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Ozone Impacts from Building Combustion Sources on Nonattainment Areas in New York

Introduction and Summary

Sonoma Technology performed source apportionment modeling using the Comprehensive Air Quality Model with Extensions (CAMx) with Ozone Source Apportionment Technology (OSAT) to evaluate ozone impacts from residential, commercial, and institutional fossil fuel combustion sources (referred to collectively as "building combustion sources" or "building sources" in this report)[1] and other emission sources on downwind receptors in nonattainment areas (NAAs). The source apportionment modeling was conducted for the 2016 ozone season (April to October) for a domain covering the continental United States at 12-km spatial resolution, and results were compiled into a database with an online dashboard application that can be used for data mining and analysis. CAMx OSAT simulations were also conducted for the 2023 future year using a projection of 2023 future-year emissions.[2]

The modeling results showed that on numerous nonattainment days in 2016, emissions from building emission sources in New York resulted in impacts of greater than 1% of the ozone National Ambient Air Quality Standard (NAAQS) (i.e., ozone impacts exceeding 0.70 ppb) at air quality station (AQS) monitoring locations and at environmental justice (EJ) zip codes within the New York ozone NAA. The maximum modeled 8-hr ozone impact occurred in the New York portion of the New York-Northern New Jersey-Long Island NAA on May 28, 2016, due to the total of all New York building source emissions, where the 2016 base-year maximum ozone modeled impact at an NAA monitor was 1.51 ppb and the 2023 future-year maximum ozone modeled impact was 2.49 ppb. Spatial plots in Figure 1 show the absolute Maximum Daily Average 8-hr ("MDA8") modeled ozone impact from all New York building sources during the 2016 ozone season (April to October) for the 2016 base year and the 2023 projected future year.

Significant impacts occurred for the 2016 base year and the 2023 projected future year for the New York NAA and EJ zip codes analyzed in this report. The substantial increase in projected ozone contributions in 2023 is tied to an increase in nitrogen oxides (NO_x) emissions from the nonpoint (*nonpt*) sector (which includes building sources) in the EPA modeling platform between 2016 and

[1] Building combustion sources that were tagged for this report include fossil fuel combustion from residential heating and appliances (excluding residential wood combustion), as well as commercial and institutional heating, appliances, boilers, and internal combustion engines. See Appendix A for additional details. Table A-3 shows the Source Classification Codes (SCCs) for the building sources that were tagged in the modeling.

[2] Future-year ozone concentrations are modeled using emissions that have been projected to the future year (in this case, 2023), but using meteorology, boundary conditions, and other inputs representative of the 2016 base year. In this report, "future year" refers to modeling results that are based on the "projected" 2023 emissions inventory.

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2023 (see Appendix A for details). On nonattainment days, 2023 projected future-year modeled impacts were approximately 1.3 to 2.1 times higher compared to 2016 base-year modeled impacts.

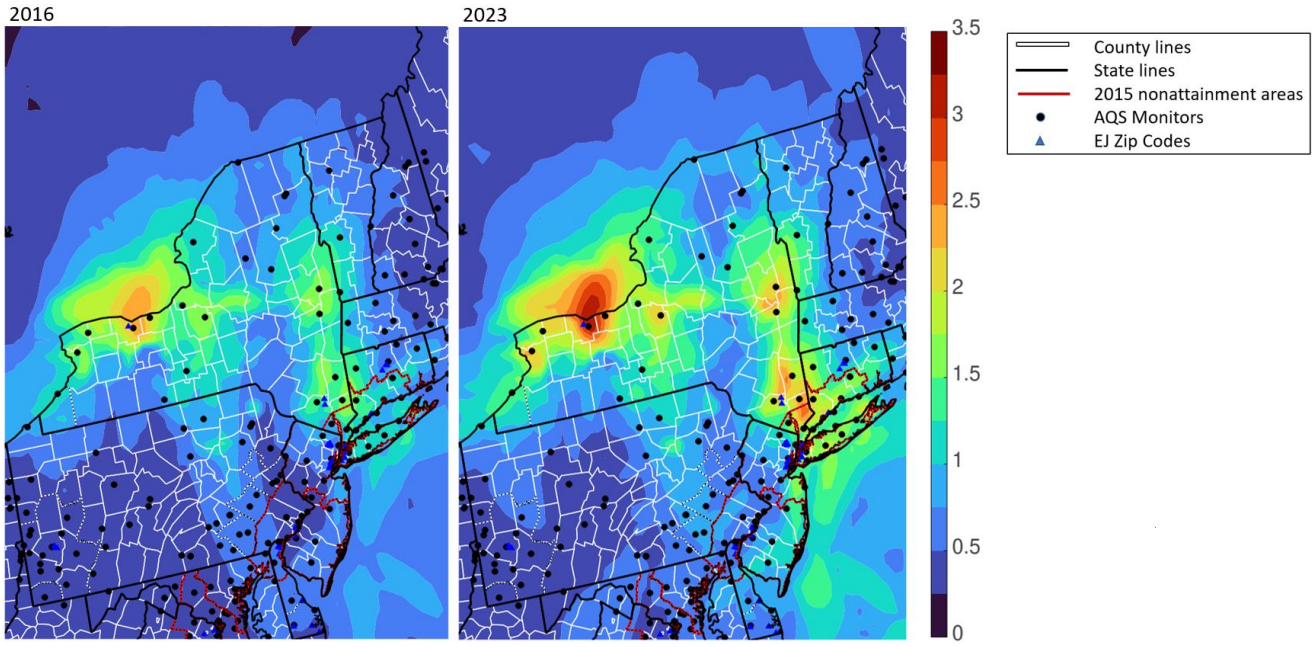

Figure 1. Absolute maximum daily average 8-hr (MDA8) modeled ozone impacts (ppb) due to all New York building combustion sources during the 2016 ozone season (April to October). The 2016 plot (left) shows base-year modeled ozone impacts, while the 2023 plot (right) shows projected future-year modeled ozone impacts.

The source apportionment modeling simulations relied on the U.S. Environmental Protection Agency (EPA) 2016v2 (2016fj_16j) modeling platform,[3] which draws on emissions data from the EPA National Emissions Inventory and data developed by the National Emissions Inventory Collaborative.[4] EPA also developed emissions inventories for the 2023 future year (2023fj_16j) to project the 2016 base-year emissions into 2023. This EPA modeling platform tends to underpredict MDA8 ozone concentrations for days when the MDA8 ozone is greater than or equal to 60 parts per billion (ppb). Modeling results for the monitoring sites included in this report generally follow this trend. Overall, EPA found that "the ozone model performance results for the CAMx 2016fj (2016v2) simulation are within or close to the ranges found in other recent peer-reviewed applications" and that "the model performance results demonstrate the scientific credibility of the 2016v2 modeling platform" (U.S. Environmental Protection Agency, 2022a).

[3] 2016v2 was the most recent version of EPA's modeling platform available at the time this modeling was conducted. EPA updated the modeling platform to 2016v3 (2016gf) in January 2023 (U.S. Environmental Protection Agency, 2023a).

[4] The National Emissions Inventory Collaborative is a partnership between state emissions inventory staff, multi-jurisdictional organizations, federal land managers, EPA staff, and others to develop a North American air pollution emissions modeling platform for use in air quality planning.

Biases in the modeled ozone concentrations can contribute to uncertainty in the source apportionment contribution results. To help mitigate this uncertainty, the source apportionment modeling results are used in a "relative" sense rather than an "absolute" sense. For this report, relative source contributions for the 2016 base year were calculated based on a daily 8-hr average basis by multiplying the absolute modeled source contribution by the ratio of the monitored concentration and the total modeled ozone value. For the future-year source contributions, the ratio of the total modeled MDA8 ozone concentration between 2023 and 2016 was used to estimate projected future-year (2023) observed ozone concentrations, and these projected observed ozone concentrations were used to apportion the modeled ozone. These approaches have been used in past ozone source apportionment modeling analyses (e.g., Craig et al., 2020) and are similar to methods used by EPA to calculate ozone source contributions from a photochemical grid model (U.S. Environmental Protection Agency, 2022a). Anchoring the modeled apportionment results to ambient monitoring data can help mitigate uncertainty associated with imperfect model performance (Foley et al., 2015; Jones et al., 2005). The ozone source apportionment results in this report should be considered indicative of the types of ozone impacts that can be expected from building sources. Additional details on the models, data, and methods used can be found in **Appendix A**.

The results from this ozone source apportionment modeling were used to analyze the impacts of emissions from building combustion sources located in NAA and attainment areas (AAs) in New York on AQS monitor locations and EJ zip codes in the New York NAA. Maximum modeled contributions are shown on days when the monitored MDA8 ozone concentration exceeded the 2015 ozone standard (70 ppb) in areas that were in nonattainment for either the 2008 National Ambient Air Quality Standard (NAAQS) and/or the 2015 NAAQS.

New York Ozone Nonattainment Areas Analysis

Modeled contributions from building combustion sources located in the New York NAA and AA are presented in this section. Modeled contributions from buildings in the New York portion of the New York-Northern New Jersey-Long Island NAA were split into two groups: 1) Buildings in Bronx, Kings, New York City, Queens, and Richmond counties (referred to as "inner New York City (NYC) counties" in this report), and 2) Buildings in Nassau, Rockland, Suffolk, and Westchester counties (referred to as "outer NYC counties" in this report). The New York NAA and AA for the 2015 ozone NAAQS are shown in **Figure 2**. Building combustion sources include commercial, institutional, and residential fossil fuel combustion emission sources that were included in both EPA's 2016v2 base-year emissions platform and 2023 emissions projections. Building source impacts were analyzed on days when the observed MDA8 ozone concentration exceeded the 2015 ozone NAAQS of 70 ppb at New York AQS monitors located within a 2008 and/or 2015 ozone NAA.

Relative source contributions at monitoring locations are presented in the tables in this section, with contributions that equal or exceed 1% of the 2015 ozone NAAQS (0.70 ppb) highlighted in red, and contributions that equal or exceed 0.5% of the 2015 ozone NAAQS (0.35 ppb) highlighted in yellow. Maximum source contributions for building sources in the NAA, AA, and the combination of all areas (NAA+AA) are highlighted in bold. Absolute source contributions from the model are adjusted to the monitoring data at AQS monitor locations using the methodology discussed in **Appendix A.** The resulting values give a relative modeled contribution during a monitor exceedance day. Modeled contributions at EJ zip codes in the NAA are presented as absolute (unadjusted) modeled concentrations since there are no ozone monitors at the EJ zip code locations.

Spatial plots showing the absolute maximum modeled MDA8 ozone impacts (ppb) from building sources are also presented for the 2016 base year and the 2023 future-year projection. Building sources were modeled as an "area wide" emissions source, where each grid cell in the model had some building combustion emissions. Emissions from these sources tend to be concentrated in urban areas. Ozone impacts were widespread and far-reaching because the model tracked ozone concentrations attributable to all the building source NO_x and volatile organic compound (VOC) emissions that are spread throughout each state. Maximum modeled impacts often occur in or near urban areas.

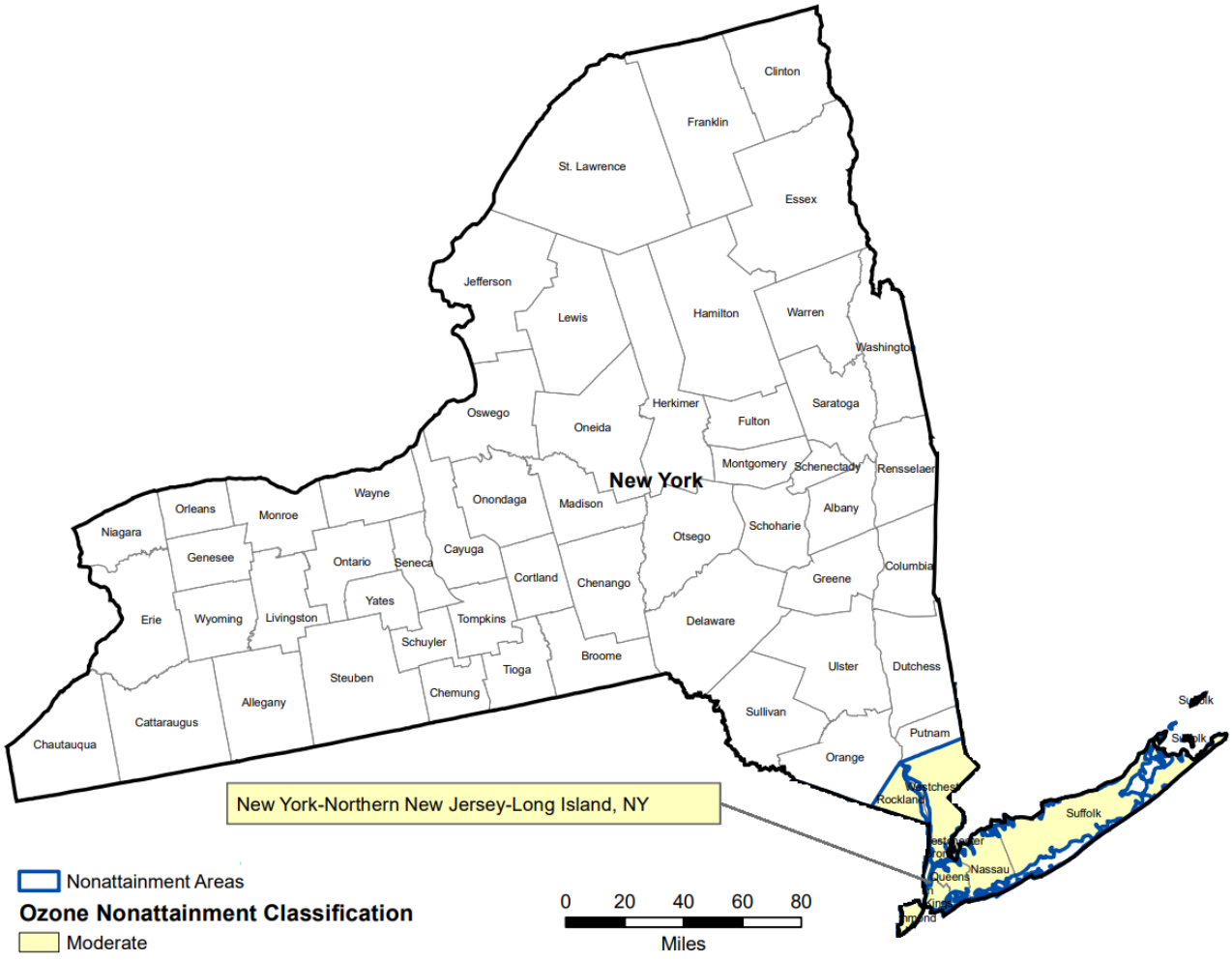

Figure 2. New York nonattainment areas (NAA) and attainment areas (AA) for the 2015 ozone NAAQS. Adapted from EPA Green Book at https://www3.epa.gov/airquality/greenbook/jnmapa.html. Accessed 11/30/2023.

New York Impacts

Impacts from New York building sources were evaluated at AQS monitors and EJ zip codes located within the New York portion of the New York-Northern New Jersey-Long Island 2015 ozone NAA. Impacts were evaluated on days in 2016 when the monitored MDA8 ozone concentrations in the NAA exceeded the 70 ppb NAAQS.

2016 modeled contributions and projected 2023 modeled contributions from New York building sources on 2016 nonattainment days are shown in **Tables 1 and 2**. Spatial plots showing absolute MDA8 modeled ozone impacts from statewide New York building sources during the 2016 ozone season (April to October) are shown in **Figure 3** for the 2016 base year and for the 2023 projected future year. Note that these modeled impacts also include some impacts from building emission sources outside of the New York portion of the New York-Northern New Jersey-Long Island area because of the imperfect overlap between the NAA boundaries and model grid cells.

Building combustion sources located within the inner NYC counties and the outer NYC counties contribute about equally to total modeled impacts at AQS monitors in the NAA. For EJ zip codes located in the NAA, the highest impacts occur from building sources located in the inner NYC counties.

Table 1. Maximum **2016** modeled impacts from New York building sources on days that exceeded the ozone NAAQS of 70 ppb at any monitor in the **New York-Northern New Jersey-Long Island, NY** NAA during the 2016 ozone season. 8-hr maximum modeled ozone contributions are relative values (ppb) at **New York-Northern New Jersey, Long Island, NY** nonattainment AQS monitors and absolute values (ppb) at EJ zip codes from sources located in NAAs and AAs. Values that equal or exceed 1% of the NAAQS (0.70 ppb) are highlighted in red, while values that equal or exceed 0.5% of the NAAQS (0.35 ppb) are highlighted in yellow. Maximum source contributions are highlighted in **bold**.

New York-Northern New Jersey-Long Island, NY, NAA Receptors

Ozone Nonattainment Day	2016 Maximum Ozone Impact at any AQS Monitor (ppb)				2016 Maximum Ozone Impact at any EJ zip code (ppb)			
	Inner NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Outer NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Attainment Counties, NY Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Total Aggregate Statewide Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Inner NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes	Outer NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes	Attainment Counties, NY Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes	Total Aggregate Statewide Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes
25-May	0.48	0.50	0.42	1.41	0.51	0.00	0.05	0.56
26-May	0.45	**0.82**	0.20	1.46	0.63	0.01	0.13	0.77
27-May	0.37	0.05	0.10	0.53	0.38	0.01	0.04	0.43
28-May	**0.67**	0.42	**0.42**	**1.51**	0.65	0.00	0.16	0.81
7-Jun	0.16	0.18	0.03	0.37	0.14	0.00	0.01	0.15
11-Jun	0.01	0.00	0.03	0.04	0.13	0.00	0.02	0.15
16-Jun	0.09	0.26	0.07	0.42	0.25	0.03	0.07	0.35
20-Jun	0.14	0.09	0.09	0.32	0.27	0.02	0.07	0.36
21-Jun	0.29	0.32	0.18	0.79	0.22	0.01	0.03	0.26
26-Jun	0.29	0.32	0.18	0.79	0.34	0.06	0.12	0.52
6-Jul	0.04	0.27	0.17	0.48	0.23	0.02	0.16	0.42
15-Jul	0.22	0.21	0.11	0.54	0.20	0.00	0.02	0.23
17-Jul	0.40	0.36	0.10	0.86	**0.95**	0.12	0.19	**1.26**
21-Jul	0.08	0.01	0.12	0.21	0.21	0.01	0.10	0.32
22-Jul	0.09	0.07	0.07	0.24	0.12	0.00	0.03	0.15
28-Jul	0.15	0.01	0.16	0.32	0.43	0.08	0.21	0.72
29-Jul	0.40	0.19	0.33	0.93	0.48	**0.24**	**0.40**	1.12
9-Aug	0.38	0.18	0.24	0.80	0.49	0.12	0.21	0.82

Table 2. Maximum **2023** modeled impacts from New York building sources on days that exceeded the ozone NAAQS of 70 ppb at any monitor in the **New York-Northern New Jersey-Long Island, NY** NAA during the 2016 ozone season. 8-hr maximum modeled ozone contributions are relative values (ppb) at **New York-Northern New Jersey, Long Island, NY** nonattainment AQS monitors and absolute values (ppb) at EJ zip codes from sources located in NAAs and AAs. Values that equal or exceed 1% of the NAAQS (0.70 ppb) are highlighted in red, while values that equal or exceed 0.5% of the NAAQS (0.35 ppb) are highlighted in yellow. Maximum source contributions are highlighted in **bold**.

New York-Northern New Jersey-Long Island, NY, NAA Receptors

Ozone Nonattainment Day	2023 Maximum Ozone Impact at any AQS Monitor (ppb)				2023 Maximum Ozone Impact at any EJ zip code (ppb)			
	Inner NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Outer NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Attainment Counties, NY Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Total Aggregate Statewide Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA Monitors	Inner NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes	Outer NYC Counties, NAA Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes	Attainment Counties, NY Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes	Total Aggregate Statewide Building Emissions Impact on New York-Northern New Jersey-Long Island, NY NAA EJ zip codes
25-May	0.77	0.92	**0.68**	2.36	0.65	0.05	0.06	0.76
26-May	0.67	**1.32**	0.29	2.27	0.83	0.01	0.25	1.09
27-May	0.50	0.09	0.16	0.74	0.47	0.01	0.07	0.56
28-May	**1.16**	0.68	0.65	**2.49**	0.93	0.03	0.27	1.24
7-Jun	0.26	0.29	0.06	0.61	0.18	0.00	0.03	0.21
11-Jun	0.02	0.00	0.06	0.08	0.16	0.00	0.03	0.18
16-Jun	0.14	0.40	0.10	0.63	0.35	0.06	0.10	0.51
20-Jun	0.25	0.16	0.13	0.54	0.35	0.04	0.12	0.51
21-Jun	0.57	0.56	0.18	1.31	0.28	0.05	0.05	0.39
26-Jun	0.80	0.21	0.31	1.31	0.56	0.08	0.18	0.82
6-Jul	0.44	0.02	0.28	0.74	0.42	0.05	0.23	0.69
15-Jul	0.58	0.34	0.11	1.02	0.32	0.03	0.04	0.40
17-Jul	1.07	0.06	0.21	1.34	**1.58**	0.17	0.27	**2.03**
21-Jul	0.13	0.02	0.20	0.34	0.33	0.02	0.14	0.49
22-Jul	0.16	0.10	0.12	0.38	0.25	0.01	0.05	0.31
28-Jul	0.25	0.02	0.25	0.52	1.04	0.16	0.31	1.52
29-Jul	0.76	0.28	0.46	1.50	0.77	**0.32**	**0.51**	1.60
9-Aug	0.77	0.31	0.38	1.46	0.77	0.20	0.29	1.25

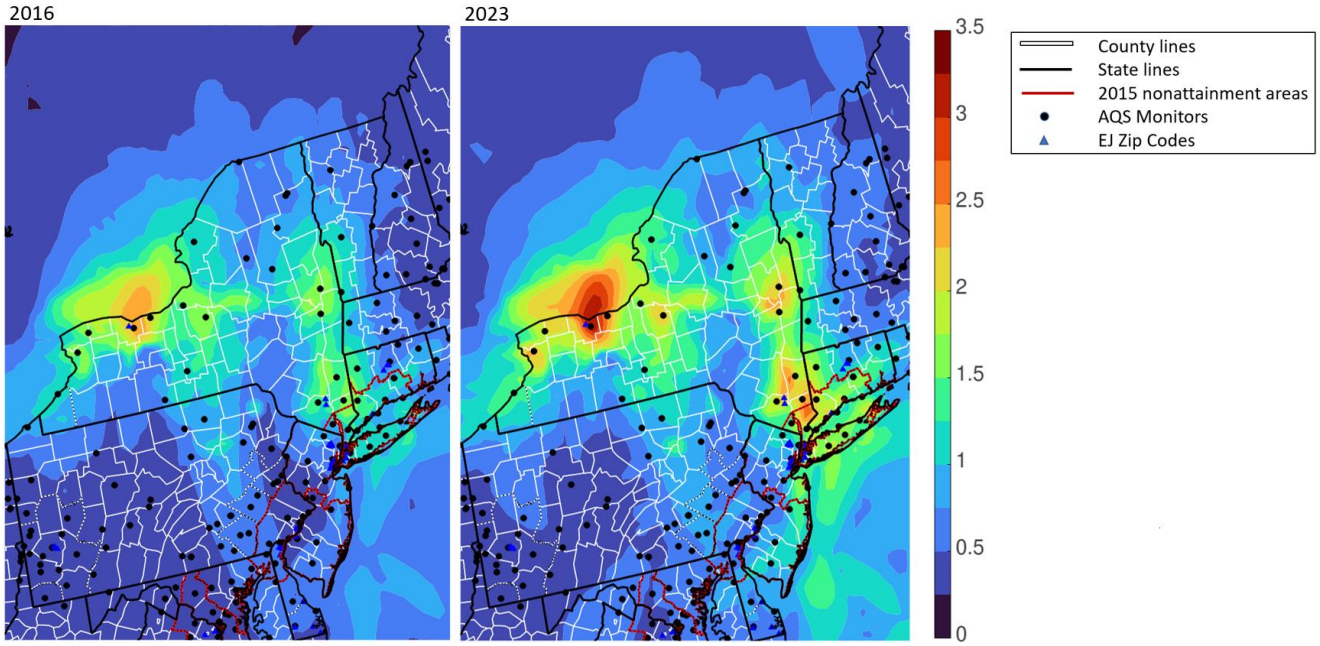

Figure 3. Absolute maximum daily average 8-hr (MDA8) modeled ozone impacts (ppb) due to all New York building combustion sources during the 2016 ozone season (April to October). The 2016 plot (left) shows base-year modeled ozone impacts, while the 2023 plot (right) shows projected future-year modeled ozone impacts

Appendix A. Modeling Methods

Photochemical Grid Model and Source Apportionment

To quantify the ozone impacts caused by to precursor emissions from residential, commercial, and institutional fossil fuel combustion sources (referred to collectively as "building combustion sources" or "building sources" in this report), as well as other emission source groups, Sonoma Technology performed CAMx OSAT source apportionment model simulations for the 2016 ozone season (April to October). CAMx OSAT simulations were also conducted for the 2023 future year.[5] The modeling domain covers all lower 48 U.S. states, plus adjacent portions of Canada and Mexico, using a horizontal grid resolution of 12 km x 12 km. The domain and configurations used were based on those developed by EPA in recent ozone transport assessments using CAMx OSAT (U.S. Environmental Protection Agency, 2022b), and included the use of the carbon-bond 6 gas phase chemistry mechanism and the two-mode course/fine (CF) aerosol chemistry mechanism.

CAMx version 7.10 (Ramboll US Corporation, 2020) is a publicly available, peer-reviewed, state-of-the-science three-dimensional grid-based (Eulerian) photochemical air quality model designed to simulate the emission, transport, diffusion, chemical transformation, and removal of gaseous and particle pollutants in the atmosphere over spatial scales ranging from continental to urban. CAMx was designed to approach air quality wholistically by including capabilities for modeling multiple air quality pollutants and issues, including tropospheric ozone, fine particles, visibility degradation, acid deposition, air toxics, and mercury. The ability of photochemical grid models, such as CAMx, to treat a large number of sources and their chemical interactions makes them well suited for assessing the impacts of natural and anthropogenic emissions sources on air quality. CAMx is widely used to support regulatory air quality assessments and air quality management policy decisions in the United States. In recent years, the EPA has used CAMx to support the NAAQS designation process (U.S. Environmental Protection Agency, 2015a) and evaluate interstate pollutant transport (U.S. Environmental Protection Agency 2015a, 2021a, 2022b, 2023b, 2023c).

CAMx also includes OSAT, which can be used to estimate the contributions of individual sources, groups of sources, or source regions to ozone concentrations at a given receptor location (Yarwood et al., 1996). Source apportionment modeling is useful for understanding model performance, designing emission control strategies, and performing culpability assessments to identify emission sources that contribute significantly to pollution. The key precursor species for ozone production are VOCs and NO_x. OSAT uses reactive tracers to track the fate of these precursor emissions and the ozone formation resulting from them within a CAMx simulation. The ozone and precursors are tracked and apportioned by OSAT without perturbing the host model chemistry; therefore, the OSAT results are fully consistent with the host model results for total concentrations. OSAT can efficiently estimate source contributions from multiple emission sources within a single model simulation.

[5] Future-year ozone is modeled using emissions that have been projected to the future year, but using meteorology, boundary conditions, and other inputs representative of the 2016 base year. In this report, "future year" refers to modeling results that are based on the projected 2023 emissions inventory.

Importantly, while source apportionment modeling can be used to estimate source contributions to ozone concentrations for a given set of emission inputs, sensitivity modeling approaches such as brute-force modeling[6] or the direct decoupled method (DDM)[7] are needed to quantify the effect of a given emission control scenario (e.g., 90% NO_x reduction) on ozone concentrations.

2016 EPA Model Platform

The CAMx OSAT simulations were based on EPA's 2016 air quality modeling platform. A modeling platform consists of a structured system of connected data and models that provide a consistent and transparent basis for assessing the air quality impact of anticipated changes in emissions. EPA typically develops and evaluates a new modeling platform each time the NEI is updated (every three years). EPA has recently used the 2016 modeling platform to support the Federal Implementation Plan ("Transport Rule") to help states fully resolve their obligations under the "Good Neighbor" provision of the Clean Air Act for the 2015 ozone NAAQS (U.S. Environmental Protection Agency, 2022b, 2023c).

The CAMx OSAT simulations relied on EPA's 2016fj_16j modeling platform.[8] This platform draws on emissions data from the 2017 NEI (released in the spring of 2020) and data developed by the National Emissions Inventory Collaborative.[9] The NEI is compiled by EPA on a triennial basis, primarily from data submitted by state, local, and tribal air agencies. The 2017 NEI includes emissions from five source sectors: point sources, nonpoint (or area) sources, onroad mobile sources, nonroad mobile sources, and fire events. These NEI source sectors are divided into 20 sectors for the modeling platform. For the 2016v2 modeling platform, EPA updated the 2017 NEI data to represent year 2016 through the incorporation of 2016-specific state and local data, along with adjustment methods appropriate for each emission sector.

For air quality modeling purposes, the 2016 NEI data was augmented by EPA to include biogenic emissions and data from Canadian and Mexican emissions inventories. In addition, the annualized point source data for electrical generating units (EGUs) in the NEI were replaced with hourly 2016 continuous emissions monitoring (CEMS) data from EPA's Clean Air Markets Division for sulfur dioxide (SO_2) and NO_x. Annual emissions for pollutants were converted to an hourly basis using CEMS input data (U.S. Environmental Protection Agency, 2022c). The EGUs in the modeling platform are matched to units found in the National Electric Energy Data System (NEEDS) v6.20 database.[10]

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[6] The brute-force modeling method involves running the model both with and without emission controls applied to the source(s) of interest. The difference in pollutant concentrations between the two simulations yields the impact of the emission control scenario.
[7] DDM provides sensitivity coefficients that indicate the relationship between emissions changes and model outcomes. These sensitivity coefficients can be used to evaluate how pollutant concentrations would respond to a range of changes in emissions from a source or group of sources.
[8] 2016v2 was the most recent version of EPA's modeling platform available at the time this modeling was conducted. EPA updated the modeling platform to 2016v3 (2016gf) in January 2023 (U.S. Environmental Protection Agency, 2023a).
[9] The National Emissions Inventory Collaborative is a partnership between state emissions inventory staff, multi-jurisdictional organizations, federal land managers, EPA staff, and others to develop a North American air pollution emissions modeling platform for use in air quality planning.
[10] https://www.epa.gov/airmarkets/national-electric-energy-data-system-needs-v6, dated 5/28/2021.

Onroad and nonroad mobile source emissions were developed using version 3 of the Motor Vehicle Emissions Simulator (MOVES3) with activity data provided by state and local agencies. Annual building emissions were spatially allocated using housing data from the U.S. Census Bureau and land-use data from the National Land Cover Database, and were temporally allocated using a "representative" week approach with day-of-week variation but not week-to-week variation within each month.

EPA also developed emissions inventories for the future years of 2023 (2023fj_16j), 2026 (2026fj_16j), and 2032 (2032fj_16j). EPA used sector-specific methods to project the 2016 base-year emissions into the future. EGU emissions were projected using the Integrated Planning Model (IPM).[11] Onroad and nonroad mobile source emissions were projected using MOVES3 and activity data based on trends derived from the Federal Highway Administration's (FHWA) county-level VM-2 reports, as well as the Energy Information Administration's 2020 and 2021 Annual Energy Outlook (AEO). Nonpoint emissions from building sources were projected using county-level human population growth data from the Benefits Mapping and Analysis Program (BenMAP) model and Energy Consumption data by source and sector from the AEO.[12] Emissions for other sectors were projected to the future years by adjusting the base-year emissions to account for on-the-books regulations, known facility openings and closures, and estimated changes in activity. Biogenic, fire, and fertilizer emissions were held constant from the base year.

Summaries of nationwide NO_x and VOC emissions for the 2016 and 2023 inventories are shown in Table A-1 and Table A-2. The total NO_x emissions are projected to decrease significantly in the future years primarily due to decreases in NO_x emissions from motor vehicles (*onroad, onroad_ca_adj*), offroad vehicles (*offroad*), and point source electric generating units (*egu*). However, NO_x emissions are projected to increase in the future years for some source sectors, including airports (*airports*), oil and gas (*pt_oilgas, np_oilgas*), and nonpoint emissions (*nonpt*). The nonpoint sector includes residential, commercial, and institutional fossil fuel combustion sources (building sources), which tend to be concentrated in urban areas.

[11] IPM is a model that accounts for variables and information such as energy demand, planned unit retirements, and planned rules to forecast unit-level energy production and configurations. EPA used IPM outputs from the Summer 2021 version of the IPM platform (see https://www.epa.gov/airmarkets/epas-power-sector-modeling-platform-v6-using-ipm-summer-2021-reference-case; https://www.epa.gov/power-sector-modeling/documentation-epas-power-sector-modeling-platform-v6-summer-2021-reference).

[12] Note that the Mid Atlantic Regional Air Management Association (MARAMA) provided nonpoint emission source projection data for Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, and Washington, D.C.

Table A-1. Summary of national ozone season NO_x emissions by source sector (tons) for the modeling domain. From U.S. Environmental Protection Agency (2022c), Table 5-7.

Sector	2016fj	2023fj	2026fj	2032fj
airports	56,300	64,779	67,546	73,465
cmv_c1c2_12	90,624	64,719	56,294	47,300
cmv_c3_12	264,816	277,635	287,826	300,207
nonpt	193,886	196,857	198,442	195,724
nonroad	566,188	377,891	334,265	284,630
np_oilgas	239,247	244,056	238,015	224,204
onroad	1,341,526	650,732	523,684	387,755
onroad_ca_adj	99,730	48,303	44,880	41,490
pt_oilgas	175,250	189,944	192,640	189,043
ptagfire	3,193	3,193	3,193	3,193
ptegu	605,014	264,200	239,930	265,088
ptnonipm	391,374	381,066	386,919	385,113
rail	236,771	198,559	186,854	176,801
rwc	4,280	4,528	4,596	4,601
Total U.S. Anthro	**4,268,199**	**2,966,463**	**2,765,084**	**2,578,614**
beis	587,057	587,057	587,057	587,057
ptfire-rx	20,531	20,531	20,531	20,531
ptfire-wild	55,500	55,500	55,500	55,500
Grand Total	**4,931,288**	**3,629,551**	**3,428,173**	**3,241,702**

Table A-2. Summary of national ozone season VOC emissions by source sector (tons) for the modeling domain. From U.S. Environmental Protection Agency (2022c), Table 5-8.

Sector	2016fj	2023fj	2026fj	2032fj
airports	24,078	25,745	26,511	28,140
cmv_c1c2_12	3,538	2,476	2,121	1,805
cmv_c3_12	14,553	17,965	19,716	21,943
livestock	156,077	164,112	167,229	170,725
nonpt	344,481	324,891	313,572	305,544
nonroad	573,637	421,807	398,145	383,526
np_oilgas	980,746	979,486	992,390	986,718
onroad	552,899	348,610	293,979	235,488
onroad_ca_adj	44,432	27,229	24,394	19,788
pt_oilgas	114,505	113,824	115,484	115,296
ptagfire	6,314	6,314	6,314	6,314
ptegu	16,215	17,999	18,313	18,934
ptnonipm	248,145	245,742	246,081	245,868
rail	11,039	8,648	7,917	6,674
rwc	36,554	37,983	38,361	38,408
solvents	1,194,840	1,249,563	1,287,153	1,325,357
Total U.S. Anthro	**4,322,053**	**3,992,395**	**3,957,681**	**3,910,526**
beis	20,896,708	20,896,708	20,896,708	20,896,708
ptfire-rx	277,019	277,019	277,019	277,019
ptfire-wild	1,005,261	1,005,261	1,005,261	1,005,261
Grand Total	**26,501,041**	**26,171,383**	**26,136,669**	**26,089,515**

Source Apportionment Tagging

Sonoma Technology worked with the Sierra Club to identify sources and source groups to be tagged for ozone attribution analysis. In total, approximately 500 emission source tags were identified and modeled across multiple simulations. The tagged sources fell into one of the following categories:

- **EGU point sources (~250 tags)**: Coal and natural gas power plants; in some cases, individual units within a facility. Units may be tagged individually, by control equipment, by retirement date, and/or grouped by region.
- **Non-EGU point sources (~150 tags)**: Industrial point sources, tagged individually and/or grouped by state.
- **Transportation**: Onroad mobile sources separated by light-, medium-, and heavy-duty vehicle emissions, grouped by state.
- **Building sources**: Residential, commercial, and institutional fossil fuel combustion sources from the NEI nonpoint (*nonpt)* sector, grouped by state or ozone NAA. Building combustion sources that were tagged include fossil fuel combustion from residential heating and

appliances (excluding residential wood combustion), as well as commercial and institutional heating, appliances, boilers, and internal combustion engines. Table A-3 provides the Source Classification Codes (SCCs) for the building sources that were tagged.

Table A-3. Residential, commercial, and institutional combustion sources were tagged collectively as building emissions in the source apportionment modeling.

SCC	Sector	Description
2104002000	Fuel Comb - Residential - Other	Bituminous/Subbituminous Coal; Total: All Combustor Types
2104004000	Fuel Comb - Residential - Oil	Distillate Oil; Total: All Combustor Types
2104006000	Fuel Comb - Residential - Natural Gas	Natural Gas; Total: All Combustor Types
2104007000	Fuel Comb - Residential - Other	Liquified Petroleum Gas (LPG); Total: All Combustor Types
2104011000	Fuel Comb - Residential - Oil	Kerosene; Total: All Heater Types
2103001000	Fuel Comb - Commercial/Institutional – Coal	Commercial/Institutional; Anthracite Coal; Total: All Boiler Types
2103002000	Fuel Comb - Commercial/Institutional – Coal	Commercial/Institutional; Bituminous/Subbituminous Coal; Total: All Boiler Types
2103004000	Fuel Comb - Industrial Boilers, ICEs - Oil	Commercial/Institutional; Distillate Oil; Total: Boilers and IC Engines
2103004001	Fuel Comb - Industrial Boilers, ICEs - Oil	Commercial/Institutional; Distillate Oil; Boilers
2103004002	Fuel Comb - Industrial Boilers, ICEs - Oil	Commercial/Institutional; Distillate Oil; IC Engines
2103005000	Fuel Comb - Industrial Boilers, ICEs - Oil	Commercial/Institutional; Residual Oil; Total: All Boiler Types
2103006000	Fuel Comb - Commercial/Institutional - Natural Gas	Commercial/Institutional; Natural Gas; Total: Boilers and IC Engines
2103007000	Fuel Comb - Commercial/Institutional - Other	Commercial/Institutional; Liquified Petroleum Gas (LPG); Total: All Combustor Types
2103008000	Fuel Comb - Commercial/Institutional - Biomass	Commercial/Institutional; Wood; Total: All Boiler Types
2103011000	Fuel Comb - Comm/Institutional - Oil	Commercial/Institutional; Kerosene; Total: All Combustor Types

Meteorology

Meteorological inputs for the CAMx-OSAT simulations were developed by EPA for the 2016 modeling platform using version 3.8 of the Weather Research and Forecasting (WRF) numerical weather prediction model (Skamarock et al., 2008). The meteorological outputs from WRF include hourly varying winds, temperature, moisture, vertical diffusion rates, clouds, and rainfall rates. Selected physics options used in the WRF simulations include the Pleim-Xiu land surface model, Asymmetric

Convective Model version 2 planetary boundary layer scheme, Kain-Fritsch cumulus parameterization, Morrison double moment microphysics, and RRTMG longwave and shortwave radiation schemes. Additional details about this WRF simulation and its performance evaluation can be found in U.S. Environmental Protection Agency (2021b).

Initial and Boundary Conditions

Initial and lateral boundary conditions for the 2016v2 modeling platform were developed from three-dimensional global atmospheric chemistry simulations with the Hemispheric version of the Community Multi-scale Air Quality Model (H-CMAQ) version 3.1.1 (Mathur et al., 2017). EPA used an H-CMAQ simulation for 2016 to develop boundary conditions for a CAMx simulation at a horizontal grid resolution of 36 km x 36 km. The outputs from this simulation were used to provide initial and boundary conditions for the 12-km model simulation. OSAT tracks ozone transported through the boundaries, as well as ozone formation resulting from precursor emissions transported through the boundaries.

Post-Processing

The raw result from the 2016 CAMx OSAT simulation is hourly ozone contributions from each source tag at each grid cell in the modeling domain for the ozone season. These hourly contributions were extracted and post-processed for several hundred receptor sites, including ozone monitoring sites, as well as locations identified by Sierra Club as environmental justice receptors within ozone NAAs. At each receptor and for each day, the 8-hr average ozone contribution was calculated for each source tag using the averaging period corresponding to the period of the highest modeled 8-hr average concentration at the receptor location. Although this analysis approach may not capture the largest ozone contributions modeled during the day, it does reflect ozone contributions during time periods when modeled ozone concentrations are highest. This analysis approach also ensures that ozone contributions from all source tags[13] sum to total modeled 8-hr ozone concentration each day. The post-processed OSAT results, along with relevant metadata, were compiled into a web-based shinyapps.io dashboard application to facilitate future data mining and analysis.

OSAT outputs can also be used in a "relative sense" (rather than a "absolute sense") to apportion an ozone observation (e.g., a monitor concentration or design value) into modeled contributions from individual source tags. One advantage to such an approach is that the modeled contribution can be tied to an observed ozone concentration, rather than tied strictly to a modeled ozone concentration that may be biased. Anchoring the modeled apportionment results to ambient monitoring data can help mitigate uncertainties associated with imperfect model performance (Foley et al., 2015; Jones et al., 2005).

[13] Including a leftover residual contribution from all untagged sources calculated by CAMx.

For receptors tied to air quality monitoring sites, ozone contributions were calculated using OSAT results in a "relative sense." For the base year (2016), relative contribution fractions for each tag on a daily basis were calculated by multiplying the absolute modeled source contribution by the ratio of the monitored MDA8 ozone concentration and the total modeled MDA8 ozone value. For the future year, the ratio of the total modeled MDA8 ozone concentration between 2023 and 2016 was used to estimate projected future-year (2023) observed ozone concentrations, and these projected observed ozone concentrations were used to apportion the modeled ozone. These approaches have been used in past ozone source apportionment modeling analyses (e.g., Craig et al., 2020) and are similar to methods used by EPA to calculate ozone source contributions from a photochemical grid model (U.S. Environmental Protection Agency, 2022a).

Model Performance Evaluation

EPA evaluated its 2016 modeling platform using statistical assessments of modeled ozone predictions versus observations paired in time and space. A summary of model performance statistics from the 2016v2 platform is shown in **Table A-4**. Generally, the modeling platform underpredicts MDA8 ozone concentrations for days when the MDA8 ozone is greater than or equal to 60 ppb. But overall, EPA found that "the ozone model performance results for the CAMx 2016fj (2016v2) simulation are within or close to the ranges found in other recent peer-reviewed applications (e.g., Simon et al., 2012 and Emery et al., 2017)" and that "the model performance results demonstrate the scientific credibility of the 2016v2 modeling platform." Additional details on the ozone model performance evaluation for EPA's 2016v2 platform can be found in the Technical Support Document (TSD) for the modeling platform (U.S. Environmental Protection Agency, 2022a).

Table A-4. Summary of ozone model performance statistics from the EPA 2016v2 modeling platform for days with MDA8 ozone ≥ 60 ppb for the period of May through September 2016. 'MB' is mean bias, 'ME' is mean error, 'NMB' is normalized mean bias, and 'NME' is normalized mean error. From U.S. Environmental Protection Agency (2022a), Table A-3.

Climate Region	Number of Site-Days ≥ 60 ppb	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
Northeast	2997	-4.1	7.1	-6.2	10.7
Ohio Valley	3211	-7.1	8.7	-10.9	13.3
Midwest	1134	-12.7	13.0	-19.1	19.5
Southeast	1477	-2.9	6.1	-4.5	9.4
South	993	-7.8	9.1	-12.0	14.1
Southwest	3054	-8.8	9.7	-13.6	15.1
Northern Rockies	215	-11.9	12.4	-19.0	19.8
Northwest	84	-5.8	10.8	-9.0	16.6
West	8279	-9.7	11.4	-13.8	16.2

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