozone AQI levels; such trends can be related to daily driving patterns or industrial activity that can affect local air quality.

From 2019-2023, Moderate-or-higher ozone AQI levels were most prevalent on Wednesdays (Figure 3) and generally occurred at a similar frequency on Tuesdays, Thursdays, Fridays, and Saturdays. While industrial and traffic activity trends downward on weekends, it is likely that pollutant carryover from Fridays led to a higher frequency of Moderate-or-higher ozone AQI levels on Saturdays in Delaware. Sundays and Mondays featured the fewest occurrences of Moderate-or-higher ozone AQI levels. This finding can be related to the reduction in industrial emissions and traffic that occurs over the weekend, and low pollutant carryover from Sundays into Mondays.

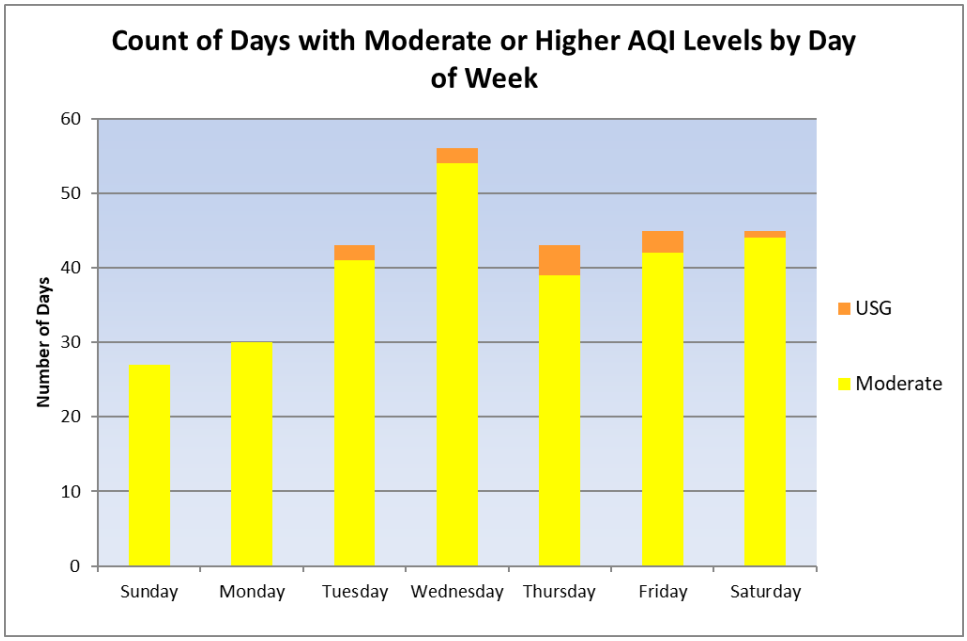

Figure 3. Number of days with Moderate-or-higher ozone AQI levels in Delaware by day of week for 2019-2023.

USG ozone events in Delaware are usually isolated occurrences; periods with multiple days of USG ozone AQI levels are rare. From 2019 to 2023, there were 12 days with USG ozone AQI levels recorded. Of these days, eight occurred on a single-day basis (Figure 4). In addition, there were two occasions where USG ozone AQI levels were recorded on back-to-back days.

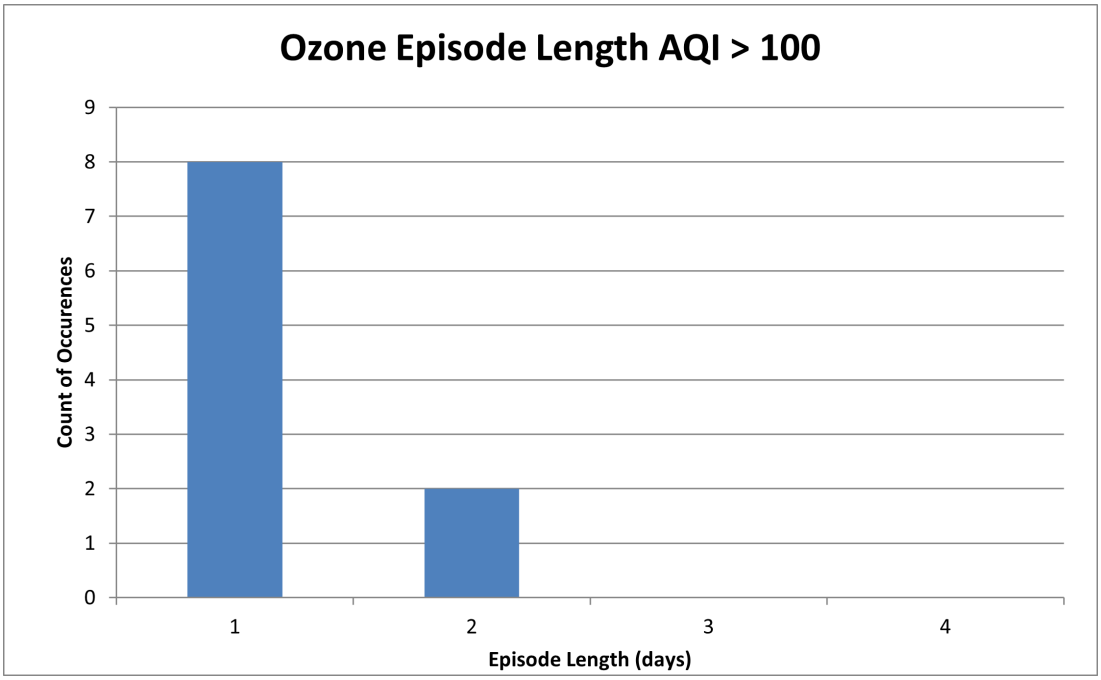

Figure 4. Count of occurrence of multiday ozone AQI levels in the USG category or higher in Delaware based on 2019-2023 data.

1.2 Climatology of $PM_{2.5}$

Throughout the year, fine particles, known as $PM_{2.5}$, impact air quality in Delaware. The sources for fine particle pollution may include local residential wood burning, industrial emissions, and long-range transport of wildfire smoke. In addition to daily ozone forecasts, $PM_{2.5}$ forecasts were issued by Sonoma Technology meteorologists from May through September 2024. As with ozone forecasting, monthly and seasonal climatologies of $PM_{2.5}$ AQI levels were developed based on 2019-2023 observed $PM_{2.5}$ AQI data in Delaware.

Based on the 2019-2023 climatology, $PM_{2.5}$ AQI levels were Good on over 60% of days (**Figure 5**), while Moderate-or-higher AQI levels were most frequent during two periods of the year, on average. The first period was November through March, when smoke from residential wood burning occurs and cold temperatures generate overnight inversions that trap smoke and other emissions near the ground. The second period was June through August, when long-range wildfire smoke transport was more likely to occur.

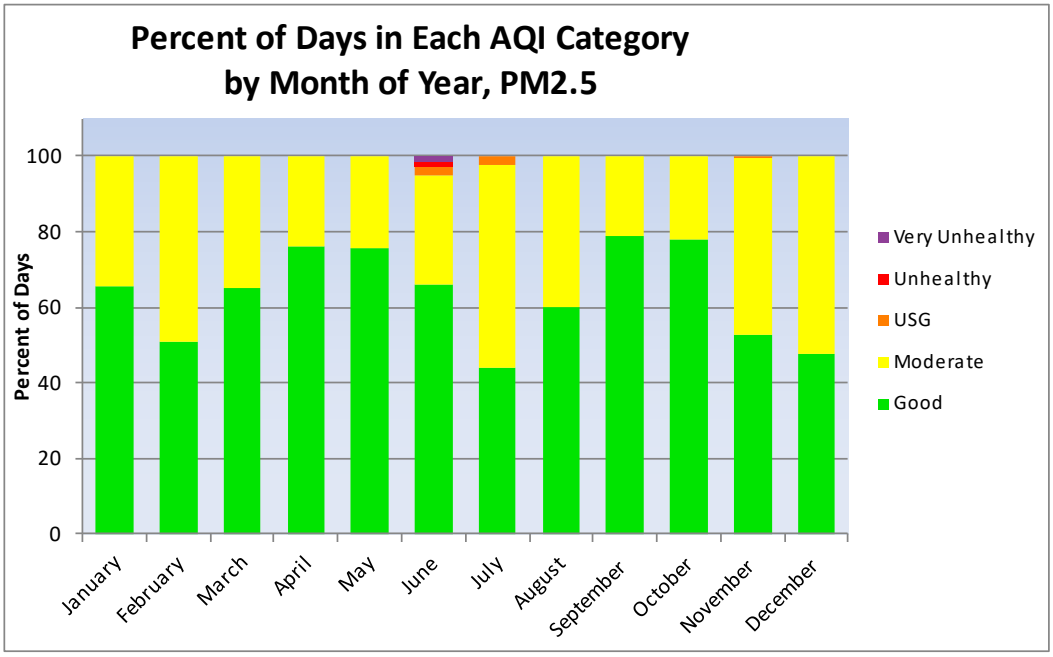

Figure 5. Monthly distribution of days falling in each AQI category based on 2019-2023 $PM_{2.5}$ data.

For the May-September forecasting season, Moderate $PM_{2.5}$ AQI levels occurred on 34% of days and USG-or-higher $PM_{2.5}$ AQI levels were recorded on roughly 1% of days. As has been shown with previous $PM_{2.5}$ climatologies, the month of July exhibited the highest percentage of days (i.e., 56%) with Moderate-or-higher $PM_{2.5}$ AQI levels from 2019-2023. Wednesdays and Thursdays were characterized by the highest number of days with Moderate-or-higher AQI levels for $PM_{2.5}$ during the 2019-2023 period (Figure 6). Most other days throughout the week had a similar number of Moderate-or-higher $PM_{2.5}$ AQI levels, with Saturdays recording notably fewer days with Moderate-or-higher $PM_{2.5}$ AQI levels.

USG-or-higher $PM_{2.5}$ AQI levels were recorded in Delaware 13 times during the 2019-2023 period. Ten of the days with USG-or-higher AQI levels for $PM_{2.5}$ were recorded in June and July 2023, when long-range transport of wildfire smoke from Canada degraded air quality across a large portion of the eastern United States, including the Mid-Atlantic region.

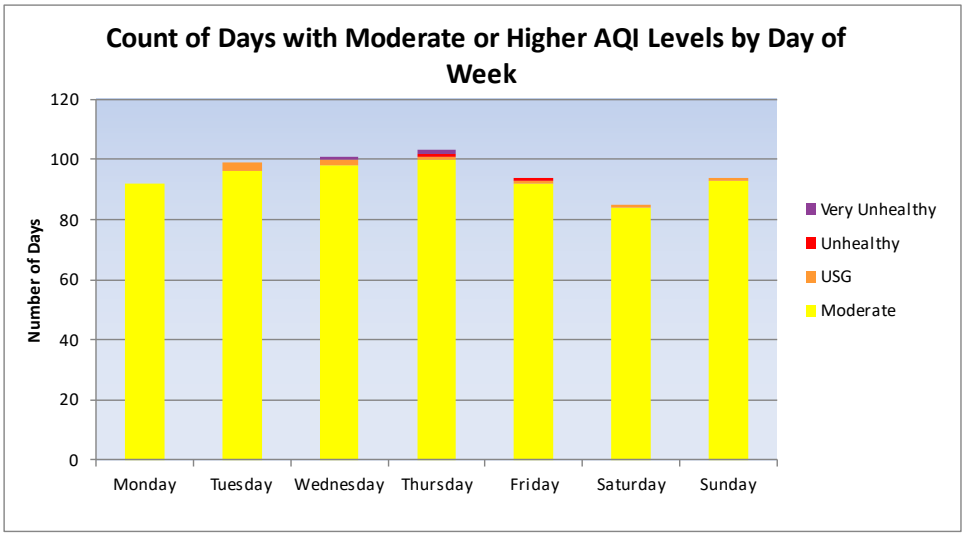

Figure 6. Number of Moderate-or-higher $PM_{2.5}$ AQI levels in Delaware by day of week based on 2019-2023 data.

With the increase in the number of days with $PM_{2.5}$ AQI levels exceeding the NAAQS, Sonoma Technology meteorologists examined whether these particle pollution events were single-day occurrences or multiday episodes. The data over the last five years indicate that while most days with $PM_{2.5}$ AQI over 100 were single-day events, there were also several multiday periods (**Figure 7**). On one occasion, $PM_{2.5}$ AQI exceeded 100 on two straight days (July 20-21, 2021). During summer 2023, there were two separate four-day periods of USG-or-higher $PM_{2.5}$ AQI levels (June 6-9 and June 28-July 1).

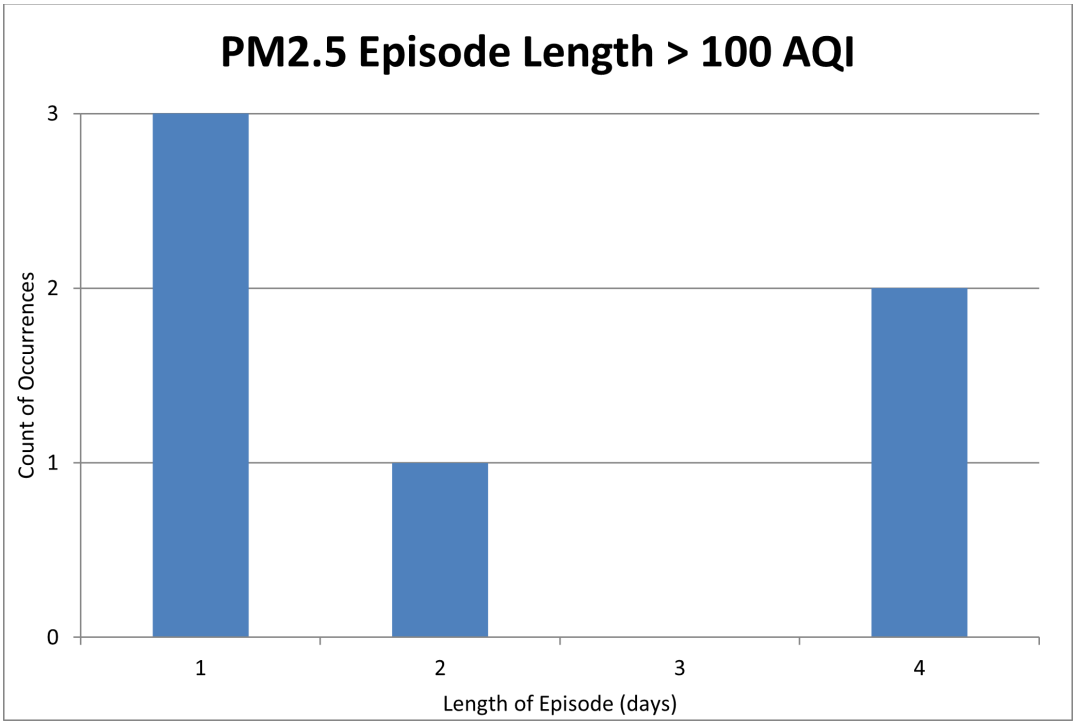

Figure 7. Number of occurrences of multiday spans of $PM_{2.5}$ AQI levels falling in the USG category or higher in Delaware based on 2019-2023 data.

2. Meteorological and Air Quality Observations in 2024

Weather can strongly influence air quality, and subsequently AQI levels, in Delaware throughout the year. During the summer, sunny and hot conditions combine with regional and local emissions to enhance the production of ground-level ozone. Wind patterns can also influence AQI values via the transport of pollutants and smoke into the state, or by allowing pollutants to accumulate across the state over time. On the other hand, cool, cloudy days tend to reduce ozone development, and days with gusty winds can effectively disperse pollutants and keep AQI levels in the Good category.

The following section reviews the prevailing meteorological conditions observed in Delaware during the 2024 summer air quality forecasting season based on data from National Weather Service Automated Surface Observation Systems (ASOS) climate sites. In addition, a summary of observed ozone and $PM_{2.5}$ AQI values is provided, including a comparison between AQI levels of this forecast season and previous ones.

2.1 May-September 2024 Meteorological Review

For the May through September 2024 period, average temperatures around the Mid-Atlantic region were generally 1-2°F warmer than the 1991-2020 long-term average (**Figure 8**). In the state of Delaware, the average temperature for the summer 2024 forecast season was 0.8°F above normal at the Wilmington ASOS site (KILG), and 0.4°F above normal at the Georgetown ASOS site (KGED).

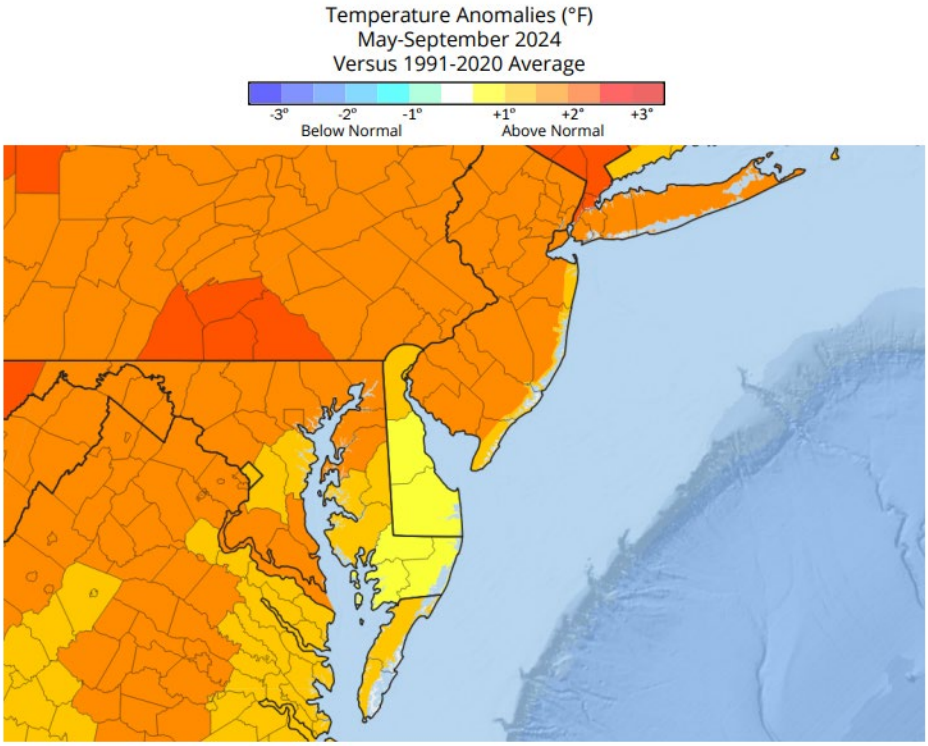

Figure 8. May-September 2024 average temperature anomaly map.

Based on historical weather data, July is the warmest month of the summer forecast season for both KILG and KGED. This trend continued in summer 2024, with July being the warmest month of the forecasting season at both ASOS sites. Like the previous summer, one factor resulting in July being the warmest month of the summer 2024 forecast season was the occurrence of daytime highs at or above the 90°F threshold. For July 2024, KILG (Table 1) and KGED (Table 2) recorded 12 days during which temperatures met or exceeded 90°F. Additionally, days at or above 90°F were most frequent in July for both ASOS sites.

Table 1. 2024 monthly meteorological summary for the Wilmington-New Castle Airport (KILG) site.

Wilmington (KILG)	May	June	July	August	September
Average Temperature (°F)	65.3	74.5	79.1	75.0	68.7
Average Temperature Departure from Normal (°F)	+1.8	+1.9	+1.5	-0.8	-0.2
Total Precipitation (inches)	2.17	6.50	1.56	6.63	0.33
Precipitation Departure from Normal (inches)	-1.40	+1.83	-2.85	+2.65	-4.05
Number of Clear Days	12	20	21	17	15
Number of 90°F+ Days	0	4	12	7	0
Average Wind Speed (mph)	7.3	8.6	7.3	7.2	7.6
Average Wind Speed Departure from Normal (mph)	-1.5	+0.5	-0.3	0.0	-0.1

Table 2. 2024 monthly meteorological summary for the Georgetown (KGED) site.

Georgetown (KGED)	May	June	July	August	September
Average Temperature (°F)	65.3	75.1	79.4	76.0	69.8
Average Temperature Departure from Normal (°F)	+0.8	+1.5	+0.8	-0.7	-0.5
Total Precipitation (inches)	2.09	2.75	8.90	2.07	0.29
Precipitation Departure from Normal (inches)	-1.54	-1.32	+4.76	-1.92	-4.25
Number of Clear Days	12	23	17	19	12
Number of 90°F+ Days	0	6	12	9	0
Average Wind Speed (mph)	6.7	6.9	6.1	5.9	6.8
Average Wind Speed Departure from Normal (mph)	-0.9	+0.4	0.0	+0.6	+0.7

Cumulative rainfall totals for May-September 2024 were drier than normal for much of the Mid-Atlantic region (Figure 9), with seasonal precipitation generally being 2-8 inches below normal.

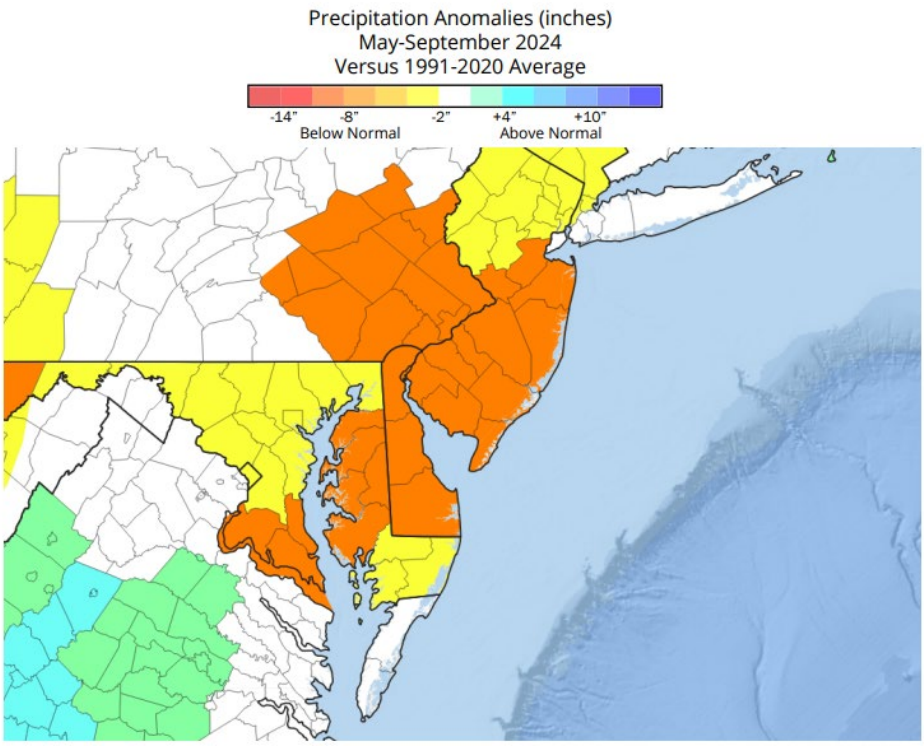

Figure 9. May-September 2024 precipitation anomaly map.

KILG recorded 17.19 inches of precipitation during the 5-month period, which was close to 4 inches below average. KGED recorded 16.10 inches of rainfall during the same period, which was over 4 inches below average. September was the driest month of the summer forecast season for both ASOS sites, with each site registering its driest September on record. The wettest months of summer 2024 varied by location. For KILG, August was the wettest month of the May-September period with 6.63 inches of rainfall recorded, which was over 2.5 inches above the August average. For KGED, July was the wettest month of the summer, when 8.90 inches of rain was recorded. Two heavy rain events led to the anomalously high July precipitation total at KGED. On July 12, KGED recorded a daily record rainfall of 4.03 inches. On July 22, 3.47 inches of rain was measured, setting another daily record. Due to these two heavy rainfall events, KGED registered its fifth-wettest July on record.

Overall, the warm, dry pattern that persisted during the summer 2024 forecast season can be partially attributed to stronger-than-normal high pressure aloft over Delaware (**Figure 10**). This aloft weather pattern promoted sinking air from the upper atmosphere to the surface, known as subsidence. As a result of this subsidence, compressional heating occurred in the lower atmosphere, which yielded warm temperatures. Furthermore, sinking air aloft suppressed cloud development, with more sunny days and fewer instances of showers and thunderstorms.

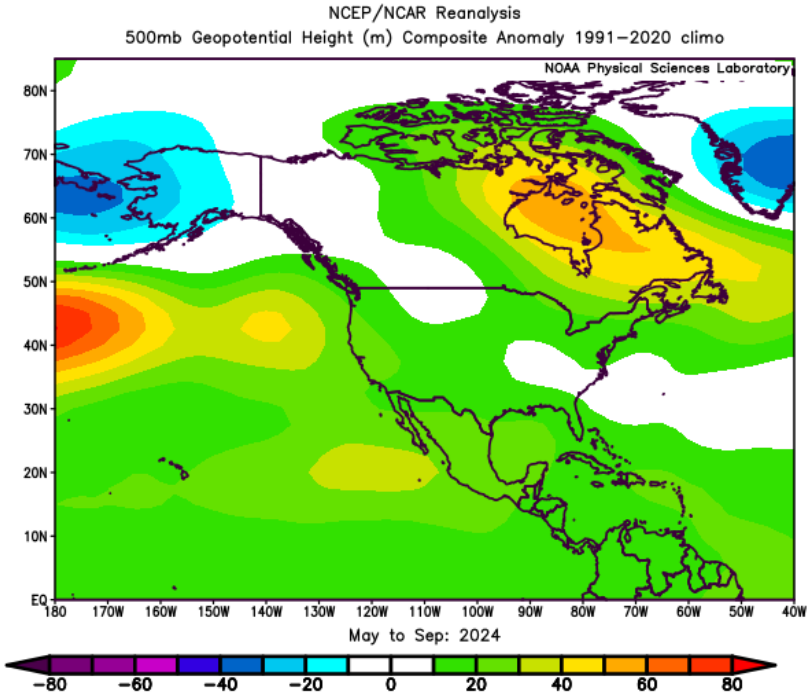

Figure 10. 500-mb geopotential height anomalies for the May-September 2024 period. The green to orange colors represent positive height anomalies that denote stronger-than-normal high pressure in the upper atmosphere.

2.2 Summer 2024 Daily Maximum AQI Observations

The summer air quality forecast season for the state of Delaware covers a total of 153 days. **Figure 11** provides a time series of observed maximum AQI values during the 2024 summer forecast season, and **Figure 12** shows the percentage of days falling in each AQI category for the 2022-2024 summer forecast seasons. Based on data from air quality monitoring sites shown in Figure 1, daily maximum AQI levels for May-September 2024 were Good on 83 days, Moderate on 66 days, and USG on 4 days. Air quality conditions in summer 2024 were better than those during the previous summer, but slightly worse than those in summer 2022.

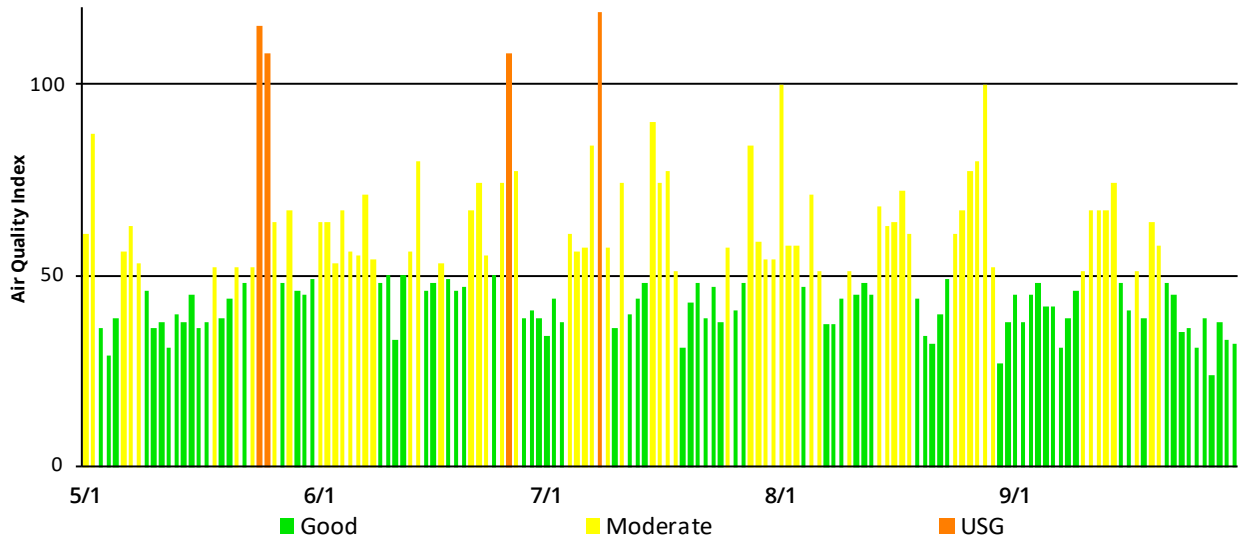

Figure 11. Daily maximum observed AQI values observed during the summer 2024 forecast season in Delaware.

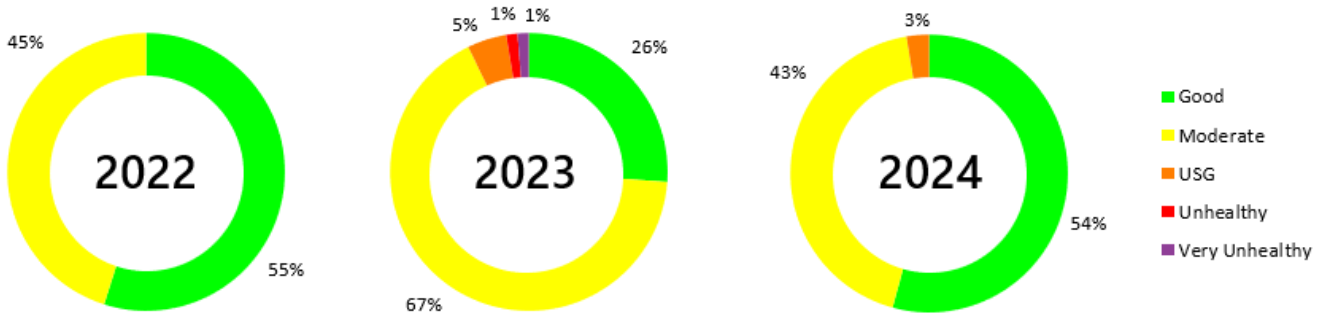

Figure 12. Percent of days with daily maximum AQI levels (including both ozone and $PM_{2.5}$) in each category during the summer 2022-2024 forecast seasons in Delaware.

Table 3 lists the monthly breakdown of daily maximum AQI values for the state of Delaware. Half of the season's NAAQS exceedances occurred in May, when ozone AQI levels exceeded 100 on May 22 and 23. This event is anomalous when compared with the 2019-2023 ozone climatology shown in Figure 2. Based on air quality data from the last five years, May days with USG ozone AQI levels occur less than 1% of the time. Additional details on the May 22-23 ozone event can be found in Section 3.

The most polluted month of the summer forecast season was June, when 17 days recorded Moderate-or-higher AQI levels. Ozone was the primary pollutant 11 times in June, including on June 26, the lone day with USG AQI levels. Despite the increased number of instances of air pollution, June 2024 witnessed a 19% decrease in Moderate-or-higher AQI levels compared with the previous June.

Table 3. Number of days with daily maximum AQI levels by month during the summer 2024 forecast season in Delaware.

Month	Good	Moderate	USG
May	19	10	2
June	13	16	1
July	15	15	1
August	14	17	0
September	22	8	0

September was the cleanest month of summer 2024. Good air quality was recorded on 22 of the 30 days during the month, as below-average temperatures and the seasonal reduction in sunlight inhibited ozone production. Furthermore, average wind speeds at KILG and KGED during September 2024 were near or above average, indicating enhanced dispersion of pollutants. Evidence of enhanced dispersion can be found in September 2024's daily AQI values for $PM_{2.5}$, which fell in the Good category on all 30 days.

2.3 Smoke Impacts on Delaware's Air Quality During Summer 2024

Summer air quality in Delaware can be impacted by the long-range transport of wildfire smoke. Wildfire smoke contains a variety of pollutants, including $PM_{2.5}$ and volatile organic compounds (VOCs). Each of these elements can add to existing $PM_{2.5}$ concentrations from local sources, as well as alter ozone chemistry to increase ozone formation. Given the importance smoke has on Delaware's air quality, Sonoma Technology meteorologists compared satellite data from the National Oceanic and Atmospheric Administration (NOAA) to determine the presence of smoke in the First State for summer 2024 and previous forecast seasons.

During the May-September 2024 period, NOAA satellites detected smoke over Delaware on 104 out of 153 days, with smoke sources ranging from wildfires in western Canadian and the Pacific Northwest to seasonal agricultural burning in the continental United States. Summer 2024 had fewer days with smoke detections over Delaware compared with the previous summer, which led to better air quality. However, summer 2021 and summer 2022 had fewer smoke days and better air quality compared with summer 2024.

Using the maximum AQI levels across both ozone and $PM_{2.5}$, 55 out of the 70 days with Moderate-or-higher AQI levels during summer 2024 (79%) had smoke analyzed over the state (**Figure 13**). On 36 out of the 44 days with Moderate-or-higher ozone AQI levels (82%), NOAA satellites analyzed smoke over Delaware. However, smoke's influence on ozone days with Moderate-or-higher ozone

AQI levels was decreased in summer 2024 compared with summer 2023, when smoke days were more frequent.

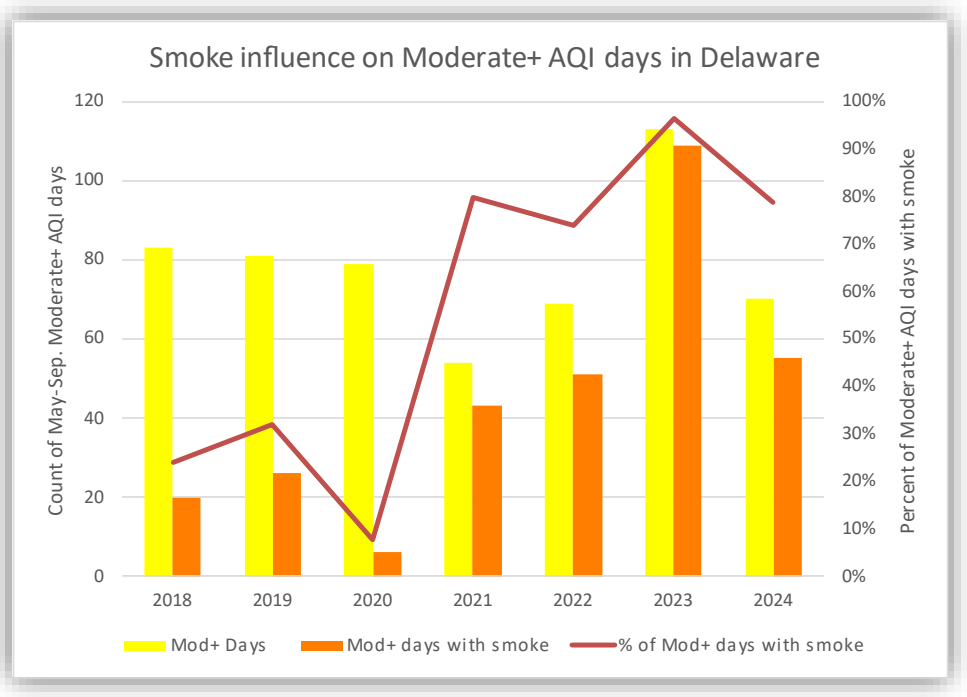

Figure 13. Influence of smoke on days with Moderate-or-higher maximum AQI levels in Delaware from 2018-2024.

On the 56 days with Moderate-or-higher $PM_{2.5}$ AQI levels this past summer, smoke was analyzed in Delaware on 45 days (80%). Smoke influence on days with Moderate-or-higher $PM_{2.5}$ AQI levels in summer 2024 was less prevalent than during the previous three summers (Table 4), but more frequent than each summer forecast season from 2018 to 2020.

Table 4. Number of smoke detections on days with Moderate-or-higher $PM_{2.5}$ AQI levels in Delaware from 2018-2024.

Year	Days with Moderate+ $PM_{2.5}$ AQI Levels	Days with Moderate+ $PM_{2.5}$ AQI Levels with Smoke	Percent of Days with Moderate+ $PM_{2.5}$ AQI Levels with Smoke
2018	65	20	31%
2019	60	23	38%
2020	46	5	11%
2021	32	28	88%
2022	47	38	81%
2023	110	106	96%
2024	56	45	80%

2.4 Summer 2024 Daily Ozone AQI Observations

Ground-level ozone observations in the state of Delaware were in the Good AQI category on 71% of days during the May-September 2024 period (Figure 14). Moderate AQI levels were recorded 26% of the time, and USG AQI levels occurred on 3% of days. There were more days with USG ozone AQI levels in summer 2024 versus the previous two summers. However, days with Good ozone AQI levels in summer 2024 were more frequent than during the previous two summers.

When compared with the 2019-2023 ozone climatology shown in Figure 2, days with Moderate-or-higher ozone AQI levels in summer 2024 decreased by 6%. While May through August witnessed fewer days with Moderate-or-higher ozone AQI levels compared with the climatology, September was the exception. During September 2024, 23% of days featured Moderate ozone AQI levels. This result marks a 40% increase compared with the 2019-2023 ozone climatology.

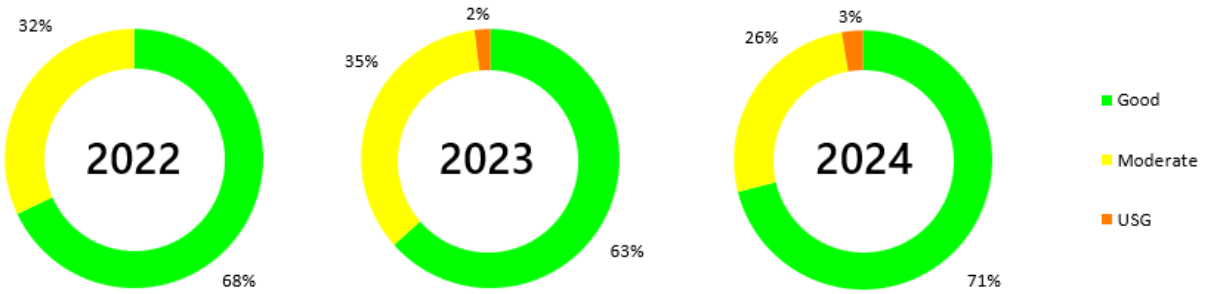

Figure 14. Percent of days with daily maximum ozone AQI levels in each AQI category for the 2022-2024 Delaware summer forecast seasons.

June featured 12 days with Moderate-or-higher ozone AQI levels, which was the most of any month during the May-September 2024 period. As shown in Table 1 and Table 2, June was the warmest month of the summer based on the average temperature departure from normal. The combination of warm temperatures, along with the presence of smoke on 67% of days with Moderate-or-higher ozone AQI levels in June, enhanced ozone formation in Delaware.

Figure 15 shows a site-by-site comparison of ozone AQI levels for the 2024 summer forecast season, and Table 5 lists a percentage breakdown of AQI categories for each ozone monitoring site in the First State. The Lewes ozone monitoring site was the cleanest during the summer 2024 forecasting season. The ocean's influence in Lewes leads to cooler temperatures, stronger winds, and better air quality compared with other Delaware ozone sites.

Moderate-or-higher ozone AQI levels were most prevalent at the Bellevue State Park (BSP) and Brandywine Creek State Park (BCS) monitoring stations, where 25% of days featured AQI levels greater than 50. USG ozone AQI levels were observed at the BSP, BCS, and MLK Boulevard (MLK) monitoring stations during summer 2024. These sites are located near major highways and in between metropolitan areas, which make them prone to local and regional emissions sources and subsequently higher ozone AQI levels compared with other ozone monitoring sites across the state.

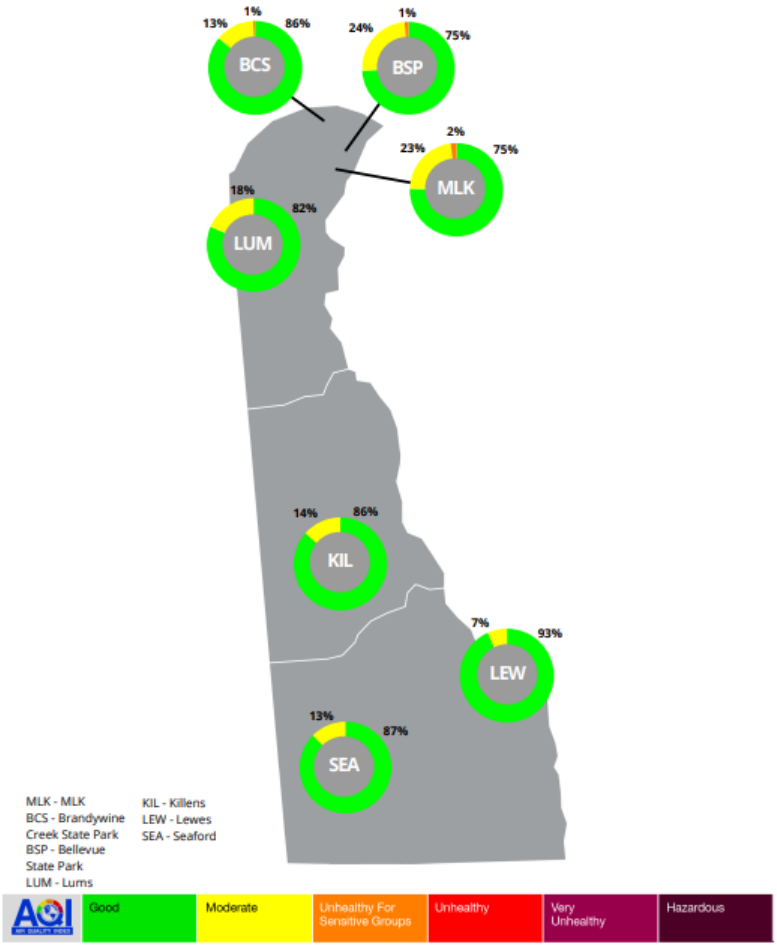

Figure 15. Percentage of days with daily maximum ozone AQI levels falling in each AQI category during the 2024 summer forecast season.

Table 5. Percent of days falling in each AQI category for ozone AQI levels by site for summer 2024. Station abbreviations from Figure 15 appear in parentheses.

Monitoring Site	Good	Moderate	USG
MLK Boulevard (MLK)	75%	23%	2%
Bellevue State Park (BSP)	75%	24%	1%
Brandywine Creek State Park (BCS)	86%	13%	1%
Lums (LUM)	82%	18%	0%
Killens (KIL)	86%	14%	0%
Seaford (SEA)	87%	13%	0%
Lewes (LEW)	93%	7%	0%

All four days with USG AQI levels during summer 2024 occurred in New Castle County. However, USG-or-higher ozone AQI levels remain infrequent across Delaware over the past decade (Figure 16). Ozone exceedances did not occur in Kent or Sussex counties in summer 2024, which is a return to a similar pattern observed dating back to 2019. In summer 2023, NAAQS exceedances in these two counties occurred due to the impacts of long-range smoke transport into central and southern Delaware.

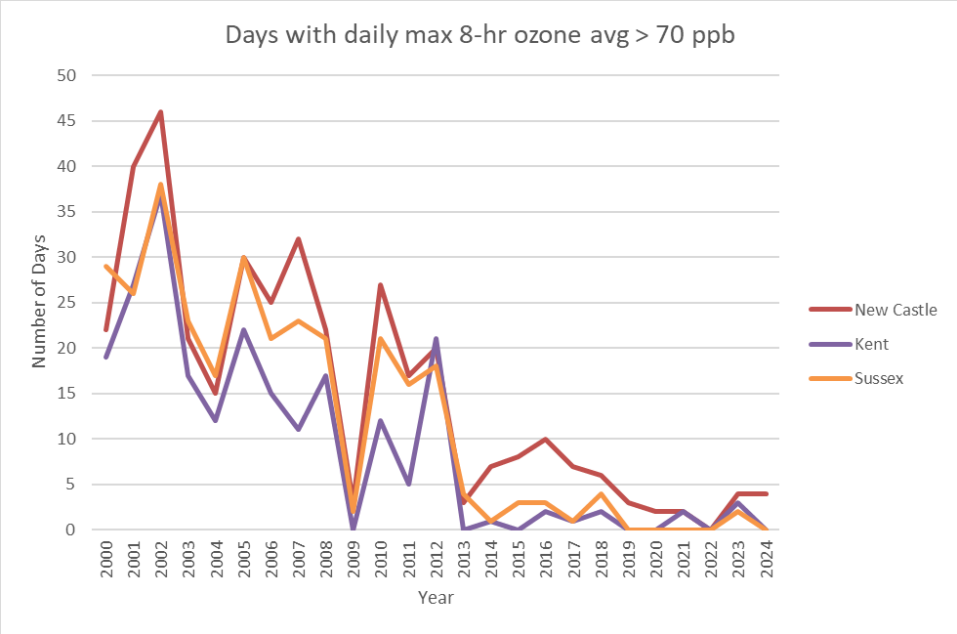

Figure 16. Year-to-year frequency of ozone exceedances by county. Source: U.S. EPA Air (https://www.epa.gov/outdoor-air-quality-data).

2.5 Summer 2024 Daily $PM_{2.5}$ AQI Observations

During the May-September 2024 period, daily $PM_{2.5}$ AQI levels across Delaware (Figure 17) were in the Good category 63% of the time and the Moderate category on 37% of the time. No days with USG-or-higher AQI levels for $PM_{2.5}$ were recorded in summer 2024. $PM_{2.5}$ AQI levels in summer 2024 were better than those in summer 2023 but slightly worse than those in summer 2022. During summer 2024, the number of days with Good $PM_{2.5}$ AQI levels increased to 97 days, compared to 43 days the previous summer; the number of days with Moderate-or-higher $PM_{2.5}$ AQI levels in summer 2024 decreased from 72% to just 37% compared with summer 2023.

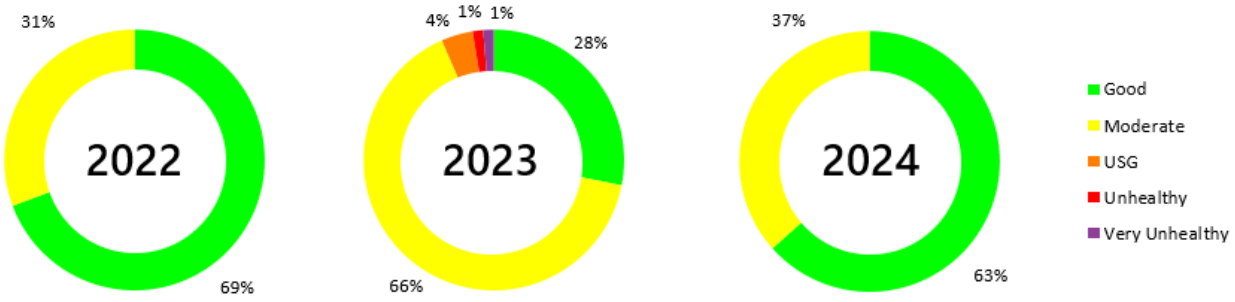

Figure 17. Percent of days with daily maximum $PM_{2.5}$ AQI levels in each AQI category for the 2022-2024 Delaware summer forecast seasons.

The influence of smoke on $PM_{2.5}$ AQI levels was most prevalent in July and August. Smoke was observed on 30 out of Delaware's 31 days with Moderate $PM_{2.5}$ AQI levels within that two-month period. In addition to the Newark monitoring site's proximity to regional emission sources, smoke was likely also a major contributor to $PM_{2.5}$ AQI levels in summer 2024 being slightly worse than summer 2022 (the Newark site did not report to AirNow in 2022).

Overall, summer 2024 $PM_{2.5}$ AQI levels were slightly worse than those in the 2019-2023 $PM_{2.5}$ climatology shown in Figure 5. During the last five years, $PM_{2.5}$ AQI values in Delaware from May-September were on average Moderate or higher on 35% of days; $PM_{2.5}$ AQI levels recorded across Delaware during the same period in 2024 were Moderate or higher on 37% of days.

Figure 18 provides a site-by-site comparison of $PM_{2.5}$ AQI values in the First State, and Table 6 lists a percentage breakdown of AQI categories for each $PM_{2.5}$ monitoring site. Around 70-80% of the time, Good air quality was present at most sites. The outlier site during summer 2024 was Lums, where 89% of days had Good AQI levels.

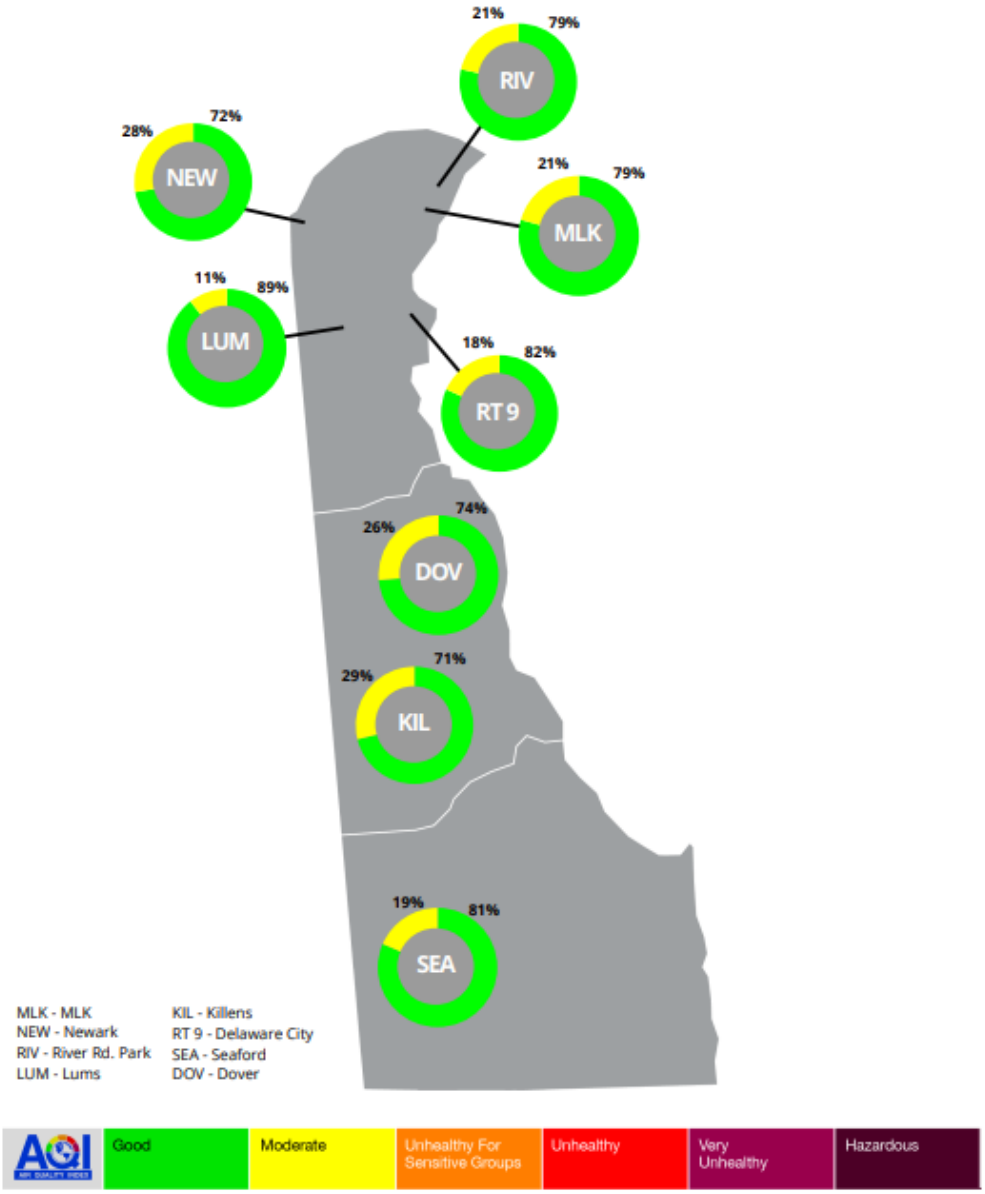

Figure 18. Percentage of days with daily maximum $PM_{2.5}$ AQI levels falling in each AQI category during the 2024 summer forecast season.

Table 6. Percentage of days with daily maximum AQI levels falling in each AQI category for $PM_{2.5}$ by site for summer 2024. Station abbreviations from Figure 18 appear in parentheses.

Monitoring Site	Good	Moderate
MLK Boulevard (MLK)	79%	21%
River Rd. Park (RIV)	79%	21%
Delaware City (RT 9)	82%	18%
Lums (LUM)	89%	11%
Killens (KIL)	71%	29%
Seaford (SEA)	81%	19%
Dover (DOV)	74%	26%
Newark (NEW)	72%	28%

2.6 Impact of $PM_{2.5}$ Threshold Rule Change on Summer 2024 Delaware $PM_{2.5}$ AQI levels

In February 2024, the EPA made changes to the 2012 rule on $PM_{2.5}$ concentration threshold values (Table 7). **Under the new rule**,[1] which went into effect on May 6, the $PM_{2.5}$ concentration threshold for the Moderate AQI category was lowered from 12 µg/m^3 to 9 µg/m^3. Threshold changes were also made for the Very Unhealthy (from 150.5 µg/m^3 to 125.5 µg/m^3) and Hazardous (from 250.5 µg/m^3 to 225.5 µg/m^3) AQI categories. With the new thresholds in place, daily $PM_{2.5}$ observations are now considered Moderate when the 24-hour average concentration is greater than or equal to 9.1 µg/m^3 (51 AQI) and less than or equal to 35.4 µg/m^3 (100 AQI).

Table 7. Comparison of $PM_{2.5}$ concentration threshold values between the 2012 and 2024 EPA rules. AQI categories with changes to concentration threshold values are bolded.

AQI Category	2012 thresholds (µg/m^3)	2024 thresholds (µg/m^3)
Good	0.0-12.0	0.0-9.0
Moderate	12.1-35.4	9.1-35.4
USG	35.5-55.4	35.5-55.4
Unhealthy	55.5-150.4	55.5-125.4
Very Unhealthy	150.5-250.4	125.5-225.4
Hazardous	250.5-350.4 and 350.5-500.0	225.5+

[1] https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-air-quality-index-fact-sheet.pdf

The 2024 $PM_{2.5}$ rule change was not triggered by worsening air quality and increasing wildfire smoke impacts across the country. Instead, the EPA rule change was influenced by recent studies of the health impacts of exposure to $PM_{2.5}$. These latest studies resulted in the EPA examining the 2012 rule and adjusting the $PM_{2.5}$ thresholds to match the current scientific thinking on the effects of particle pollution on health.

Given the lowering of the Moderate $PM_{2.5}$ AQI threshold to 9 µg/m^3, the number of observed days with Moderate $PM_{2.5}$ AQI levels will increase. This fact was evident with the 2019-2023 $PM_{2.5}$ climatology shown in Section 2.4, which exhibited a larger number of days with Moderate $PM_{2.5}$ AQI levels compared with previous Delaware end-of-season reports. To further highlight the impact that the $PM_{2.5}$ threshold change will have on air quality reporting and forecasting in Delaware, Sonoma Technology meteorologists compared the summer 2024 observed $PM_{2.5}$ AQI levels using the rules from both 2012 and 2024 (Figure 19).

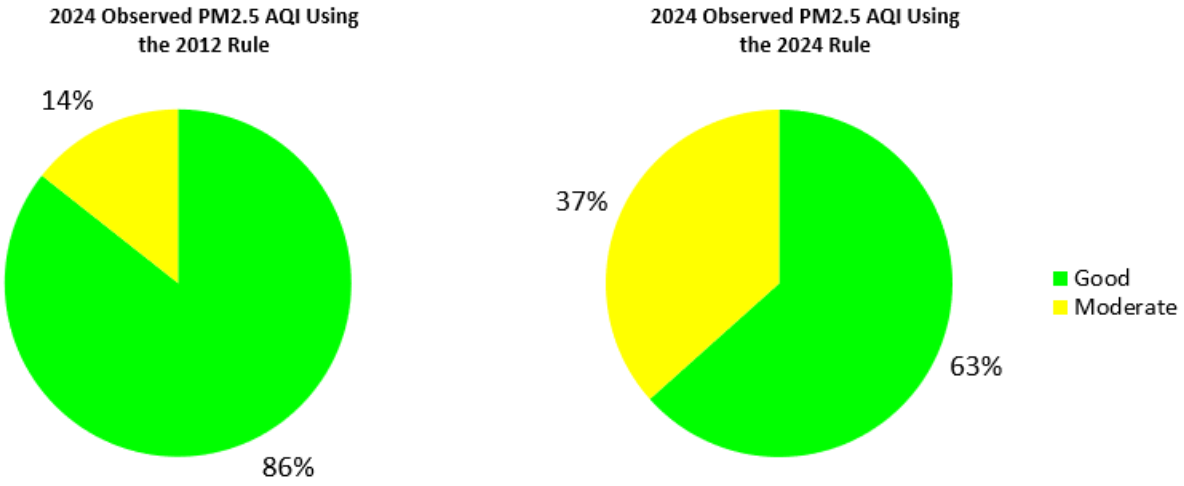

Figure 19. Percentage of days in 2024 with daily maximum $PM_{2.5}$ AQI levels falling in the Good and Moderate AQI categories for the Delaware 2024 summer forecast season based on the 2012 rule and 2024 rule.

Using the 2012 rule, the 2024 summer forecast season would have recorded 131 days with Good AQI levels (86%), and 22 days with Moderate AQI levels (14%). However, with the 2024 rule in place, there were 56 observed days with Moderate AQI levels in Delaware for the May-September 2024 period (37%). Because of EPA's 2024 rule change, Sonoma Technology meteorologists will be closely scrutinizing daily $PM_{2.5}$ forecasts that may be issued close to the 9 µg/m^3 threshold and determining whether increased emissions or background conditions typical for Delaware will be impacting air quality levels.

3. Meteorological Analysis of Days with High AQI Levels in Summer 2024

3.1 Introduction

Based on the daily maximum AQI levels across all Delaware air quality monitoring sites, four days with USG AQI levels were recorded during summer 2024. Ozone was the primary pollutant on all four occasions, and two of the four days occurred in late May. Sonoma Technology meteorologists issued two Code Orange next-day forecasts this summer for anticipated ozone AQI levels exceeding 100. Due to the decreased impact of wildfire smoke on the state's air quality in 2024 compared with 2023, there were fewer observed days with USG-or-higher AQI levels, and fewer Code Orange or Code Red next-day forecasts were issued this summer compared with summer 2023.

Table 8 lists days from May through September 2024 with observed ozone AQI levels above 100 or when a Code Orange forecast was issued. The following sections provide a detailed review of the meteorological and air quality conditions for each day with USG ozone AQI levels or a Code Orange next-day forecast.

Table 8. Observed ozone AQI levels over 100 and Code Orange next-day forecasts for the May-September 2024 period. Bold values indicate observed AQI levels or next-day forecasts exceeding the NAAQS, or 100 AQI.

Date	Next-Day Forecast Ozone AQI	Maximum Ozone AQI	Maximum Ozone AQI Location	Number of Sites > 100 AQI
May 24	46	**115**	MLK	2
May 25	80	**108**	MLK	1
June 26	74	**108**	BSP	1
July 8	90	**112**	MLK	2
July 15	**101**	90	BSP, SEA	0
August 27	**112**	80	BSP	0

3.2 May 24-25, 2024

The day with the highest AQI levels of the summer 2024 forecast season occurred on May 24. On this day, an upper-level trough of low pressure passed over Delaware, which aided vertical mixing in the atmosphere. In addition, Sonoma Technology forecasters anticipated that this upper-level feature would interact with atmospheric moisture to support clouds and scattered thunderstorm development across the First State. These anticipated weather conditions resulted in a next-day ozone AQI forecast of 46 being issued, which is at the high end of the Good AQI category.

However, skies on May 24 were sunny across central and northern Delaware, with clouds and isolated thunderstorm activity confined to Sussex County (**Figure 20**). Due to the abundance of sunshine, afternoon high temperatures in New Castle County were able to reach the mid- to upper-80s, which promoted ozone development. Additionally, periods of calm-to-light northeasterly winds during the morning transported ozone precursors into the Wilmington area from the northeast. Later in the afternoon, a weak low-pressure center at the surface resulted in light and variable winds, which allowed pollutants to accumulate. These conditions yielded a daily ozone AQI of 115 at the MLK monitoring site. Furthermore, the daily ozone AQI levels at the BSP monitoring site also exceeded the NAAQS.

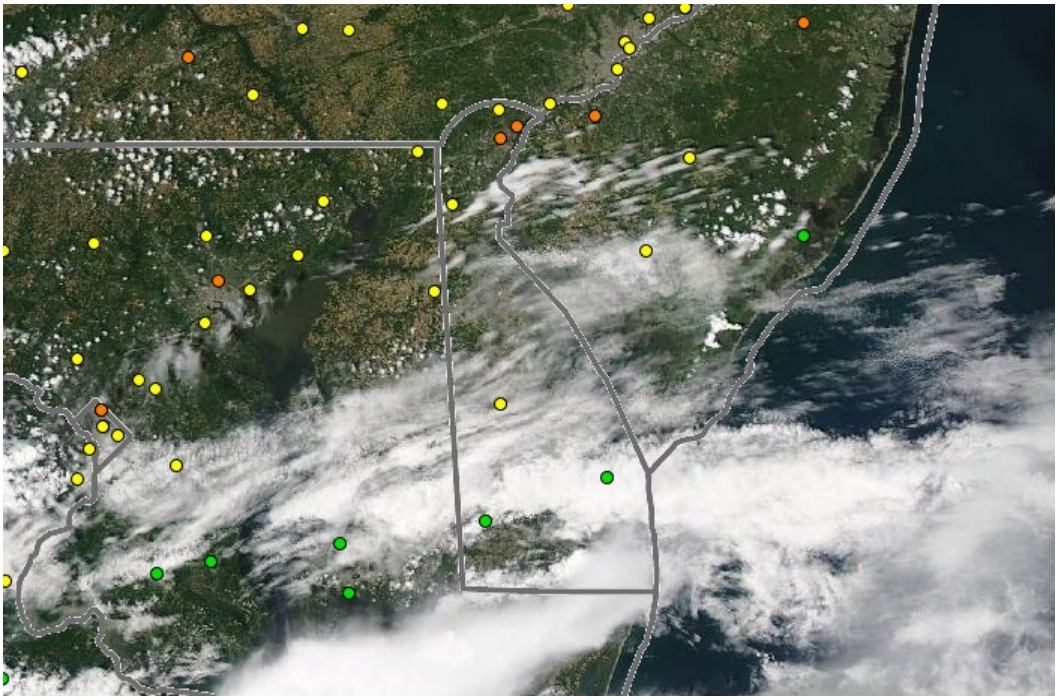

Figure 20. MODIS-Aqua satellite imagery valid for 1:30 p.m. EDT on May 24, 2024. Sunny skies, warm temperatures, and light winds over the Wilmington area resulted in USG ozone AQI levels (orange dots) at the MLK and BSP monitoring sites. Clouds and isolated thunderstorms in Sussex County reduced ozone formation, yielding Good ozone AQI levels (green dots). Image courtesy: AirNow-Tech.

On the following day, May 25, an upper-level ridge of high pressure moved from the Great Lakes into the Mid-Atlantic region (Figure 21). This upper-level feature inhibited vertical mixing in the atmosphere and produced another day with mostly sunny skies. Additionally, high temperatures reached the upper-80s, which was warmer than forecast models indicated. Surface winds during the morning hours were generally calm, which allowed pollutants from the prior day to carry over and hindered dispersion of ozone precursors. Furthermore, NOAA satellites detected smoke from fires across Canada and Mexico over the eastern United States seaboard, which likely enhanced ozone formation. As a result, the daily ozone AQI at the MLK monitoring site reached 108.

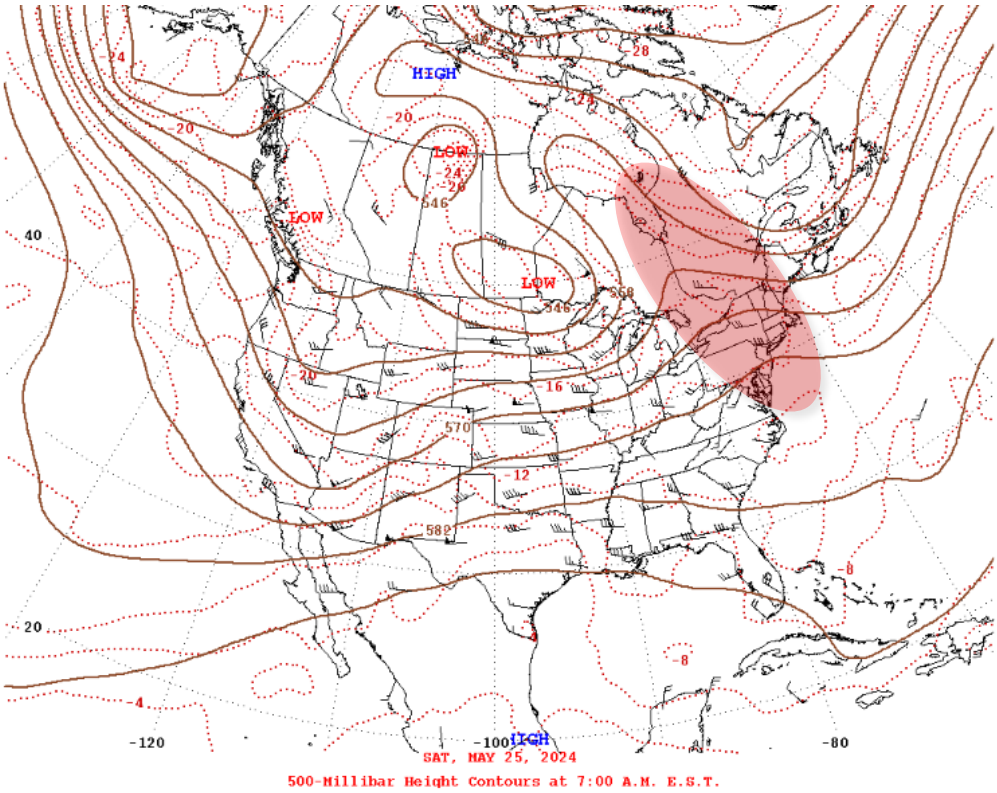

Figure 21. 500 mb map valid for 8:00 a.m. EDT on May 25, 2024. A ridge of high pressure aloft (red shading) resulted in limited vertical mixing and yielded USG ozone AQI levels. Image courtesy: NOAA.

Based on the 2019-2023 ozone climatology discussed in Section 1, ozone AQI levels in the USG category prior to June are exceedingly rare for the state of Delaware. Reduced daylight hours and relatively cooler temperatures are the primary factors that normally keep ozone under the USG threshold in April and May. Over the previous five years, there have been only two single-day NAAQS exceedances for ozone prior to June: April 13, 2023, and May 19, 2021. Furthermore, the May 24-25, 2024, period with back-to-back days with USG ozone AQI levels marks only the third occurrence of consecutive days with USG ozone AQI levels in the last five years, with other instances recorded on June 27-28, 2019, and June 29-30, 2023.

3.3 June 26, 2024

The lone day with USG ozone AQI levels in June was recorded on June 26. On this day, weather conditions were anticipated to be mostly sunny and hot, with light southwesterly winds reducing dispersion. While these conditions were expected to support ozone formation, increasing clouds and scattered thunderstorms were forecast to develop by late afternoon, limiting ozone development. As a result, the next-day ozone forecast called for ozone AQI levels to reach 74, which is in the Moderate AQI category.

Sunny skies prevailed across Delaware throughout much of the day on June 26, which led to afternoon high temperatures reaching the low-90s. Furthermore, light southwesterly winds developed during the morning and early afternoon hours, reducing dispersion and gradually transporting pollutants into the First State. NOAA's Hazard Mapping System (HMS) also analyzed smoke over Delaware (Figure 22), which likely increased ozone formation. Finally, the anticipated thunderstorm activity did not reach the state until 8:00-9:00 p.m. These conditions, combined with pollutant carryover from the previous day, resulted in a daily observed ozone AQI of 108 at the BSP monitoring site. For other ozone monitoring sites across Delaware, observed ozone AQI levels ranged from high-Moderate in New Castle County to low-Moderate in Kent and Sussex counties.

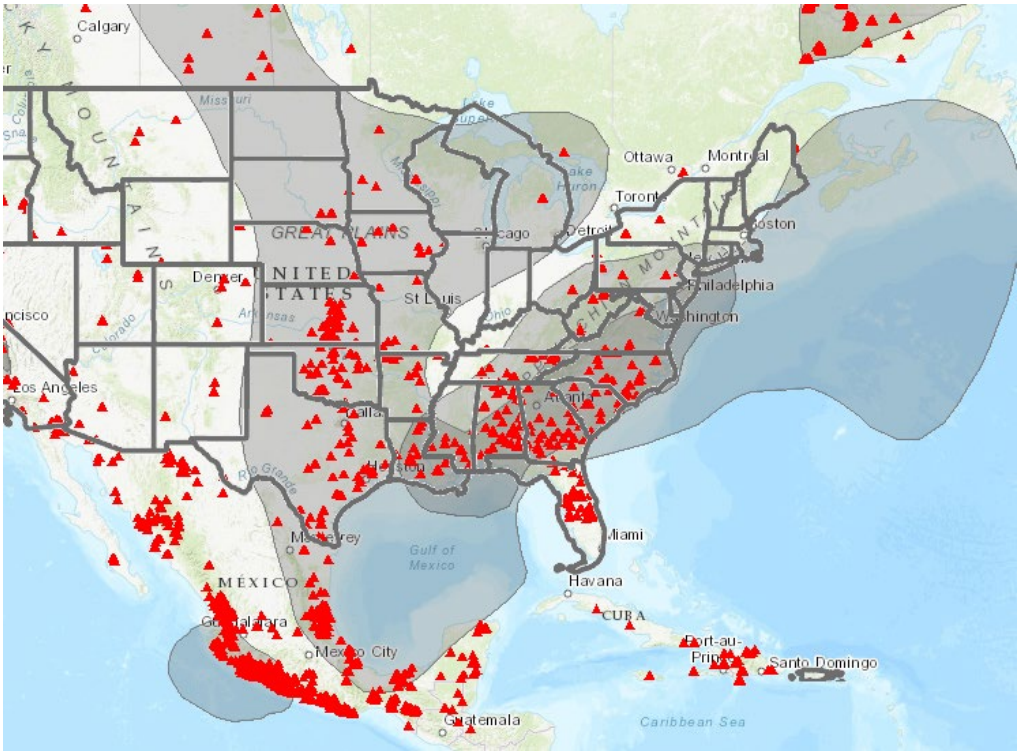

Figure 22. NOAA HMS smoke analysis (grey contours) and satellite fire detections (red triangles) on June 26, 2024. Smoke, primarily from fires in Alaska, Canada, and the central and southeastern United States, impacted ozone AQI levels in Delaware. Image courtesy: AirNow-Tech.

3.4 July 8, 2024

The final day with USG ozone AQI levels observed during the summer 2024 forecasting season was recorded on July 8. A next-day ozone AQI forecast of 90 had been issued by Sonoma Technology meteorologists. Anticipated weather conditions leading to a high-Moderate ozone AQI forecast for the day included calm winds during the morning, which would allow pollutants to accumulate, and mostly sunny skies through midday, which would aid in ozone formation. By the afternoon and evening, increasing clouds and scattered rain showers were expected to develop across the state, which would enhance atmospheric mixing and limit ozone production.

On July 8, the anticipated sunshine through the middle of the day occurred. However, winds during the morning were light easterly to northeasterly, which transported ozone precursors into the Wilmington area. Back trajectory analysis (Figure 23) supports these wind observations and the potential for thin-density smoke transport from a lingering wildfire burning in the Wharton State Forest in New Jersey.

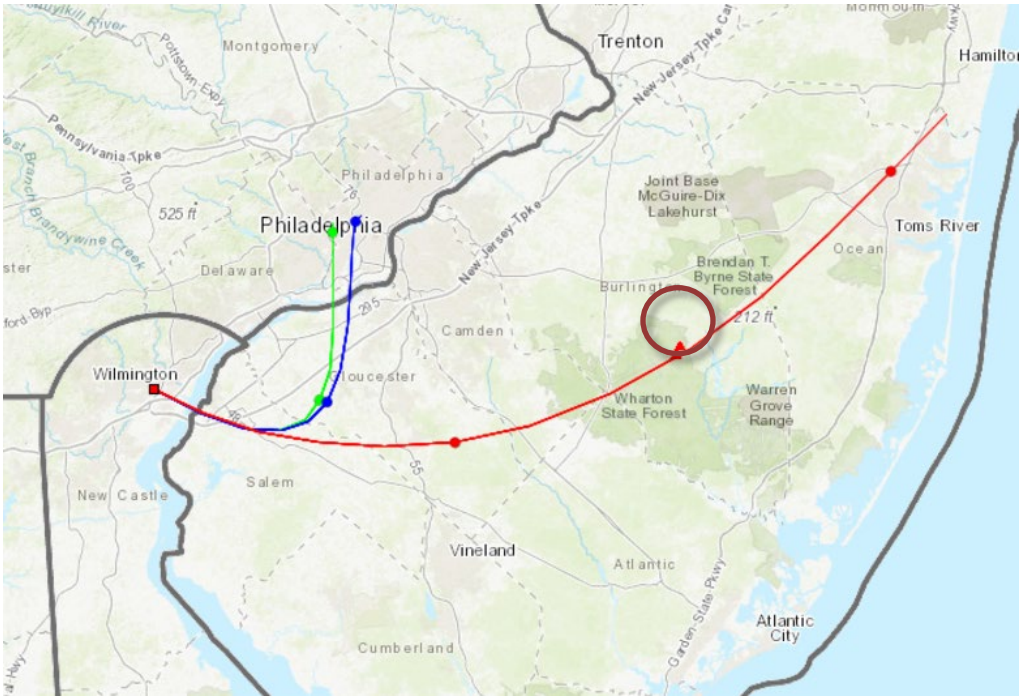

Figure 23. 12-hr back trajectory analysis (green: 50 m above ground level, blue: 100 m, red: 500 m) ending at 12:00 p.m. EDT on July 8, 2024. Easterly to northeasterly winds early in the day transported ozone precursors and possible smoke from a wildfire (red triangles, circled) into the Wilmington area. Image courtesy: AirNow-Tech.

By the afternoon of July 8, cloud coverage increased across Delaware, which was expected. However, the anticipated shower and thunderstorm development was confined to only Sussex County. Due to the limited coverage of thunderstorm activity, along with ample sunshine in the first part of the day, daytime highs reached the low-90s at KILG. Furthermore, with reduced thunderstorm activity, atmospheric mixing was inhibited. These conditions, combined with pollutant carryover from the previous days, led to two ozone monitoring sites exceeding the NAAQS: 112 AQI at MLK and 108 AQI at BCS.

3.5 July 15, 2024

Sonoma Technology meteorologists issued the season's first Code Orange Air Quality Action Day for Delaware on July 15. On this day, USG ozone AQI levels were predicted due to reduced vertical mixing and light and variable winds hindering dispersion early in the day. Additionally, abundant sunshine and high temperatures near 100°F were predicted, with thin-density smoke potentially enhancing ozone formation. Therefore, the next-day ozone AQI forecast issued by Sonoma Technology was 101.

By July 15, recorded winds at KILG were light southerly to southwesterly from the overnight to mid-morning hours. Around 9:00 a.m. EDT, the winds shifted to northwesterly as a surface trough of low pressure moved across Delaware. Northwesterly winds continued through mid-afternoon, becoming moderate at times. These winds likely aided dispersion of ozone precursors from regional sources and remnant wildfire smoke, reducing ozone production. Due to the issuance of a Code Orange Air Quality Action Day, emissions from factories and vehicles might have also been slightly diminished, helping to keep ozone AQI levels from exceeding the NAAQS. Therefore, despite sunshine and temperatures in the mid- to upper-90s, the daily observed ozone AQI reached 90 at BSP and SEA.

3.6 August 27, 2024

The final Code Orange Air Quality Action Day for Delaware was issued on August 27. Despite the five-year ozone climatology for Delaware showing no occurrences of USG ozone during the month of August, Sonoma Technology meteorologists noted several factors that favored an ozone NAAQS exceedance. These factors included sunny skies and forecasted high temperatures near 90°F that would aid ozone development, light and variable winds that would reduce pollutant dispersion, and regional thin-density smoke that would enhance production of ground-level ozone. Because of these expected conditions, a next-day ozone AQI forecast of 112 was issued.

On August 27, skies were mostly sunny, and high temperatures were in the upper-80s to low-90s across the state. Additionally, NOAA HMS analyzed smoke over the Mid-Atlantic region, and surface wind speeds were light throughout much of the day. However, winds during the first half of the day were generally northerly to northwesterly, which tended to transport clean air into the state. In

addition, a departing upper-level trough of low pressure likely aided vertical mixing during the afternoon hours, which limited ozone production. This enhanced mixing may have allowed ozone production to peak in the early afternoon and then drop for the remainder of the day. Evidence of this situation can be found in Figure 24. The BSP and LUM monitors reached their daily maximum hourly ozone concentration from 12:00-1:00 p.m. and then dropped and hovered around 60-65 ppb until the early evening.

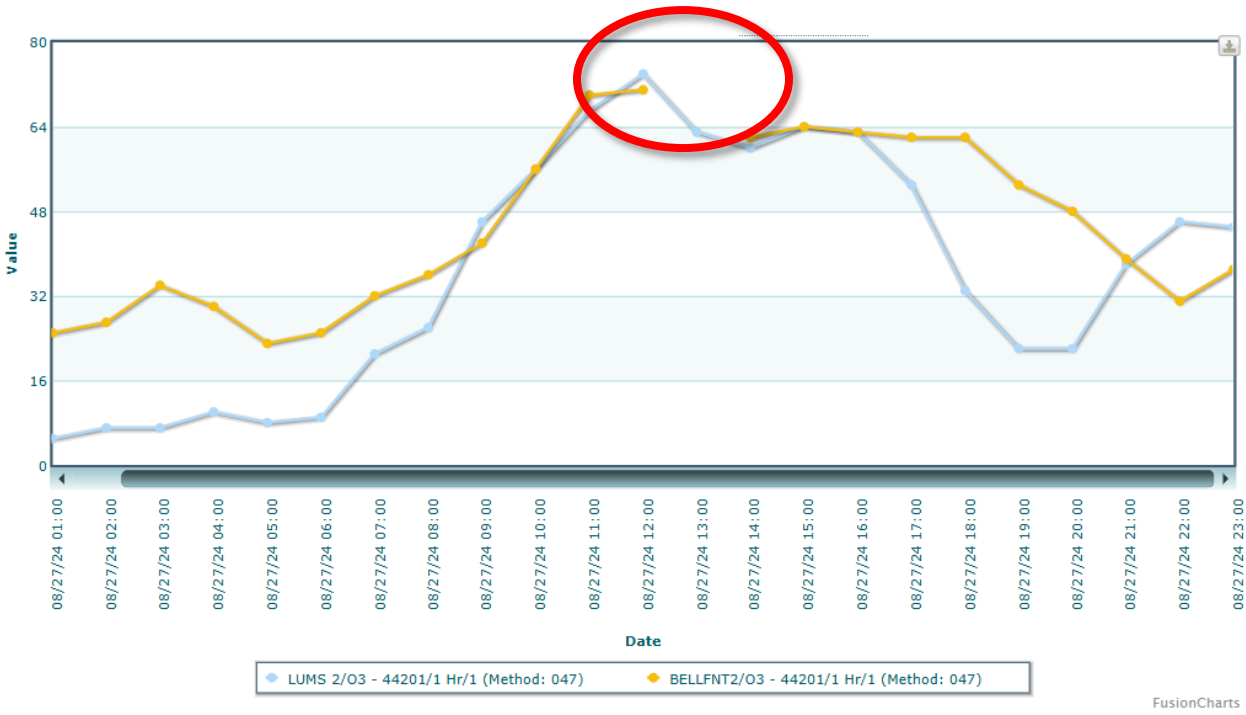

Figure 24. Hourly ozone concentrations (ppb) for the LUM and BSP monitors (labelled as BELLEFNT2) monitoring sites on August 27, 2024. Due in part to enhanced vertical mixing, ozone concentrations peaked for both sites between 12:00-1:00 p.m. EDT and then decreased in the following hours. Image courtesy: AirNow-Tech.

Despite the presence of smoke on this day, it is likely that ozone formation was limited by enhanced atmospheric mixing, wind directions unfavorable for pollutant transport, and the seasonal decrease in sunlight. Reduced emissions from factories and vehicles in response to the Code Orange forecast might have also been a factor. As a result, the observed daily ozone AQI reached 80 at BSP, which is in the high-Moderate category.

4. Accuracy of Air Quality Forecasts in 2024

4.1 Introduction to Sonoma Technology Forecasts

During the summer 2024 forecast season in Delaware, Sonoma Technology meteorologists issued ozone forecasts for the next day and following two days daily from April 30 through September 30. Daily $PM_{2.5}$ forecasts were also issued for the next day and following two days. In the following sections, the performance of Sonoma Technology next-day forecasts for ozone and $PM_{2.5}$ are analyzed and compared with previous years' forecast statistics. Additionally, the performance of Sonoma Technology's next-day forecasts is compared against the NOAA National Air Quality Forecast Capability (NAQFC) model.

4.2 2024 Ozone Forecast Statistics

A comparison between Sonoma Technology forecasts and observed ozone levels in Delaware during summer 2024 is shown in **Figure 25**. 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. Sonoma Technology next-day ozone forecasts in Delaware were correct 69% of the time during summer 2024.

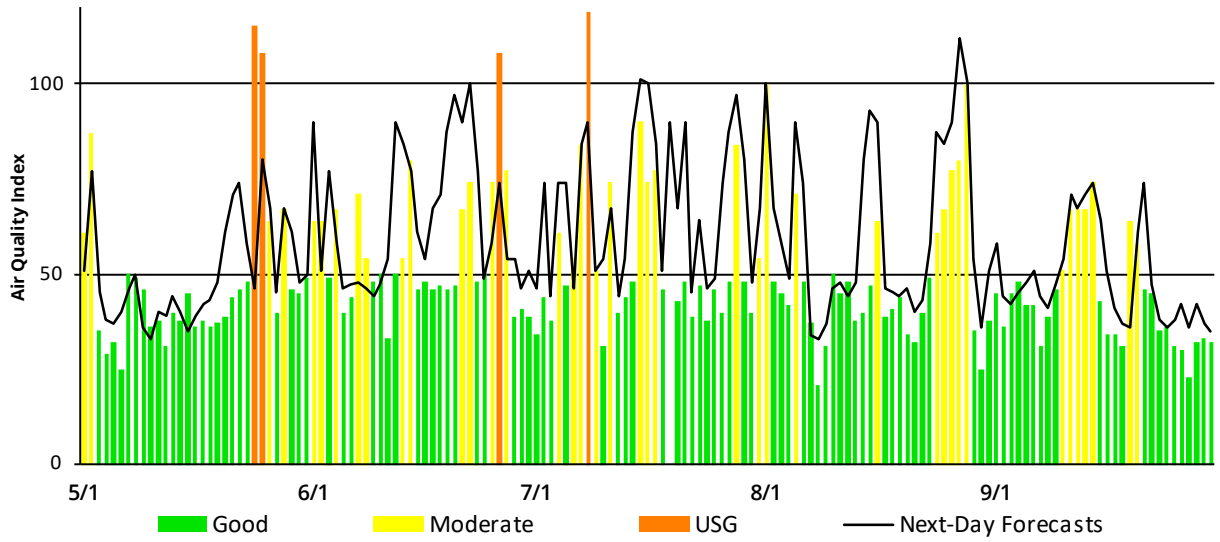

Figure 25. Daily observed 2024 ozone levels (bars) in Delaware versus Sonoma Technology next-day forecasts (black line).

Moderate-or-higher ozone levels occurred on 44 out of the 153 forecast days in summer 2024, which was a 21% decrease compared with summer 2023. Sonoma Technology issued forecasts at the Moderate AQI level on 39 of the 44 days with observed Moderate-or-higher ozone AQI levels. As a result, the POD was 89% for days with Moderate ozone AQI levels, which is an improvement over the 77% POD from summer 2023.

Forecast false alarms occur when the forecast ozone AQI category is higher than the observed ozone AQI category. Of the 82 days during summer 2024 when Moderate-or-higher ozone levels were forecast, there were 42 instances when observed ozone AQI levels were lower than the forecast levels (i.e., in the Good AQI category). As a result, the FAR for Moderate-or-higher ozone forecasts during summer 2024 was 51%, which marked a 6% increase compared with summer 2023.

USG ozone levels were forecast twice this past summer: June 15 (101 AQI) and August 27 (112 AQI); both forecasts ended up being false alarms. On days with USG false alarms, the average observed ozone concentration came within 7.0 ppb of the USG category, with an average observed ozone concentration of 66 ppb. Figure 26 shows a comparison of percent correct (PC), POD, and FAR for Sonoma Technology ozone forecasts over the last four years. The statistics for each year are comparable, with the highest POD occurring in summer 2024, and the highest PC being recorded in summer 2022.

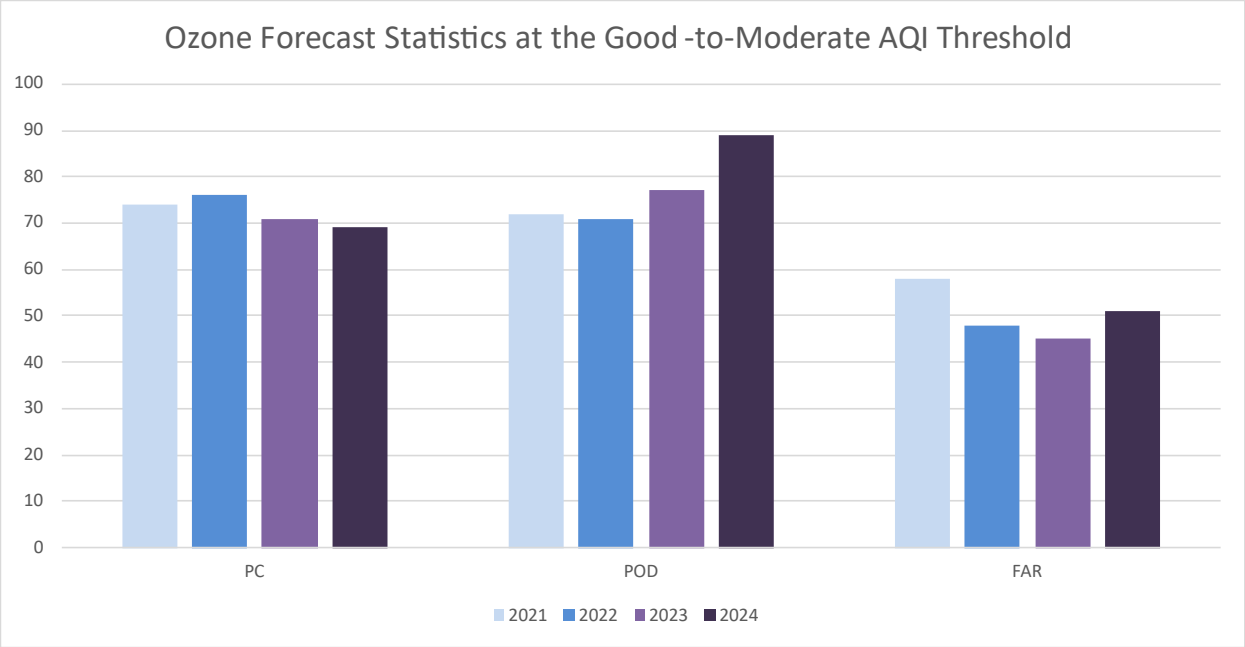

Figure 26. Percent Correct (PC), Probability of Detection (POD), and False Alarm Rate (FAR) at the Good-to-Moderate AQI threshold for 2021-2024.

Forecast accuracy can also be assessed by calculating forecast bias and MAE, which is done by comparing the forecast ozone concentrations with observed ozone concentrations. Bias is the average difference between forecast and observed concentrations, with a positive bias indicating forecast concentrations that tend to be higher than the observed concentrations. Conversely, a negative bias indicates forecast concentrations that tend to be lower than the observed concentrations. MAE indicates the average absolute error between forecast and observed concentrations, with a low MAE indicating that the forecasts were fairly accurate.

Table 9 provides the forecast bias and MAE for all Sonoma Technology ozone forecasts during summer 2024 based on daily maximum 8-hour average ozone concentrations. For the May-September 2024 period, Sonoma Technology forecasts exhibited a bias of +4.8 ppb over observed ozone concentrations, with an MAE of 7.4 ppb. Both the bias and MAE for ozone forecasts in summer 2024 were worse than those in summer 2023 (bias +3.8 ppb, MAE 6.5 ppb), summer 2022 (bias +4.2 ppb, MAE 7.1 ppb), and summer 2021 (bias +4.7 ppb, MAE 6.8 ppb). While Sonoma Technology strives to maintain forecast accuracy, next-day forecasts are also aimed at protecting the public from high-pollution events, which results in a consistent positive forecast bias.

During summer 2024, Sonoma Technology forecasts for ozone concentrations had their highest bias in July (+6.8 ppb) and August (+6.5 ppb). However, this high bias was due in large part to the presence of smoke in Delaware during this two-month period; 18 of the 19 days with Moderate-or-higher ozone AQI levels featured NOAA satellite-analyzed smoke over the state. To account for the potential for smoke enhancement of ozone production, Sonoma Technology meteorologists aim to err on the side of caution and issue forecasts that may ultimately be higher than the observed AQI

levels. The lowest bias for next-day ozone forecasts were in May, where the average forecast bias was only 2.2 ppb over the observed ozone concentrations.

Table 9. Sonoma Technology bias and MAE for next-day ozone forecasts for summer 2024.

Month	Bias (ppb)	Mean Absolute Error (ppb)
May	+2.2	7.2
June	+4.1	8.1
July	+6.8	8.1
August	+6.5	7.5
September	+4.2	6.3
Average	**+4.8**	**7.4**

4.3 2024 $PM_{2.5}$ Forecast Statistics

At the request of the Delaware Department of Natural Resources and Environmental Control (DNREC), Sonoma Technology issued next-day forecasts for $PM_{2.5}$ for the entire May-September forecasting season. A comparison between Sonoma Technology next-day forecasts and observed $PM_{2.5}$ levels in Delaware during summer 2024 is shown in Figure 27. Using the Good-to-Moderate threshold, Sonoma Technology next-day $PM_{2.5}$ forecasts in Delaware were correct 76% of the time during summer 2024.

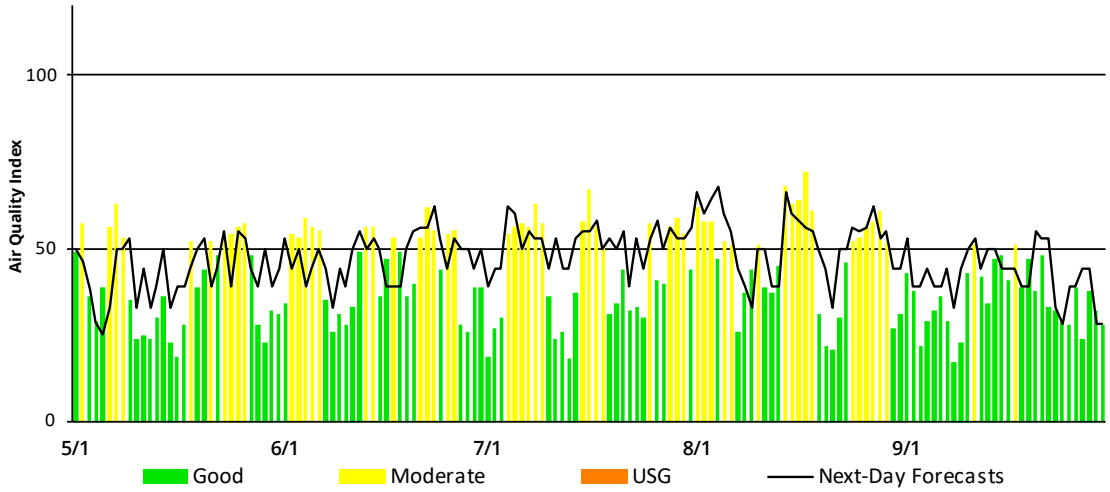

Figure 27. Daily observed May-September 2024 $PM_{2.5}$ levels in Delaware versus Sonoma Technology next-day forecasts.

Moderate $PM_{2.5}$ AQI levels were observed on 56 days between May and September. Sonoma Technology issued Moderate $PM_{2.5}$ AQI level forecasts on 38 of those 56 days with Moderate $PM_{2.5}$ AQI levels, resulting in a POD of 68%. Of the 57 Moderate AQI level forecasts issued for $PM_{2.5}$, there were 19 occurrences when the observed $PM_{2.5}$ AQI levels were lower than the forecast levels. As a result, the FAR for Moderate $PM_{2.5}$ forecasts was 33%. Summer 2024 marked the first full forecast season where $PM_{2.5}$ forecasts were issued daily during the May-September period. Therefore, a direct comparison with the previous season's forecast statistics is not possible.

Table 10 provides the forecast bias and MAE for all Sonoma Technology next-day forecasts for $PM_{2.5}$ during summer 2024. For the forecast season, next-day forecasts exhibited a bias of only 0.8 $\mu g/m^3$ above observed $PM_{2.5}$ concentrations, with an MAE of 2.4 $\mu g/m^3$.

Table 10. Sonoma Technology bias and MAE for next-day $PM_{2.5}$ forecasts for summer 2024.

Month	Bias ($\mu g/m^3$)	Mean Absolute Error ($\mu g/m^3$)
May	+0.5	2.4
June	+0.3	2.7
July	+1.1	2.8
August	+0.9	2.6
September	+1.3	1.6
Average	**+0.8**	**2.4**

While September 2024 featured the largest $PM_{2.5}$ monthly bias of the summer, the bias for $PM_{2.5}$ next-day forecasts that month was still only 1.3 $\mu g/m^3$ above observed $PM_{2.5}$ concentrations on average. The MAE for the month was 1.6 $\mu g/m^3$, which was the lowest of any month for the forecast season. These metrics suggest that Sonoma Technology next-day forecasts for September 2024 were generally accurate.

4.4 Introduction to Sonoma Technology Forecasts Versus Model Forecasts

To support air quality forecasting for the state of Delaware, Sonoma Technology meteorologists employ a variety of tools when issuing ozone and $PM_{2.5}$ forecasts. One such tool is NOAA's NAQFC model. This model updates twice daily, at 2:00 a.m. (06Z) and 8:00 a.m. (12Z) EDT (**https://airquality.weather.gov/**) and 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

The following sections analyze the accuracy of each model's next-day forecast output, based on the Wilmington, Delaware, location, and compare model performance with Sonoma Technology's next-day forecasts issued in summer 2024.

4.5 Comparison of Sonoma Technology Forecasts with 2024 NAQFC Ozone Forecasts

Table 11 provides the NAQFC next-day forecast bias and MAE for the raw and bias-corrected ozone product for Wilmington, Delaware, during the summer 2024 forecast season. All NAQFC ozone products exhibited a positive bias. However, the NAQFC bias-corrected products exhibited the smallest bias in their next-day ozone forecasts compared with the raw NAQFC ozone forecasts. For all NAQFC ozone products, the MAE was less than 6 ppb.

Table 11. May-September 2024 next-day ozone forecast model statistics for Wilmington, Delaware.

Model	Bias (ppb)	MAE (ppb)
NAQFC 06Z Raw	+2.0	5.9
NAQFC 06Z Bias-Corrected	+0.2	5.7
NAQFC 12Z Raw	+2.1	5.8
NAQFC 12Z Bias-Corrected	+0.3	5.6

Figures 28 and 29 compare the next-day forecast bias and MAE for each month during the 2024 forecasting season. These figures include the modeled ozone predictions from NAQFC and Sonoma Technology's next-day ozone forecasts issued (blue bars at the left of each grouping). The annual averages for bias and MAE during the May-September 2024 period appear at the far right of each figure.

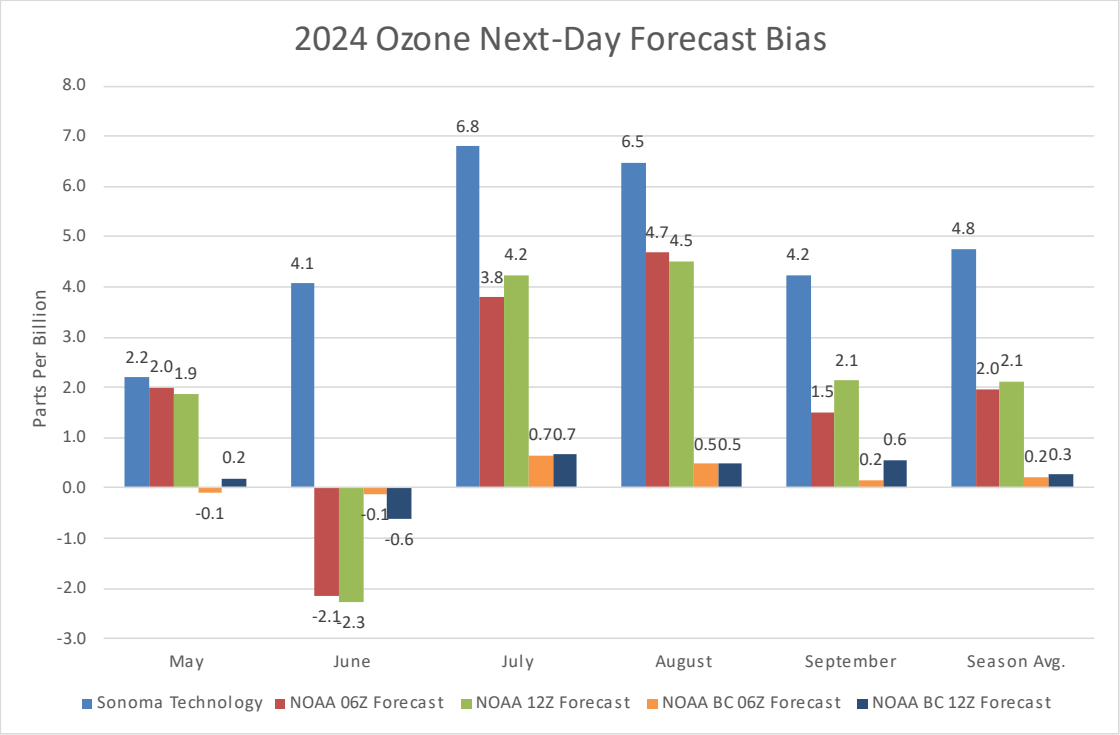

Figure 28. Monthly NOAA NAQFC model ozone forecast for Wilmington, Delaware, and Sonoma Technology next-day ozone forecast bias during the 2024 summer forecast season.

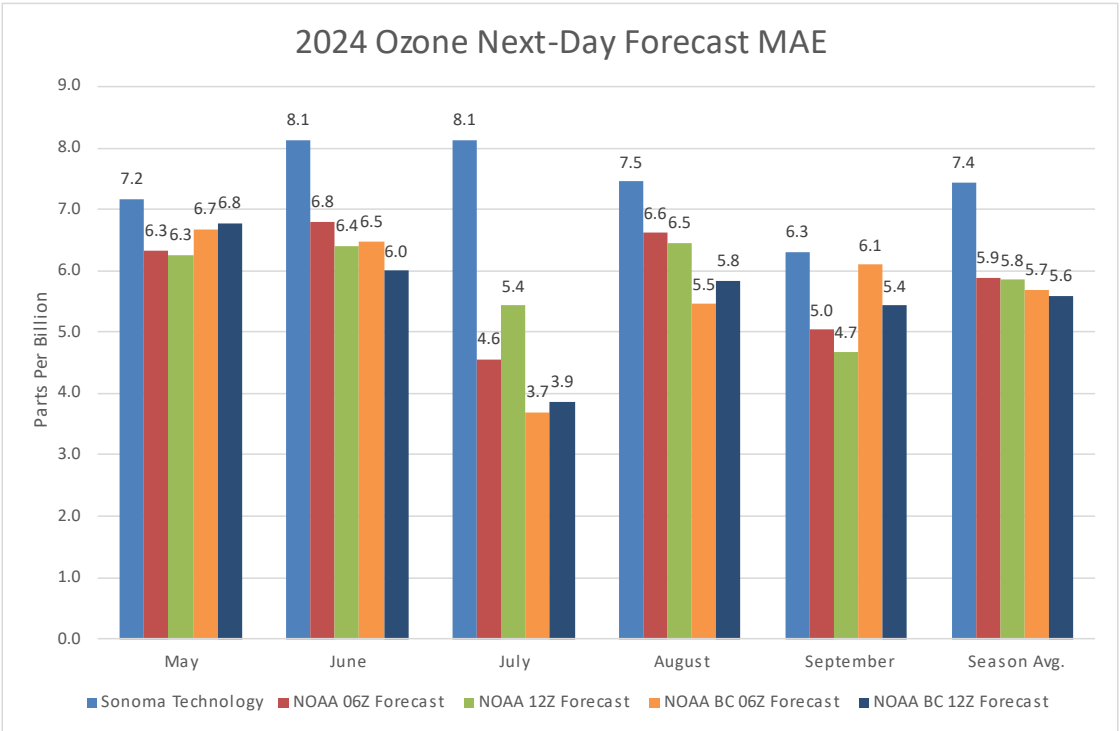

Figure 29. Monthly NOAA NAQFC model ozone forecast for Wilmington, Delaware, and Sonoma Technology next-day ozone forecast MAE during the 2024 summer forecast season.

Over the previous two summers, the NAQFC raw and bias-corrected ozone forecasts typically exhibited a negative bias, resulting in the predicted ozone concentrations being lower than the observed ozone concentrations. However, during the 2024 forecast season, small positive biases existed nearly every month for all four NAQFC model outputs. Ozone model performance was best in May, where the raw NAQFC products exhibited a small positive bias versus observed ozone concentrations, and bias-corrected NAQFC models were close to exhibiting zero bias. In comparison, Sonoma Technology next-day ozone forecasts exhibited a small positive bias in May, which was comparable to the raw NAQFC model output. As was observed in summer 2023, the largest bias for Sonoma Technology next-day ozone forecasts occurred in July, as the NAQFC raw and bias-corrected ozone products had better forecast performance and lower biases. Overall, the seasonal average ozone bias and MAE for Sonoma Technology next-day ozone forecasts were higher than the NAQFC model output. As noted 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 decision-making support for air quality outreach programs in Delaware.

4.6 Comparison of Sonoma Technology Forecasts with 2024 NAQFC $PM_{2.5}$ Forecasts

Table 12 provides the NAQFC next-day forecast bias and MAE for the raw and bias-corrected $PM_{2.5}$ products for Wilmington, Delaware, during the May-September 2024 period. The 06Z and 12Z raw NAQFC model runs each had a bias of +0.5 µg/m^3 and an MAE of 3.1 µg/m^3. For the 06Z and 12Z bias-corrected NAQFC models, both runs had a bias of -0.4 µg/m^3; the 06Z MAE was 2.6 µg/m^3, and the 12Z MAE was 2.5 µg/m^3. These metrics suggest all four NAQFC model runs were generally accurate in their next-day predictions for $PM_{2.5}$.

Table 12. May-September 2024 next-day $PM_{2.5}$ forecast model statistics for Wilmington, Delaware.

Model	Bias (µg/m^3)	MAE (µg/m^3)
NAQFC 06Z Raw	+0.5	3.1
NAQFC 06Z Bias-Corrected	-0.4	2.6
NAQFC 12Z Raw	+0.5	3.1
NAQFC 12Z Bias-Corrected	-0.4	2.5

Figures 30 and 31 compare the NAQFC $PM_{2.5}$ next-day forecast bias and MAE for the May-September 2024 period. These figures also include the $PM_{2.5}$ next-day forecasts that Sonoma Technology issued (blue bars at the left of each grouping). The annual averages for bias and MAE during the May-September 2024 period are shown at the far right of each figure.

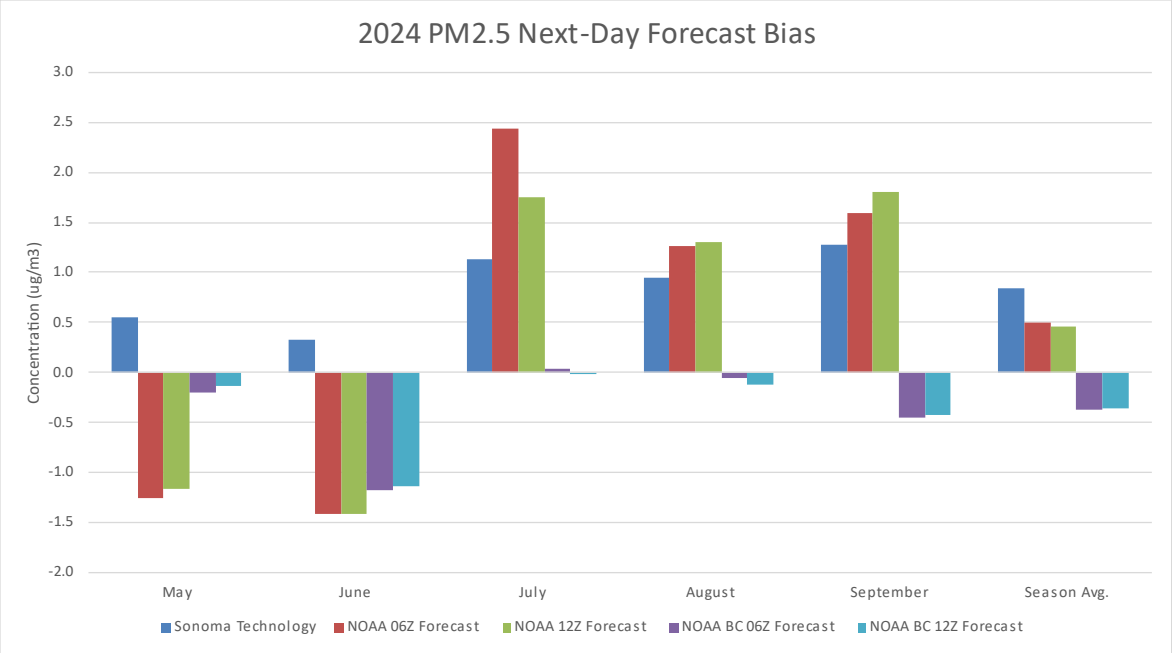

Figure 30. Monthly NOAA NAQFC model $PM_{2.5}$ forecast for Wilmington, Delaware, and Sonoma Technology next-day $PM_{2.5}$ forecast bias during the 2024 summer forecast season.

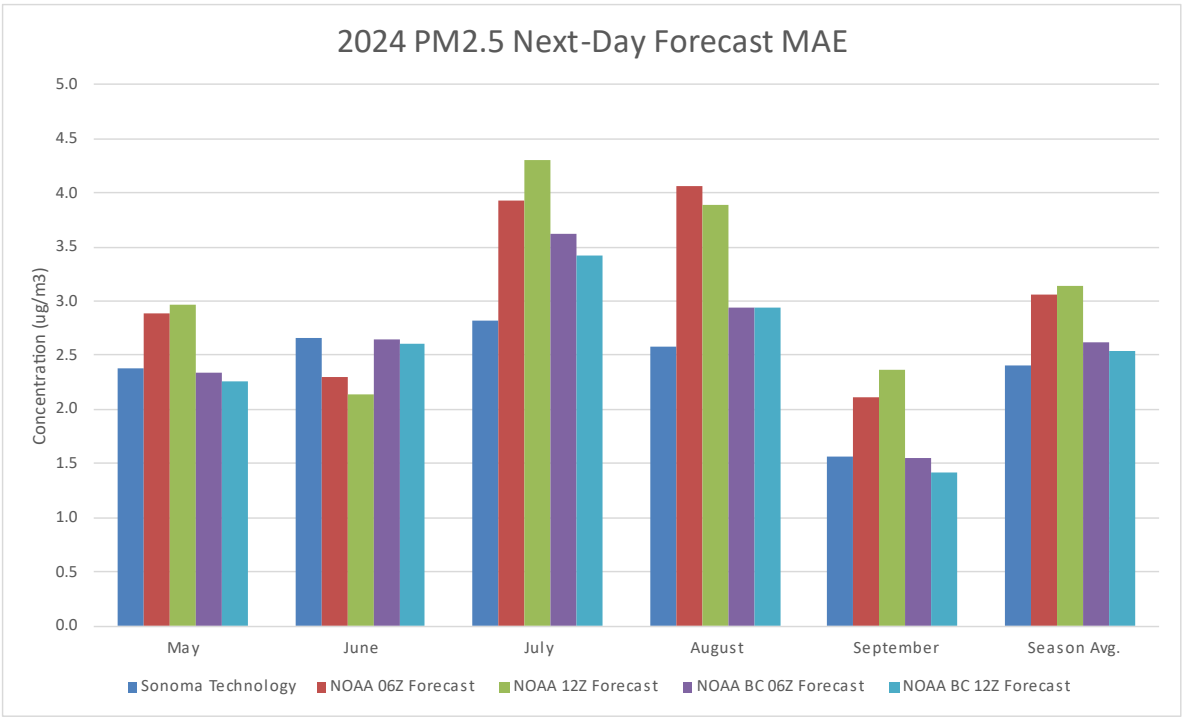

Figure 31. Monthly NOAA NAQFC model $PM_{2.5}$ forecast for Wilmington, Delaware, and Sonoma Technology next-day $PM_{2.5}$ forecast MAE during the 2024 summer forecast season.

Next-day $PM_{2.5}$ forecast biases for Sonoma Technology forecasts and the NAQFC raw model output had a slight positive bias for the season, while the bias-corrected NAQFC model output exhibited a small negative bias. Sonoma Technology forecast biases in May and June outperformed most NAQFC model runs. In May, Sonoma Technology's forecast bias was +0.5 µg/m^3, while the NAQFC raw model output underpredicted $PM_{2.5}$ concentrations by over 1 µg/m^3. For the bias-corrected NAQFC model runs in May, biases were close to 0 µg/m^3. By June, all NAQFC model output underpredicted $PM_{2.5}$ concentrations by over 1 µg/m^3. Conversely, Sonoma Technology $PM_{2.5}$ forecasts were better, with a small positive bias of +0.3 µg/m^3 for the month.

For the May-September period, Sonoma Technology forecasts recorded a lower MAE compared with the bias-corrected NAQFC and raw NAQFC model runs. The raw NAQFC model runs had the highest seasonal MAE compared with their bias-corrected counterparts and Sonoma Technology forecasts. Month-by-month MAE varied, with Sonoma Technology forecasts recording a lower MAE than all NAQFC models during the July-August timeframe. MAE for the NAQFC bias-corrected model runs was smaller than that of their raw counterparts and Sonoma Technology forecasts in May and September. The raw NAQFC model registered a smaller MAE in June compared with the bias-corrected model and Sonoma Technology forecasts.

While variations in forecast performance varied month to month, $PM_{2.5}$ forecasts overall from Sonoma Technology and the NAQFC models were accurate in summer 2024. Although smoke was analyzed over the state on several days throughout the May-September period, observed concentrations did not exceed the USG AQI threshold. The impact of this thin-density smoke on $PM_{2.5}$ concentrations was easier to predict for models and Sonoma Technology alike, which resulted in good $PM_{2.5}$ forecasting statistics during summer 2024.

5. Seasonal Forecast Review and Outlook

5.1 Review of Sonoma Technology's Summer 2024 Outlook

Each spring, meteorologists at Sonoma Technology use several methods to predict temperature and precipitation anomalies for the upcoming summer and discuss how these anomalies might impact air quality in Delaware in June, July, and August. The methods include a review of long-range meteorological forecast model output, an analysis of summer temperature and precipitation trends in the Mid-Atlantic, and a comparison of summers with similar El Niño-Southern Oscillation (ENSO) conditions. In addition, the official seasonal climate forecast from NOAA's Climate Prediction Center (CPC) is reviewed for comparison with the information provided by the other methods. Furthermore, in the 2023 end-of-season report for Delaware, Sonoma Technology meteorologists reviewed forecast upper-level weather patterns and ambient drought conditions across Canada and the western United States to discern the potential for the influence of wildfire smoke on summer air quality along the Eastern Seaboard in 2024.

Summer 2024 Temperature Forecast

Both the Canadian Seasonal to Inter-annual Prediction System (CanSIPS) model and European Centre for Medium Range Weather Forecasting (ECMWF) seasonal weather model agreed that temperatures were anticipated to be above average in Delaware during summer 2024. Temperature trends also indicated warming summers along the Mid-Atlantic over the last decade, raising the likelihood for above-average temperatures. In addition, La Niña conditions were forecast to develop over the summer, which historically have led to above-average summer temperatures in Delaware. Finally, CPC's official temperature forecast for summer 2024 indicated a good chance of above-average temperatures. Given the good agreement among all of these methods and products, Sonoma Technology meteorologists predicted above-average temperatures for Delaware over the summer.

Summer 2024 Precipitation Forecast

The precipitation forecast for summer 2024 was less certain, with ENSO analogs and forecast models and trends predicting different outcomes for Delaware. ENSO analogs indicated that drier-than-average conditions were favored in response to the potential for a developing La Niña, while forecast models were split on whether it would be a dry or wet summer in the Mid-Atlantic. Trends showed some potential for above-average precipitation, although the signal was stronger north of the First State. In addition, with above-average sea surface temperatures across the Atlantic and La Niña

conditions potentially supporting increased tropical cyclone development, there was some question as to how much tropical activity could influence rainfall in Delaware over the summer. Given precipitation deficits in Delaware during previous ENSO-similar years, as well as some model support for dry conditions in the region, Sonoma Technology forecasters predicted near- to below-average precipitation in Delaware for summer 2024.

Summer 2024 Smoke and Air Quality Forecast

The smoke forecast for summer 2024 called for the potential for increased smoke production across Canada due to an ongoing drought across the country during the spring and the potential for summer temperatures to be above normal. Although forecasts of the upper-level weather pattern were not as conducive to smoke transport into the Mid-Atlantic as in 2023, it did appear that there was potential for smoke events along the East Coast due to long-range smoke transport from western and southcentral Canada.

Considering the forecast potential for above-normal temperatures, near- to below-normal precipitation, and increased smoke production across Canada, meteorologists at Sonoma Technology predicted that AQI levels for $PM_{2.5}$ and ozone could be above normal over the summer.

Summer 2024 Observed Temperatures

The observed temperature anomalies for the United States during summer 2024 are shown in Figure 32.

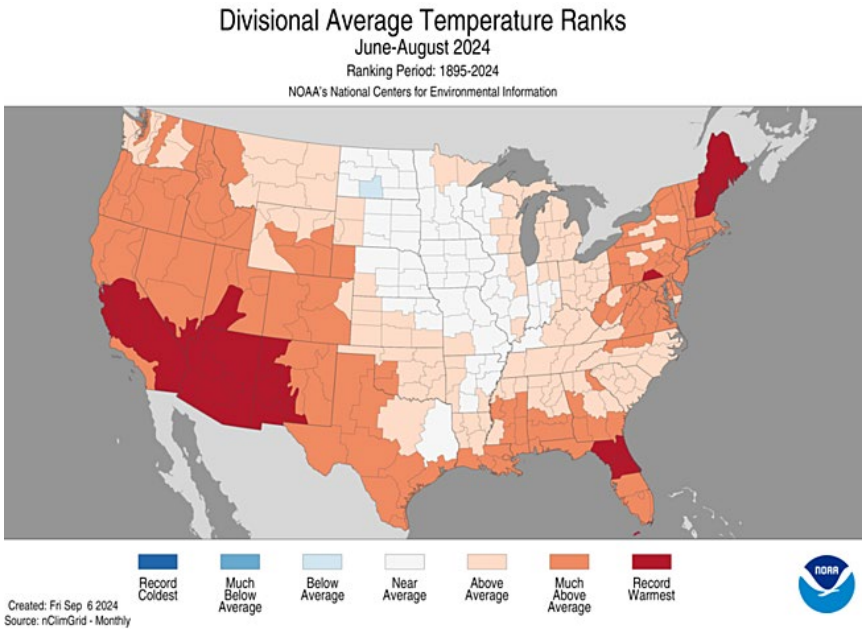

Figure 32. Temperature anomalies in summer 2024. Source: NOAA/NCEI.

Figure 32 shows that Delaware's average temperatures during summer 2024 were much above average, with some record warmth in nearby southern Pennsylvania. These warm conditions were partly in response to above-average sea surface temperatures in the western Atlantic, as well as anomalous high pressure aloft that peaked over the region in June and July. Furthermore, southerly winds occurred more often than normal during summer 2024 in Delaware, drawing warmer air into the Mid-Atlantic around a surface high pressure system centered east of the state. These conditions were consistent with the forecast for above-average temperatures in Delaware for summer 2024. Note that the expected La Niña conditions never developed over the summer as ENSO remained in a neutral phase in June through August.

Summer 2024 Observed Precipitation

The observed precipitation anomalies for the United States during summer 2024 are shown in Figure 33.

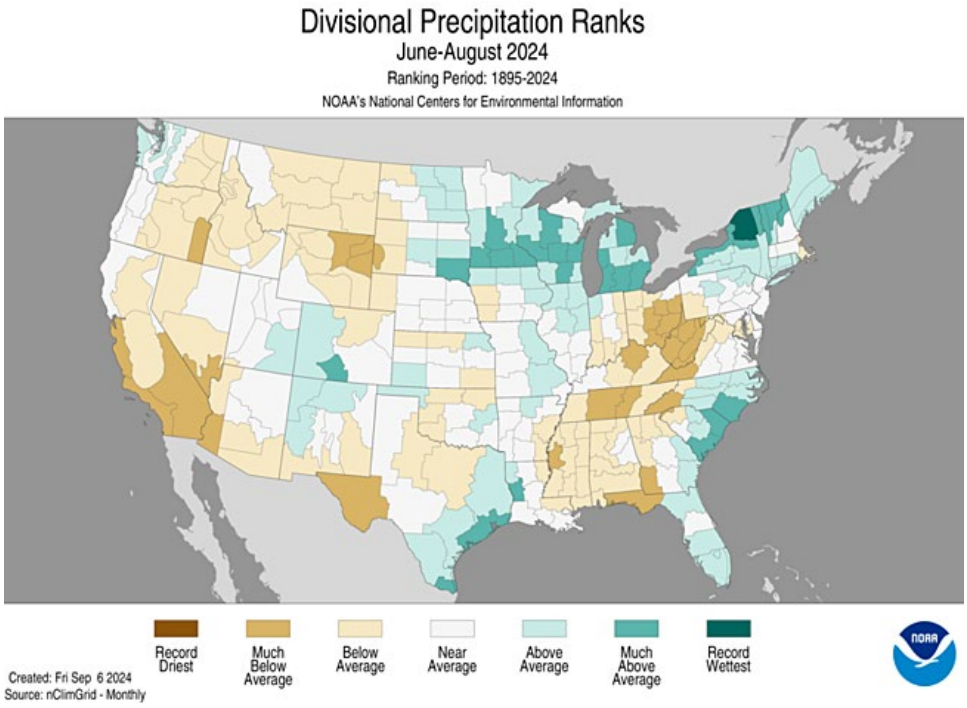

Figure 33. Precipitation anomalies for summer 2024. Source: NOAA/NCEI.

Figure 33 shows that Delaware's precipitation during summer 2024 was near average, with below-average precipitation just west of the region. These conditions compare favorably with Sonoma Technology's forecast for near- to below-average precipitation in Delaware in summer 2024.

Summer 2024 Observed Smoke and Air Quality

2024 was another active wildfire season across Canada, with the Canadian Wildland Fire Information System reporting more than 5.3 million hectares (just over 13 million acres) burned through October 1, 2024. While shy of the record levels of 2023, these numbers put Canada's fire season at the second highest since 1995, according to the Canadian Broadcasting Corporation (Figure 34).

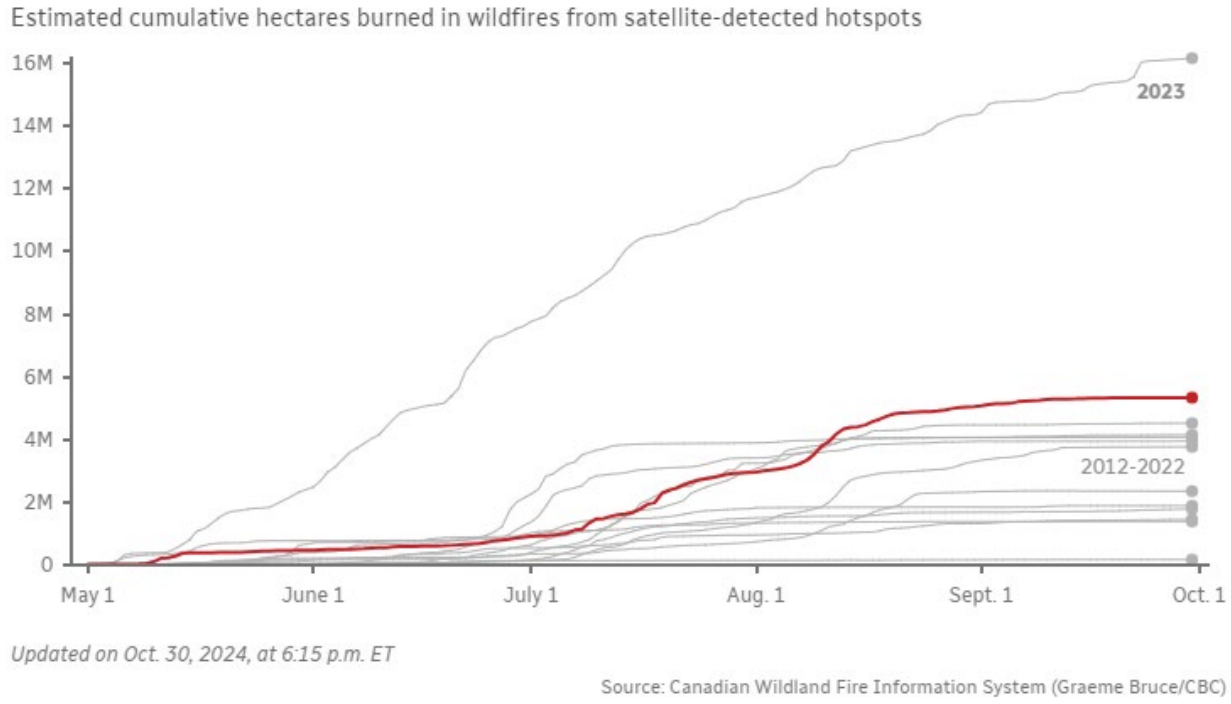

Figure 34. Annual satellite-estimated cumulative number of hectares burned by wildfires in Canada. Source: Canadian Wildland Fire Information System (Graeme Bruce/CBC).

However, most of these fires occurred in western Canada (Figure 35), compared with the previous year, when large fires were burning across the country. The worst smoke impacts in the Mid-Atlantic in 2023 came from fires in western Quebec, which saw fewer large fires during the 2024 season.

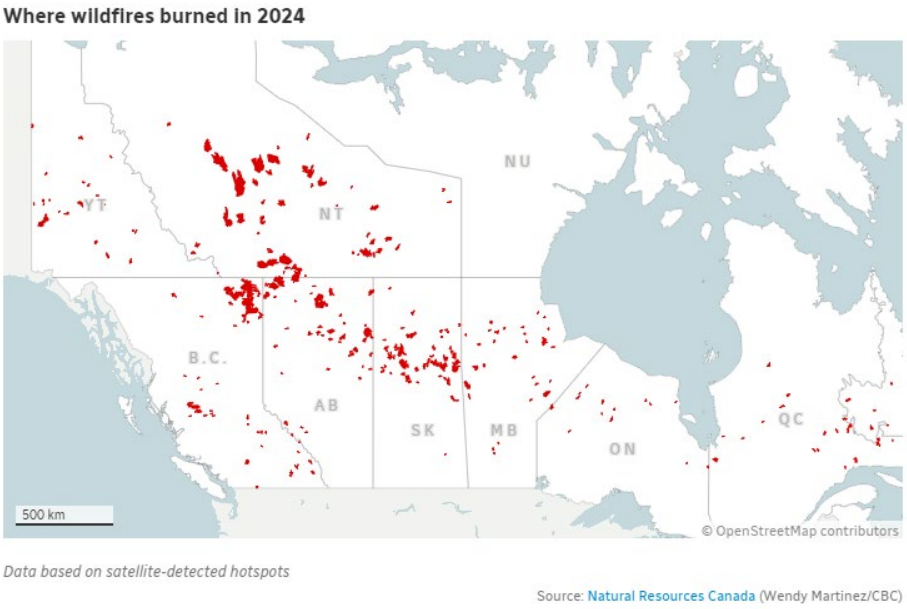

Figure 35. Canadian wildfire activity during the 2024 fire season. Source: Canadian Wildland Fire Information System (Graeme Bruce/CBC).

The combination of increased southerly winds in Delaware and an increased distance from the largest active Canadian wildfires kept the majority of dense smoke north of the region. The reduction of smoke over the Mid-Atlantic had positive impacts on air quality in Delaware in summer 2024. Despite the above-normal temperatures, ozone AQI levels were Moderate or higher on 35% of the days in June, July, and August, which is slightly below the average of 39% over the previous five summers. In addition, $PM_{2.5}$ AQI levels were Moderate or higher on 41% of days, which is just below the average of 43% over the previous five summers.

5.2 Climate Prediction Center Summer Outlook

To gauge the potential for ozone development during the upcoming 2025 summer season, Sonoma Technology meteorologists reviewed seasonal forecasts by NOAA's CPC, composites of temperature and precipitation anomalies for years with similar ENSO conditions, and model output from seasonal weather models. Recent trends in summer temperatures and precipitation were also considered. This analysis focuses on the forecast for June, July, and August 2025, as these months represent the peak of ozone season in Delaware.

CPC's forecast for temperature and precipitation anomalies for summer 2025 are shown below.

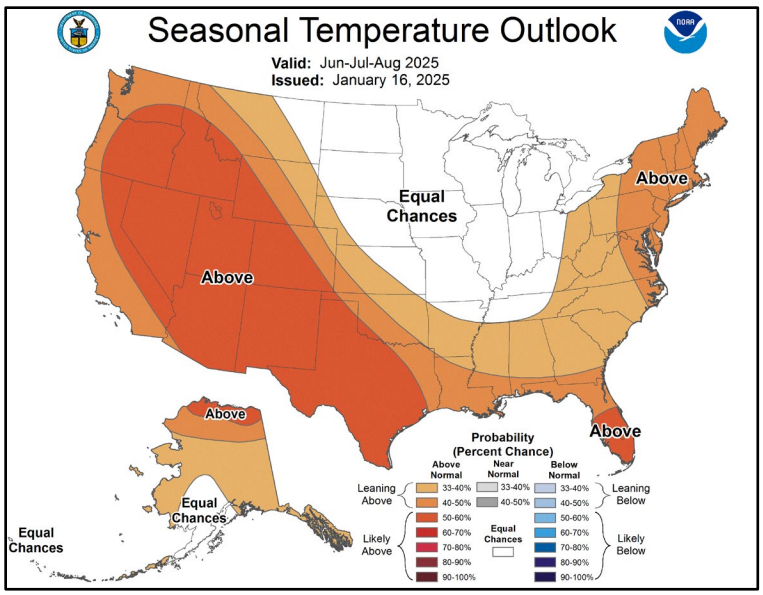

Figure 36. Forecast probability of surface temperature anomalies for June, July, and August 2025. Source: CPC.

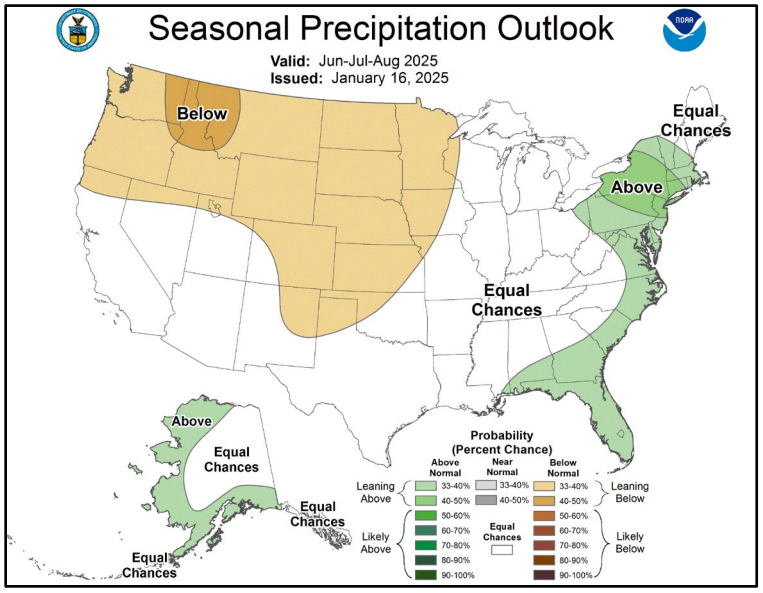

Figure 37. Forecast probability of precipitation anomalies for June, July, and August 2025. Source: CPC.

Figures 36 and 37 indicate that the CPC is predicting a 40-50% chance of above-average temperatures and a 33-40% chance of above-average precipitation in Delaware for summer 2025. The following sections detail how other data sources compare with the official forecast and provide a brief discussion of how meteorology could impact ozone and $PM_{2.5}$ in Delaware during the summer.

5.3 El Niño Southern Oscillation

CPC's ENSO outlook is predicting a transition from weak La Niña conditions observed over winter 2024-2025 to ENSO-neutral conditions during summer 2025. 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 insights 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 weak La Niñas to ENSO-neutral summertime conditions. Since 1990, similar transitions occurred in 2005, 2008, 2016, and, most recently, 2017. Figures 38 and 39 are composites of the temperature and precipitation anomalies that occurred during those analogous summers.

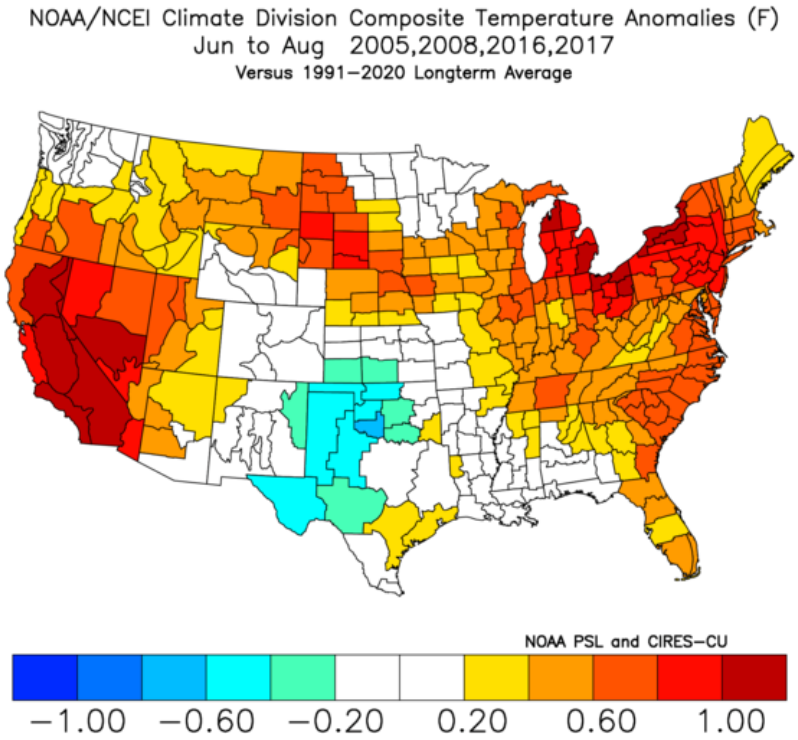

Figure 38. Temperature anomalies (°F) for ENSO-neutral summers after winters with weak La Niña conditions. Source: NOAA PSL and CIRES-CU.

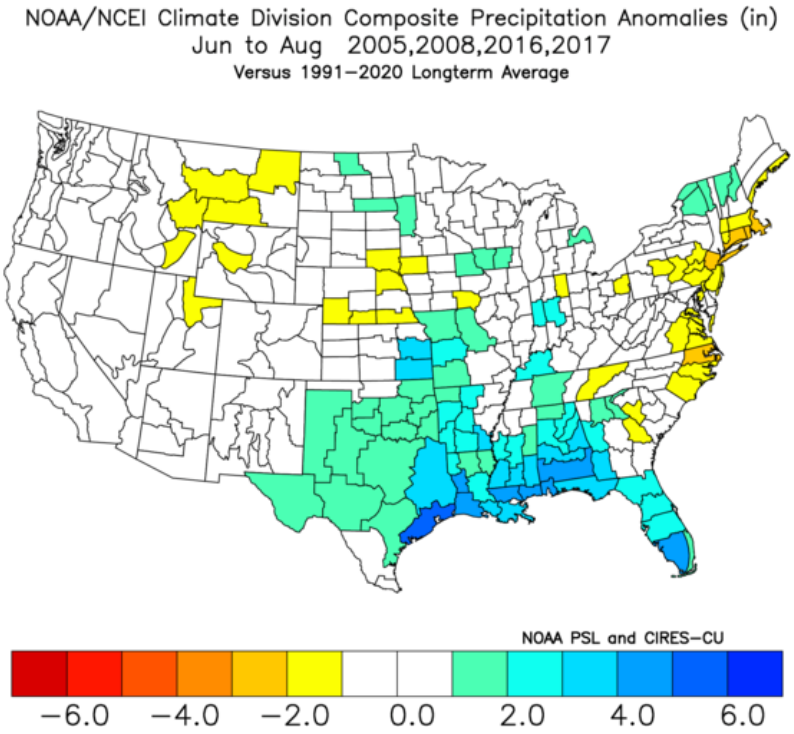

Figure 39. Precipitation anomalies (inches) for ENSO-neutral summers after winters with weak La Niña conditions. Source: NOAA PSL and CIRES-CU.

Comparing the CPC's temperature forecast in Figure 36 with historical temperature anomalies during ENSO-neutral summers following winters with weak La Niñas in Figure 38, one can see that there is good agreement in the potential for another summer with above-normal temperatures. The precipitation forecast for Delaware from the CPC in Figure 37 differs from the historical precipitation anomalies in Delaware in Figure 39, with the CPC forecasting above-average precipitation; near-normal conditions occurred during ENSO-similar summers over the Mid-Atlantic.

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 forecasts from climate models to see how they compare with the overall forecast.

5.4 Model Forecasts

The seasonal temperature and precipitation forecasts from the CanSIPS model are shown in **Figures 40 and 41**. 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.

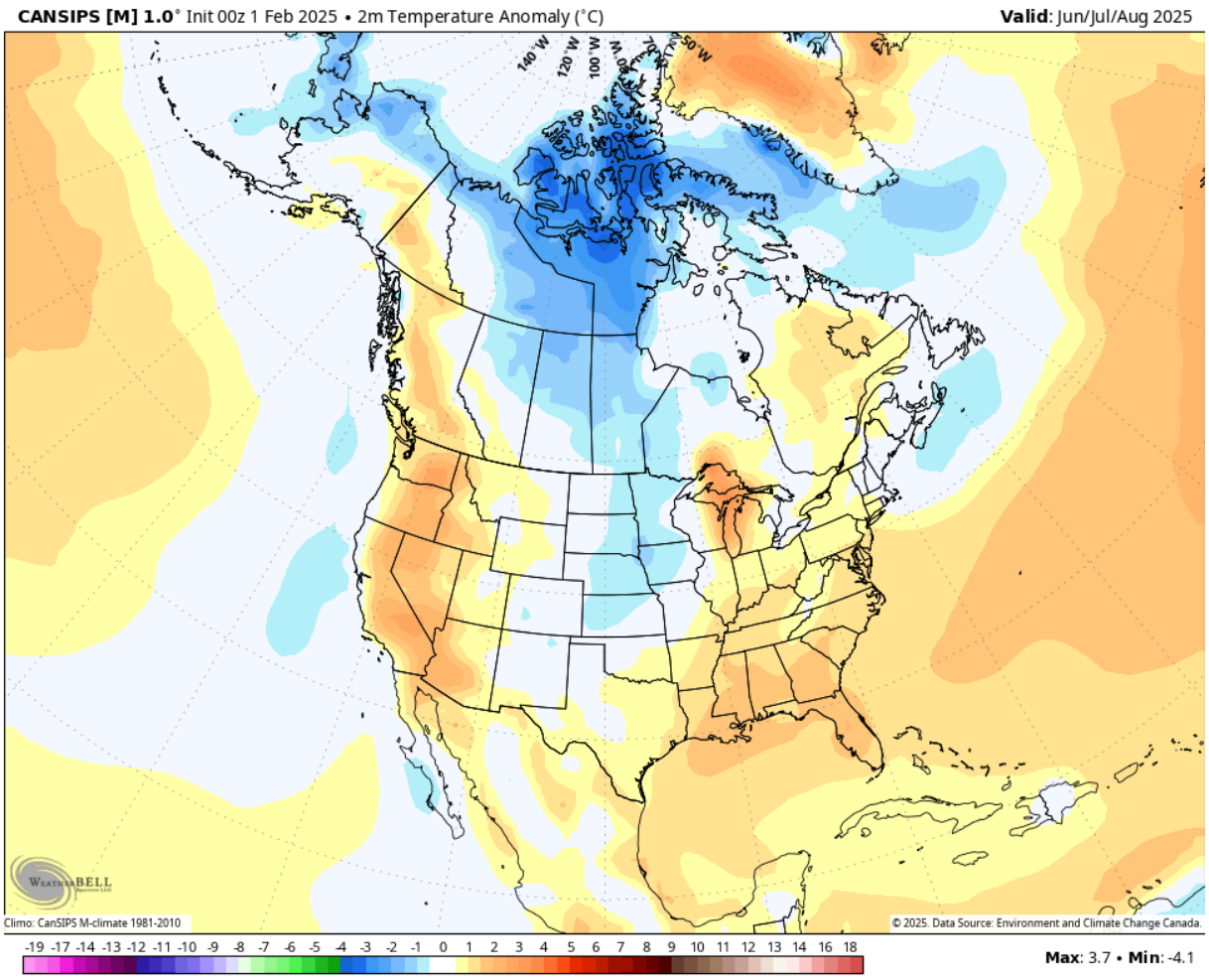

Figure 40. CanSIPS forecast temperature anomalies (Celsius) for June-August 2025. Source: WeatherBell.

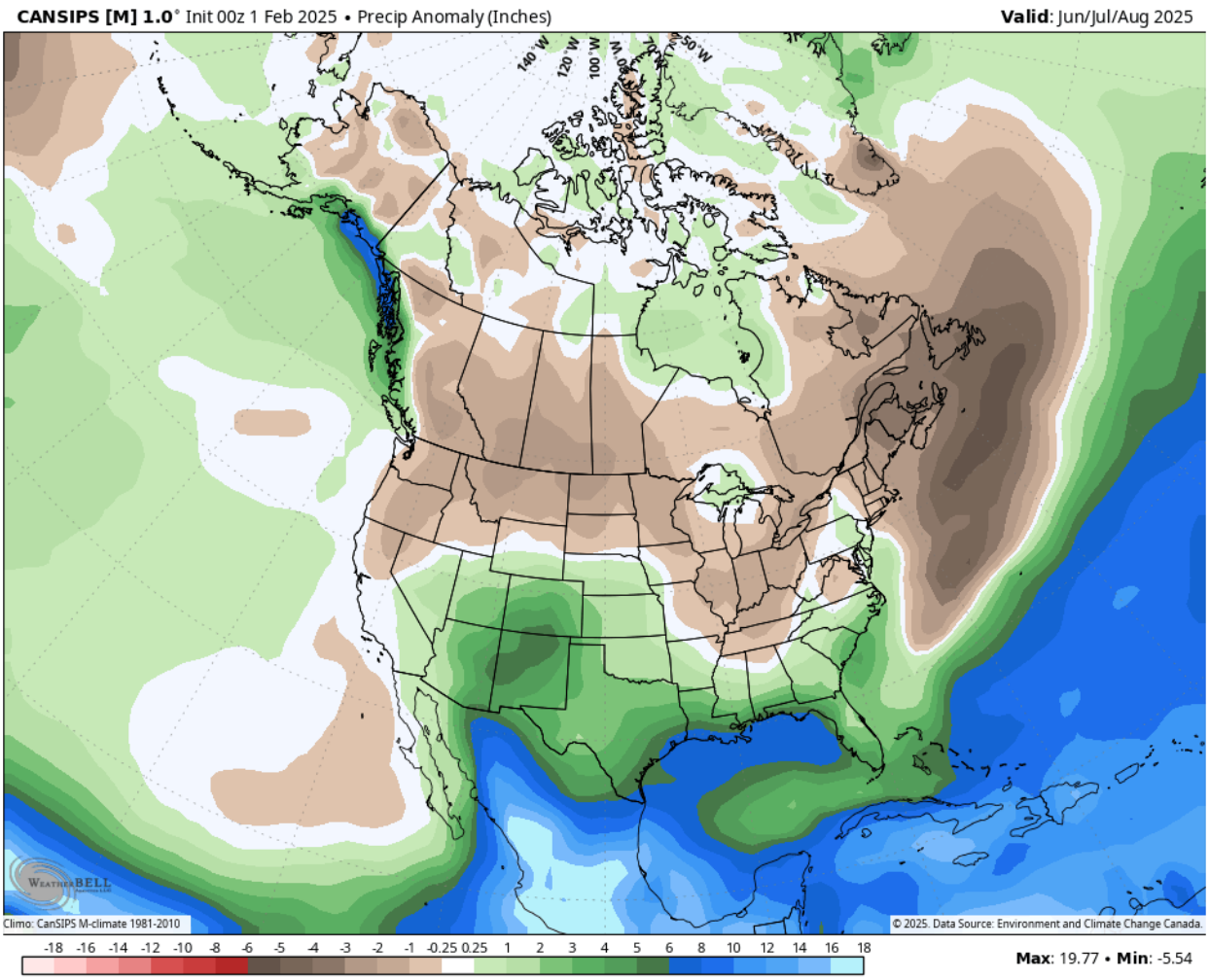

Figure 41. CanSIPS forecast precipitation anomalies (inches) for June-August 2025. Source: WeatherBell.

Similar to the CPC's forecast and the ENSO analogs, the CanSIPS model is forecasting above-average temperatures for Delaware during summer 2025. Meanwhile, the precipitation forecast from CanSIPS for the Mid-Atlantic is similar to CPC's forecast, with the potential for slightly above-average rainfall in Delaware.

Summer temperature and precipitation outlooks are also available from the ECMWF seasonal weather model. Similar to the CanSIPS model, the ECMWF seasonal model is forecasting above-average temperatures for June, July, and August in Delaware. However, the magnitude of the anomaly is smaller, indicating temperatures closer to normal (Figure 42).

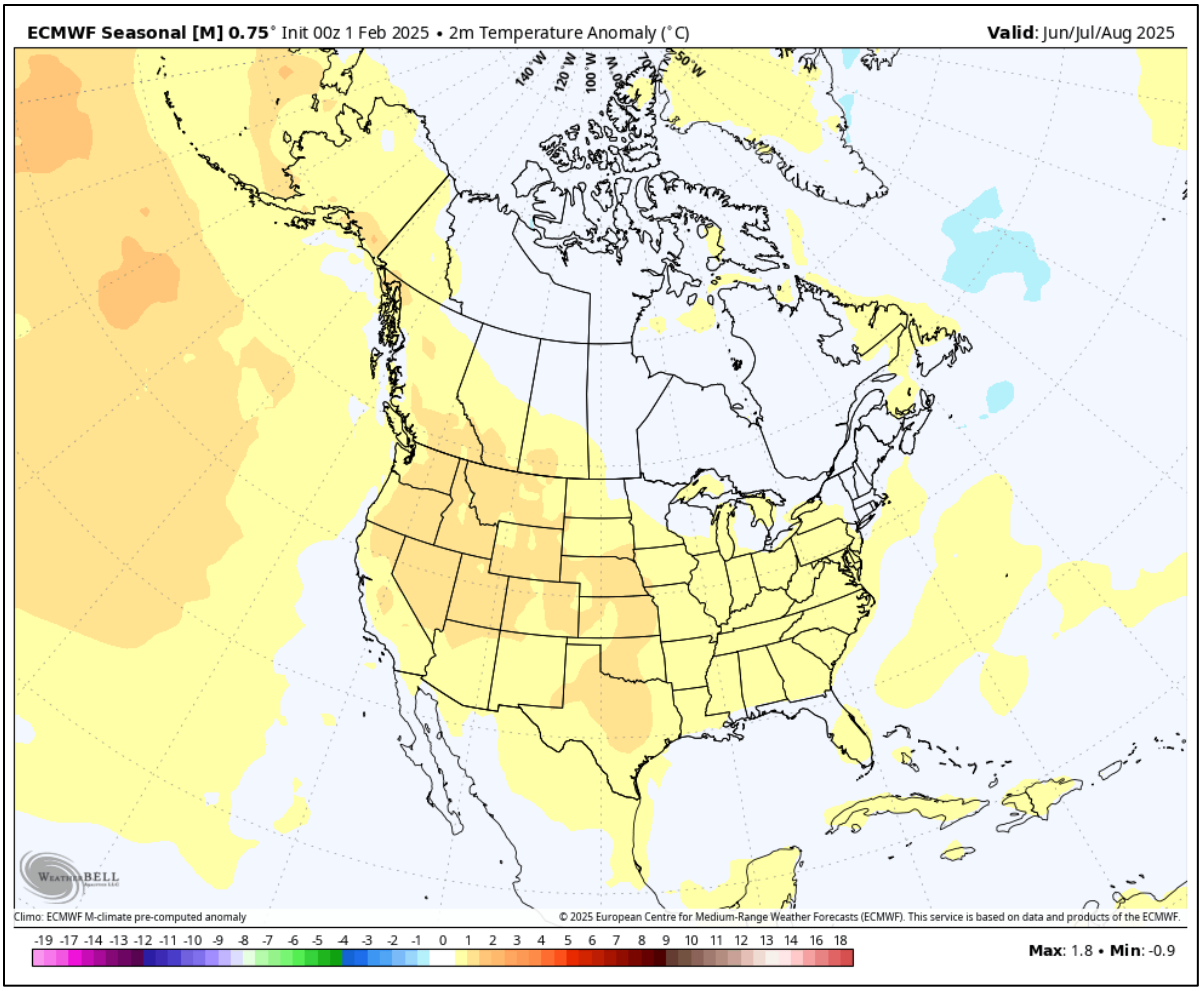

Figure 42. ECMWF temperature outlook for June, July, and August 2025. Source: WeatherBell.

The summer precipitation forecast for Delaware from the ECMWF is also similar to the CanSIPS model, with a forecast of slightly above-average precipitation across the Mid-Atlantic (**Figure 43**).

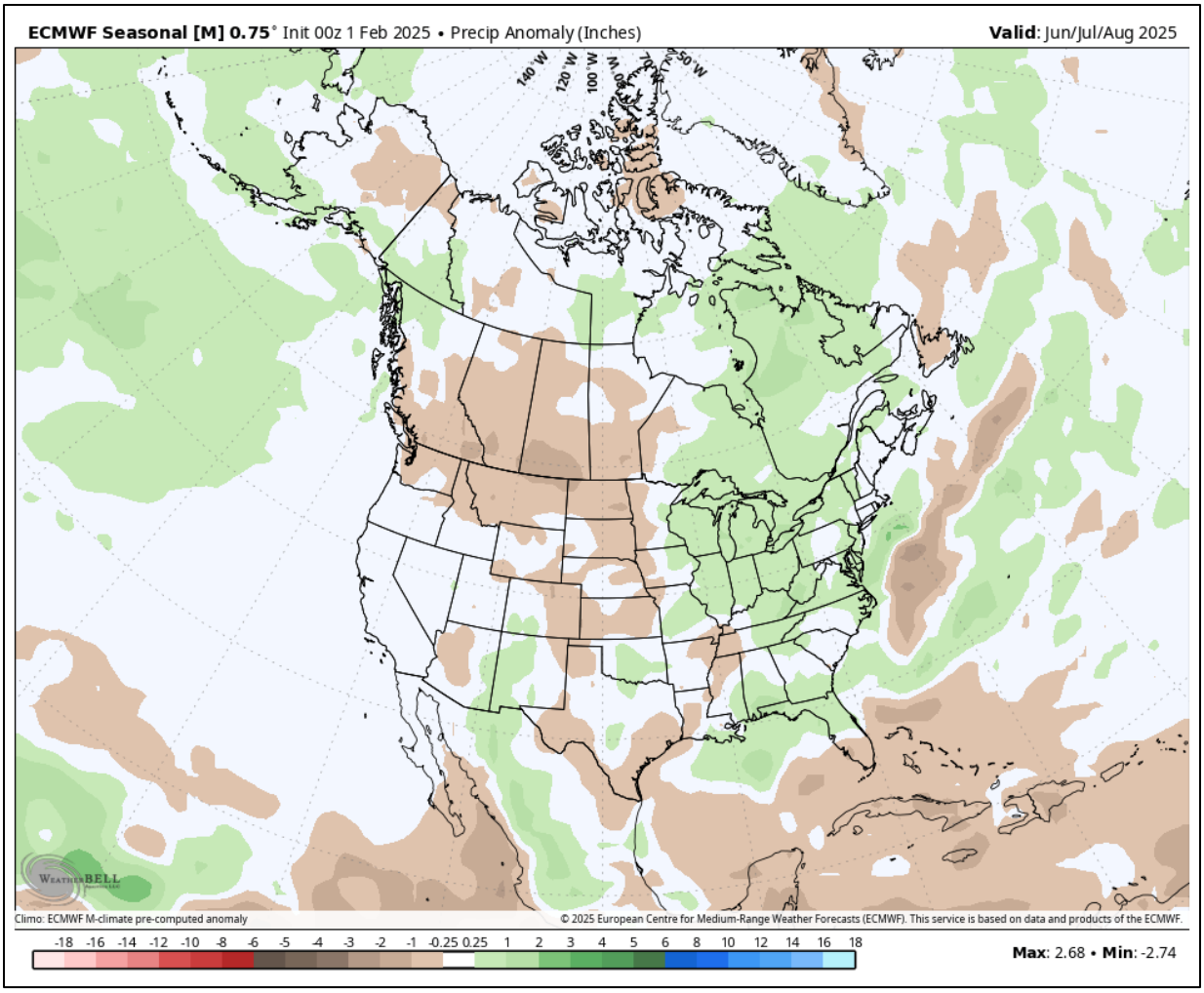

Figure 43. ECMWF precipitation outlook for June, July, and August 2025. Source: WeatherBell.

5.5 Trends in Summer Temperatures and Precipitation

Another factor to consider in seasonal weather predictions is recent weather trends compared with 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 44**.

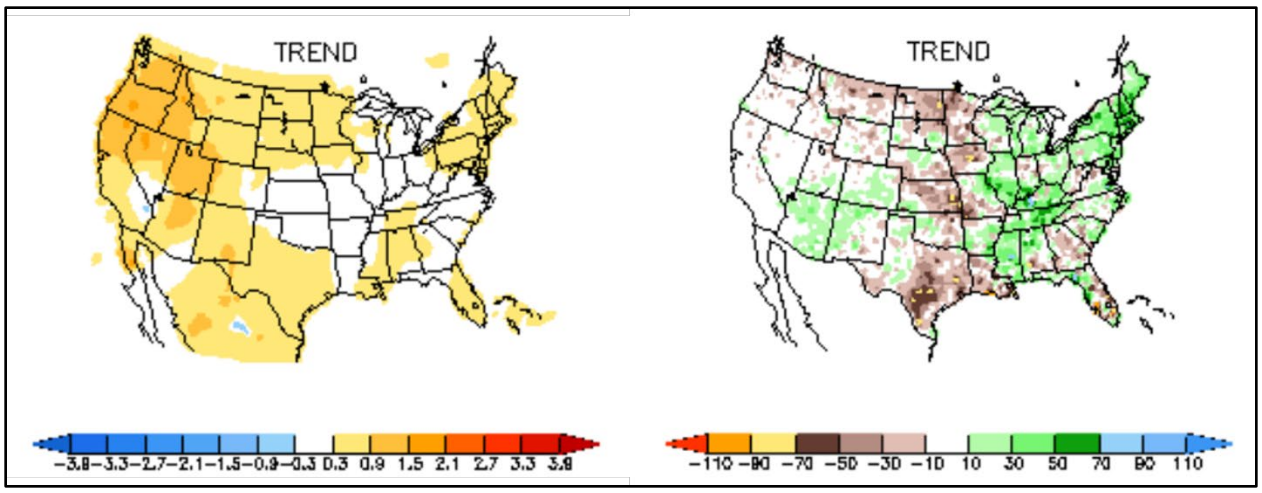

Figure 44. Recent trends in temperature in ˚C (left) and precipitation in millimeters (right) for June, July, and August. The recent trend is estimated by the Optimal Climate Normal (OCN) of Huang et al. (1996).[2]

Trends in summertime temperatures and precipitation show that, in general, temperatures exhibit a slight tendency toward warming from the Northeast into the Mid-Atlantic. Meanwhile, summertime precipitation is increasing in many areas east of the Mississippi River.

5.6 Canadian Smoke Factors

As noted 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 $PM_{2.5}$. Previous seasons have shown that Canadian wildfire smoke can increase above average seasonal levels when spring temperatures are above average, or abnormally dry antecedent conditions exist as summer approaches. Figure 45 shows forecast 500-mb geopotential height anomalies for the period from March-May 2025, as forecast by the CanSIPS and ECMWF models.

[2] Huang et al. "Long-lead seasonal temperature prediction using optimal climate normals." Journal of Climate, vol. 9, no. 4, Apr. 1996.

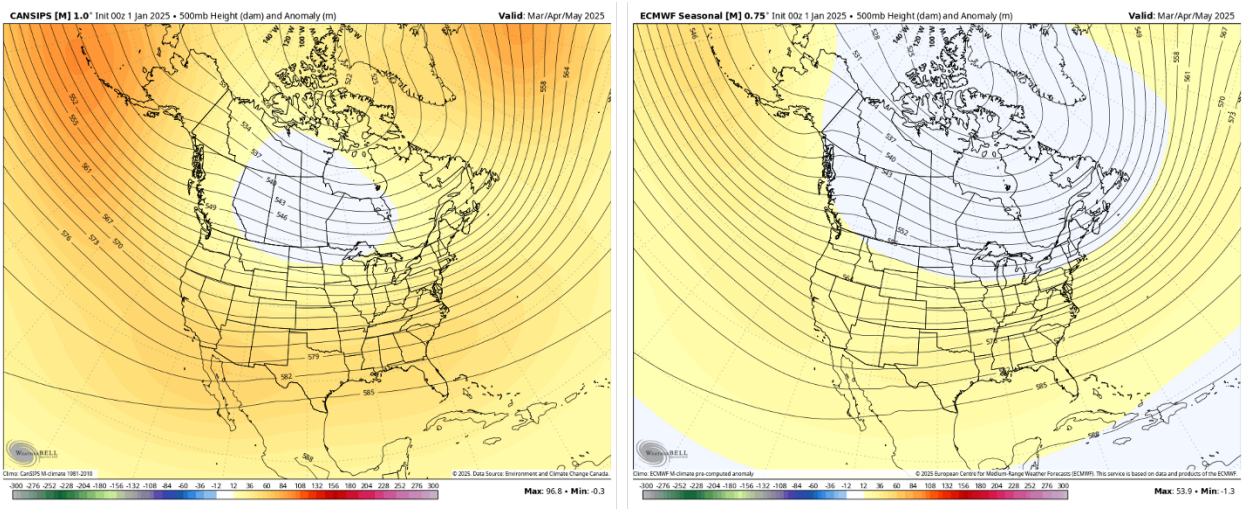

Figure 45. Forecast 500-mb height anomalies from March-May 2025 from the CanSIPS model (left) and the ECMWF model (right). Source: WeatherBell.

Positive 500-mb height anomalies (warm colors) can indicate the potential for above-average surface temperatures; the white portions of the maps show near-average 500-mb heights. As shown in Figure 45, both models are forecasting near-average 500-mb heights across Canada during spring 2025. This situation would reduce the potential for widespread spring warmth and rapid drying of vegetation. In addition, with positive height anomalies off both Canadian coasts, the pattern is favorable for weak upper-level troughing over eastern Canada, which could bring about a cooler, wetter spring for the eastern provinces. This information is useful when assessing current drought conditions and trends across Canada.

Although drought conditions have improved across much of Canada since the winter of 2023-24, areas of moderate drought have developed across far southeastern Ontario and southern Quebec (Figure 46). While this situation would normally raise concerns about a potential increase in fire activity as summer approaches, the forecast for weak troughing over this region in the spring could alleviate those concerns.

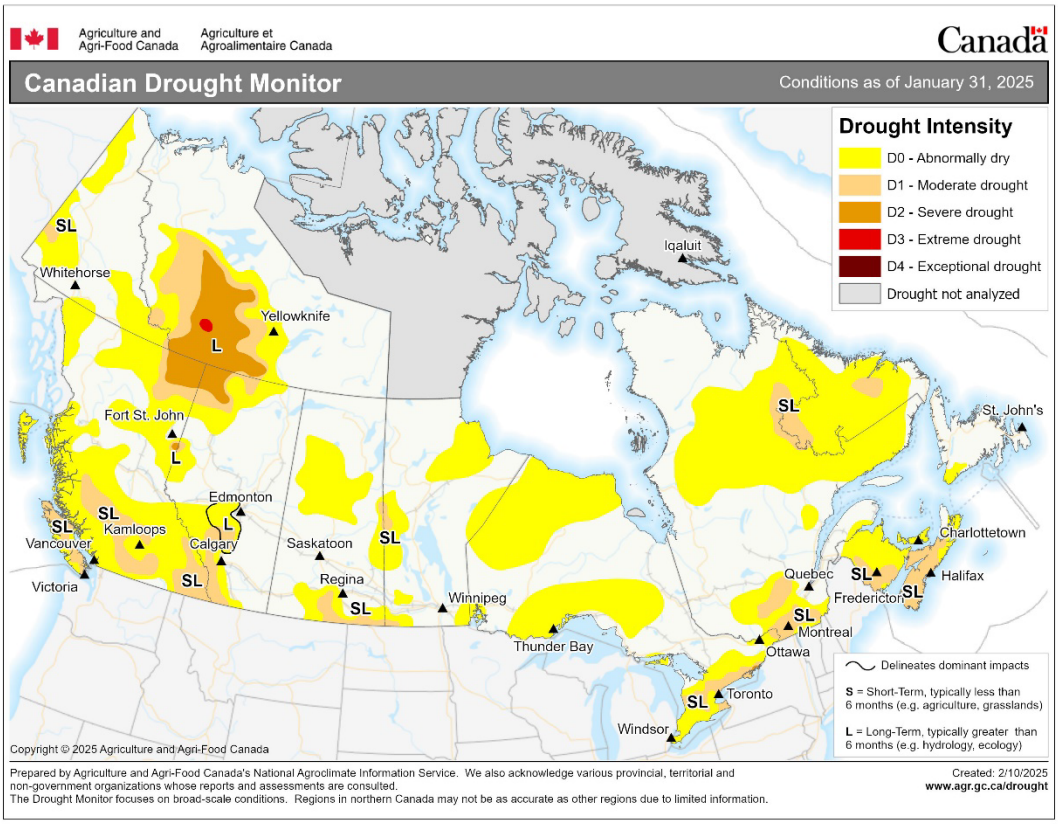

Figure 46. Drought conditions as of January 31, 2025. Source: Agriculture and Agri-Food Canada.

The "SL" designation for this region shown in Figure 46 means that the drought across southeastern Canada is expected to be a mix of short-term (6 months or less) and long-term (more than 6 months). Model forecasts provide additional evidence for some of these impacts being short-lived; the CanSIPS and ECMWF models are predicting the potential for near- to below-average temperatures and above-average precipitation in this region during the spring (Figure 47).

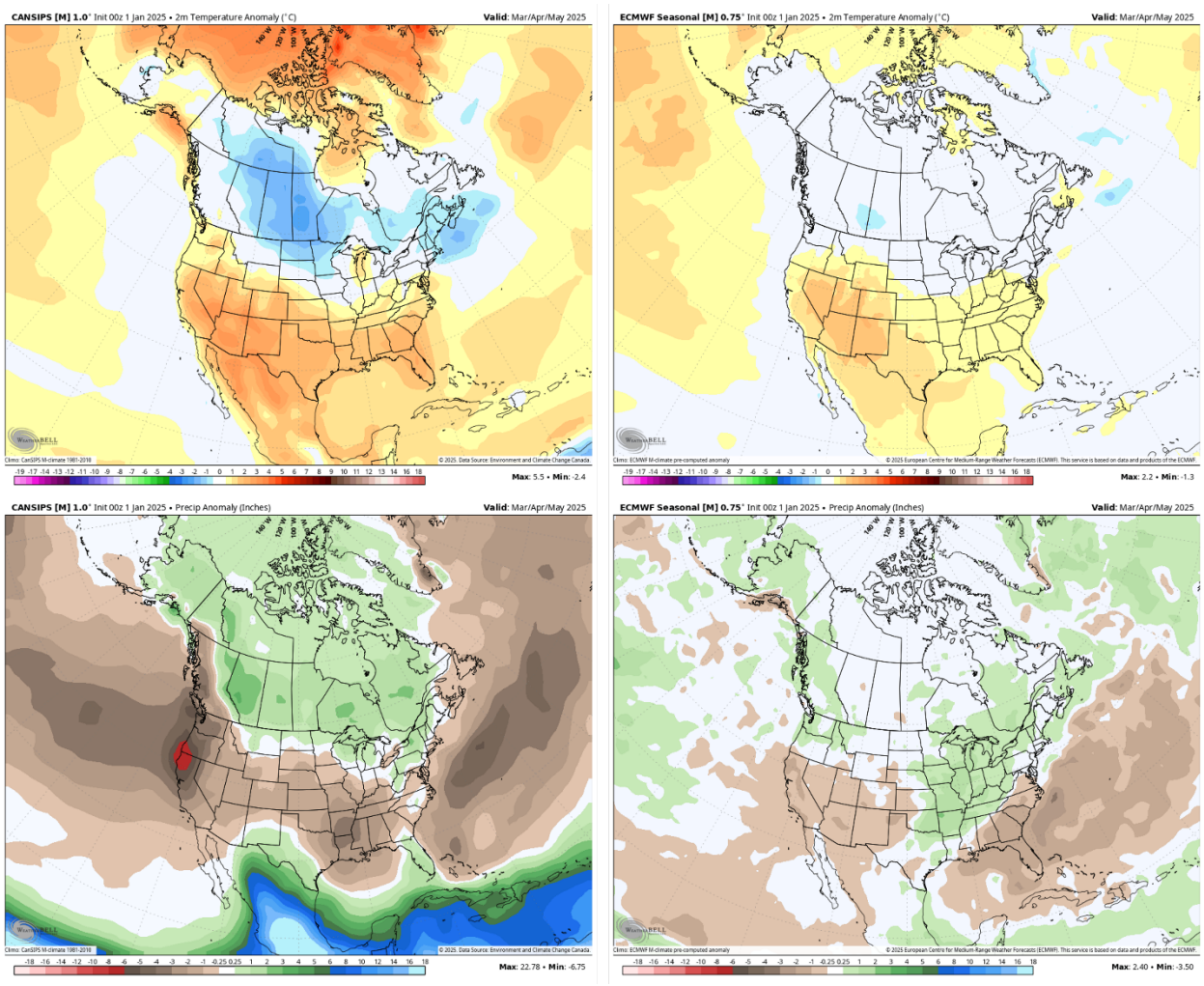

Figure 47. Forecast temperature anomalies in degrees Celsius (top) and forecast precipitation anomalies in inches (bottom) from the CanSIPS model (left) and ECMWF model (right).

In addition, snow cover is running near- to above-average across much of Canada this season (Figure 48).

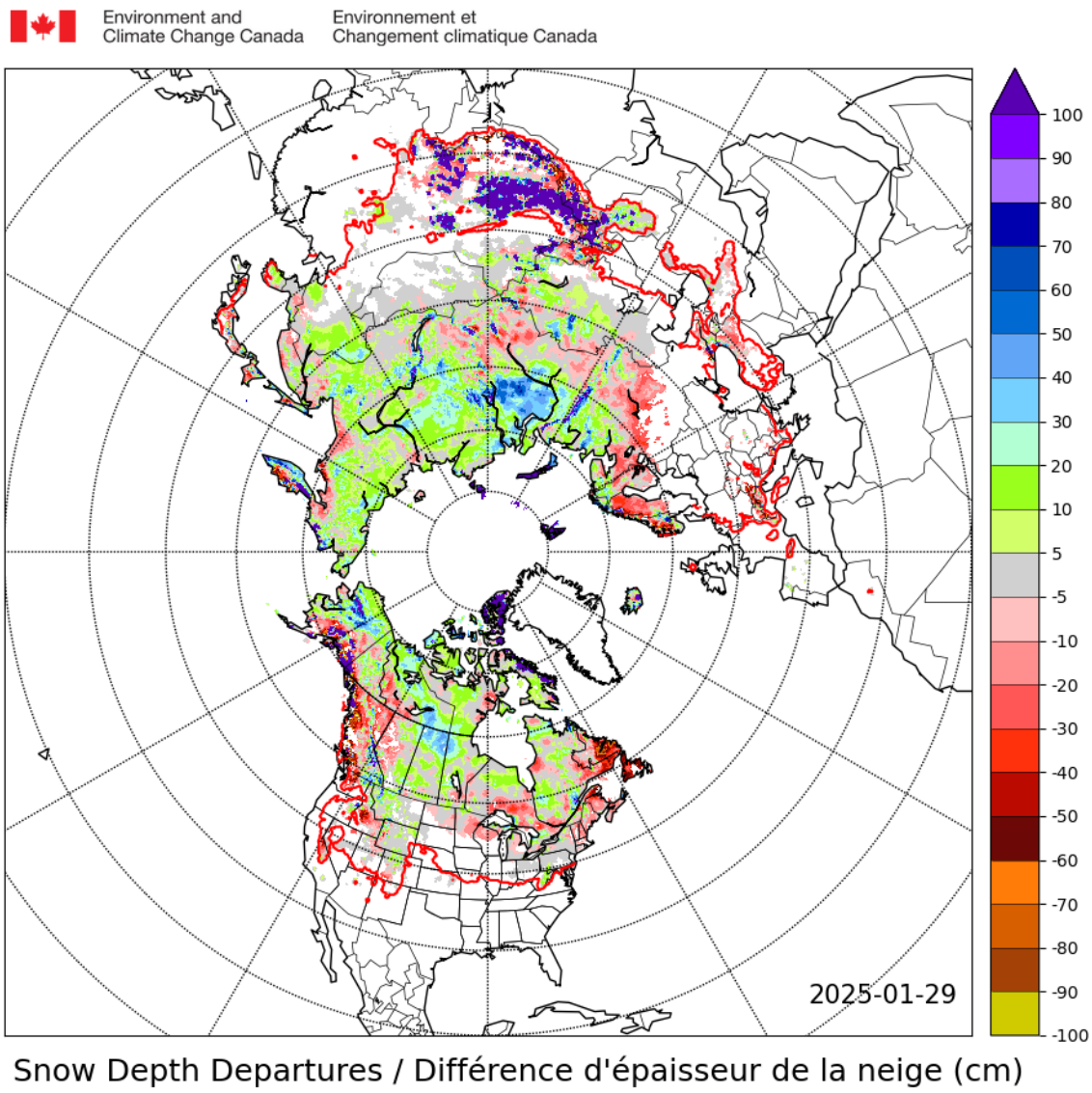

Figure 48. Snow depth departures (cm) for the northern hemisphere, as of January 29, 2025, compared with the period from 1998-1999 through 2011-2012. The thick red contour line indicates the historical location of the snowline (50% probability of snow depth of at least 2 cm). Source: Environment and Climate Change Canada.

The combination of a near- to above-average winter snowpack and the potential for a cool and wet spring across Canada provide early indications that there could be some reprieve from the well-above-average smoke production that has been observed over the last two summers.

5.7 Implications for Summer 2025 Ozone and $PM_{2.5}$ 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 ENSO-neutral conditions in the equatorial Pacific during summer 2025. On average over the last few decades, ENSO-neutral summers following weak La Niñas 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 for summer 2025 in Delaware.

For the precipitation forecast for summer 2025, there is good agreement between forecast model predictions for above-average rainfall in the mid-Atlantic this summer. In addition, precipitation trends are also toward gradually increasing rainfall for much of the eastern United States during the summer. Furthermore, CPC's forecast for the summer indicates a 33-40% chance of above-normal precipitation. While ENSO-similar summers have resulted in near-average precipitation in the region, with all other methods indicating the potential for increased moisture over along the East Coast meteorologists at Sonoma Technology are forecasting above-average rainfall in the Mid-Atlantic this summer.

While the forecast for above-average temperatures could result in increased ozone formation in Delaware this summer, the effects of the warm temperatures are expected to be balanced by increased precipitation, which could result in decreased solar insolation and ozone development. In addition, with Canadian smoke impacts potentially staying closer to average this summer, meteorologists at Sonoma Technology are not anticipating a significant increase in $PM_{2.5}$ or ozone due to wildfire smoke this summer. Taking all these factors into consideration, ozone and $PM_{2.5}$ concentrations are forecast to be near average across the Mid-Atlantic during summer 2025.