



# Attainment Demonstration Modeling for the 2015 Ozone National Ambient Air Quality Standard

## Technical Support Document

Lake Michigan Air Directors Consortium

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Version	Date	Comments/Changes
1	July 7, 2025	Initial draft version for review by LADCO members and U.S. EPA
2	July 31, 2025	Final version with updates based on comments by US EPA and WI DNR
3	August 19, 2025	Updated final version with comments by MI EGLE

## Errata/Known Issues

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## Executive Summary

LADCO prepared this Technical Support Document (TSD) to support the development of 2015 ozone (O<sub>3</sub>) national ambient air quality standard (NAAQS) nonattainment area (NAA) state implementation plans (SIPs). LADCO used the Comprehensive Air Quality Model with Extensions (CAMx) v7.31 photochemical model to support these analyses. The LADCO CAMx modeling results are used here to identify O<sub>3</sub> monitoring sites that may have nonattainment or maintenance problems for the 2015 O<sub>3</sub> NAAQS by the August 3, 2027 attainment date for serious NAAs. Because the attainment date occurs during the 2027 O<sub>3</sub> season, the effective attainment deadline is the end of the 2026 O<sub>3</sub> season and thus resulted in the selection of 2026 as the projection year for this modeling application. LADCO used 2022 as the base modeling year from which we projected air quality in 2026.

LADCO based our 2026 O<sub>3</sub> air quality and NAA attainment forecasts on meteorology modeling that was optimized for conditions in the Great Lakes Basin. We used U.S. EPA 2022hc emissions modeling platform data, and other CAMx modeling platform inputs released by the U.S. EPA in 2024 for this application. LADCO replaced the Electricity Generating Unit (EGU) emissions in the 2022hc platform with 2026 EGU forecasts estimated with the ERTAC EGU Tool version 22.1. ERTAC EGU 22.1 integrates state-reported information on EGU operations and forecasts as of September 2024. Overall, the CO, NO<sub>x</sub>, and VOC ozone season emissions are projected to decrease in 2026 relative to 2022 in all LADCO states.

The LADCO 2026 CAMx simulation predicts that fourteen monitors in our member state region will have an average future year design value (DV<sub>2026</sub>) that exceeds the 2015 O<sub>3</sub> NAAQS. All the monitors that are projected to exceed the standard border Lake Michigan.

## 1. Introduction

The Lake Michigan Air Directors Consortium (LADCO) was established by the states of Illinois, Indiana, Michigan, and Wisconsin in 1989. The four states and U.S. EPA signed a Memorandum of Agreement (MOA) that initiated the Lake Michigan Ozone Study and identified LADCO as the organization to oversee the study. Additional MOAs were signed by the states in 1991 (to establish the Lake Michigan Ozone Control Program), January 2000 (to broaden LADCO's responsibilities), and June 2004 (to update LADCO's mission and reaffirm the commitment to regional planning). In March 2004, Ohio joined LADCO. Minnesota joined the Consortium in 2012. LADCO consists of a Board of Directors (i.e., the State Air Directors), a technical staff, and various workgroups. The main purposes of LADCO are to provide technical assessments for and assistance to its member states, to provide a forum for its member states to discuss regional air quality issues, and to facilitate training for staff in the member states.

On October 26, 2015 the U.S. EPA revised the primary and secondary National Ambient Air Quality Standard (NAAQS) for ozone (O<sub>3</sub>), strengthening the standard to a level of 0.070 parts per million (ppm) for a maximum daily 8-hour average (80 FR 65291)<sup>1</sup>. The form of the 8-hour O<sub>3</sub> NAAQS remained the same as the previous standard, the annual fourth-highest daily maximum averaged over three consecutive years. When U.S. EPA adopts a new or revises an existing NAAQS, it is required by Section 107(d)(1) of the Clean Air Act (CAA) to designate areas as nonattainment, attainment, or unclassifiable. Accordingly, on November 6, 2017 U.S. EPA considered recommendations from states and tribes and designated as attainment/ unclassifiable 2,646 counties and tribal lands across the U.S. (82 FR 54232). The U.S. EPA followed up this action on June 4, 2018 and initially designated several areas in the Great Lakes region, among other areas in the country, as "marginal" O<sub>3</sub> nonattainment areas (NAA) based on 2014-2016 ambient air quality data (85 FR 25776). Table 1-1 shows the areas in the LADCO region initially designated by U.S. EPA as nonattainment of the 2015 O<sub>3</sub> NAAQS.

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<sup>1</sup> The final rule was effective December 8, 2015.

**Table 1-1. June 4, 2018 designations of 2015 Ozone NAAQS NAAs in the LADCO region**

Area	State	Designation
Allegan County	MI	Marginal
Berrien County	MI	Marginal
Chicago	IL, IN, WI	Marginal
Cincinnati	OH, KY	Marginal
Cleveland	OH	Marginal
Columbus	OH	Marginal
Detroit	MI	Marginal
Door County	WI	Marginal
Louisville	KY, IN	Marginal
Manitowoc County	WI	Marginal
Milwaukee	WI	Marginal
Muskegon County	MI	Marginal
St. Louis	MO, IL	Marginal
Sheboygan County	WI	Marginal

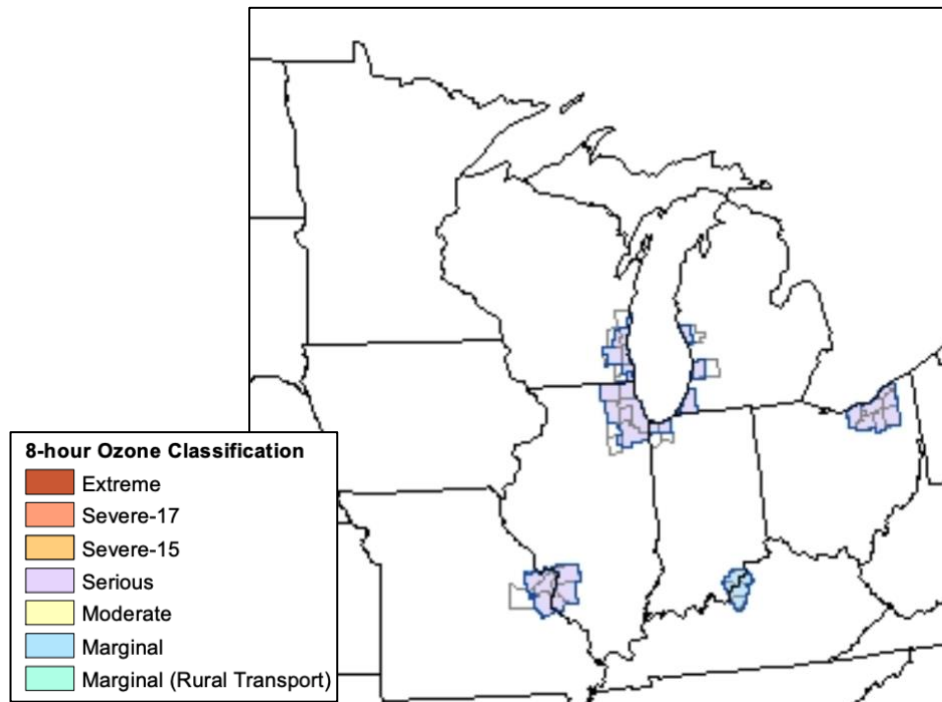
Several follow-up U.S. EPA actions redesignated some of the areas in the LADCO region from nonattainment to maintenance areas or changed the boundaries of the nonattainment areas. Table 1-2 summarizes the subsequent 2015 O<sub>3</sub> NAAQS final actions taken by U.S. EPA on NAAs in the LADCO region.

**Table 1-2. U.S. EPA latest actions on 2015 Ozone NAAQS NAAs in the LADCO region as of June 2025**

Area	State	Action	Date
Allegan County	MI	Reclassification to serious NAA	12/17/2024
Berrien County	MI	Reclassification to serious NAA	12/17/2024
Chicago	IL, IN, WI	Reclassification to serious NAA	12/17/2024
Cincinnati	OH, KY	Redesignation to maintenance	6/9/2022
Cleveland	OH	Reclassification to serious NAA	12/17/2024
Columbus	OH	Redesignation to maintenance	8/21/2019
Detroit	MI	Redesignation to maintenance	5/19/2023
Door County-Revised	WI	Redesignation to maintenance	4/29/2022
Louisville	IN	Redesignation to maintenance	7/5/2022
Manitowoc County	WI	Redesignation to maintenance	3/31/2022
Milwaukee	WI	Reclassification to serious NAA	12/17/2024
Muskegon County	MI	Reclassification to serious NAA	12/17/2024
Sheboygan County	WI	Reclassification to serious NAA	12/17/2024
St. Louis	MO, IL	Reclassification to serious NAA	12/17/2024

On December 17, 2024, U.S. EPA determined that several NAAs in the LADCO region failed to attain the 2015 O<sub>3</sub> NAAQS by the August 3, 2024 attainment date and proposed to reclassify the areas as “serious” O<sub>3</sub> NAAs. The attainment deadline for serious NAAs to meet the 2015 O<sub>3</sub> NAAQS is August 3, 2027.

The 2015 O<sub>3</sub> NAAQS nonattainment areas in the LADCO region as June 1, 2025 are shown in Figure 1-1. The states with NAAs shown in this figure must submit State Implementation Plans (SIPs) to U.S. EPA that meet the requirements applicable to “serious” O<sub>3</sub> NAAs. The NAA SIPs, or attainment demonstrations, must include a demonstration which identifies emissions reduction strategies that are enough to achieve the NAAQS by August 3, 2027, the attainment date for serious NAAs. Because the attainment deadline occurs during the 2027 O<sub>3</sub> season, the effective attainment deadline is the end of the 2026 O<sub>3</sub> season.



**Figure 1-1. Nonattainment areas in the Lake Michigan region for the 2015 O<sub>3</sub> NAAQS (Source: U.S. EPA, June 1, 2025).**

One of LADCO’s responsibilities is to provide technical air quality modeling guidance and support to the LADCO member states. LADCO prepared this Technical Support Document (TSD) to support the development of the O<sub>3</sub> NAA SIPs (e.g., attainment plans)

for our members pursuant to the 2015 O<sub>3</sub> NAAQS. The analyses prepared by LADCO include preparation of modeling emissions inventories for the base year (2022) and the last completed ozone season (2026) before the attainment year (2027), evaluation and application of meteorological and photochemical grid models, analysis of ambient monitoring data, and a modeled attainment test for surface O<sub>3</sub> monitors in the existing NAAs. In this report LADCO provides technical information on the validity of the model used to forecast future air quality, and our predictions of future O<sub>3</sub> design values for the following 2015 O<sub>3</sub> NAAQS nonattainment and maintenance areas:

- Chicago, IL/IN/WI
- St. Louis, MO/IL
- Allegan County, MI
- Berrien County, MI
- Muskegon County, MI
- Detroit, MI
- Cleveland, OH
- Cincinnati, OH
- Milwaukee, WI
- Sheboygan County, WI

### **1.1. Ozone Formation in the LADCO Region**

An O<sub>3</sub> conceptual model is a qualitative description of the physical and chemical parameters that drive ground level O<sub>3</sub> formation in a specific area. The purpose of the model is to build understanding of the meteorological and chemical factors contributing to high O<sub>3</sub> concentrations. Ozone conceptual models are a component of attainment plans because a fundamental understanding of the cause of O<sub>3</sub> pollution is needed to enable the development of effective mitigation strategies. In 2023 LADCO developed a comprehensive report with conceptual models of O<sub>3</sub> formation in all the 2015 O<sub>3</sub> NAAQS nonattainment and maintenance areas in the region (LADCO, 2023).

Starting in 2017 with the Lake Michigan Ozone Study, LADCO has been building a library of contemporary, state-of-the-science information on ground level O<sub>3</sub> pollution in

the Great Lakes Basin. The purpose of this effort was to synthesize all known, recent information about O<sub>3</sub> in the region into a coherent picture of the drivers of and potential solutions to O<sub>3</sub> air pollution. The goal of the effort was to provide the LADCO member states with comprehensive decision support resources that are based on the best available information on emissions, ambient observations, satellite-based remote sensing, and modeling.

The LADCO O<sub>3</sub> Synthesis Project supplements this TSD with reports on the following areas:

- Ozone chemistry
- Satellite-based remote sensing
- Ozone trends
- Ozone precursor emissions reduction options
- Machine learning applications for understanding ozone
- Insights from recent monitoring and modeling intensives (LMOS and MOOSE)

The LADCO O<sub>3</sub> Synthesis Project reports are available on the O<sub>3</sub> Science page of the LADCO website:

[LADCO Ozone Science for the Great Lakes Basin<sup>2</sup>](https://www.ladco.org/public-issues/ozone/ozone-science/)

## **1.2. Project Overview**

LADCO conducted regional air quality modeling to support the statutory obligations of the LADCO member states under Clean Air Act Section 172. These obligations include SIP revisions that are plans to describe how states with designated NAAs will bring the areas back into attainment of the NAAQS. LADCO used the Comprehensive Air Quality Model with Extensions (CAMx<sup>3</sup>) to support these analyses. LADCO used CAMx version 7.31 to predict O<sub>3</sub> concentrations in 2026 to determine if current emissions control programs in the region will lead to attainment of the 2015 O<sub>3</sub> NAAQS.

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<sup>2</sup> <https://www.ladco.org/public-issues/ozone/ozone-science/>

<sup>3</sup> [www.camx.com](http://www.camx.com)

### 1.3. Organization of the Technical Support Document

This TSD is presented to the LADCO member states for estimating year 2026 O<sub>3</sub> design values (DVF<sub>2026</sub>). The TSD is organized into the following sections.

- [Section 2](#) describes current surface O<sub>3</sub> conditions in the LADCO region and trends in O<sub>3</sub> concentrations over the past decade
- [Section 3](#) describes the methods and data that LADCO used for air quality modeling, model performance evaluation, and source apportionment modeling.
- [Section 4](#) describes the 2022 and 2026 emissions used for the modeling and attainment testing described in this TSD
- [Section 5](#) summarizes the results of LADCO 2022 air quality model performance evaluation, including a summary and references to details of the WRF meteorology modeling used to support the CAMx simulations
- [Section 6](#) describes LADCO's model attainment testing methods and results
- The TSD concludes with a [summary of significant findings](#) and observations from the LADCO modeling.
- The [TSD Supplement](#) is a separate document that includes additional supplementary technical information to support this TSD.

Throughout the TSD, the modeling and analysis results are organized by the 2015 O<sub>3</sub> NAAQS NAAs where appropriate. The TSD presents average ozone season day emissions summaries, CAMx model performance, O<sub>3</sub> attainment test results, and source apportionment results for each 2015 O<sub>3</sub> NAAQS NAA in the LADCO region.

## 2. 2024 Ambient Air Quality Data Analysis

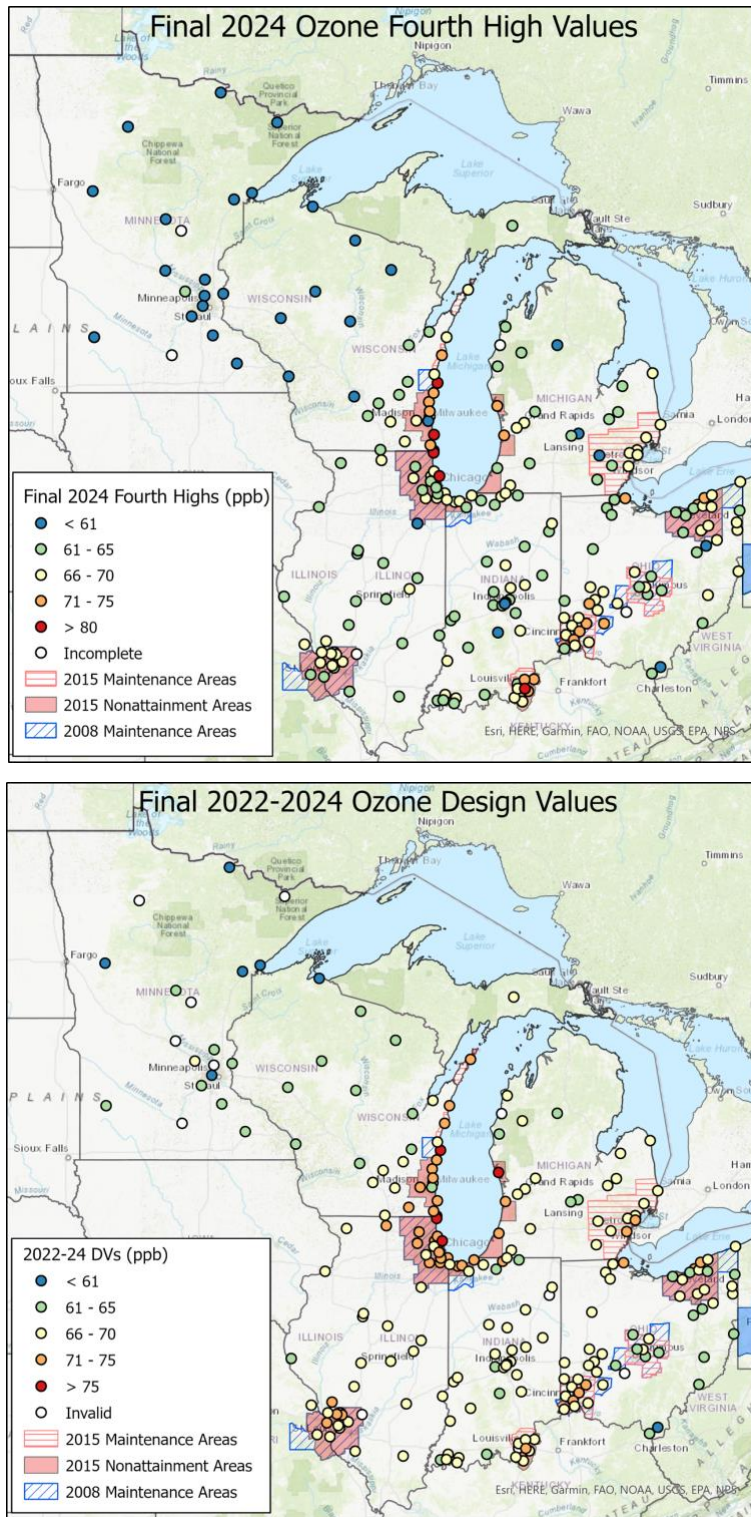
LADCO retrieves and conducts analyses on surface O<sub>3</sub> data collected at routine and special-purpose ambient monitors throughout the region. The current monitored O<sub>3</sub> design values (DVs), or the three-year average of the 4<sup>th</sup> highest daily maximum 8-hour average (MDA8) O<sub>3</sub> concentrations, are presented in this section along with a discussion of trends in O<sub>3</sub> DVs and other metrics for tracking the changes in surface O<sub>3</sub> concentrations in the region. Design values are labeled by the last year of the three-year average. For example, the 2024 O<sub>3</sub> DV is the average of the annual 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations for the years 2022-2024.

### 2.1. Current Conditions

Figure 2-1 shows maps of the 2024 annual 4<sup>th</sup> high MDA8 values and the 2024 DVs for the LADCO region. Figure 2-2 shows the same DV data for each O<sub>3</sub> NAA and maintenance area. DVs exceeding the level of the 2015 O<sub>3</sub> NAAQS (70 ppb) are shown in orange or red. These figures also show the locations of the 2015 O<sub>3</sub> NAAQS NAAs and maintenance areas.

Table 2-1 and Table 2-2 show the historical trends in O<sub>3</sub> DVs in O<sub>3</sub> nonattainment and maintenance areas in the region. Table 2-1 shows the annual DVs for each area from 2016 to 2024; these values show the DV from the “controlling” monitor, or the monitor with the highest 3-year DV in the entire area for that year. Table 2-2 shows the annual DVs for all currently operating monitors in the NAAs and maintenance areas from 2016 to 2024.

The DV tables and figures show that of the nonattainment and maintenance areas in the LADCO region, only Columbus was attaining the 2015 O<sub>3</sub> NAAQS in 2024. All other areas were violating the 2015 O<sub>3</sub> NAAQS, and three areas (Muskegon County, MI, Sheboygan County, WI, and Chicago, IL-IN-WI) violated the 2008 ozone NAAQS in 2024.



**Figure 2-1. 2024 4<sup>th</sup> high ozone MDA8 values (top) and draft 2022-2024 ozone design values (bottom) for the LADCO region. Nonattainment and maintenance areas for the 2008 and 2015 ozone NAAQS are shown for comparison.**



**Table 2-1. LADCO nonattainment and maintenance area maximum design values (ppb). Values exceeding the 2015 NAAQS are highlighted in light orange. Values exceeding the 2008 NAAQS are highlighted in medium orange. Design values were downloaded from AQS.**

Designated Area	2016	2017	2018	2019	2020	2021	2022	2023	2024
Allegan County, MI	75	73	73	72	73	75	75	75	74
Berrien County, MI	74	73	73	69	72	71	73	73	72
Muskegon County, MI	75	74	76	74	76	74	79	77	76
Door County, WI	72	73	73	70	72	70	73	72	71
Manitowoc County, WI	72	74	73	71	70	68	73	73	73
Milwaukee County, WI	73	74	78	74	73	73	75	74	74
Sheboygan County, WI	79	80	81	75	75	72	75	77	78
Chicago, IL-IN-WI	77	78	79	75	77	75	75	77	78
Cincinnati, OH-KY	72	73	75	74	74	70	69	70	72
Cleveland, OH	74	73	74	73	74	72	74	73	73
Columbus, OH	71	71	69	68	67	66	66	67	69
Detroit, MI	73	73	74	72	72	70	70	71	71
Louisville, KY-IN	74	74	75	72	72	69	70	72	75
St. Louis, MO-IL	72	72	74	71	71	69	71	74	74

**Table 2-2. LADCO nonattainment and maintenance area monitor design values (ppb). Values exceeding the 2015 NAAQS are highlighted in light orange. Values exceeding the 2008 NAAQS are highlighted in medium orange. Design values were downloaded from AQS.**

Site	Site Name	2016	2017	2018	2019	2020	2021	2022	2023	2024
<i>Allegan County, MI</i>										
260050003	Holland	75	73	73	72	73	75	75	75	74
<i>Berrien County, MI</i>										
260210014	Coloma	74	73	73	69	72	71	73	73	72
<i>Muskegon County, MI</i>										
261210039	Muskegon	75	74	76	74	76	74	79	77	76
<i>Door County, WI</i>										
550290004	Newport	72	73	73	70	72	70	73	72	71
<i>Manitowoc County, WI</i>										
550710007	Manitowoc	72	74	73	71	70	68	73	73	73
<i>Milwaukee, WI</i>										
550790010	Milw-16th St	64	65	67	64	62	61	63	66	64
550790068	Milw-UWM UPark	68	67	69	65	68	68	72	72	70
550790085	Bayside	71	71	73	69	70	70	73	74	74
550890008	Grafton	71	71	72	71	71	71	72	73	74

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Site	Site Name	2016	2017	2018	2019	2020	2021	2022	2023	2024
550890009	Harrington Beach	73	73	74	70	70	70	71	73	74
551010020	Racine-P&D		74	78	74	73	73	75	74	74
551330027	Waukesha	66	65	66	63	64	65	68	73	71
<i>Sheboygan County, WI</i>										
551170006	Sheboygan KA	79	80	81	75	75	72	75	77	78
<i>Chicago, IL-IN-WI</i>										
170310001	Alsip	69	73	77	75	75	71	72	74	74
170310032	Chicago SWFP	70	72	75	73	74	75	75	77	73
170310076	Chicago Com Ed	69	72	75	72	69		70	74	72
170311003	Chicago Taft HS	69	67	69	67	73	71	71	70	71
170311601	Lemont	69	69	70	68	71	72	73	74	73
170313103	Schiller Park	62	62	64	63	65	64	63	67	69
170314002	Cicero	66	68	72	68	71	70	71	71	71
170314007	Des Plaines	71	71	74	70	71	69	70	74	74
170314201	Northbrook	71	72	77	74	77	74	74	77	75
170317002	Evanston	72	73	77	75	75	73	74	76	76
170436001	Lisle	68	70	71	70	71	70	70	73	70
170890005*	Elgin	68	69	71	70	72	70	70	74	73
170971007	Zion	73	73	75	71	72	73	74	76	76
171110001	Cary	68	69	72	71	73	71	71	74	73
171971011	Braidwood	64	65	67	66	66	64	65	69	68
180890022	Gary-IITRI	67	68	70	68	70	69	71	72	72
180892008	Hammond	65		66	65	66	68	69	70	70
181270024	Ogden Dunes	69	69	71	70	71	72	73	74	73
181270026	Valparaiso	66	69	73	73	69	68	66	68	68
550590019	Chiwaukee	77	78	79	75	74	74	75	77	78
550590025	Kenosha WT	71	73	77	74	74	72	73	74	74
<i>Cincinnati, OH-KY</i>										
210150008	Nature Center	63	62	64	63	64	61	63	68	68
210373002	N Kentucky Univ	70	69	67	65	63	63	63	64	66
390170018	Middletown	70	71	73	71	71	67	67	67	68
390170023	Crawford Woods	72	72	73	70	69	66	67	68	68
390179991	Oxford	69	69	70	68	66	64	64	66	67
390250022	Batavia	70	70	70	69	68	66	64	65	66
390610006	Sycamore	72	73	75	74	74	70	69	70	71
390610010	Colerain	72	70	72	70	70	67	67	68	70
390610040	Taft	71	71	72	71	70	69	68	70	71
391650007	Lebanon	72	71	72	71	72	70	69	70	72
<i>Cleveland, OH</i>										
390350034	District 6	69	68	70	69	71	70	72	71	72
390350060	GT Craig	64	62	62	63	65	63	62	61	63

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Site	Site Name	2016	2017	2018	2019	2020	2021	2022	2023	2024
390350064	Berea BOE	64	66	66	64	65	66	66	69	68
390355002	Mayfield	67	70	71	71	71	68	67	68	69
390550004	Notre Dame	70	72	72	70	68	66	65	65	65
390850003	Eastlake	74	73	74	73	74	72	74	73	73
390850007	Painesville	67	70	70	70	68	66	64	66	68
390930018	Elyria-Sheffield	65	65	67	64	62	58	60	62	62
391030004	Chippewa Lake	64	64	65	61		61	65	68	68
391331001	Lake Rockwell	61	62	63	63	62	62	67	69	69
391530026	North HS	61	64	65	67	65	64	65	68	69
<i>Columbus, OH</i>										
390410002	Delaware	67	65	64	63	64	62	61	62	64
390490029	New Albany	71	71	69	68	67	66	66	67	69
390490081	Columbus-Maple	67	66	66	62	62	62	62	63	64
390890005	Heath	67	66	64	61	60	59	60	61	62
390890008	Reynoldsburg					61	58	59	60	62
<i>Detroit, MI</i>										
260990009	New Haven	72	71	72	68	71	68	69	68	69
260991003	Warren	67	66	69	66	68	66	68	69	69
261250001	Oak Park	69	70	73	70	72	69	69	69	69
261470005	Port Huron	73	71	72	71	71	70	69	70	69
261610008	Ypsilanti	67	67	69	66	67	66	68	68	68
261619991	Dexter	68	69	71	66	65	62	65	67	66
261630001	Allen Park	65	66	68	66	67	67	70	70	71
261630019	Detroit-E 7 Mile	72	73	74	72	71	70	69	71	71
<i>Louisville, KY-IN</i>										
180190008	Charlestown SP	70	71	70	67	65	63	63	66	69
180430008	New Albany - 4H Road	69	71	73	70	67	64	64	66	66
210290006	Shepherdsville	66	65	66	64	65	64	64	67	67
211110051	Watson Ln	69	68	68	66	65	65	65	68	68
211110067	Cannons Lane	74	74	75	72	72	69	70	72	75
211110080	Carrithers MS					67	68	69	70	70
211850004	Buckner	70	68	67	66	65	63	63	65	67
<i>St. Louis, MO-IL</i>										
171190120	Alton-HM Sch	71	69	70	68	69	68	71	74	74
171190122	Maryville	67	68	72	71	68	67	68	71	70
171193007	Wood River	71	70	71	69	70	69	70	73	72
171630010	East St. Louis	68	68	71	68	67	65	66	70	69
291831002	West Alton	72	72	74	71	71		69	72	73
291831004	Orchard Farm	71	70	72	69	68	66	65	68	69
291890005	Pacific	65	64	66	65	66	64	63	67	67
291890014	Maryland Heights	71	69	70	68	71	69	68	71	71

Site	Site Name	2016	2017	2018	2019	2020	2021	2022	2023	2024
295100085	Blair Street	65	66	71	69	68	65	67	71	70

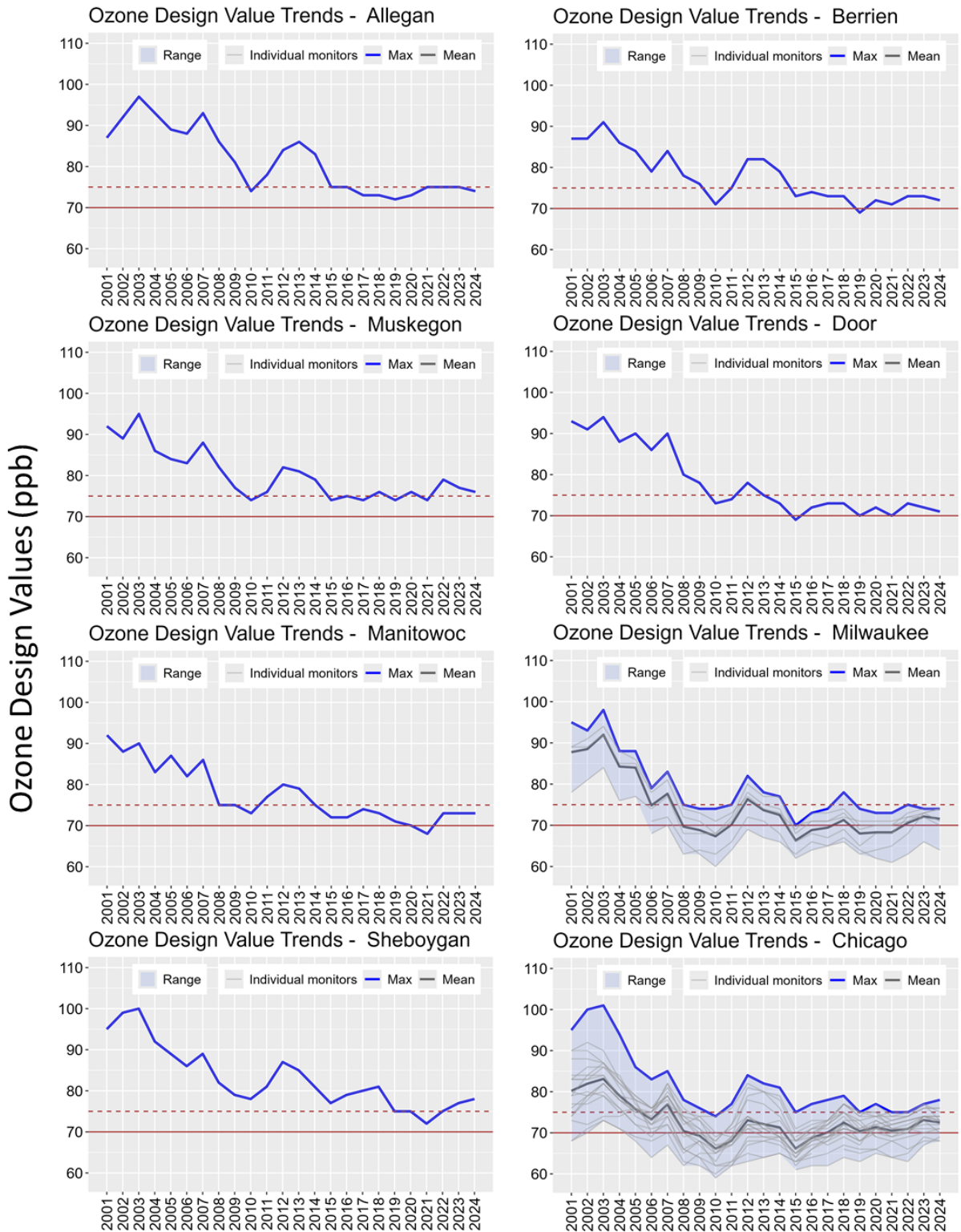
\* The Elgin record is from the 170890005 except for 2024, which includes the relocated 170890124 site.

## 2.2. Ozone Trends

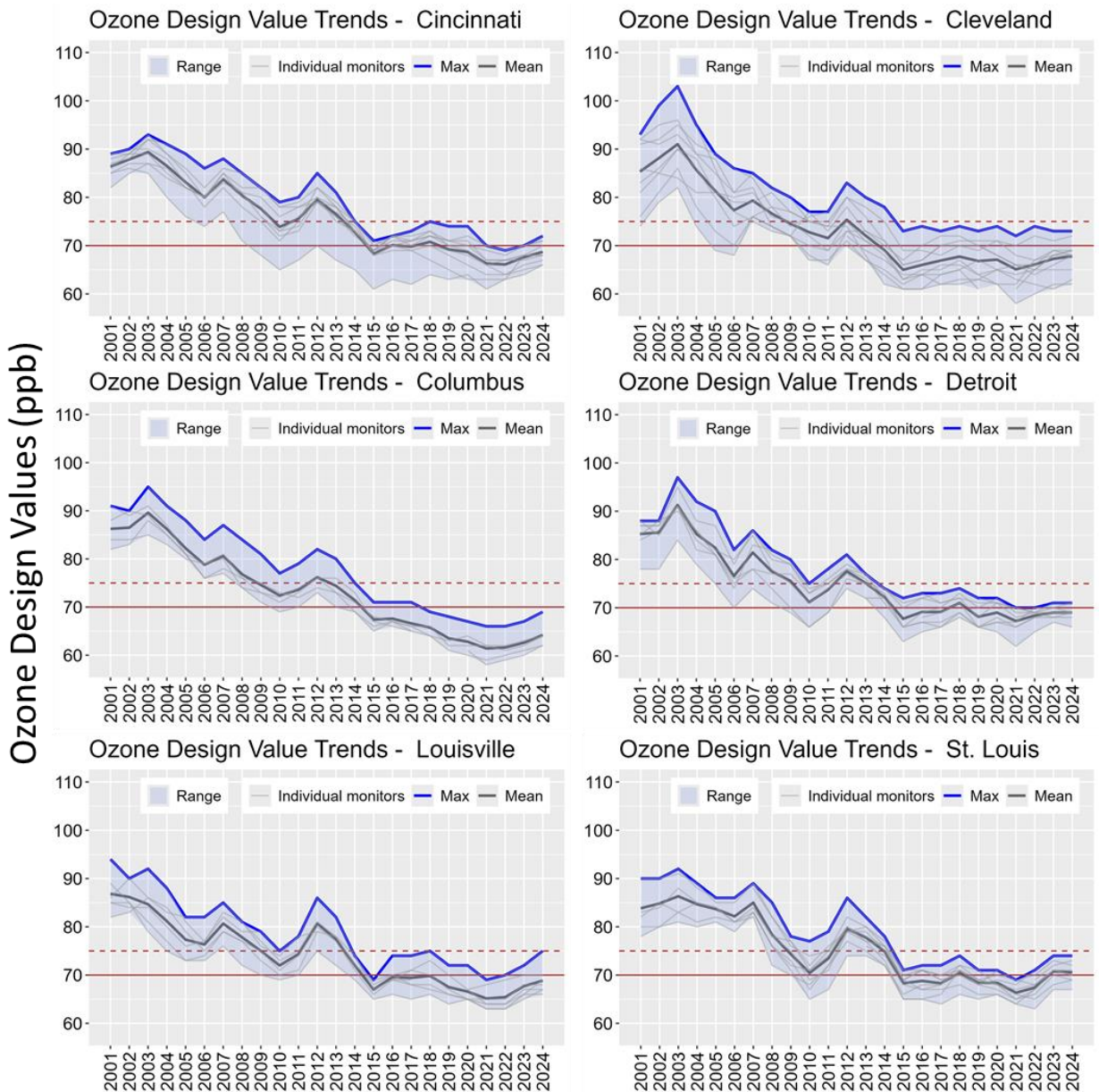
Figure 2-3 and Figure 2-4 illustrate the 24-year trends in O<sub>3</sub> DVs at surface monitors in the different O<sub>3</sub> NAAs and maintenance areas. Ozone DVs in all areas decreased over this period from high values in the early 2000s to much lower values in the last 5-10 years. Ozone DVs in many areas reached a minimum around 2019 to 2021 and have increased somewhat since then. The visible increases in the 2023 and 2024 DVs can be partly attributed to enhanced production of O<sub>3</sub> due to the presence of large amounts of wildfire smoke in the summer of 2023.<sup>4</sup> However, the origin of the overall relatively flat trend in O<sub>3</sub> in many areas in recent years is not clear, particularly since emissions inventories of O<sub>3</sub> precursors are continuing to decrease. This question was the focus of a major field campaign, AEROMMA, in 2023, on which LADCO collaborated.<sup>5</sup>

<sup>4</sup> Cooper, O. R., Chang, K.-L., Bates, K., Brown, S. S., Chace, W. S., Coggon, M. M., et al. (2024). Early season 2023 wildfires generated record-breaking surface ozone anomalies across the U.S. Upper Midwest. *Geophysical Research Letters*, 51, e2024GL111481. <https://doi.org/10.1029/2024GL111481>

<sup>5</sup> <https://csl.noaa.gov/projects/aeromma/>



**Figure 2-3. 3-year O<sub>3</sub> design value trends from 2001 to 2024 in the LADCO ozone nonattainment and maintenance areas. Area mean and maximum values are shown, along with values for individual monitors. The solid red line shows the level of the 2015 ozone NAAQS, and the dashed line shows the level of the 2008 ozone NAAQS.**



**Figure 2-4. 3-year O<sub>3</sub> design value trends from 2001 to 2024 in the LADCO ozone nonattainment and maintenance areas. Area mean and maximum values are shown, along with values for individual monitors. The solid red line shows the level of the 2015 ozone NAAQS, and the dashed line shows the level of the 2008 ozone NAAQS.**

### 2.3. Meteorology and Transport

Ozone concentrations are greatly influenced by meteorological factors. Qualitatively, O<sub>3</sub> episodes in the region are associated with hot weather, clear skies (sometimes hazy), low relative humidity, low wind speeds, high solar radiation, and winds with a southerly

component. These conditions are often a result of a slow-moving high-pressure system to the east of the region. The relative importance of various meteorological factors in select NAAs is discussed later in this section. LADCO has developed a report that looks at the drivers of O<sub>3</sub> formation in the region and presents conceptual models for O<sub>3</sub> formation in each area.<sup>6</sup>

Transport of O<sub>3</sub> and its precursors is a significant factor in the LADCO region and occurs on several spatial scales. Regionally, over a multi-day period, somewhat stagnant summertime conditions can lead to the build-up of O<sub>3</sub> and O<sub>3</sub> precursor concentrations over a large spatial area. This polluted air mass can be transported long distances, resulting in elevated O<sub>3</sub> levels in locations far downwind. Locally, emissions from urban areas add to the regional background leading to O<sub>3</sub> concentration hot spots downwind. Depending on the synoptic wind patterns and presence of local land-lake breezes in some areas, different downwind areas are affected.

The following key findings related to transport can be made:

- Ozone transport is an issue affecting much of the eastern half of the U.S. The NAAs in the LADCO region receive high concentrations of incoming (transported) O<sub>3</sub> and O<sub>3</sub> precursors from upwind source areas on some hot summer days. Sources in the LADCO region also contribute to the high concentrations of O<sub>3</sub> and O<sub>3</sub> precursors affecting downwind receptor areas.
- Lake Michigan and Lake Erie influence the formation and transport of O<sub>3</sub> in the region, particularly at sites within a few kilometers of the shoreline. Depending on large-scale synoptic winds and local-scale lake breezes, different parts of the area experience high O<sub>3</sub> concentrations. For example, during southerly flow, high O<sub>3</sub> can be transported from Chicago to the Wisconsin lakeshore, whereas during southwesterly flow, high O<sub>3</sub> from Chicago can be transported to western Michigan.

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<sup>6</sup> Dickens (2023) Technical Report: Conceptual Models of Ozone Formation in the Great Lakes Region. <https://www.ladco.org/wp-content/uploads/Projects/Ozone/Ozone-conceptual-model-report-FINAL-Feb-2023.pdf>

## **2.4. Adjustment of Ozone Trends for Meteorology**

Given the importance of the impacts of meteorology on ambient O<sub>3</sub> concentrations, year-to-year variations in meteorology can make it difficult to assess short term (e.g. less than 10 years) trends in O<sub>3</sub> concentrations. One approach to adjust the trends in O<sub>3</sub> concentrations for meteorological influences uses Classification and Regression Trees (CART). CART is a statistical tool to classify data (Breiman et al., 1984). We applied CART to MDA8 O<sub>3</sub> and meteorological data to determine the meteorological conditions most associated with high O<sub>3</sub> days in nonattainment and maintenance areas in the LADCO region. Once days are classified by their unique, shared meteorological characteristics, O<sub>3</sub> concentration trends among days with similar meteorological conditions can be examined. The LADCO CART analysis normalizes the influence of year-to-year meteorological variability on O<sub>3</sub> concentrations, and any remaining trend is assumed to be the result of non-meteorological factors, such as reductions in emissions of O<sub>3</sub> precursors.

LADCO conducted the CART analyses using MDA8 O<sub>3</sub> monitoring data from regulatory monitors in the NAAs and daily meteorological data from airport weather stations. The analysis included data from the years 2001 through 2022<sup>7</sup> to identify the trends in ambient, surface O<sub>3</sub> concentrations after adjustment for meteorology. LADCO developed regression trees to classify each summer day (May – September) by a common set of meteorology variables. Each branch in a regression tree describes the meteorological conditions associated with different O<sub>3</sub> concentrations. We assigned meteorologically similar days to day-type groups (known in CART as “nodes”), which are equivalent to branches of the regression tree. Grouping days with similar meteorology normalizes the influence of meteorological variability on the underlying trend in O<sub>3</sub> concentrations. The remaining trend in O<sub>3</sub> concentrations can be presumed to be due to trends in non-meteorological predictors, such as precursor emissions. We then plotted the O<sub>3</sub> trends for each of the different CART nodes.

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<sup>7</sup> We excluded 2023 from the analysis because of the unusually large influence of smoke-enhanced O<sub>3</sub> this year. (See footnote 5.)

This TSD gives a high-level summary of the CART results for the currently designated ozone NAAs. A brief description of CART analysis is provided in Section S3 of the Supplement to this TSD. A more complete description of the results for all nonattainment and maintenance areas, along with the CART methodology, is available in a LADCO report on CART.<sup>8</sup>

Although the exact selection of predictive variables changes from site to site, the most common predictors of high surface O<sub>3</sub> concentrations during the period we analyzed are temperature, wind direction, and relative humidity. Trends in O<sub>3</sub> concentrations in high-O<sub>3</sub> nodes were found to be declining over the 22-year period for almost all areas studied (Figure 2-5 through Figure 2-7). These plots reflect long term trends and are not meant to depict trends over shorter time periods. Note that data was fit with both linear and segmented regressions; the best-fit of these two regressions is shown in the figures.

#### **2.4.1. Western Michigan NAA CART Analyses**

LADCO conducted CART analyses for each of the three NAAs along Michigan's Lake Michigan shoreline. This TSD examines the analyses for these three NAAs, all of which are currently designated nonattainment for the 2015 O<sub>3</sub> NAAQS. The high-ozone nodes from the CART analysis for the Muskegon and Allegan County monitors generally have southerly transport and hot temperatures (Supplement Table S11). The most important factors for the high-ozone nodes for the Berrien County monitor were hot temperatures and low relative humidity (Supplement Table S11). One Berrien County node also has high atmospheric pressure on the previous day. Mean O<sub>3</sub> concentrations in all high-ozone nodes in Muskegon, Allegan, and Berrien counties have decreased from 2001 to 2022 (Figure 2-5).

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<sup>8</sup> [https://www.ladco.org/wp-content/uploads/Projects/Ozone/LADCO\\_O3\\_CART-Analysis\\_2025\\_v2.pdf](https://www.ladco.org/wp-content/uploads/Projects/Ozone/LADCO_O3_CART-Analysis_2025_v2.pdf)

#### **2.4.2. Wisconsin NAA CART Analyses**

LADCO conducted CART analyses for each of the four NAAs along Wisconsin's Lake Michigan shoreline, including three CART analyses for different parts of the Milwaukee nonattainment area. The high-ozone nodes from the CART analyses for the three northernmost areas (Door, Manitowoc, and Sheboygan counties) generally have southerly winds/transport and hot temperatures (Supplement Table S11). Mean O<sub>3</sub> concentrations in all these high-ozone nodes have decreased from 2001 to 2022 with the exception of the highest-O<sub>3</sub> node in Manitowoc, which has been relatively steady since around 2008 (Figure 2-6). Similarly, the high-ozone nodes from the CART analysis for the Milwaukee monitors generally have hot temperatures and southerly winds, except in Racine County, where southerly transport wasn't a driving factor (Supplement Table S11). The highest O<sub>3</sub> node for all three Milwaukee area analyses also have afternoon winds that are from the east, suggesting the presence of onshore flow from a lake breeze, or weak westerly to strong easterly transport. Mean O<sub>3</sub> concentrations in all the high-ozone nodes have decreased from 2001 to 2022 (Figure 2-6).

#### **2.4.3. Chicago, IL-IN-WI, CART Analyses**

LADCO conducted CART analyses for three different parts of the large Chicago NAA: the far north (Kenosha and Lake counties, WI-IL), central (Cook County, IL), and the far east (Lake and Porter counties, IN). The high-ozone nodes from all three CART analyses have hot temperatures (Supplement Table S11). The northern Kenosha and Lake County monitors were impacted by the strength of the westerly/easterly component of the winds, with the highest-O<sub>3</sub> node having weak westerly to easterly transport and westerly winds in the morning, suggesting the presence of a morning land breeze ahead of an afternoon lake breeze. Most of the nodes in the Indiana monitor analysis also have low relative humidity. The Cook County monitors had stagnant conditions (little transport) on the highest-O<sub>3</sub> days. O<sub>3</sub> concentrations in almost all the high-O<sub>3</sub> nodes decreased during the first part of the study period (Figure 2-5). However, O<sub>3</sub>

concentrations in the highest-O<sub>3</sub> nodes in all three areas have increased more recently, likely due to changes in O<sub>3</sub> formation chemistry.

#### **2.4.1. Detroit, MI, CART Analyses**

LADCO conducted CART analyses for the Detroit maintenance area. The high-ozone nodes from the CART analysis for the Detroit monitors generally have hot temperatures (Supplement Table S11). The highest ozone nodes also have stagnant conditions. Figure 2-7 shows that the mean O<sub>3</sub> concentrations in all the high-concentration nodes for Detroit have decreased from 2001 to 2022.

#### **2.4.2. St. Louis, MO-IL, CART Analyses**

LADCO conducted CART analyses for the St. Louis nonattainment area. The high-ozone nodes from the CART analysis for the St. Louis monitors generally have hot temperatures and low relative humidity (Supplement Table S11). The highest ozone nodes also have stagnant conditions (little transport). Figure 2-7 shows that the mean O<sub>3</sub> concentrations in all the high-concentration nodes for St. Louis have decreased from 2001 to 2022.

#### **2.4.3. Cleveland, OH, CART Analyses**

LADCO conducted CART analyses for the Cleveland nonattainment area. The high-ozone nodes from the CART analysis generally have hot temperatures (Supplement Table S11). The highest ozone nodes for Cleveland also have stagnant conditions (little transport). Figure 2-7 shows that the mean O<sub>3</sub> concentrations in all the high-concentration nodes for Cleveland decreased over most of the study period (Figure 2-7). However, recent concentrations in the highest-O<sub>3</sub> node have been increasing since 2016.

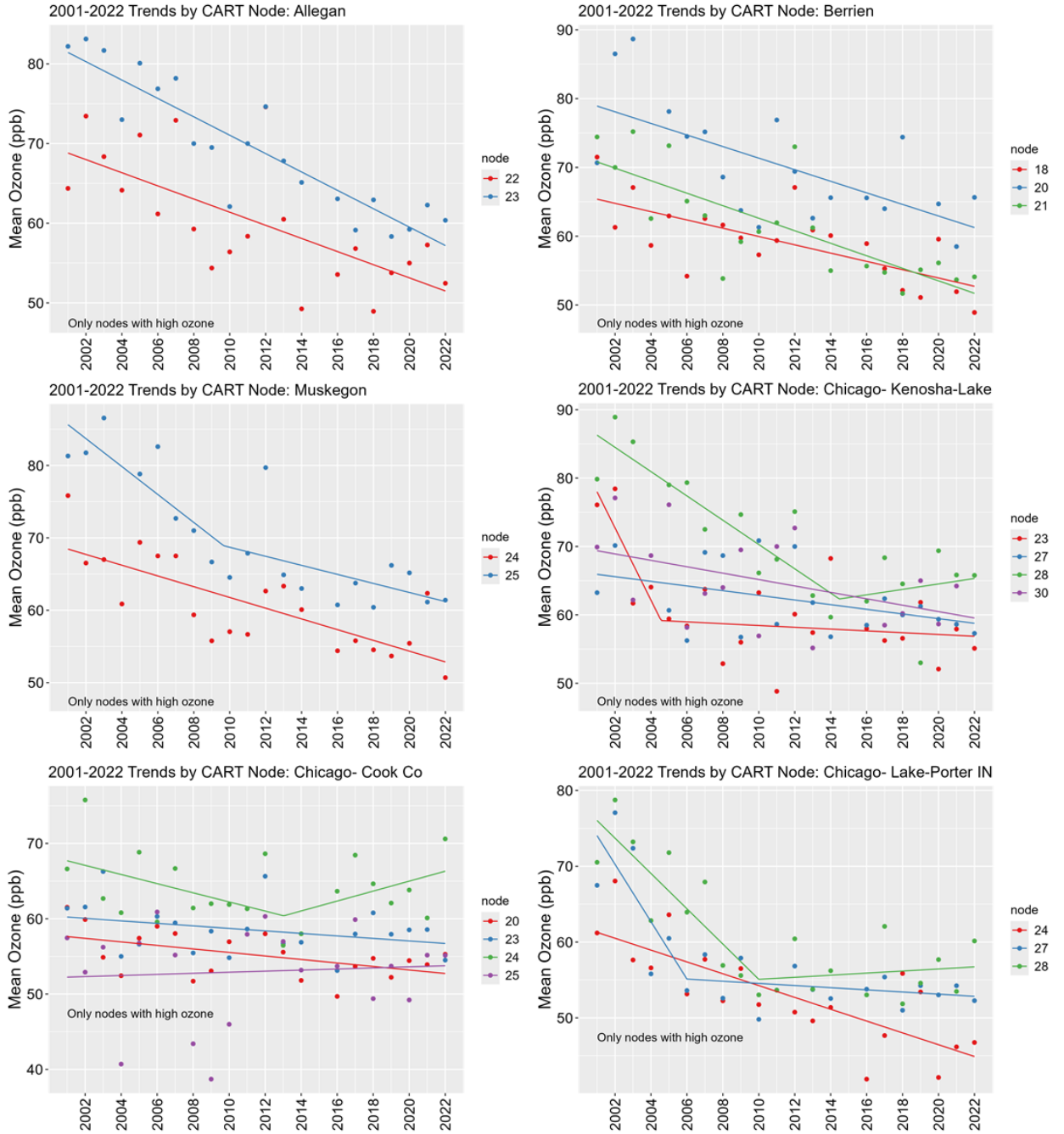
#### **2.4.4. Cincinnati, OH, CART Analyses**

LADCO conducted CART analyses for the Cincinnati maintenance area. The high-ozone nodes from the CART analysis generally have hot temperatures (Supplement

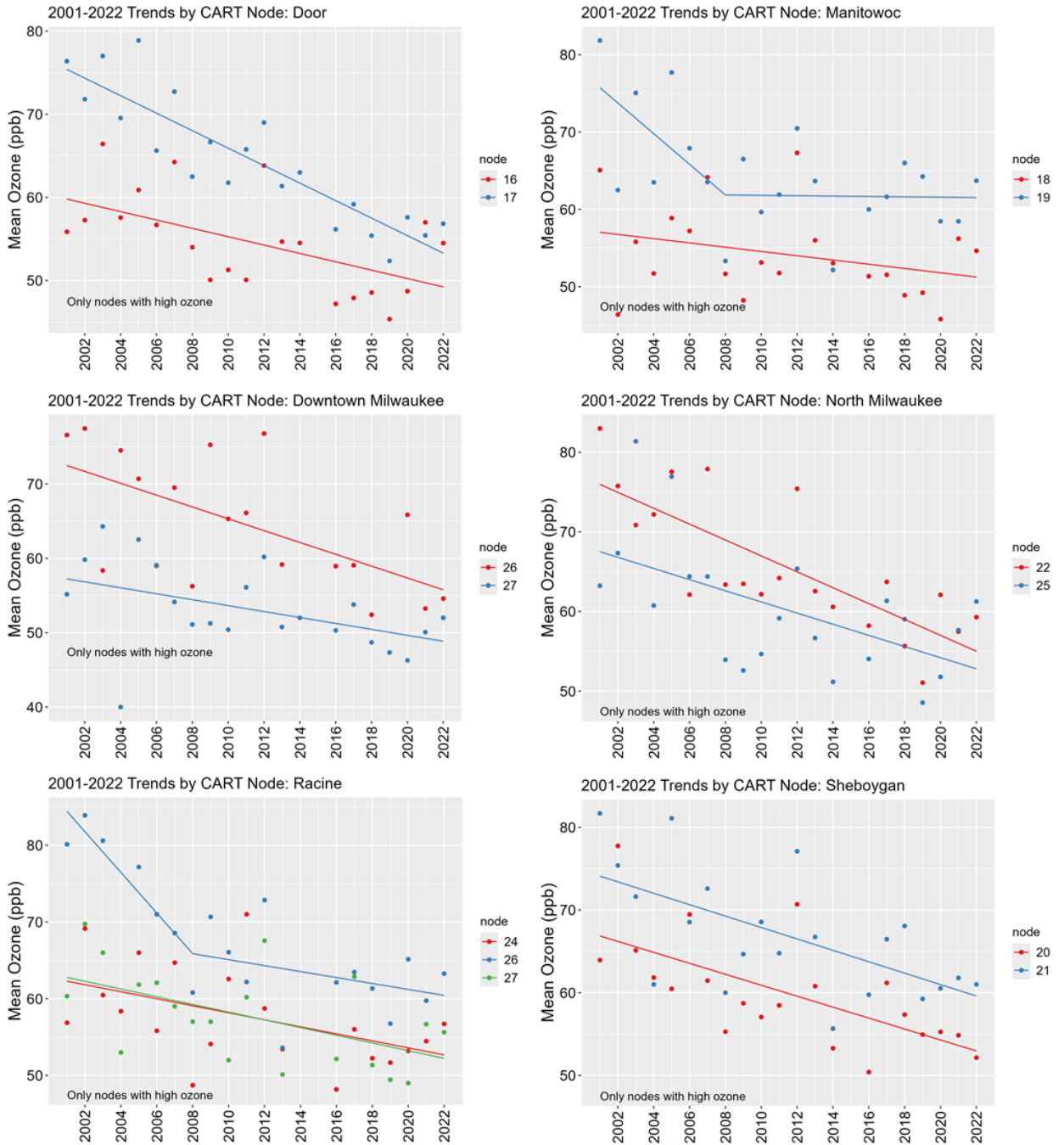
Table S11). The highest ozone nodes for Cincinnati also have stagnant conditions (little transport) and high pressure. Figure 2-7 shows that the mean O<sub>3</sub> concentrations in all the high-concentration nodes for Cincinnati have decreased from 2001 to 2022 (Figure 2-7).

#### **2.4.5. Louisville, OH, CART Analyses**

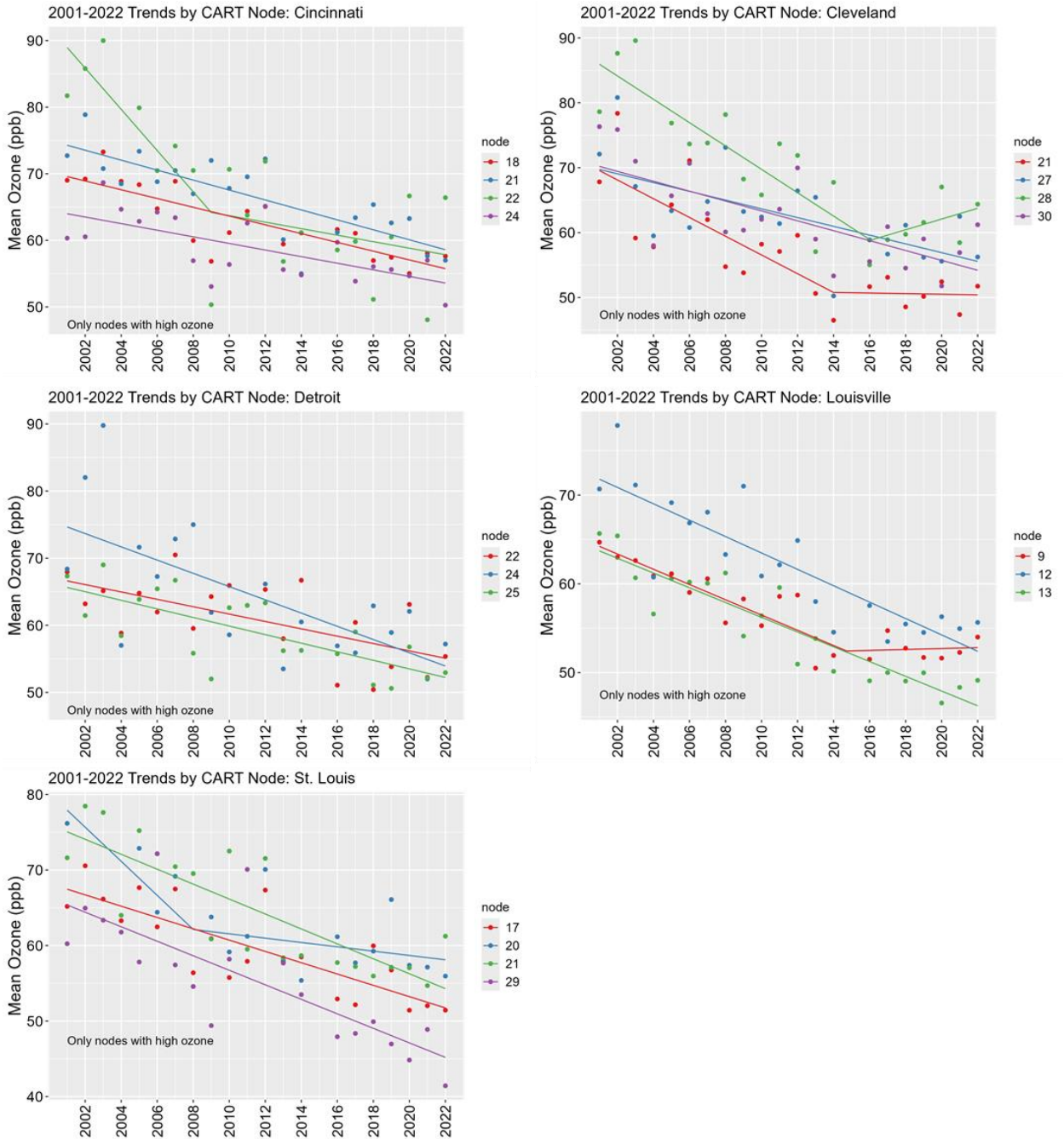
LADCO conducted CART analyses for the Louisville maintenance area. The high-ozone nodes from the CART analysis generally have low relative humidity, hot temperatures, and stagnant conditions (Supplement Table S11). Figure 2-7 shows that the mean O<sub>3</sub> concentrations in all the high-concentration nodes for Louisville have decreased from 2001 to 2022 (Figure 2-7), although concentrations for node 9 have been steady over the last decade or so.



**Figure 2-5. Ozone trends in high-ozone nodes in the western Michigan and Chicago ozone nonattainment areas in the LADCO region.**



**Figure 2-6. Ozone trends in high-ozone nodes in the Wisconsin lakeshore ozone nonattainment and maintenance areas in the LADCO region.**



**Figure 2-7. Ozone trends in high-ozone nodes in the southern and eastern urban ozone nonattainment and maintenance areas in the LADCO region.**

## 2.5. Summary

Overall, the LADCO CART analysis shows that O<sub>3</sub> DVs have decreased considerably since 2001. Ozone concentrations in the different areas are impacted by different

meteorological factors, with all areas impacted by high temperatures and many areas impacted by southerly transport and low relative humidity. When adjusted for meteorology using CART, O<sub>3</sub> concentrations on high-ozone days in select NAAs (those that did not attain the 2015 ozone NAAQS in 2021) decreased for almost all types of days in almost all NAAs. The notable exception is for the highest-O<sub>3</sub> nodes in Chicago and Cleveland, where meteorologically adjusted O<sub>3</sub> concentrations appear to have increased in recent years. The CART trends indicate that ongoing reductions of O<sub>3</sub> precursor emissions are continuing to reduce O<sub>3</sub> concentrations in most areas of the LADCO region.

### 3. Air Quality Modeling Platform

#### 3.1. 2022 Modeling Platform

LADCO based our 2022 O<sub>3</sub> air quality predictions on the 2022v1 National Emission Inventory Collaborative emissions inventory<sup>9</sup> and the U.S. EPA 2022v1 (herein referred to as 2022v1) emissions modeling platform (US EPA, 2025). LADCO generated the Weather Research Forecast (WRF) model meteorology (LADCO, 2024) and used initial and boundary conditions from the U.S. EPA 2022 CAMx modeling platform. LADCO processed the 2022 emissions using the U.S. EPA Sparse Matrix Operator Kernel Emissions (SMOKE) scripts distributed with the 2022v1 emissions modeling platform. The CAMx inputs, including the meteorology data simulated with the Weather Research Forecast (WRF) model, emissions data, and boundary conditions represent year 2022 conditions.

#### 3.2. Modeling Year Justification

LADCO selected 2022 as a modeling year for this study because at the initiation of this project in late 2024 CAMx input data for 2022 were available and they represented the state-of-the-science for emissions and meteorology data. In 2024, a group of multi-jurisdictional organizations (MJOs), states, and EPA established a rationale for 2022 as the new base year for a national air quality modeling platform<sup>10</sup>. The group concluded that if only one recent year could be selected, that 2022 would serve as a good base year because of typical O<sub>3</sub> conditions and average wildfire conditions. Following from the base year recommendations from that group, several modeling centers, including U.S. EPA and LADCO, developed data and capabilities for simulating and evaluating air quality in 2022.

Following from the selection of 2022 as the base year for a national modeling platform, starting in late 2024, the MJOs, states, and EPA formed the National Emissions Inventory Collaborative to develop a 2022 emissions inventory and modeling platform.

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<sup>9</sup> <https://views.cira.colostate.edu/wiki/SiteSettings/Wiki/Index/11209>

<sup>10</sup> <https://drive.google.com/file/d/1JbZgflfzVYSleg7XI7B5rjgn758xKWi4/view>

Over 200 participants collaborated across 12 workgroups to develop base and future year emissions to support upcoming regulatory modeling applications. This effort was designed to involve a broad group of emissions experts in the development of a new national emissions modeling platform. LADCO used the 2022 and 2026 inventories developed by the Collaborative for the modeling presented here.

The attainment date for 2015 O<sub>3</sub> NAAQS serious NAAs is August 3, 2027. LADCO selected 2026 as the future projection year because it aligns with the last complete O<sub>3</sub> season that will be used to determine attainment of these areas.

### **3.3. Air Quality Model Configuration and Data**

LADCO based our CAMx air quality modeling platform for this application on the configuration that we recently used for 2015 O<sub>3</sub> NAAQS attainment demonstration modeling (LADCO, 2022b) and regional haze modeling for the Regional Haze Rule 2<sup>nd</sup> implementation period (LADCO, 2021). LADCO used CAMx 7.31 (Ramboll, June 2024) as the photochemical grid model for this application. CAMx is a three-dimensional, Eulerian air quality model that simulates the chemical transformation and physical transport processes of air pollutants in the troposphere. It includes capabilities to estimate the concentrations of primary and secondary gas and particle phase air pollutants, and dry and wet deposition, from urban to continental spatial scales. As CAMx associates source-level air pollution emissions estimates with air pollution concentrations, it can be used to design and assess emissions reduction strategies pursuant to NAAQS attainment goals.

LADCO selected CAMx for this study because it is a component of recent LADCO and U.S. EPA modeling platforms for investigating the drivers of ground level O<sub>3</sub> in the Great Lakes region and across the U.S. As CAMx is a component of U.S. EPA studies with a similar scope to this project, LADCO was able to leverage the data and software elements that are distributed with recent U.S. EPA regulatory air quality modeling platforms. Using these elements saved LADCO significant resources relative to building a modeling platform from scratch.

Figure 3-1 shows the LADCO WRF modeling domains used for this application. A 12-km uniform grid (12US2) covers all the continental U.S. and includes parts of Southern Canada and Northern Mexico. A 4-km domain covers all the LADCO member states in their entirety. The vertical modeling domain has 36 layers with a model top at about 17,550 meters (50 mb). LADCO used the same U.S. EPA 12-km domain for this project because it supported the use of initial and boundary conditions data that were readily available from U.S. EPA.

Table 3-1 summarizes the CAMx science configurations and options LADCO used for the 2022 and 2026 CAMx modeling for this application. We used the Piecewise Parabolic Method (PPM) advection solver for horizontal transport along with the spatially varying (Smagorinsky) horizontal diffusion approach. We used K-theory for vertical diffusion using the CMAQ-like vertical diffusivities from WRFCAMx. The CB7r1 gas-phase chemical mechanism was selected because it includes the latest chemical kinetic rates and represents improvements over the other alternative CB06 and SAPRC chemical mechanisms as well as active methane chemistry. Additional CAMx inputs were as follows:

[Meteorological Inputs:](#) The LADCO WRF-derived meteorological fields (LADCO, 2022) were processed to generate CAMx meteorological inputs using the WRFCAMx v5.2 processor, as described in Section 3.3.1.

[Initial/Boundary Conditions:](#) LADCO used 2022 initial and boundary conditions for CAMx generated by the U.S. EPA from a northern hemisphere simulation of the Community Multiscale Air Quality (CMAQ) model (s3://epa-2022-modeling-platform/bcon/HEMI\_CMAQ\_12US2\_CAMxBC ). EPA generated hourly, one-way nested boundary conditions (i.e., hemispheric-scale to regional-scale) from a 2022 108-km x 108-km polar stereographic CMAQ simulation of the northern hemisphere. Following the convention of the U.S. EPA 2022 regional haze modeling (U.S. EPA, 2019b), LADCO used year 2022 CMAQ boundary conditions for modeling 2022 and 2026 air quality with CAMx.

**Photolysis Rates:** LADCO prepared the photolysis rate and total ozone columns inputs for CAMx. Day-specific O<sub>3</sub> column data were based on the Total Ozone Mapping Spectrometer (TOMS) data measured using the satellite-based Ozone Monitoring Instrument ([OMI](#)). LADCO used the TUV photolysis rate processor to prepare clear-sky photolysis rates for CAMx. If there were periods where daily TOMS data were unavailable in 2022, the TOMS measurements were interpolated between the days with valid data. CAMx was also configured to use the in-line TUV to adjust for cloud cover and account for the effects that modeled aerosol loadings have on photolysis rates; this latter effect on photolysis may be especially important in adjusting the photolysis rates due to the occurrence of PM concentrations associated with emissions from fires.

**Landuse:** LADCO used NCLD 2011 40 classifications of land use dataset in LADCO WRF 2022 simulation.

**Spin-Up Initialization:** A minimum of ten days of model spin up (e.g., December 21-31, 2021) was used for all modeling domains. LADCO ran monthly CAMx simulations, initializing each month with a 10-day spin-up period.

As the focus of this study is on O<sub>3</sub>, LADCO used CAMx to simulate the 2022 O<sub>3</sub> season. LADCO simulated April 1 through September 30, 2022 as individual months using 10-day model spin-up periods for each month. LADCO selected a CAMx configuration that was consistent with previous O<sub>3</sub> modeling applications performed by LADCO (2020) and U.S. EPA (2019).

**Table 3-1. LADCO 2022 CAMx modeling platform configuration**

Science Options	Configuration
Model Codes	CAMx v7.31
Simulation Period	March 20-September 30, 2022
Horizontal Grid Mesh	12 km, 396 cols x 246 rows 4 km, 420 cols x 390 rows
Vertical Grid Mesh	36 layers up to 50 mb
Grid Interaction	Two-way nested
Initial Conditions	10-day spin up on all grids
Boundary Conditions	12km from hemispheric CMAQ (U.S. EPA 2022)
Emissions	
Baseline Emissions Processing	Sparse Matrix Operator Kernel Emissions (SMOKE), EPA's MOfor Vehicle Emission Simulator (MOVES4) and Biogenic Emission Inventory System (BEIS)

Science Options	Configuration
Emissions Modeling Platform	U.S. EPA 2022 Platform with 22.1 EGU Point and hourly CEMs
Chemistry	
Gas Phase Chemistry	CB7r1
Aerosol Chemistry	CF + SOAP3
Meteorological Processor	WRFCAMx_v4.9.1
Horizontal Diffusion	Spatially varying
Vertical Diffusion	CMAQ-like in WRF2CAMx
Diffusivity Lower Limit	Kz_min = 0.1 to 1.0 m <sup>2</sup> /s or 2.0 m <sup>2</sup> /s
Dry Deposition	Zhang dry deposition scheme (CAMx)
Wet Deposition	CAMx-specific formulation
Gas Phase Chemistry Solver	Euler Backward Iterative (EBI) -- Fast Solver
Vertical Advection Scheme	Implicit scheme w/ vertical velocity update (CAMx)
Horizontal Advection Scheme	Piecewise Parabolic Method (PPM) scheme
Integration Time Step	Wind speed dependent

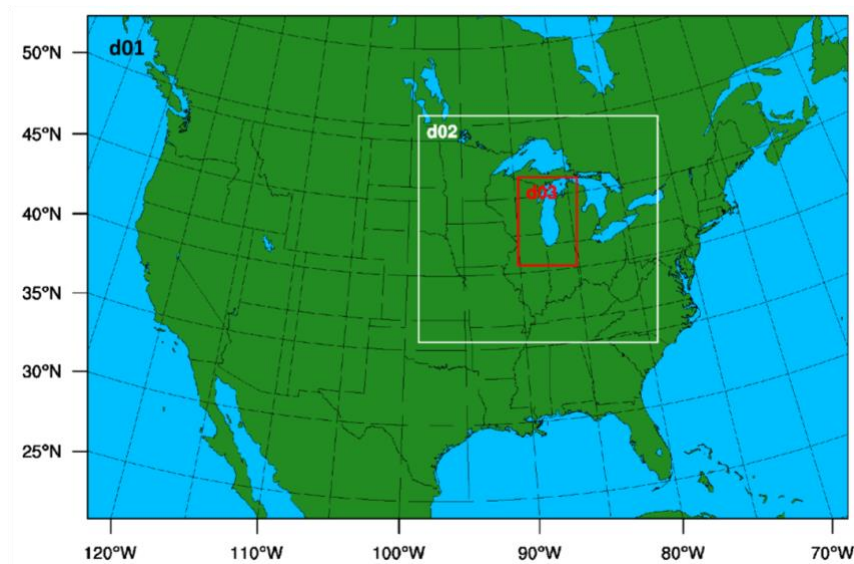


Figure 3-1. LADCO WRF modeling domains

### 3.3.1. Meteorology Data

LADCO developed 2022 WRF data for this application (LADCO, 2024). We used version 4.5 of the WRF model, initialized with a blend of the 12-km North American Model (NAM) from the National Climatic Data Center (NCDC) and the 3-km High Resolution Rapid Refresh (HRRRv4) from NOAA to simulate 2022 meteorology. Complete details of the WRF simulation, including the input data, physics options, and

four-dimensional data assimilation (FDDA) configuration are detailed in the LADCO Meteorology Model Performance for Annual 2022 Simulation report (LADCO, 2024). LADCO prepared the WRF data for input to CAMx with version 4.8 of the WRFCAMx software.

### **3.4. 2022 and 2026 Emissions Data**

LADCO collected 2022 and 2026 emissions data for this study primarily from the U.S. EPA 2022hc emissions modeling platform (U.S. EPA, 2025). U.S. EPA and the 2022 Emissions Inventory Collaborative<sup>11</sup> generated version 1 of the 2022 (2022v1) inventory for use in O<sub>3</sub> NAAQS and PM<sub>2.5</sub> SIPs. Table 3-2 lists the 2022 base year inventory components that LADCO used to simulate 2022 air quality for this application.

LADCO replaced the 2026 EGU emissions in the U.S. EPA 2022hc emissions modeling platform with 2026 EGU forecasts estimated with the February 2025 version of the ERTAC EGU Tool version 22.1 (MARAMA, 2012). LADCO also used a version of the 2026hc non-EGU point inventory that is synchronized with the ERTAC EGU inventory in our 2026 modeling platform runs to ensure consistency with the EGU sector. The ERTAC model defines EGUs as power generating units with Continuous Emissions Monitoring (CEM). The U.S. EPA EGU inventory encompasses all power generating units, including industrial facilities such as paper mills and aluminum foundries that sell power to the electricity grid. The non-EGU point inventory needed to be modified to work with the ERTAC EGU inventory by including the industrial sources from the U.S EPA EGU point inventory that are not included in the ERTAC model.

Supplement Section S4 to this TSD is a table of all the EGU sources that operated in 2022 but were removed from the 2026 inventory and LADCO CAMx simulation due to retirement dates that occurred before the end of 2026.

Table 3-2 lists the 2022 base year and 2026 future year inventory components that LADCO used to simulate 2022 and 2026 air quality for this application. LADCO processed

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<sup>11</sup> <https://views.cira.colostate.edu/wiki/SiteSettings/Wiki/Index/11209>

the inventories into CAMx binary format with SMOKE to estimate hourly emissions on two nested modeling domains (12/4) for April 1, 2022 through October 31, 2022.

**Table 3-2. LADCO 2022 emissions modeling platform inventory components**

Sector	Abbreviation	Base Year Data Source	Future Year Data Source
Agriculture	ag	U.S. EPA 2022hc	U.S. EPA 2026hc
Fugitive Dust	afdust	U.S. EPA 2022hc	U.S. EPA 2026hc
Airports	airports	U.S. EPA 2022hc	U.S. EPA 2026hc
Biogenic	BEIS3	U.S. EPA 2022hc	U.S. EPA 2022hc
C1/C2 Commercial Marine	cmv_c1c2	U.S. EPA 2022hc	U.S. EPA 2026hc
C3 Commercial Marine	cmv_c2	U.S. EPA 2022hc	U.S. EPA 2026hc
Livestock	livestock	U.S. EPA 2022hc	U.S. EPA 2026hc
Nonpoint	nonpt	U.S. EPA 2022hc	U.S. EPA 2026hc
Offroad Mobile	nonroad	U.S. EPA 2022hc	U.S. EPA 2026hc
Nonpoint Oil & Gas	np_oilgas	U.S. EPA 2022hc	U.S. EPA 2026hc
Nonpoint Solvents	np_solvents	U.S. EPA 2022hc	U.S. EPA 2026hc
Onroad Mobile	Onroad onroad_ca_adj	U.S. EPA 2022hc	U.S. EPA 2026hc
Point Oil & Gas	pt_oilgas	U.S. EPA 2022hc	U.S. EPA 2026hc
Electricity Generation	ptegu pt	ERTAC 22.1	ERTAC 22.1
Industrial Point	ptnonipm ptnonertac	U.S. EPA 2022hc	U.S. EPA 2026hc modified
Rail	rail	U.S. EPA 2022hc	U.S. EPA 2026hc
Residential Wood Combustion	rwc	U.S. EPA 2022hc	U.S. EPA 2022hc
Agricultural Fires	ptagfire	U.S. EPA 2022hc	U.S. EPA 2026hc
Wild and Prescribed Fires	ptfire_othna ptfire_rx ptfire_wild openburn	U.S. EPA 2022hc	U.S. EPA 2022hc
Mexico Anthropogenic	othar/othpt	U.S. EPA 2022hc	U.S. EPA 2026hc
Canada Anthropogenic	othar/othpt	U.S. EPA 2022hc	U.S. EPA 2026hc

### 3.4.1. Spatial Surrogates and Emissions Grids

LADCO’s 2022 air quality modeling platform uses two nested modeling grids that focus on the Great Lakes region. We processed the 2022hc emissions on the LADCO modeling grids using U.S. EPA 12-km and 4-km spatial surrogates. We processed all the sectors emissions inventory modeling files for CAMx.

### 3.5. LADCO Modeling Platform Summary

Table 3-3 summarizes the LADCO 2022 air quality modeling platform elements.

**Table 3-3. Listing of the LADCO 2022 air quality modeling platform components**

Platform Element	Configuration	Reference	Data source
Meteorology Data	WRFv4.5	LADCO, 2024	LADCO
Initial and Boundary Conditions	2022 Hemispheric CMAQ		U.S. EPA
2022 Emissions Data	Inventory Collaborative 2022v1 ERTAC 22.1 EGU Point and hourly CEMs	US EPA, 2025	Inventory Collaborative and ERTAC
2026 Emissions Data	Inventory Collaborative 2022v1 ERTAC 22.1 EGU Point	US EPA, 2025	LADCO and ERTAC
Emissions Modeling Platform	U.S. EPA 2022hc	US EPA, 2025	U.S. EPA
Photochemical Grid Model	CAMxv7.31	Ramboll, 2024	LADCO

### 3.6. 2022 CAMx Model Performance Evaluation Methods

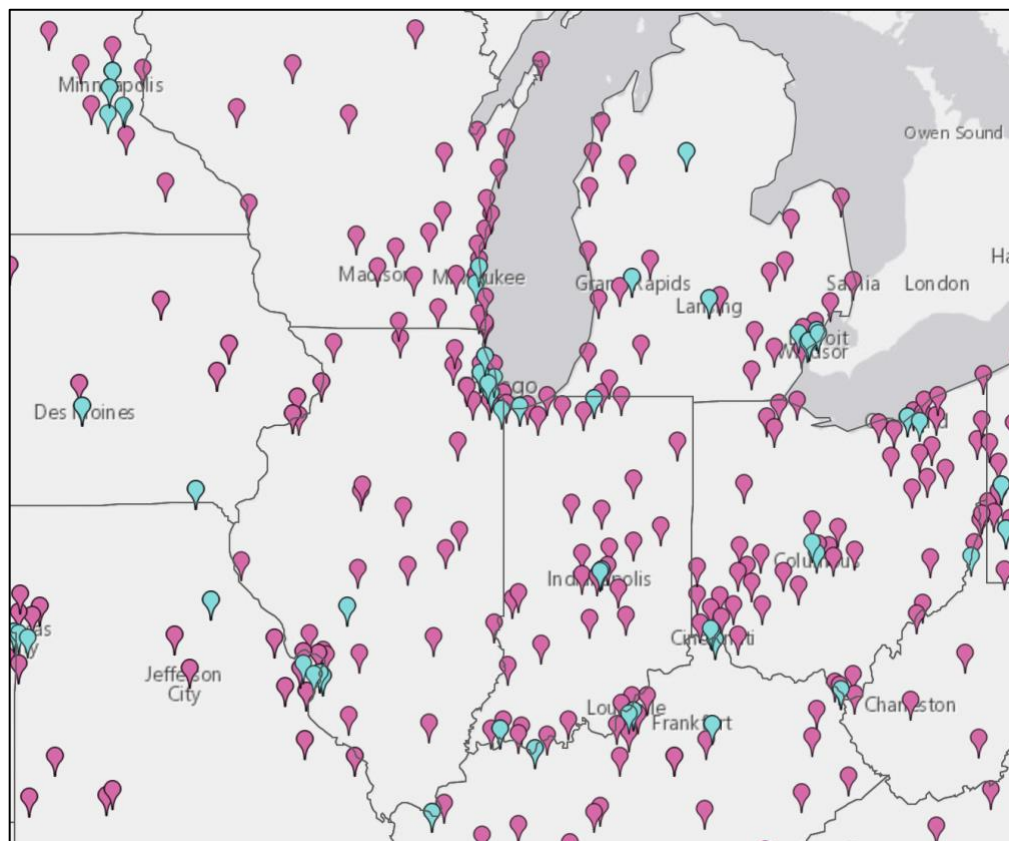
LADCO simulated 2022 air quality with CAMx using data derived from the U.S. EPA 2022hc emissions modeling platform. The CAMx model performance evaluation (MPE) presented here focuses on O<sub>3</sub> at surface monitors in the LADCO states with 2015 O<sub>3</sub> NAAQS NAAs, including Illinois (IL), Indiana (IN), Michigan (MI), Ohio (OH), and Wisconsin (WI). These states will use the information in this TSD as weight of evidence in support of the serious area NAA SIPs. LADCO used the Atmospheric Model Evaluation Tool (AMET) version 1.4 to pair the model results and surface observations in space and time, generate bi-variate statistics of model performance, and to produce MPE plots.

LADCO evaluated the CAMx 2022 modeled O<sub>3</sub> concentrations against concurrent measured surface ambient O<sub>3</sub> concentrations using graphical displays of model performance and statistical model performance measures. We compared the statistical measures against established model performance goals and criteria (Emery et al., 2017) and following the procedures recommended in EPA’s photochemical modeling guidance document (US EPA, 2018).

### 3.6.1. Available Air Quality Data for the Model Evaluation

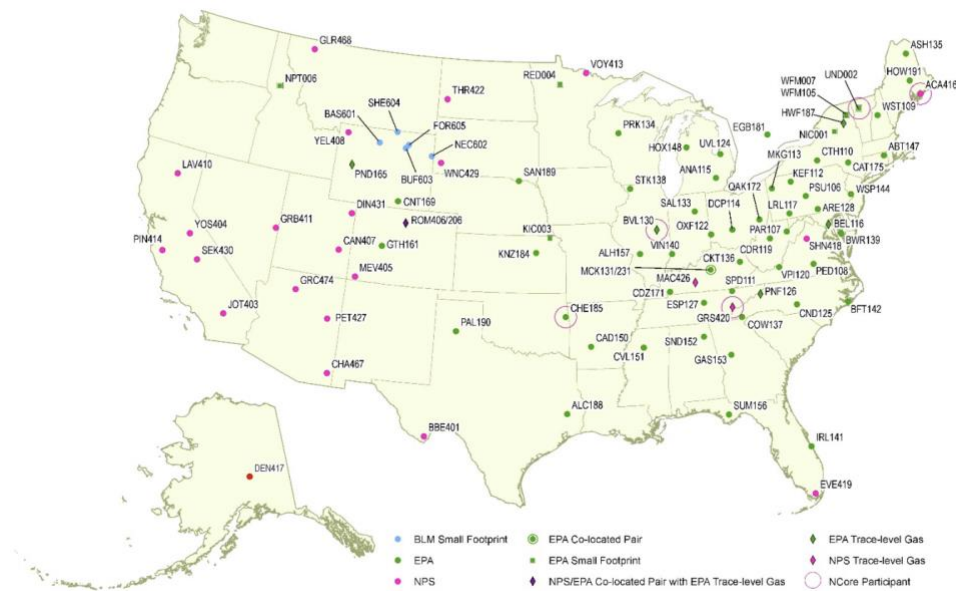
LADCO used the following routine air quality measurement data networks operating in 2022 to assess CAMx O<sub>3</sub> model performance:

**U.S. EPA AQS Surface Air Quality Data:** Data files containing hourly-averaged concentration measurements at a wide variety of state and U.S. EPA monitoring networks are available in the Air Quality System ([AQS](#)) database throughout the U.S. The AQS consists of many sites that tend to be mainly located in and near major cities. There are several types of networks within AQS that measure different species. The standard hourly AQS AIRS monitoring stations typically measure hourly O<sub>3</sub>, NO<sub>2</sub>, NO<sub>x</sub> and CO concentration and there are thousands of sites across the U.S. Figure 3-2 shows the locations of AQS surface monitors in the LADCO region.



**Figure 3-2. Locations of AQS monitors in the LADCO region, O<sub>3</sub> monitors are pink and NO<sub>2</sub> monitors are blue; source: U.S. EPA AirData**

**CASTNet Monitoring Network:** The Clean Air Status and Trends Network ([CASTNet](https://www.epa.gov/castnet)) operates approximately 80 monitoring sites in mainly rural areas across the U.S. CASTNet sites typically collect hourly O<sub>3</sub>, temperature, wind speed and direction, the standard deviation of the wind direction, solar radiation, relative humidity, precipitation and surface wetness. CASTNet also collects weekly (Tuesday to Tuesday) samples of speciated PM<sub>2.5</sub> sulfate, nitrate, ammonium and other relevant ions and weekly gaseous SO<sub>2</sub> and nitric acid (HNO<sub>3</sub>). Figure 3-3 displays the locations of the approximately 80 CASTNet sites across the U.S.



**Figure 3-3. Locations of CASTNet monitoring sites; source:**  
<https://www.epa.gov/castnet>

### 3.6.2. Model Performance Statistics, Goals and Criteria

U.S. EPA (2018) recommended a 60 ppb observed O<sub>3</sub> cut-off threshold when calculating O<sub>3</sub> model performance statistics. Emery et al., (2017) conducted a meta-analysis of 38 peer-reviewed articles from 2005 through 2015 on photochemical grid modeling applications to update the MPE benchmarks for O<sub>3</sub> and particulate matter modeling. Table 3-4 lists their recommended MPE goals and criteria, and cutoff concentrations. In addition, Emery et al., recommended that MPE statistics for O<sub>3</sub> should be calculated for time periods of roughly 1 week (episodic) and not to exceed 1 month.

**Table 3-4. Ozone model performance benchmarks by Emery, et al. (2017)**

Metric	Goal	Criteria	Cutoff
Normalized Mean Bias (NMB)	$\leq \pm 5\%$	$\leq \pm 15\%$	40 ppb for 1-hour O <sub>3</sub> , no cutoff for MDA8 O <sub>3</sub>
Normalized Mean Error (NME)	< 15%	< 25%	40 ppb for 1-hour O <sub>3</sub> , no cutoff for MDA8 O <sub>3</sub>
Correlation Coefficient (r)	> 0.75	> 0.5	No cutoff

The model performance goals by U.S. EPA and Emery et al. are not used to assign passing or failing grades to model performance, but rather to help interpret the model performance and intercompare across locations, species, time periods and model applications. The model inputs to CAMx vary hourly but tend to represent average conditions that do not account for unusual or extreme conditions. For example, an accident or large event could cause significant increases in congestion and motor vehicle emissions that are not accounted for in the average emissions inputs used in the model.

U.S. EPA compiled and interpreted the model performance from 69 air quality modeling studies in the peer-reviewed literature between 2006 and March 2012 and developed recommendations on what should be reported in a model performance evaluation (Simon, et al., 2012). Included in the most recent U.S. EPA guidance (U.S. EPA, 2018), they are useful and were used by LADCO in our model performance evaluation:

- Photochemical modeling MPE studies should at a minimum report the Mean Bias (MB) and Error (ME or RMSE) and Normalized Mean Bias (NMB) and Error (NME) and/or Fractional Bias (FB) and Error (FE). The NMB and NME are unbounded on the positive end ( $+\infty$ ) but bounded at -100% for bias and 0% for error, while FE is bounded in 0-200% and FB is bounded in -200% to +200%.
- The model evaluation statistics should be calculated for the highest temporal resolution available and for important regulatory averaging times (e.g., daily maximum 8-hour O<sub>3</sub>).
- It is important to report processing steps in the model evaluation and how the predicted and observed data were paired and whether data are spatially/temporally averaged before the statistics are calculated.

- Predicted values should be taken from the grid cell that contains the monitoring site, although bilinear interpolation to the monitoring site point can be used for higher resolution modeling (< 12 km).
- Evaluation should be performed for subsets of the data including, high observed concentrations (e.g., O<sub>3</sub> > 60 ppb), by subregions and by season or month.
- Evaluation should include more than just O<sub>3</sub> and PM<sub>2.5</sub>, such as SO<sub>2</sub>, NO<sub>2</sub> and CO.
- Spatial displays should be used in the model evaluation to evaluate model predictions away from the monitoring sites. Time series of predicted and observed concentrations at a monitoring site should also be used.
- It is necessary to understand measurement artifacts to make meaningful interpretation of the model performance evaluation.

We incorporated the recommendations of U.S. EPA (2018) and Emery et al. (2017) into the LADCO CAMx model performance evaluation. The LADCO evaluation products include qualitative and quantitative evaluation for MDA8 O<sub>3</sub> with and without a 60 ppb threshold.

**Table 3-5. Definition of model performance evaluation statistical measures used to evaluate CAMx.**

Statistical Measure	Mathematical Expression	Notes
Normalized Mean Error (NME)	$\frac{\sum_{i=1}^N  P_i - O_i }{\sum_{i=1}^N O_i}$	Reported as %
Normalized Mean Bias (NMB)	$\frac{\sum_{i=1}^N (P_i - O_i)}{\sum_{i=1}^N O_i}$	Reported as %
Correlation Coefficient (r)	$\frac{\sum [(P_j - \bar{P}) \times (O_j - \bar{O})]}{\sqrt{\sum (P_j - \bar{P})^2 \times \sum (O_j - \bar{O})^2}}$	Unitless, $-1 \leq r \leq +1$ $r = 1$ is perfectly correlated $r = 0$ is totally uncorrelated
Root Mean Square Error (RMSE)	$\sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}}$	Same units as variable, RMSE > 0 RMSE = 0 is perfectly predicted

### 3.7. Subregional Evaluation of Model Performance

The evaluation of the LADCO 2022 CAMx simulations focuses on monthly and O<sub>3</sub> season model performance at monitors in IL, IN, MI, OH and WI. We also examined summer season high O<sub>3</sub> episodes in the 2015 O<sub>3</sub> NAAQS NAAs in the LADCO region to determine how well the model performs on O<sub>3</sub> exceedance days in policy relevant locations.

## 4. 2022 and 2026 Emissions Summary

In this section we summarize the base and future year emissions modeling results used to forecast ground-level O<sub>3</sub> concentrations in 2026. The emissions projections from the 2022 base year to 2026 are the foundation of the air quality model forecasts of future year air quality. The emissions plots and tables in this section illustrate and quantify how the U.S. emissions modeling community, including LADCO, U.S. EPA, and state air quality planning agencies forecasted air pollution emissions for the current round of 2015 O<sub>3</sub> NAAQS attainment demonstrations. As described in Section 3.4, LADCO based the 2022 and 2026 emissions data for this application on the U.S. EPA 2022hc emissions modeling platform (US EPA, 2025). LADCO replaced the EGU emissions in the U.S. EPA 2022hc platform with 2026 EGU forecasts estimated with the ERTAC EGU Tool version 22.1 beta (MARAMA, 2012). Table 3-2 Table 3-2 lists the 2022 base year and 2026 future year inventory components that LADCO used to simulate 2022 and 2026 air quality for this application.

The following sections summarize the 2022 and 2026 emissions used by LADCO for simulating O<sub>3</sub> and O<sub>3</sub> precursors during these years. Tabulated ozone season total emissions by state, county, and sector for the data used by LADCO for this TSD are include in the supporting materials to this TSD:

[2022 and 2026 State, County, and Sector Emissions Summary \(XLSX\)](#)

### 4.1. 2022 Emissions Summary

The tables and figures in this section summarize the emissions used in the LADCO 2022 CAMx simulation. Table 4-1 shows the LADCO state 2022 average O<sub>3</sub> season (May – September) day emissions (OSDE) for CO, NO<sub>x</sub>, and VOC for all sectors, including natural sources like biogenics and fires. The calculation for average OSDE is shown in Equation 4-1.

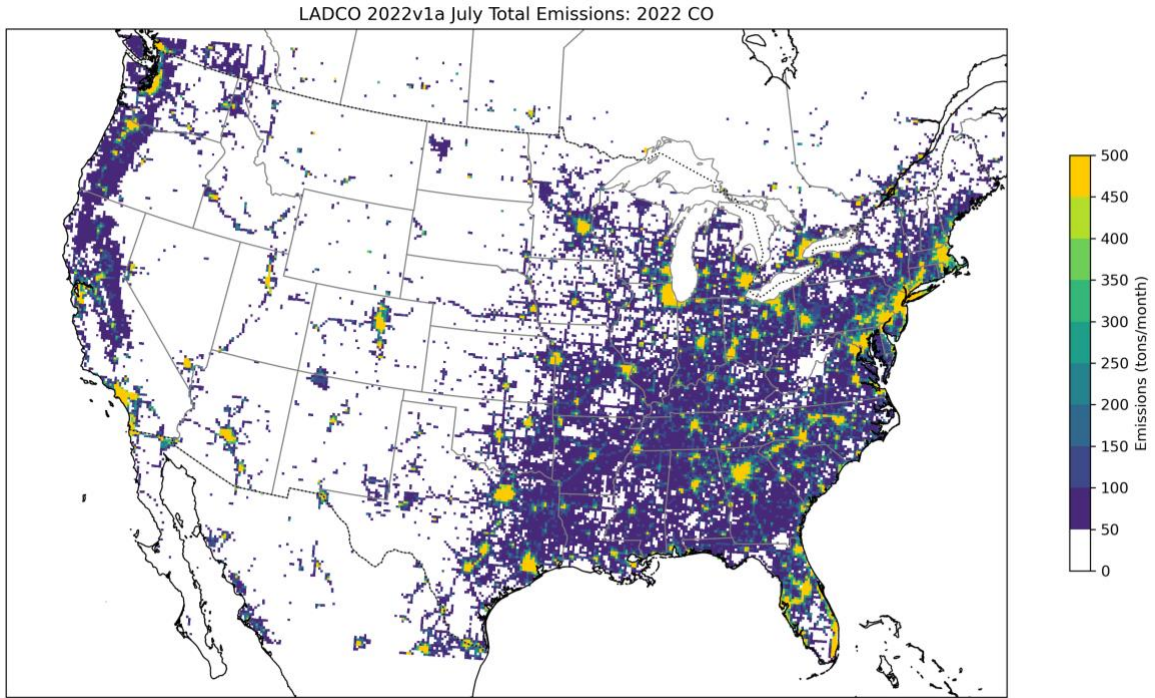
**Table 4-1. 2022 average ozone season day emissions (OSDE) by state (tons/day)**

State	CO	NOX	VOC
Illinois	3,599	849	4,884
Indiana	3,111	634	3,294
Michigan	3,323	606	3,526
Minnesota	3,192	624	3,227
Ohio	4,090	653	3,896
Wisconsin	2,492	439	3,208

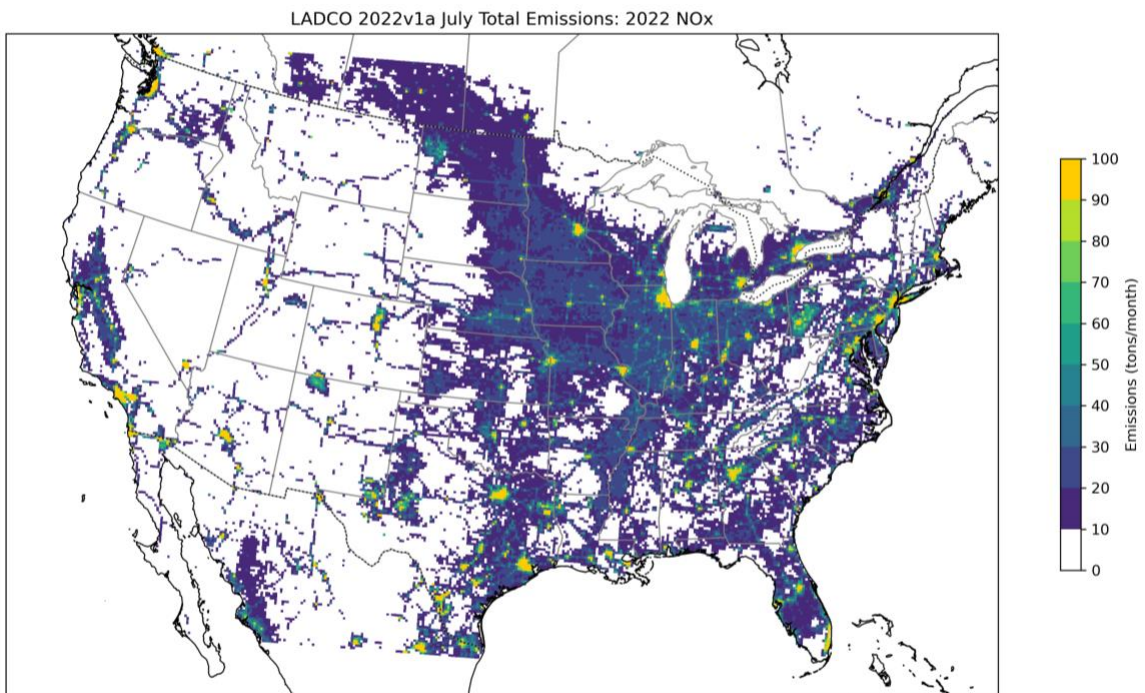
$$OSDE_{s,p} = \frac{\sum_{m=may}^{sep} \sum_{y=1}^n E_{m,y,s,p}}{153} \quad (\text{Equation 4-1})$$

Where  $E$  = monthly total emissions,  $s$  = state,  $p$  = pollutant,  $m$  = month,  $y$  = inventory sector,  $n$  = number of inventory sectors; note that 153 is the number of days in May - September 2022

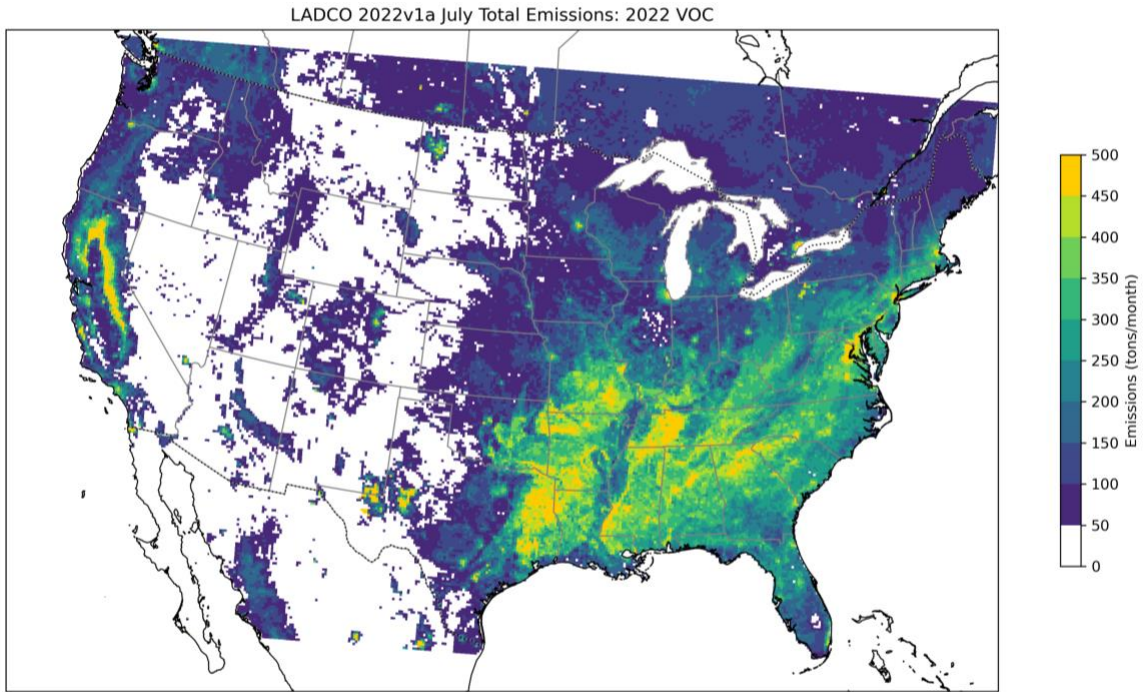
Figure 4-1 through Figure 4-6 are tile plots of the 12-km and 4-km gridded, July 2022 total CO, NOx, and VOC surface layer emissions, respectively. The CO and NOx plots illustrates that the highest emissions occur in proximity to urban areas and roadways. The VOC plot shows high emissions around urban areas, oil and gas development basins, and a diffuse emissions signal from biogenic sources. Table 4-2 through Table 4-4 show the 2022 average OSDE for CO, NOx, and VOC, respectively, by LADCO member state and inventory sector.



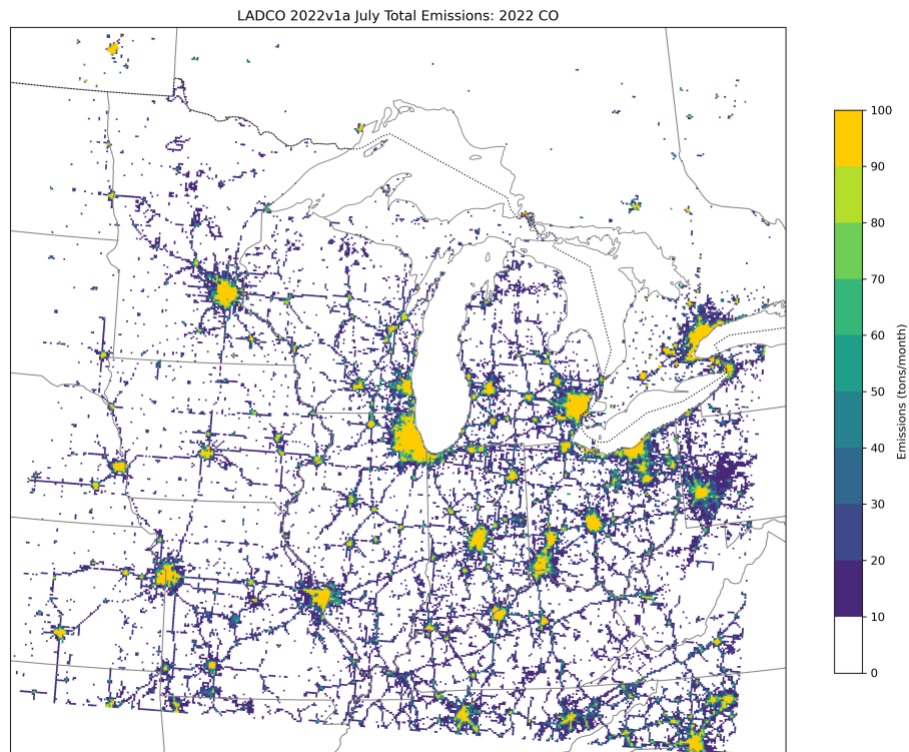
**Figure 4-1. July 2022 total 12-km gridded CO surface layer emissions (tons/month)**



**Figure 4-2. July 2022 total 12-km gridded NOx surface layer emissions (tons/month)**



**Figure 4-3. July 2022 total 12-km gridded VOC surface layer emissions (tons/month)**



**Figure 4-4. July 2022 4-km gridded CO surface layer emissions (tons/month)**

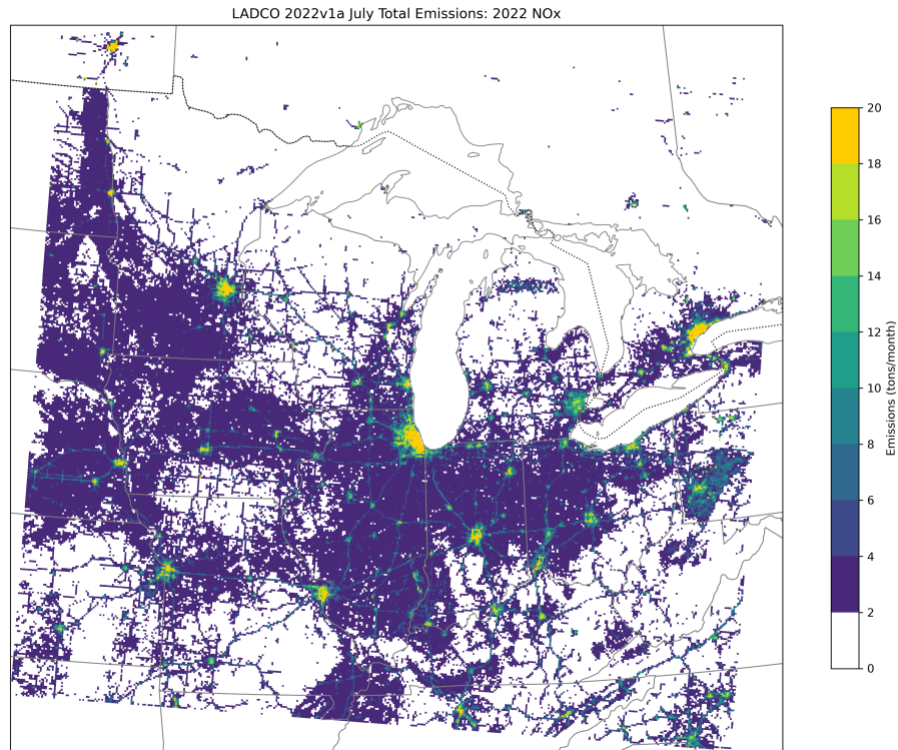


Figure 4-5. July 2022 4-km gridded NOx surface layer emissions (tons/month)

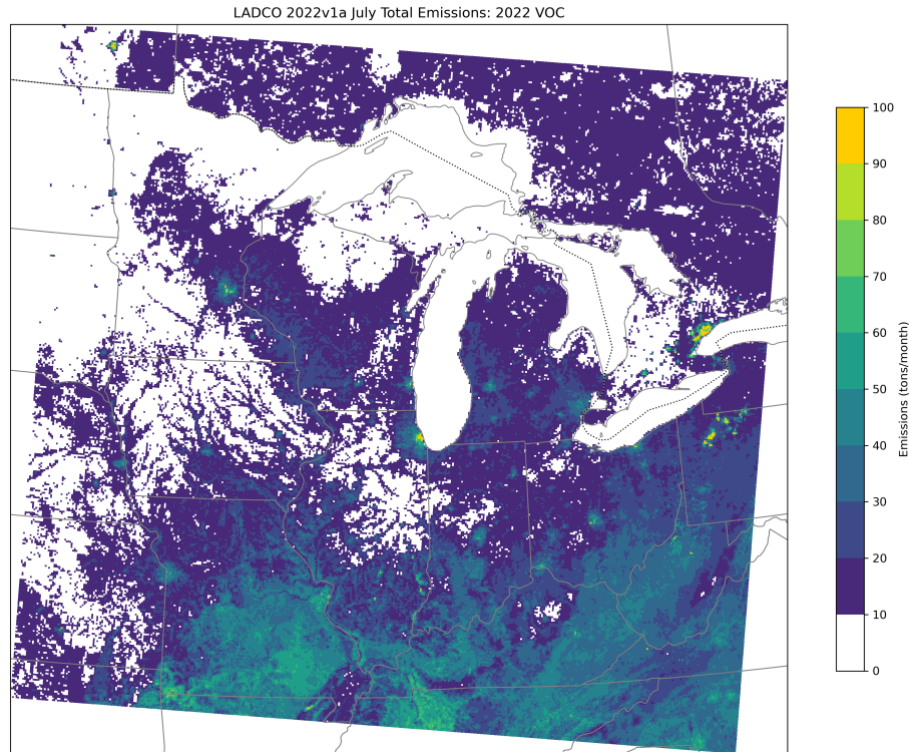


Figure 4-6. July 2022 4-km gridded VOC surface layer emissions (tons/month)

Table 4-2. 2022 average ozone season day CO emissions by inventory sector (tons/day)

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	39	14	21	20	25	17
Biogenics	391	262	293	336	289	270
C1/C2 Commercial Marine	2	0	2	0	1	1
C3 Commercial Marine	0	0	2	0	0	0
Fertilizer	0	0	0	0	0	0
Livestock	0	0	0	0	0	0
Nonpoint	56	54	55	41	44	56
Offroad Mobile	1,559	849	1,152	957	1,509	833
Nonpoint Oil & Gas	58	11	44	0	11	0
Nonpoint Solvents	0	0	0	0	0	0
Onroad Mobile Diesel	84	62	46	45	67	53
Onroad Mobile Gas	1,135	1,173	1,263	746	1,452	778
Open Burning	45	91	131	51	136	112
Point Oil & Gas	4	2	11	2	7	0
Agricultural Fires	3	2	5	30	1	5
Electricity Generation	29	28	58	19	18	16
Prescribed Fires	35	32	43	586	30	217

Wildfires	0	0	21	15	0	0
Industrial Point	96	475	89	39	417	44
Rail	18	7	2	7	10	6
Residential Wood Comb	45	49	86	296	73	83
<b>Total</b>	<b>3,599</b>	<b>3,111</b>	<b>3,323</b>	<b>3,192</b>	<b>4,090</b>	<b>2,492</b>

**Table 4-3. 2022 average ozone season day NOx emissions by inventory sector (tons/day)**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	13	3	5	4	3	2
Biogenics	186	109	82	166	99	95
C1/C2 Commercial Marine	12	1	15	2	4	5
C3 Commercial Marine	0	0	20	1	2	2
Fertilizer	0	0	0	0	0	0
Livestock	0	0	0	0	0	0
Nonpoint	49	48	39	31	23	33
Offroad Mobile	108	80	66	108	102	58
Nonpoint Oil & Gas	38	8	31	0	8	0
Nonpoint Solvents	0	0	0	0	0	0
Onroad Mobile Diesel	161	102	75	83	118	98
Onroad Mobile Gas	47	54	55	35	68	39
Open Burning	2	3	5	2	5	4
Point Oil & Gas	13	3	25	7	24	1
Agricultural Fires	0	0	0	1	0	0
Electricity Generation	53	92	86	42	60	33
Prescribed Fires	1	1	1	6	1	2
Wildfires	0	0	0	0	0	0
Industrial Point	77	96	90	99	87	39
Rail	87	34	10	32	47	28
Residential Wood Comb	1	1	1	5	1	1
<b>Total</b>	<b>849</b>	<b>634</b>	<b>606</b>	<b>624</b>	<b>653</b>	<b>439</b>

**Table 4-4. 2022 average ozone season day VOC emissions by inventory sector (tons/day)**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	4	1	2	1	2	1
Biogenics	4,026	2,695	2,840	2,497	3,077	2,581
C1/C2 Commercial Marine	1	0	0	0	0	0
C3 Commercial Marine	0	0	1	0	0	0

Fertilizer	0	0	0	0	0	0
Livestock	26	25	12	50	20	17
Nonpoint	47	58	87	83	108	154
Offroad Mobile	97	56	88	83	110	69
Nonpoint Oil & Gas	136	38	39	0	86	0
Nonpoint Solvents	346	224	281	220	290	206
Onroad Mobile Diesel	9	7	6	6	8	6
Onroad Mobile Gas	79	71	78	46	94	50
Open Burning	3	7	9	5	10	8
Point Oil & Gas	3	0	3	0	4	1
Agricultural Fires	0	0	1	4	0	0
Electricity Generation	2	3	3	1	2	1
Prescribed Fires	9	7	10	139	6	49
Wildfires	0	0	5	3	0	0
Industrial Point	87	94	49	47	68	51
Rail	4	1	0	1	2	1
Residential Wood Comb	6	7	12	39	10	12
<b>Total</b>	<b>4,884</b>	<b>3,294</b>	<b>3,526</b>	<b>3,227</b>	<b>3,896</b>	<b>3,208</b>

#### 4.2. 2026<sub>2022</sub> Emissions Summary

The tables and figures in this section summarize the emissions used in the LADCO 2022-based 2026 CAMx simulation. Table 4-5 shows the LADCO state 2026 average OSDE for CO, NOx, and VOC for all sectors, including natural sources like biogenics and fires. Table 4-6 shows the percent difference in average OSDE between 2026 and 2022. Figure 4-7 through Figure 4-18 are tile plots of the 12-km and 4-km gridded, July 2026 total CO, NOx, and VOC surface layer emissions, and emissions differences between 2026 and 2022. The difference plots show the locations where emissions are projected to change in 2026 relative to 2022. The emissions differences indicate widespread reductions across the region. The largest CO and NOx emissions reductions will occur along roadways and in urban areas where mobile sources activity is highest. Emissions reductions are also forecast to occur where coal-fired power plants are scheduled to shut down. Increases in CO and NOx emissions are forecast to occur near airports in oil and gas basins with active exploration and development. VOC emissions reductions are projected to occur in urban areas and in oil and gas development areas; only isolated increases are seen across the domain.

**Table 4-5. 2026<sub>2022</sub> average ozone season day emissions (OSDE) by state (tons/day)**

State	CO	NOx	VOC
Illinois	3,413	738	4,871
Indiana	2,889	543	3,277
Michigan	3,067	517	3,506
Minnesota	3,044	556	3,221
Ohio	3,828	560	3,858
Wisconsin	2,361	379	3,209

**Table 4-6. 2026-2022 percent difference in average OSDE by state**

State	CO	NOx	VOC
Illinois	-5.2%	-13.1%	-0.3%
Indiana	-7.1%	-14.4%	-0.5%
Michigan	-7.7%	-14.7%	-0.6%
Minnesota	-4.6%	-11.0%	-0.2%
Ohio	-6.4%	-14.2%	-1.0%
Wisconsin	-5.2%	-13.7%	0.0%

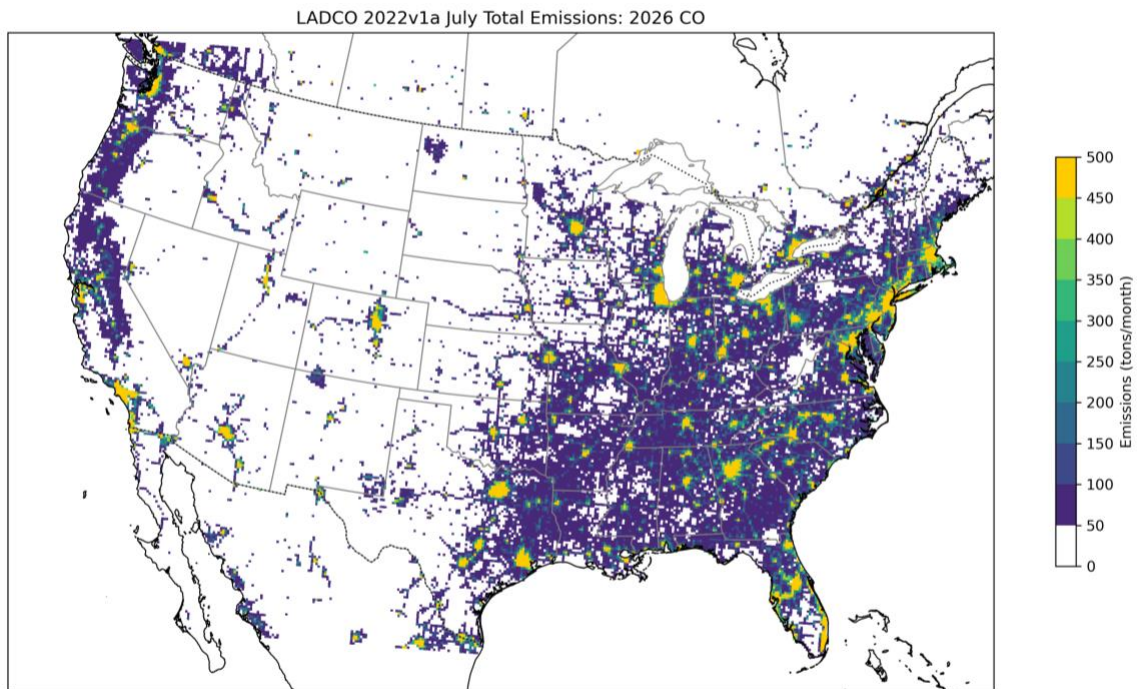


Figure 4-7. July 2026 total 12-km gridded CO surface layer emissions (tons/month).

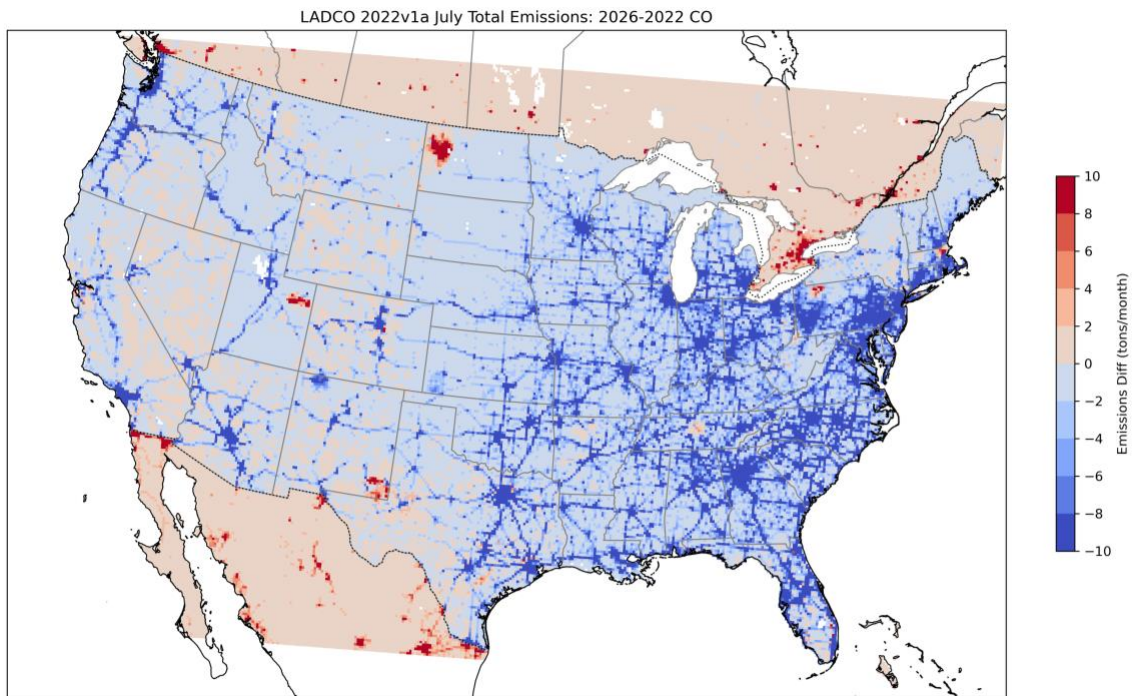
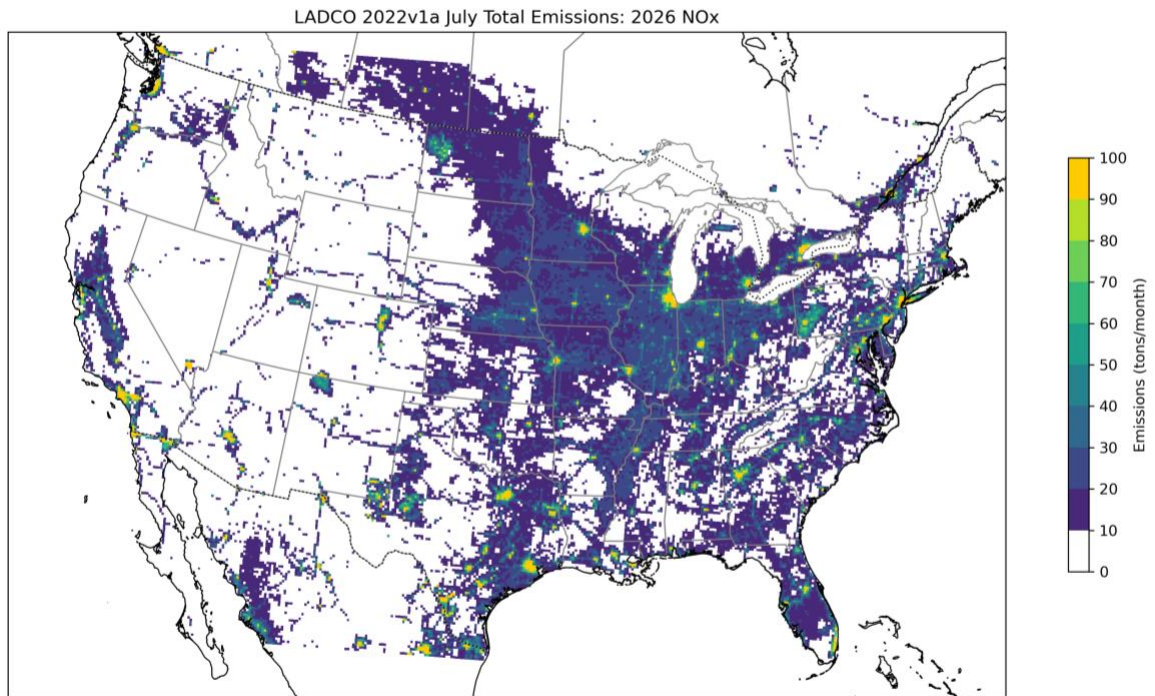
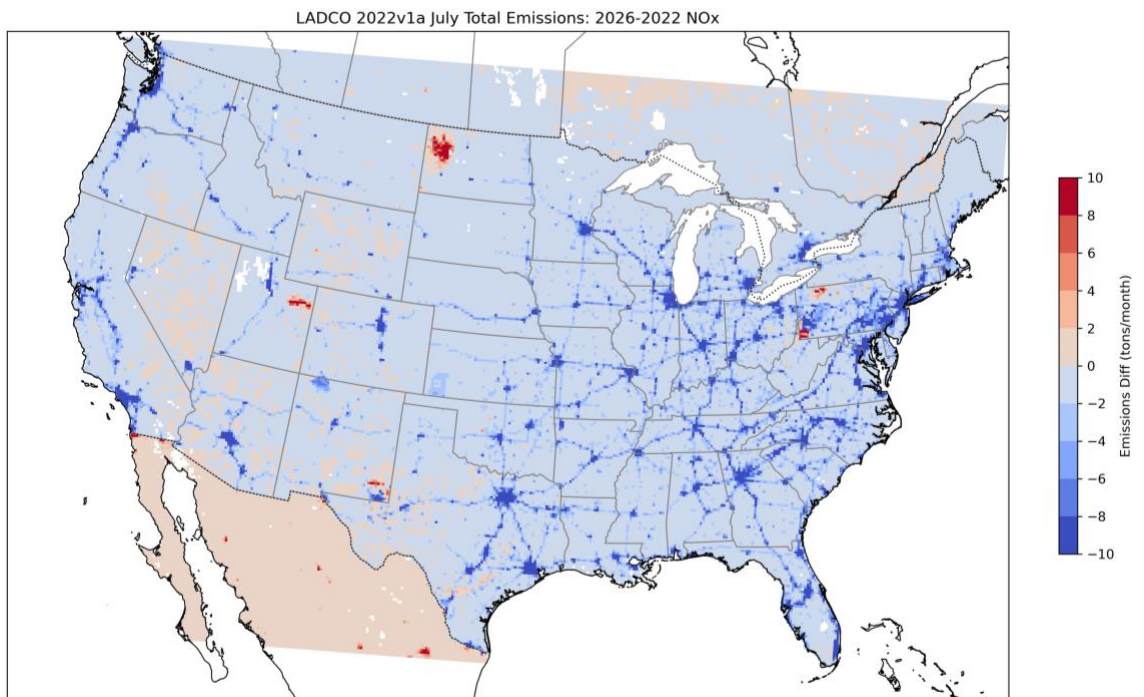


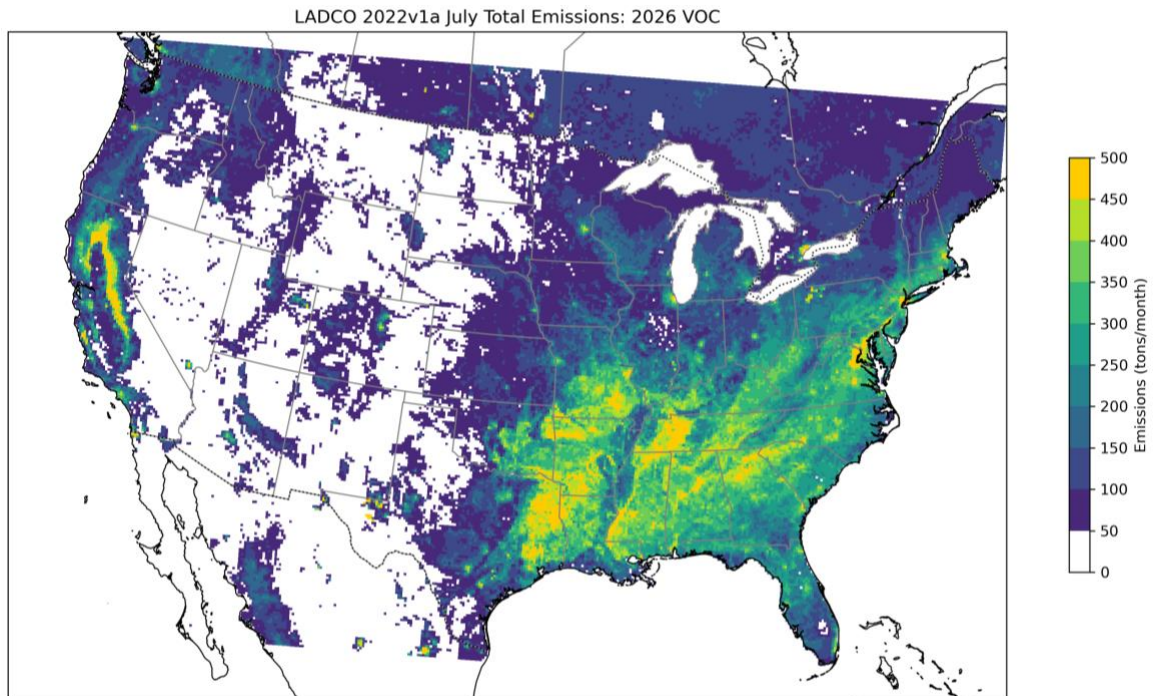
Figure 4-8. Difference (2026-2022) in July 12-km gridded CO surface layer emissions



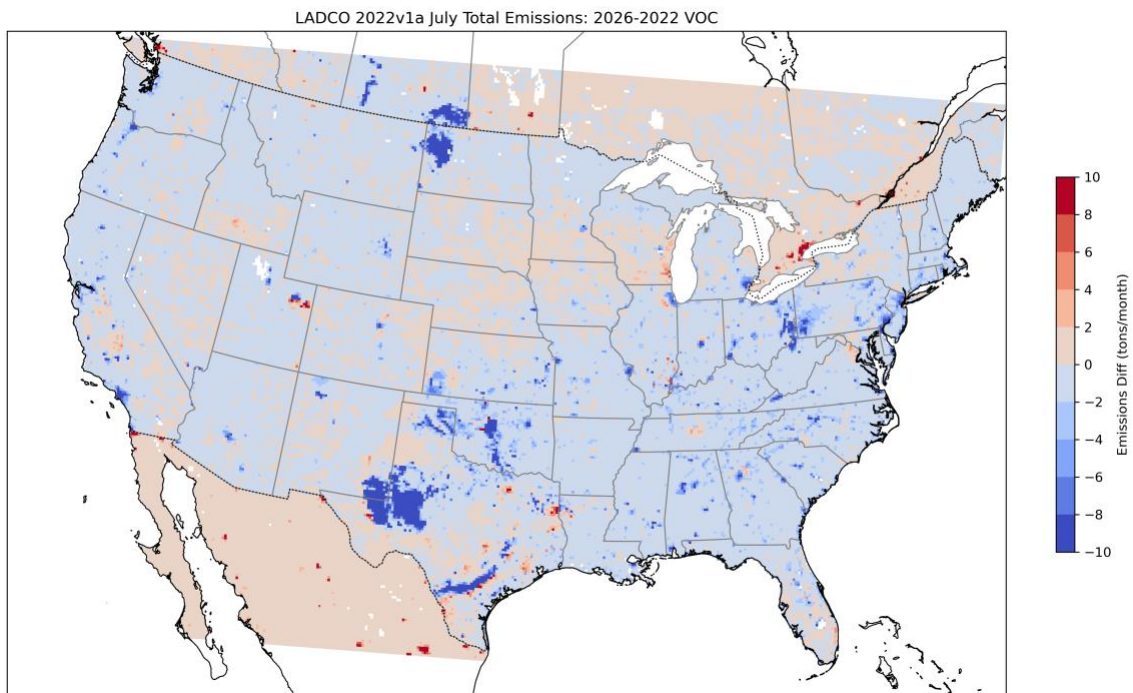
**Figure 4-9. July 2026 total 12-km gridded NOx surface layer emissions (tons/month).**



**Figure 4-10. Difference (2026-2022) in July 12-km gridded NOx surface layer emissions (tons/month)**



**Figure 4-11. July 2026 total 12-km gridded VOC surface layer emissions (tons/month).**



**Figure 4-12. Difference (2026-2022) in July 12-km gridded VOC surface layer emissions (tons/month)**

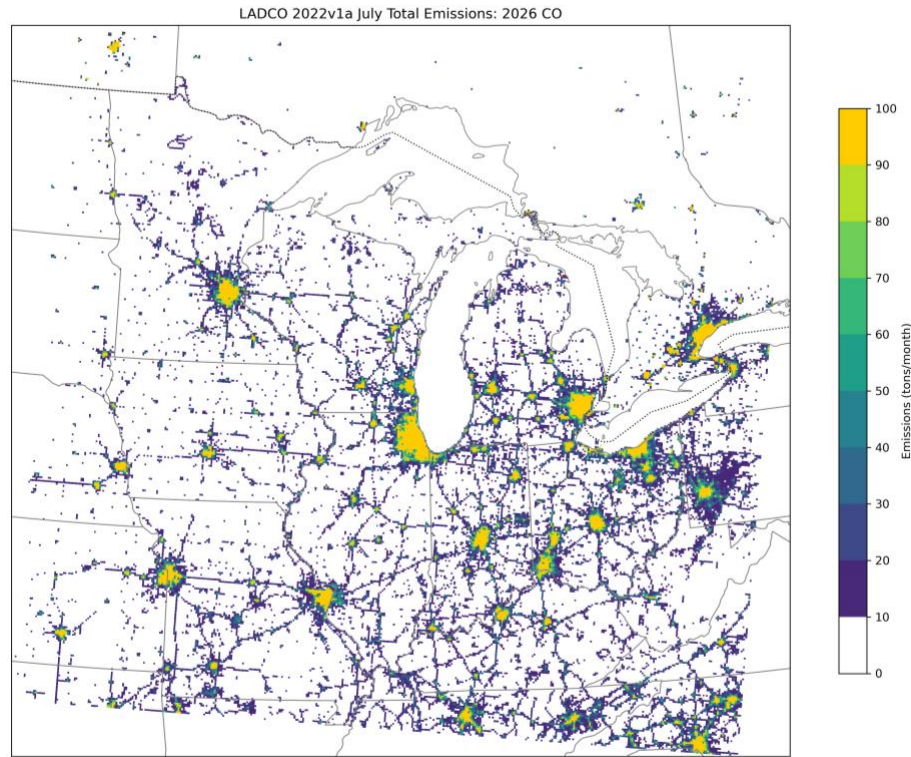


Figure 4-13. July 2026 total 4-km gridded CO surface layer emissions (tons/month).

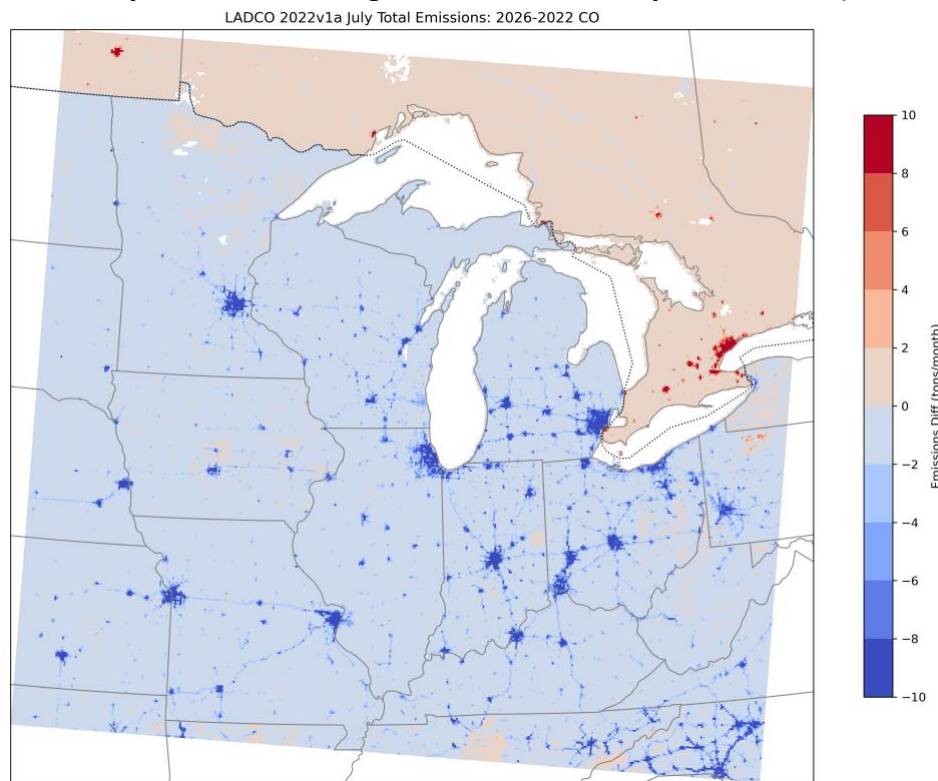
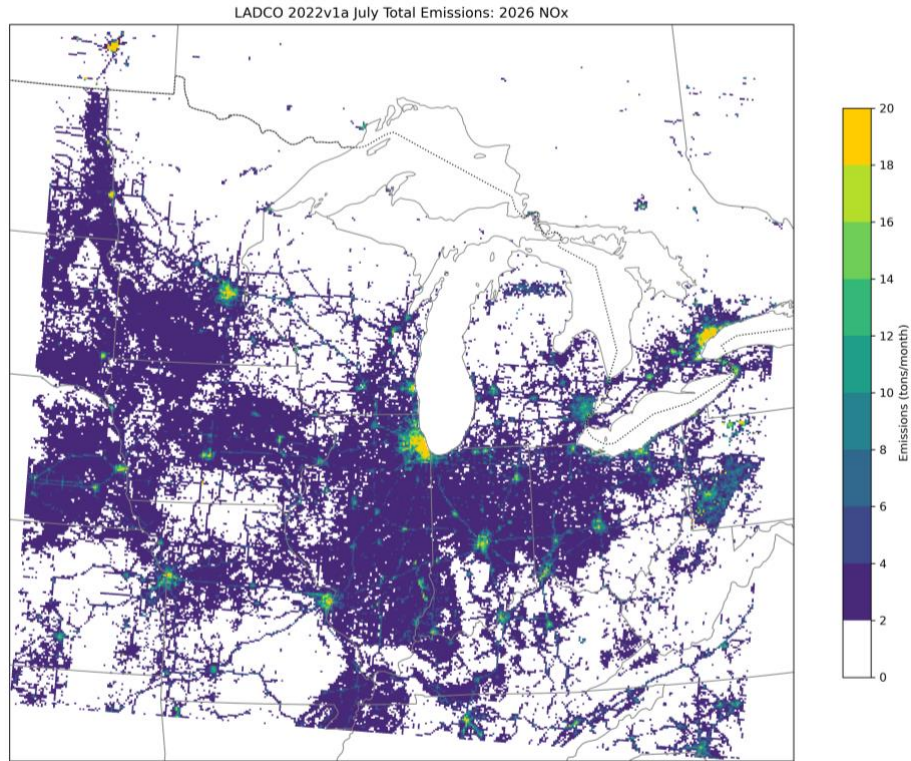
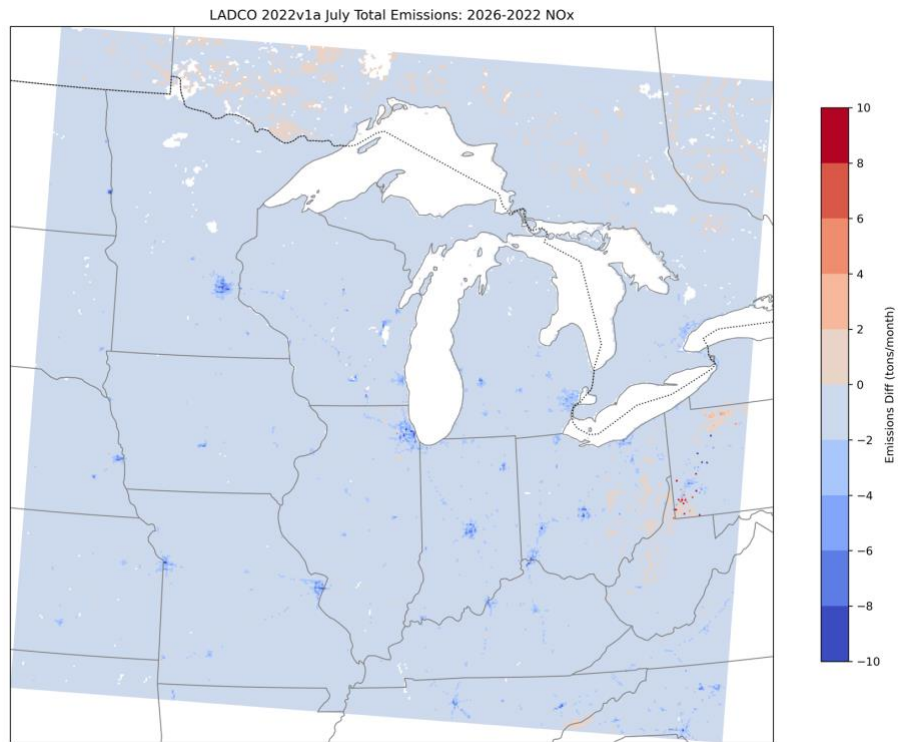


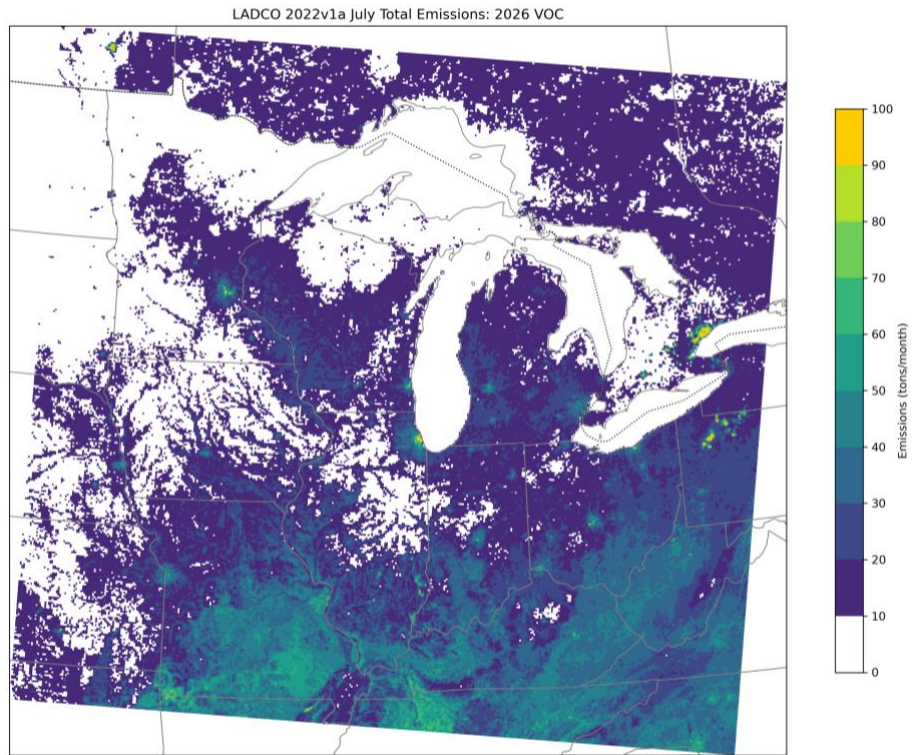
Figure 4-14. Difference (2026-2022) in July 4-km gridded CO surface layer emissions (tons/month)



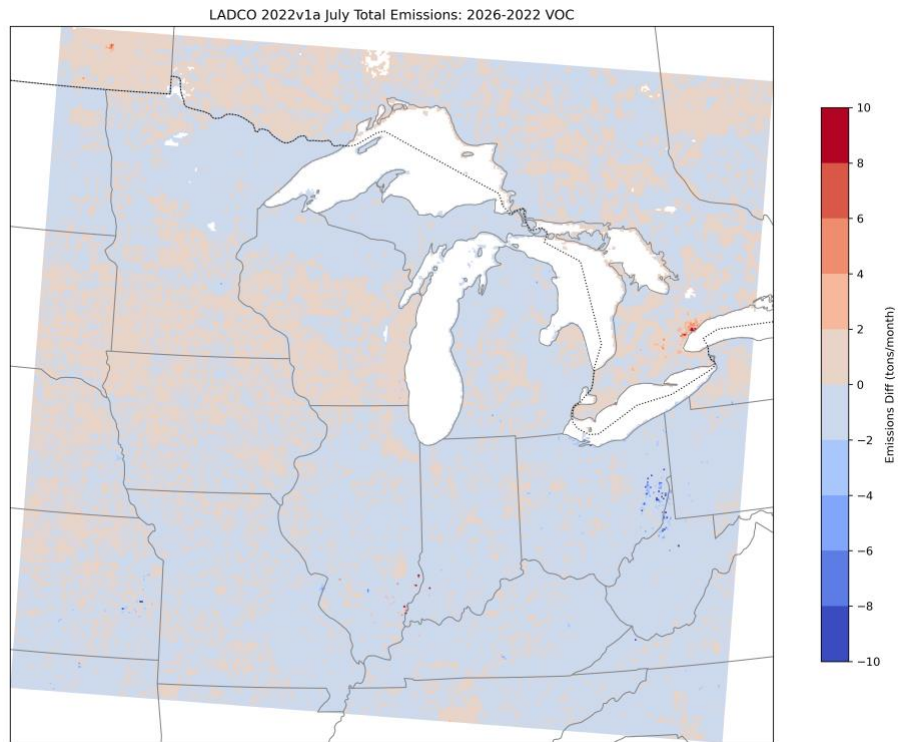
**Figure 4-15. July 2026 total 4-km gridded NOx surface layer emissions (tons/month).**



**Figure 4-16. Difference (2026-2022) in July 4-km gridded NOx surface layer emissions (tons/month).**



**Figure 4-17. July 2026 total 4-km gridded VOC surface layer emissions (tons/month).**



**Figure 4-18. Difference (2026-2022) in July 4-km gridded VOC surface layer emissions (tons/month)**

Table 4-7 through Table 4-12 show the LADCO state 2026<sub>2022</sub> average OSDE CO, NO<sub>x</sub>, and VOC emissions, and compare the future and base year OSDE values by state and inventory sector. Negative numbers in the percent difference tables indicate emissions reductions in 2026 relative to 2022. Comparisons of the EGU and industrial point source emissions changes between 2022 and 2026 is confounded by the different methods used by the U.S EPA and ERTAC EGU projection models for distinguishing EGU from non-EGU industrial point sources. ERTAC only forecasts emissions for sources with continuous emissions monitoring (CEM) data while EPA does economic projections of all units that sell power to the grid including facilities with co-generation units like paper mills and aluminum foundries. For the LADCO modeling that used ERTAC to project power plant emissions, we used the EPA 2026 inventory projections for those sources that generate power but do not have CEMs.

LADCO projects that overall CO, NO<sub>x</sub>, and VOC emissions will decrease in 2026 relative to 2022 in each of the LADCO states. The total statewide NO<sub>x</sub> reductions range from -11% to -14.7% across the LADCO states, driven primarily by reductions in EGU point, onroad mobile, and offroad mobile source emissions. We project that the total VOC emissions reductions will range from -0.03% to -1.0% across the LADCO states. These reductions are driven by changes to onroad and offroad mobile sources.

Table 4-10 reports the NO<sub>x</sub> emissions differences by sector and state and shows that some sectors are forecast to have large changes between 2022 and 2026. Airport NO<sub>x</sub> emissions are projected to increase in all LADCO states in 2026 from 9-26%. Offroad mobile NO<sub>x</sub> emissions are projected to decrease from 12-19%. Onroad mobile NO<sub>x</sub> emissions from gasoline vehicles are projected to decrease between 40-45% and diesel vehicle NO<sub>x</sub> emissions between 27-29%.

**Table 4-7. 2026 average ozone season day CO emissions by inventory sector (tons/day)**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	42	15	22	21	28	18
Biogenics	391	262	293	336	289	270
C1/C2 Commercial Marine	2	0	2	0	1	1
C3 Commercial Marine	0	0	2	0	0	0
Fertilizer	0	0	0	0	0	0
Livestock	0	0	0	0	0	0
Nonpoint	56	53	55	41	44	56
Offroad Mobile	1,573	864	1,151	959	1,511	825
Nonpoint Oil & Gas	57	10	42	0	14	0
Nonpoint Solvents	0	0	0	0	0	0
Onroad Mobile Diesel	76	55	41	40	58	50
Onroad Mobile Gas	950	953	1,052	603	1,176	662
Open Burning	45	91	131	51	136	112
Point Oil & Gas	4	2	10	2	6	0
Agricultural Fires	3	2	5	30	1	5
Electricity Generation	21	32	19	13	31	11
Prescribed Fires	35	32	43	586	30	217
Wildfires	0	0	21	15	0	0
Industrial Point	95	464	91	41	419	45
Rail	18	7	2	7	10	6
Residential Wood Comb	45	49	86	296	73	83
<b>Total</b>	<b>3,413</b>	<b>2,889</b>	<b>3,067</b>	<b>3,044</b>	<b>3,828</b>	<b>2,361</b>

**Table 4-8. Percent difference between base and future year (2026-2022) average ozone season day CO emissions**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	9%	8%	8%	7%	11%	3%
Biogenics	0%	0%	0%	0%	0%	0%
C1/C2 Commercial Marine	-1%	1%	-2%	-1%	-1%	-1%
C3 Commercial Marine	-3%	-2%	-3%	-3%	-2%	-2%
Fertilizer	0%	0%	0%	0%	0%	0%
Livestock	0%	0%	0%	0%	0%	0%
Nonpoint	-2%	-3%	-1%	0%	0%	0%
Offroad Mobile	1%	2%	0%	0%	0%	-1%
Nonpoint Oil & Gas	-1%	-10%	-6%	0%	26%	0%
Nonpoint Solvents	0%	0%	0%	0%	0%	0%
Onroad Mobile Diesel	-10%	-12%	-11%	-11%	-14%	-6%

LADCO 2015 O3 NAAQS Serious NAA SIP Attainment Demonstration TSD

Onroad Mobile Gas	-16%	-19%	-17%	-19%	-19%	-15%
Open Burning	0%	0%	0%	0%	0%	0%
Point Oil & Gas	-3%	-5%	-3%	0%	-3%	-2%
Agricultural Fires	0%	0%	0%	0%	0%	0%
Electricity Generation	-28%	11%	-68%	-30%	74%	-28%
Prescribed Fires	0%	0%	0%	0%	0%	0%
Wildfires	0%	0%	0%	0%	0%	0%
Industrial Point	-2%	-2%	2%	6%	1%	3%
Rail	1%	-1%	-1%	-1%	-1%	-1%
Residential Wood Comb	0%	0%	0%	0%	0%	0%

**Table 4-9. 2026 average ozone season day NOx emissions by inventory sectors (tons/day)**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	16	3	6	6	3	2
Biogenics	186	109	82	166	99	95
C1/C2 Commercial Marine	12	1	15	2	4	4
C3 Commercial Marine	0	0	18	1	1	2
Fertilizer	0	0	0	0	0	0
Livestock	0	0	0	0	0	0
Nonpoint	47	44	37	30	22	32
Offroad Mobile	89	66	58	88	86	49
Nonpoint Oil & Gas	38	7	29	0	9	0
Nonpoint Solvents	0	0	0	0	0	0
Onroad Mobile Diesel	116	74	54	60	84	74
Onroad Mobile Gas	28	30	32	20	38	23
Open Burning	2	3	5	2	5	4
Point Oil & Gas	12	3	24	6	23	1
Agricultural Fires	0	0	0	1	0	0
Electricity Generation	32	74	52	26	53	27
Prescribed Fires	1	1	1	6	1	2
Wildfires	0	0	0	0	0	0
Industrial Point	70	94	93	105	85	35
Rail	88	33	10	32	47	27
Residential Wood Comb	1	1	1	5	1	1
<b>Total</b>	<b>730</b>	<b>532</b>	<b>506</b>	<b>543</b>	<b>550</b>	<b>400</b>

**Table 4-10. Percent difference between base and future year (2026-2022) average ozone season day NOx emissions**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	21%	13%	20%	26%	9%	13%
Biogenics	0%	0%	0%	0%	0%	0%
C1/C2 Commercial Marine	-1%	1%	-2%	-1%	-1%	-1%
C3 Commercial Marine	-8%	-8%	-8%	-8%	-8%	-7%
Fertilizer	0%	0%	0%	0%	0%	0%
Livestock	0%	0%	0%	0%	0%	0%
Nonpoint	-5%	-7%	-5%	-4%	-4%	-3%
Offroad Mobile	-18%	-18%	-12%	-19%	-16%	-16%
Nonpoint Oil & Gas	-1%	-12%	-7%	0%	5%	0%
Nonpoint Solvents	0%	0%	0%	0%	0%	0%
Onroad Mobile Diesel	-28%	-28%	-29%	-27%	-29%	-25%
Onroad Mobile Gas	-40%	-45%	-42%	-43%	-45%	-40%
Open Burning	0%	0%	0%	0%	0%	0%
Point Oil & Gas	-5%	-3%	-5%	-2%	-5%	-5%
Agricultural Fires	0%	0%	0%	0%	0%	0%
Electricity Generation	-40%	-20%	-40%	-38%	-12%	-18%
Prescribed Fires	0%	0%	0%	0%	0%	0%
Wildfires	0%	0%	0%	0%	0%	0%
Industrial Point	-10%	-2%	4%	6%	-3%	-9%
Rail	2%	-1%	-2%	-1%	-1%	-1%
Residential Wood Comb	0%	0%	0%	0%	0%	0%

**Table 4-11. 2026 average ozone season day VOC emissions by inventory sectors (tons/day)**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	4	1	2	1	2	1
Biogenics	4,026	2,695	2,840	2,497	3,077	2,581
C1/C2 Commercial Marine	1	0	0	0	0	0
C3 Commercial Marine	0	0	1	0	0	0
Fertilizer	0	0	0	0	0	0
Livestock	26	25	12	51	20	16
Nonpoint	48	59	89	88	109	167
Offroad Mobile	90	53	79	73	100	60
Nonpoint Oil & Gas	136	34	38	0	73	0
Nonpoint Solvents	352	228	284	226	294	212
Onroad Mobile Diesel	6	5	4	4	5	4
Onroad Mobile Gas	67	57	65	39	75	44

Open Burning	3	7	9	5	10	8
Point Oil & Gas	3	0	3	0	4	1
Agricultural Fires	0	0	1	4	0	0
Electricity Generation	1	3	2	1	2	1
Prescribed Fires	9	7	10	139	6	49
Wildfires	0	0	5	3	0	0
Industrial Point	89	94	49	48	69	51
Rail	4	1	0	1	2	1
Residential Wood Comb	6	7	12	39	10	12
<b>Total</b>	<b>4,860</b>	<b>3,266</b>	<b>3,500</b>	<b>3,215</b>	<b>3,850</b>	<b>3,204</b>

**Table 4-12. Percent difference between base and future year (2026-2022) average ozone season day VOC emissions**

Sector Name	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin
Airports	12%	8%	7%	11%	-3%	3%
Biogenics	0%	0%	0%	0%	0%	0%
C1/C2 Commercial Marine	-1%	0%	-2%	-1%	-1%	-1%
C3 Commercial Marine	-3%	-2%	-3%	-3%	-2%	-2%
Fertilizer	0%	0%	0%	0%	0%	0%
Livestock	3%	3%	1%	3%	2%	-1%
Nonpoint	2%	2%	3%	6%	1%	8%
Offroad Mobile	-7%	-5%	-10%	-12%	-9%	-13%
Nonpoint Oil & Gas	0%	-9%	-2%	0%	-15%	0%
Nonpoint Solvents	2%	2%	1%	3%	1%	3%
Onroad Mobile Diesel	-33%	-34%	-36%	-34%	-37%	-30%
Onroad Mobile Gas	-15%	-19%	-16%	-16%	-20%	-13%
Open Burning	0%	0%	0%	0%	0%	0%
Point Oil & Gas	4%	1%	0%	-2%	-3%	6%
Agricultural Fires	0%	0%	0%	0%	0%	0%
Electricity Generation	-42%	-14%	-30%	-33%	2%	-26%
Prescribed Fires	0%	0%	0%	0%	0%	0%
Wildfires	0%	0%	0%	0%	0%	0%
Industrial Point	2%	0%	0%	2%	1%	0%
Rail	2%	-1%	-2%	-1%	-1%	-1%
Residential Wood Comb	0%	0%	0%	0%	0%	0%

**4.2.1. LADCO 2026 Electricity Generating Unit Emissions**

The ERTAC EGU model was developed using EGU activity pattern matching algorithms designed to provide hourly EGU emissions data for air quality planning

(MARAMA, 2012). The original goal of the model was to create low-cost software that air quality planning agencies could use for developing EGU emissions projections. States needed a transparent model that was numerically stable and did not produce dramatic changes to the emissions forecasts with small changes in inputs. A key feature of the model includes data transparency; all the inputs to the model are publicly available. The code is also operationally transparent and includes accessible documentation, open source code, and a diverse user community to support new users of the software.

Operation of the ERTAC EGU model is straightforward given the complexity of the projection calculations and inputs. The model imports base year CEM data from U.S. EPA and sorts the data from the peak to the lowest generation hour. It applies hour-specific growth rates that include peak and off-peak emissions rates. The model then balances the system for all units and hours that exceed physical or regulatory limits. ERTAC EGU applies future year controls to the emissions estimates and tests for reserve capacity, generates quality assurance reports, and converts the outputs to SMOKE-ready modeling files.

ERTAC EGU has distinct advantages over other EGU growth methodologies because it can generate hourly future year estimates that are key to understanding O<sub>3</sub> episodes. The model does not shutdown existing units because economics algorithms suggest they are not economically viable. Additionally, alternate control scenarios are easy to simulate with the model. Significant effort has been put into the model to help users to prevent the generation of new coal plants to fit demand. The model allows portability of generation to different fuels like renewables and natural gas to prevent this.

Differences between the U.S. EPA and ERTAC EGU emissions forecasts arise from alternative forecast algorithms and from the data used to inform the model predictions. The U.S. EPA based the EGU emissions forecast in their 2022hc modeling platform on comments from states and stakeholders received through Spring 2024. ERTAC EGU 22.1 used CEM data from 2022 and state-reported changes to EGUs received through August 2024. The ERTAC EGU 22.1 emissions used for this modeling application represented the

best available information on EGU forecasts for the Midwest and Eastern U.S. that was available in December 2024.

### 4.3. Emissions Summaries by Nonattainment Area

Table 4-13 presents average OSDE for CO, NO<sub>x</sub>, and VOC in 2022 and 2026 for each of the 2015 O<sub>3</sub> NAAQS nonattainment and maintenance areas in the LADCO region. These emissions include all sources, anthropogenic and natural, in all counties contained in each NAA. The emissions in this table include the total county emissions and do not reflect counties with partial county designations for those NAAs. Multistate areas include the area total OSD emissions and the total emissions for the counties in each state contained in the nonattainment or maintenance area.

**Table 4-13. 2022/2026 Average ozone season day emissions by nonattainment area (tons/day)**

NAA	2022 CO	2026 CO	2022 NOX	2026 NOX	2022 VOC	2026 VOC	CO % Diff	NOX % Diff	VOC % Diff
Chicago, IL-IN-WI	2,265	2,176	323	293	570	567	-4%	-9%	-0.5%
Illinois	1,659	1,591	239	212	448	443	-4%	-11%	-1%
Indiana	569	548	78	75	99	98	-4%	-3%	-1%
Wisconsin	37	37	6.2	6.4	23	23	-2%	-8%	1%
Cincinnati, OH-KY	582	536	82	69	288	284	-8%	-16%	1%
Kentucky	112	105	23	21	77	76	-7%	-9%	-1%
Ohio	470	431	59	48	211	208	-8%	-19%	-1%
Cleveland, OH	773	739	84	71	324	319	-4%	-15%	-1%
Detroit, MI	1,170	1,063	171	143	517	511	-9%	-16%	-1%
St. Louis, MO-IL	865	798	161	118	658	649	-8%	-27%	1%
Illinois	171	161	36	32	207	206	-5%	-12%	0%
Missouri	694	640	125	87	451	444	-8%	-30%	-2%
Milwaukee, WI	419	414	62	53	195	198	-1%	-15%	1%
Door County, WI	28	26	5	4	20	20	-5%	-9%	-1%
Manitowoc, WI	29	28	7	7	32	32	-3%	-9%	1%
Sheboygan, WI	37	35	8	7	31	31	-6%	-9%	1%
Allegan, MI	50	46	8	7	76	76	-8%	-16%	0%
Berrien, MI	54	49	7	6	53	52	-9%	-17%	-1%
Muskegon, MI	52	48	6	5	50	50	-8%	-16%	-1%

## 5. Model Performance Evaluation

### 5.1. WRF 2022 Meteorology Modeling Performance Evaluation

LADCO used the WRF version 4.5 model (Advanced Research WRF dynamic core WRF-ARW) to simulate meteorology on 12-km, 4-km, and 1.33-km domains focused on the Great Lakes Basin for the year 2022. The configuration of the final 2022 WRF simulation was based on results from a series of model configuration experiments completed by LADCO. As LADCO used only the 12-km and 4-km WRF data for CAMx modeling, the 1.33-km WRF results will not be discussed in this report.

LADCO conducted qualitative and quantitative analysis to assess operational performance of the 2022 WRF modeling. Focus of this analysis is on the states in the LADCO region and the WRF performance was evaluated by state. LADCO compared modeled surface pressure, precipitation, and wind vectors against observations by season and for selected high-concentration O<sub>3</sub> events. We also performed a detailed analysis of the model during lake-breeze events at the shoreline monitors of Lake Michigan.

LADCO found that the 12-km and 4-km WRF simulations adequately captured the observed meso- and synoptic-scale processes during June 2022, during which observed surface O<sub>3</sub> and PM<sub>2.5</sub> were elevated due to fire smoke transport into the region. The LADCO WRF simulation represents very close approximation of the actual meteorology that occurred in 2022. While the WRF performance statistics for the 12-km and 4-km grid resolution simulations are within the acceptable performance benchmarks, the 12-km simulation has a slight cold and wet bias in the summer across much of the Eastern U.S. For the 4-km WRF simulation all the summer season metrics, except for wind direction error, fall within the simple terrain model performance benchmarks; the wind direction error falls within the complex terrain benchmark (Table 5-1).

Analysis of WRF performance at shoreline monitors during lake-breeze events showed that the model successfully reproduced the surface conditions. LADCO used a novel CART statistical model using data from selected surface stations on the shorelines of Lake Michigan for identifying lake-breeze days in 2022. WRF performed well

predicting temperature, moisture, and winds at the shoreline monitors during lake-breeze events. The model performance is slightly better on the lake-breeze days compared to the non-lake-breeze days on shoreline of Lake Michigan. The 4-km simulation had better performance simulating lake breeze conditions than the 12-km simulation.

**Table 5-1. 2022 summer season (JJA) 4-km WRF model performance for the LADCO states**

State*	Temp2m (K)		MixingRatio2m (g/kg)		WS10m (m/s)		WD10m (degrees)	
	MAE	MB	MAE	MB	MAE	MB	MAE	MB
IL	1.0	0.3	1.2	0.2	0.9	-0.2	35.8	0.0
IN	1.1	0.3	1.2	0.6	0.9	-0.1	37.1	1.6
MI	1.2	0.2	1.0	0.5	1.0	0.1	35.6	4.7
MN	1.1	0.2	1.1	0.7	1.1	0.1	31.9	-0.8
OH	1.1	0.1	1.2	0.6	0.9	-0.2	41.0	7.1
WI	1.1	0.3	1.1	0.6	1.0	0.1	33.3	-0.2

\*Green shading indicates a metric that meets the performance benchmark for simple conditions, orange shading indicates that the model meets the benchmark for complex conditions, and red shading indicates that model fails to meet the performance benchmarks

Accurate knowledge of WRF model performance during the lake-breeze events is needed to understand and anticipate its impact on simulating surface ozone concentrations in the Great Lakes Basin, especially near the shorelines of the lakes. Qualitative comparison of WRF modeled PBL height and wind fields with the lake-breeze front identified by satellite imagery and observed wind fields revealed that WRF successfully reproduced lake-breeze conditions and the associated inland surface convergence zones during selected high ozone days in 2022. Local scale convective processes were better resolved by the 4-km grid resolution compared to the 12-km simulation, which lead to better simulations of the land and lake circulation near the lake shores.

LADCO identified lake-breeze days during summer 2022 using satellite imagery, radar imagery, and NOAA’s GFS model wind fields to visualize lake-breeze fronts and surface convergence zones. The identified days were used to develop a CART statistical

model using data from selected METAR surface stations on the shoreline of Lake Michigan for predicting lake-breeze days. The CART model regression and classification accuracies for lake-breeze days were 92% for Lake Michigan on average. LADCO used the CART model to determine the typical meteorological conditions and indicators for lake-breeze days along the shores of Lake Michigan and then used the model to identify all lake breeze days during April through October 2022.

LADCO calculated WRF model performance for lake-breeze and non-lake-breeze days (Table 5-2). WRF performed well predicting temperature, humidity, and winds at the shoreline stations of Lake Michigan. The WRF model errors and biases for temperature, specific humidity, wind speed, and wind direction are well within the performance benchmarks for simple meteorological conditions, particularly along the southwest and eastern shores of Lake Michigan. The model performance is equivalent on the lake-breeze days compared to the non-lake-breeze days at most of stations examined. Model errors and biases were significantly reduced on lake-breeze days at the 4-km grid resolution (MAEs are 1.1K for temperature, 0.9 g/kg for specific humidity, 1.1 m/s for wind speed, and 20 degrees for wind direction) compared to the 12-km simulation.

**Table 5-2. Average WRF model performance summary for lake breeze and non-lake breeze days along the shoreline of Lake Michigan**

Variable*	Lake Breeze (n=150)		Non-Lake Breeze (n=144)	
	MAE	MB	MAE	MB
Temp2m	1.3	-0.1	1.3	-0.1
MixingRatio2m	1.0	-0.4	1.0	-0.1
Wind speed10m	1.1	-0.4	1.2	-0.5
Wind direction10m	22.5	-1.2	20.1	1.1

\*Green shading indicates a metric that meets the performance benchmarks for simple conditions, orange

Additional details and results for the LADCO 2022 WRF model performance analysis are available in the LADCO Weather Research and Forecast 2022 Meteorological Model Simulation and Evaluation TSD (<https://www.ladco.org/technical/modeling/ladco-2022-wrf-modeling/>).

## **5.2. CAMx 2022 Ozone Modeling Performance Evaluation**

The CAMx MPE results presented in this section establish the validity of the photochemical modeling platform that LADCO developed to support O<sub>3</sub> planning in the Great Lakes region. The MPE results are presented by increasing spatial resolution, first from a regional perspective, averaged across each state, and then by 2015 O<sub>3</sub> NAAQS nonattainment area.

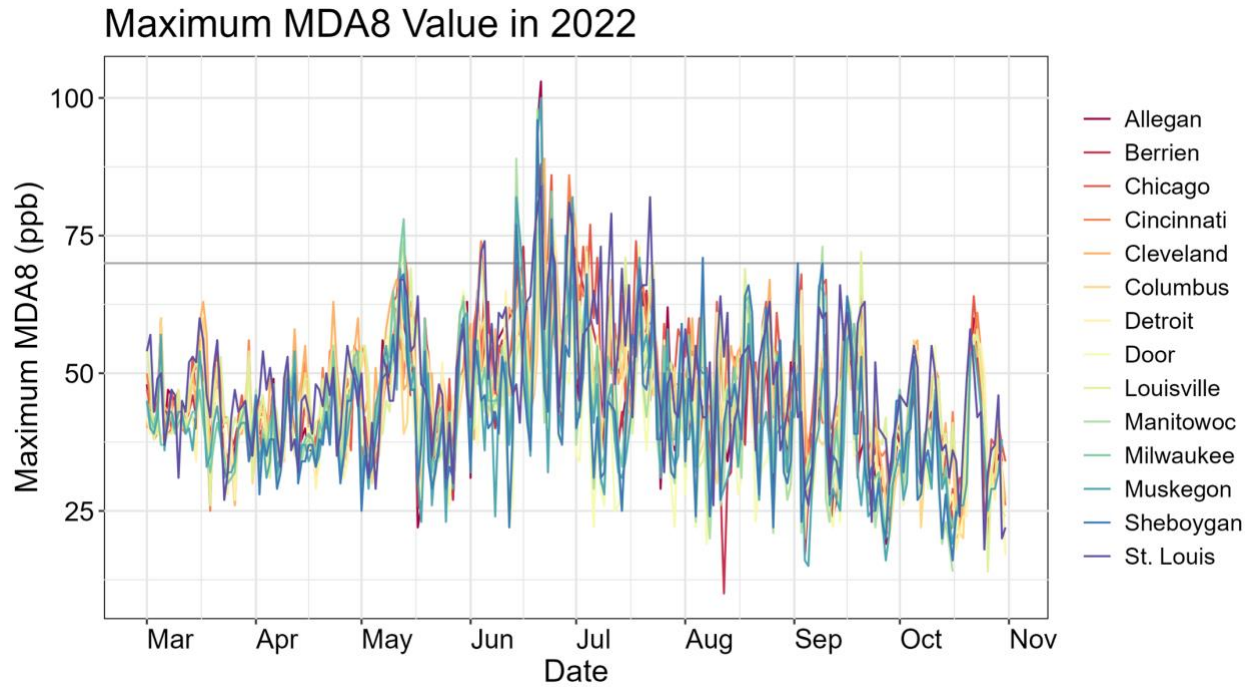
LADCO simulated the April 1 – September 30, 2022 with CAMx using the 2022 CAMx modeling platform described previously. Figure 5-1 summarizes ground level O<sub>3</sub> concentrations during the 2022 O<sub>3</sub> season across the 2015 O<sub>3</sub> NAAQS NAAs in the LADCO region. The first high concentration O<sub>3</sub> episode in the season was a regional event in the middle of May. The last regional O<sub>3</sub> episode happened in early September. The model performance evaluation presented here will focus on April through September as these were the months in 2016 that experienced high O<sub>3</sub> concentration periods in this region.

### **5.2.1. Regional Model Performance Evaluation**

Figure 5-2 includes spatial plots of monthly average normalized mean bias (NMB) for MDA8 O<sub>3</sub> estimated by the LADCO 4-km CAMx simulation. Each colored symbol in the figure is an AQS monitoring location. Cool colors represent monitors at which the observed MDA8 O<sub>3</sub> concentrations were underestimated by the CAMx simulation; warm colors represent where CAMx overestimated the observations. Grey and lighter shades represent low bias, or better model performance, relative to the model performance goals discussed in Section 3.6.2. The CAMx average monthly MDA8 O<sub>3</sub> NMB plots in Figure 5-2 show that average model bias is low (+/- 5%) across all months at most of the monitors in the region. In general, the model slightly overestimates MDA8 O<sub>3</sub> across the region in all months other than May and June. In May and June, the model tends to underestimate MDA8 O<sub>3</sub> across large areas of the region.

Figure 5-3 shows NMB spatial plots for observed monthly average MDA8 O<sub>3</sub> values greater than 60 ppb. The concentration cutoff highlights model performance on days with higher observed O<sub>3</sub>. While the model generally underestimates O<sub>3</sub> on higher

concentration days across all months, the NMB is within the model performance criteria for all but a few sites. Note that there are fewer sites on the map with the concentration cutoff because only sites with observed monthly MDA8 O<sub>3</sub> > 60 ppb are shown.



**Figure 5-1. March 1 – October 31, 2022 observed MDA8 O<sub>3</sub> concentrations in the LADCO region 2015 O<sub>3</sub> NAAQS nonattainment and maintenance areas**

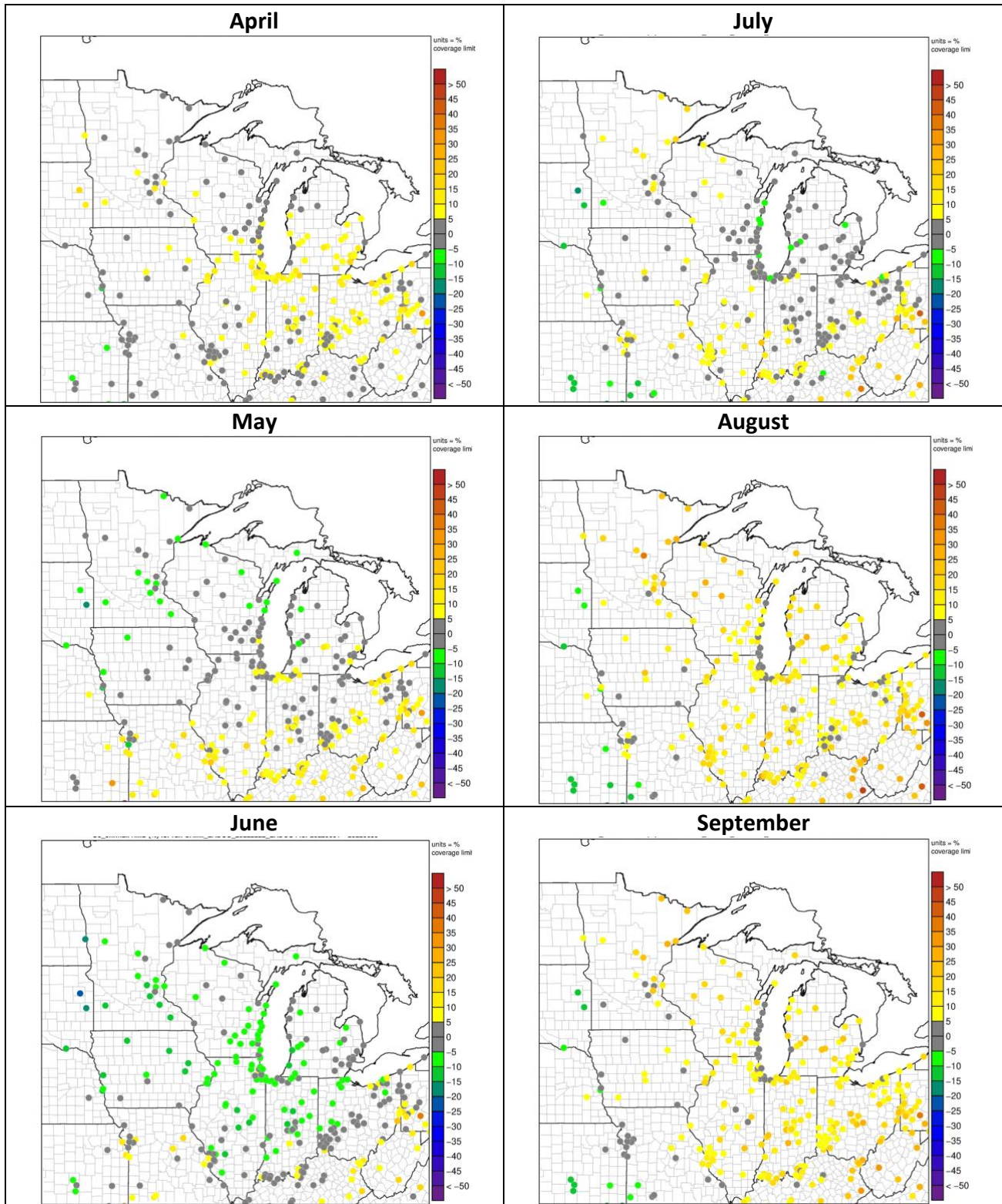


Figure 5-2. Monthly 2022 MDA8 O<sub>3</sub> normalized mean bias spatial stats plots; no concentration cutoff

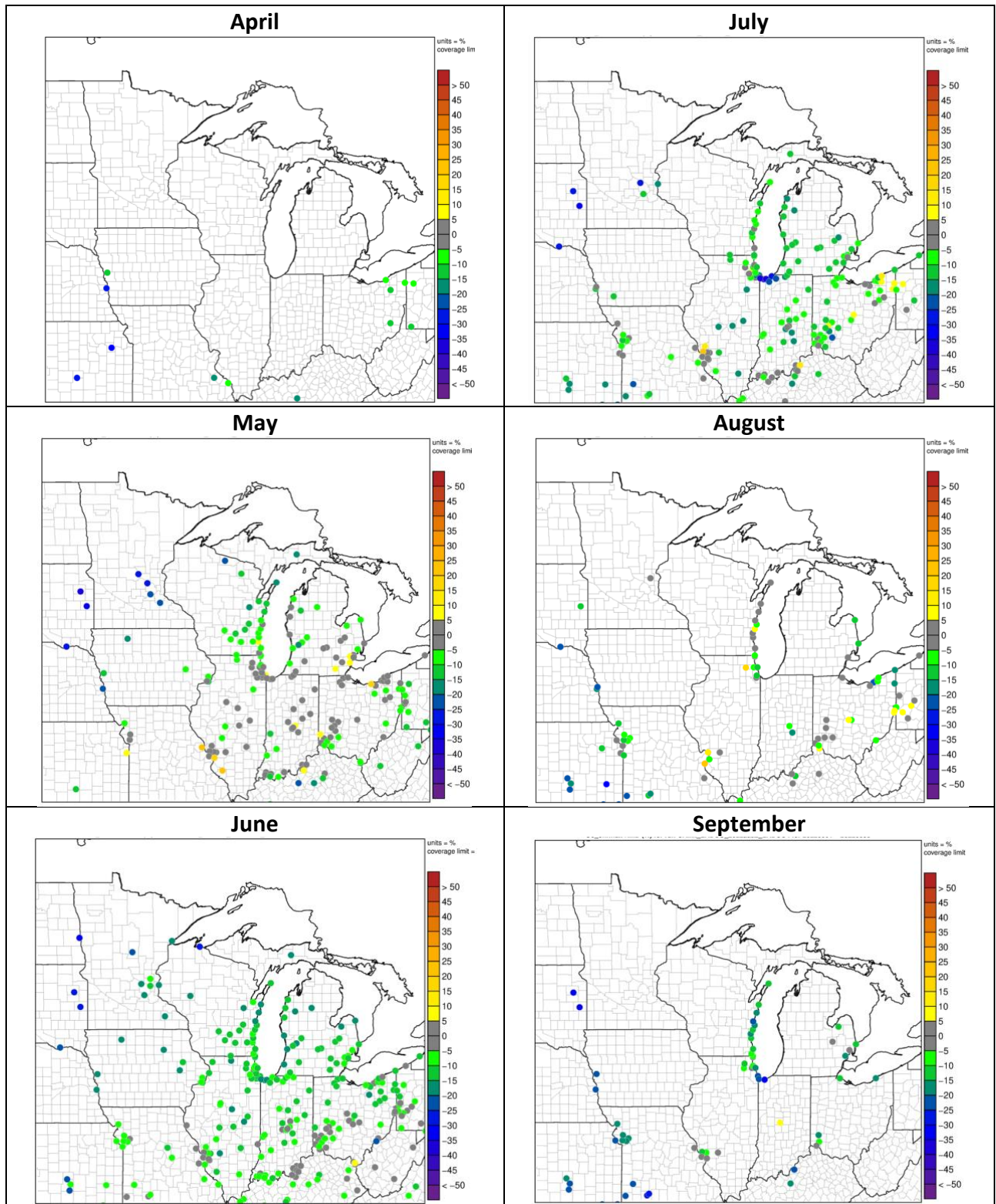


Figure 5-3. Monthly 2022 MDA8 O<sub>3</sub> normalized mean bias spatial stats plots for observed values > 60 ppb

### 5.2.2. Performance Evaluation by LADCO State

Table 5-3 through Table 5-7 show MDA8 O<sub>3</sub> performance statistics by month and state for the LADCO 2022 4-km CAMx simulation. The NMB, NME, correlation coefficients, and RMSE in these tables are monthly averages across all Air Quality System (AQS) sites in each state. Each statistic is calculated for all days and for days only with observed MDA8 O<sub>3</sub> > 60 ppb.

These statistics quantify the LADCO CAMx 4-km simulation seasonal O<sub>3</sub> biases and show that the model performance degrades slightly (increases in NMB and NME) at higher observed concentrations. The orange shading in these tables indicate the statistics which fall outside of the benchmark model performance criteria for O<sub>3</sub>; the green shading indicates model performance that meets or exceeds the Emery, et al. (2017) benchmark goal for O<sub>3</sub>.

The statistics in these tables highlight that averaged across all sites in a state, the model generally overestimates (positive NMBs) O<sub>3</sub> in all months but June. On high O<sub>3</sub> concentration days (> 60 ppb) the model underestimates O<sub>3</sub> in all months. The model errors (NME) by state and month are all within the performance criteria, and for most months, they meet or exceed the performance goal of NME <15%. While the correlation (r) of the model with the observations on all days is within the performance benchmark criteria (> 0.5), on high O<sub>3</sub> days the correlations are outside of the benchmarks, particularly in July - September. Monthly state averaged root mean square error (RMSE) is also reported to show a performance statistic in ppb units. RMSE ranges from 4.62 to 7.85 ppb for all days, and from 4.56 to 14.50 ppb for days with concentrations > 60 ppb.

The state and monthly averaged model performance for MDA8 O<sub>3</sub> falls almost entirely within the performance criteria for bias, error, and correlation coefficient.

Table 5-3. CAMx 4-km monthly MDA8 O<sub>3</sub> performance at AQS sites in IL

Region	NMB (%)		NME (%)		r		RMSE (ppb)	
	> 60ppb	All	> 60ppb	All	> 60ppb	All	> 60ppb	All
April		6.05		9.73		0.77		4.82
May	-2.40	4.20	5.58	12.60	0.61	0.76	4.56	7.13
June	-11.00	-5.41	12.00	10.70	0.64	0.79	9.06	7.05
July	-6.58	3.50	10.10	10.50	0.31	0.73	8.47	6.35
August	-1.76	9.85	10.20	14.30	-0.33	0.68	8.45	7.33
September	-8.40	8.40	8.53	12.60	-0.27	0.83	6.94	6.46

Table 5-4. CAMx 4-km monthly MDA8 O<sub>3</sub> performance at AQS sites in IN

Region	NMB (%)		NME (%)		r		RMSE (ppb)	
	> 60ppb	All	> 60ppb	All	> 60ppb	All	> 60ppb	All
April		6.68		9.30		0.77		4.73
May	-1.02	6.08	5.30	11.60	0.04	0.72	4.67	6.80
June	-8.85	-3.71	10.20	9.90	0.40	0.77	8.19	6.64
July	-13.80	3.31	15.00	12.40	-0.30	0.55	13.20	7.52
August	-13.30	11.70	13.30	15.20	-1.00	0.65	8.47	7.66
September	-15.90	12.30	19.20	14.40	-0.45	0.85	14.50	6.78

Table 5-5. CAMx 4-km monthly MDA8 O<sub>3</sub> performance at AQS sites in MI

Region	NMB (%)		NME (%)		r		RMSE (ppb)	
	> 60ppb	All	> 60ppb	All	> 60ppb	All	> 60ppb	All
April		7.28		10.20		0.78		5.11
May	-5.61	2.16	7.20	10.40	0.64	0.83	5.55	6.23
June	-13.20	-4.20	13.50	10.90	0.74	0.86	10.50	7.11
July	-11.60	-2.06	12.10	8.00	0.40	0.89	8.58	4.65
August	-4.99	11.90	6.15	16.00	-0.78	0.67	5.10	7.85
September	-9.76	12.10	9.76	17.20	0.00	0.85	7.19	7.65

Table 5-6. CAMx 4-km monthly MDA8 O<sub>3</sub> performance at AQS sites in OH

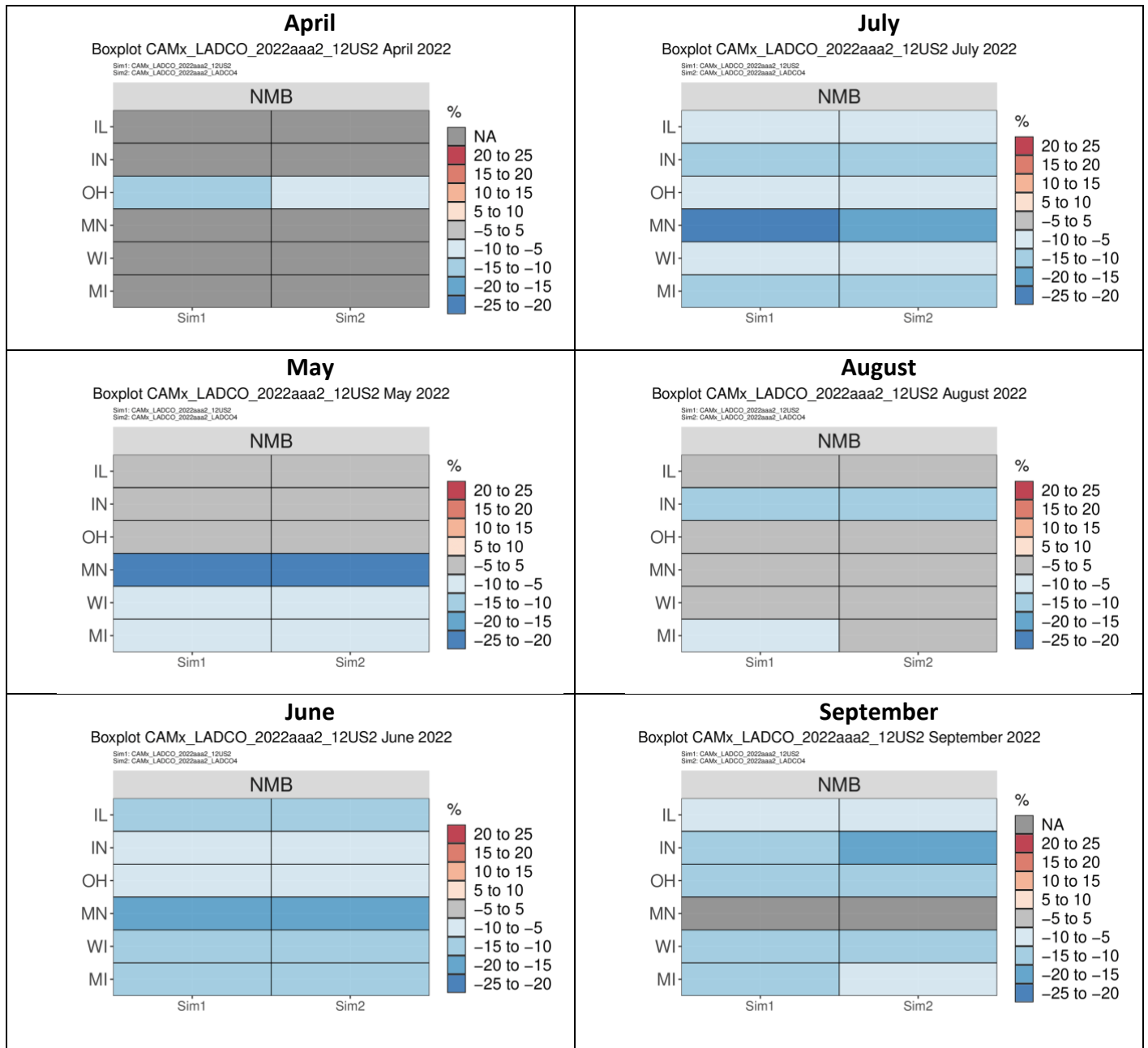
Region	NMB (%)		NME (%)		r		RMSE (ppb)	
	> 60ppb	All	> 60ppb	All	> 60ppb	All	> 60ppb	All
April	-9.89	6.55	9.89	9.74	0.79	0.75	6.21	5.21
May	-2.41	6.34	5.63	10.90	0.49	0.78	4.20	6.37
June	-7.90	-1.34	9.50	8.93	0.52	0.81	8.09	6.02
July	-7.30	2.87	10.20	10.90	0.24	0.69	7.53	6.45
August	-4.57	8.32	7.60	13.10	0.02	0.69	6.02	7.06
September	-10.00	10.80	10.00	13.80	0.46	0.85	7.34	6.38

**Table 5-7. CAMx 4-km monthly MDA8 O<sub>3</sub> performance at AQS sites in WI**

Region	NMB (%)		NME (%)		r		RMSE (ppb)	
	> 60ppb	All	> 60ppb	All	> 60ppb	All	> 60ppb	All
April		2.60		9.22		0.74		4.62
May	-8.97	-2.77	9.37	9.80	0.77	0.86	7.42	5.66
June	-12.40	-5.80	13.20	9.99	0.71	0.86	10.70	6.39
July	-8.38	-0.44	9.00	8.72	0.61	0.84	6.89	4.69
August	-3.10	10.50	6.05	15.30	0.45	0.77	5.22	7.31
September	-13.50	7.59	13.80	14.80	0.29	0.88	10.20	6.56

Figure 5-4 compares monthly, state averaged model performance (NMB) for MDA8 O<sub>3</sub> days > 60 ppb across both the 12-km and 4-km CAMx simulations. These plots show the same model underestimates as the bubble plots in Figure 5-3. The plots also show that from a state-wide average, there is not a significant performance difference between the model grid resolutions. The CAMx two-way nested configuration used for these simulations explains the similarity in performance across the three resolutions<sup>12</sup>. The key takeaway from Figure 5-4 is that for most months and states, on average, the LADCO 2022 CAMx modeling predicts MDA8 O<sub>3</sub> concentrations > 60 ppb within the performance NMB benchmark ( $\leq \pm 15\%$ ).

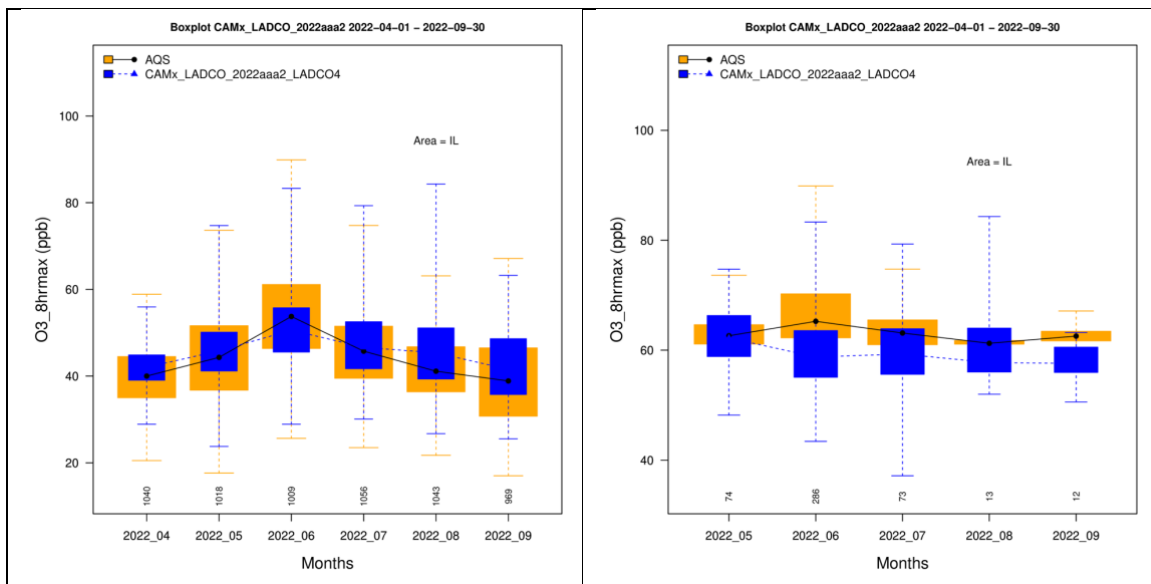
<sup>12</sup> With CAMx two-way nesting the fine grid, nested domains provide much of the solution to the parent grid



**Figure 5-4. Monthly 2022 MDA8 O<sub>3</sub> normalized mean bias state summary plots on days with observed values > 60 ppb**

Figure 5-5 through Figure 5-9 are monthly box and whisker plots of the LADCO 2022 4-km CAMx estimates and observed MDA8 O<sub>3</sub> concentrations for AQS sites in IL, IN, MI, OH, WI, respectively. The box and whisker plots show the observed and model median concentrations as symbols connected by lines (blue for CAMx and orange for

observations), the 25<sup>th</sup> and 75<sup>th</sup> percentile concentrations as the bottom and top of each box, and the 5<sup>th</sup> and 95<sup>th</sup> percentile concentrations as the bottom and top of each whisker. Each figure compares CAMx and observations on all days, and only on days with MDA8 O<sub>3</sub> > 60 ppb. The plots highlight the differences in model performance across the distribution of observed concentrations. For all days, the model performance is good for observed concentrations within the 25<sup>th</sup> to 75<sup>th</sup> quartiles. The model consistently overestimates the lowest 5% of observed values and generally underestimates the highest 5% of observed values. On high O<sub>3</sub> concentration days, the model underestimates the observations across the entire distribution of values. Both the 2022 CAMx predictions and observations have a seasonal profile with peak median values in June in most states for both all days and high O<sub>3</sub> days.



**Figure 5-5. 2022 monthly MDA8 O<sub>3</sub> box and whisker plots comparing CAMx with AQS monitors for sites in IL; all days (left) and days with obs > 60 ppb (right)**

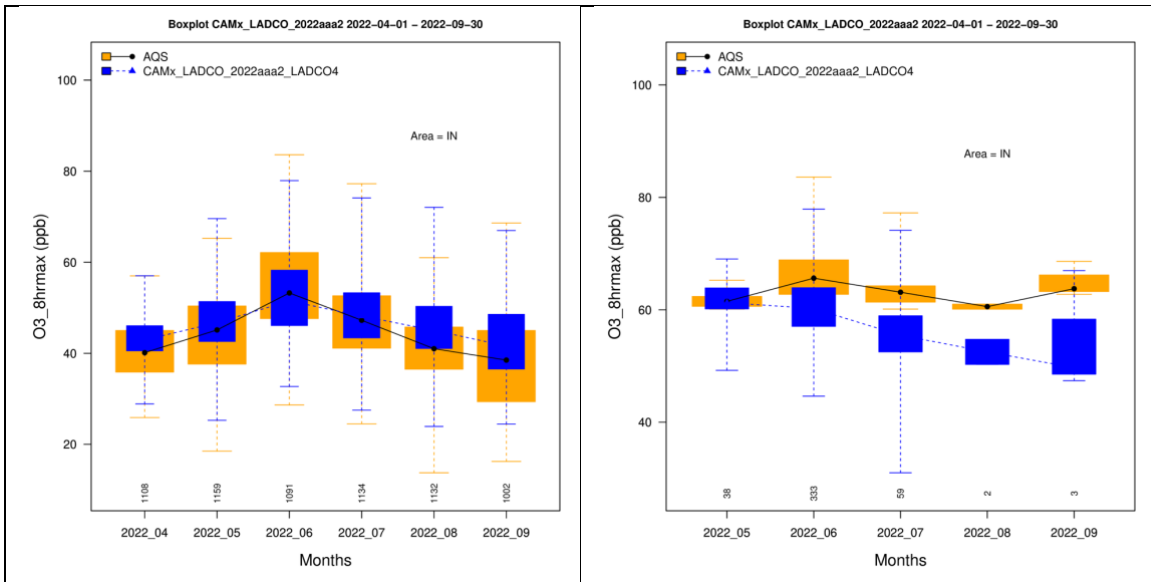


Figure 5-6. 2022 monthly MDA8 O<sub>3</sub> box and whisker plots comparing CAMx with AQS monitors for sites in IN; all days (left) and days with obs > 60 ppb (right)

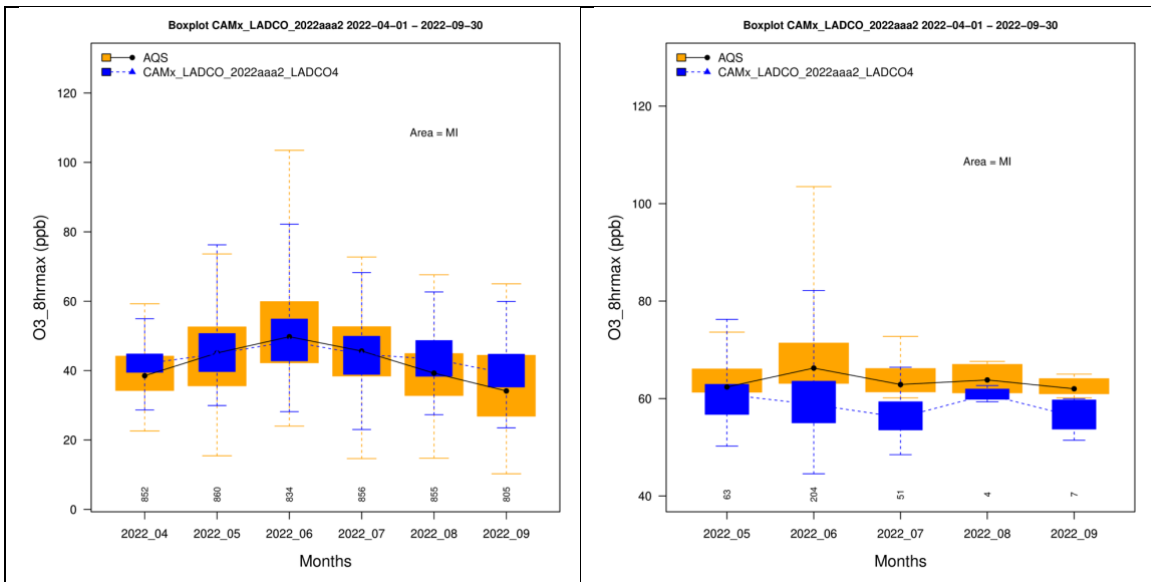
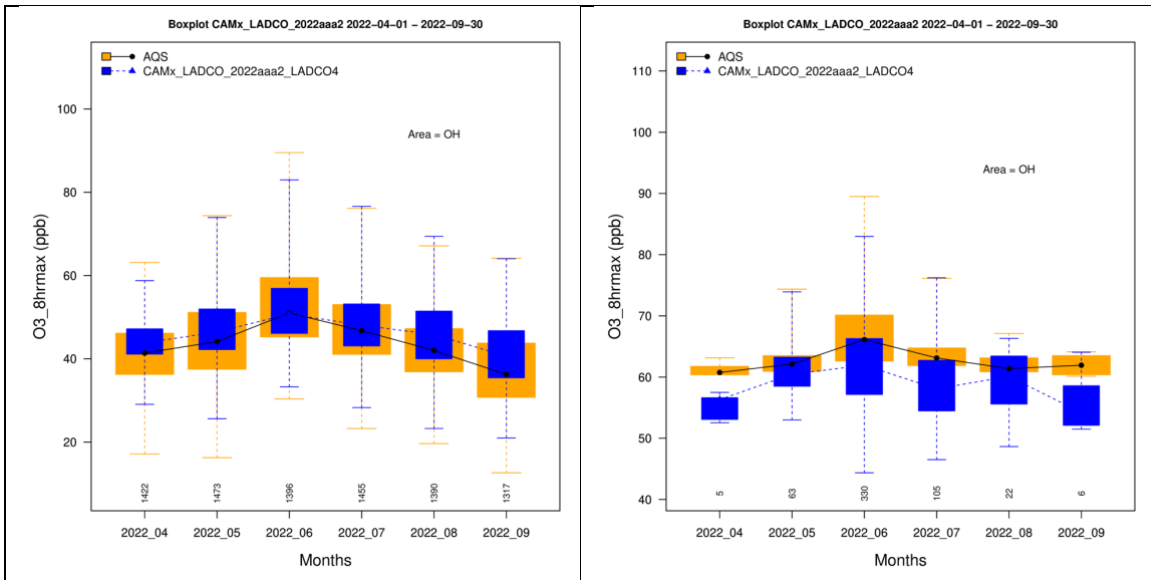
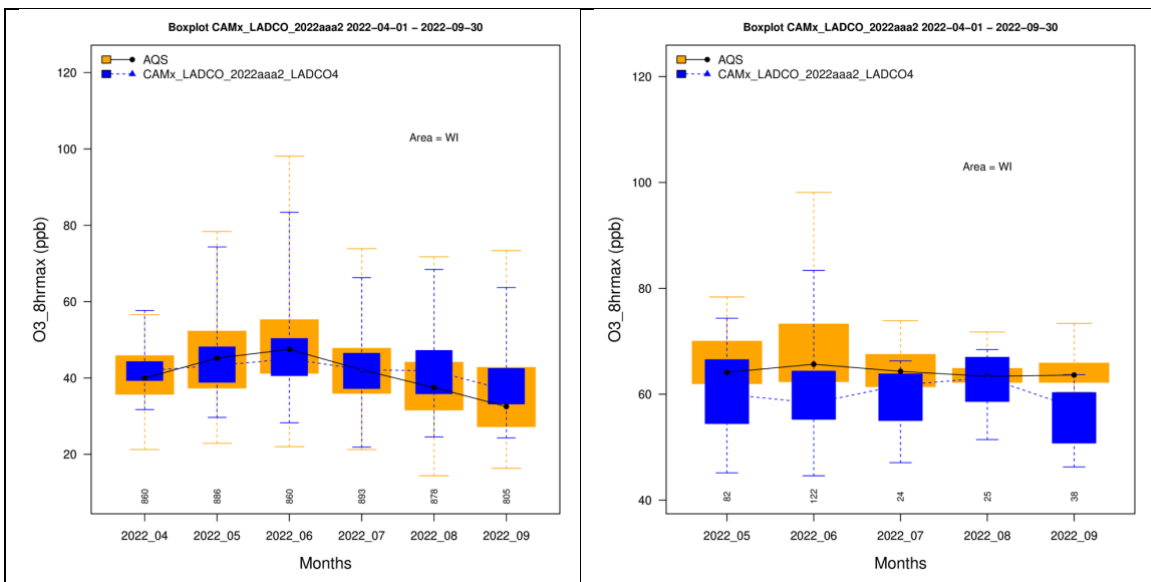


Figure 5-7. 2022 monthly MDA8 O<sub>3</sub> box and whisker plots comparing CAMx with AQS monitors for sites in MI; all days (left) and days with obs > 60 ppb (right)



**Figure 5-8. 2022 monthly MDA8 O<sub>3</sub> box and whisker plots comparing CAMx with AQS monitors for sites in OH; all days (left) and days with obs > 60 ppb (right)**



**Figure 5-9. 2022 monthly MDA8 O<sub>3</sub> box and whisker plots comparing CAMx with AQS monitors for sites in WI; all days (left) and days with obs > 60 ppb (right)**

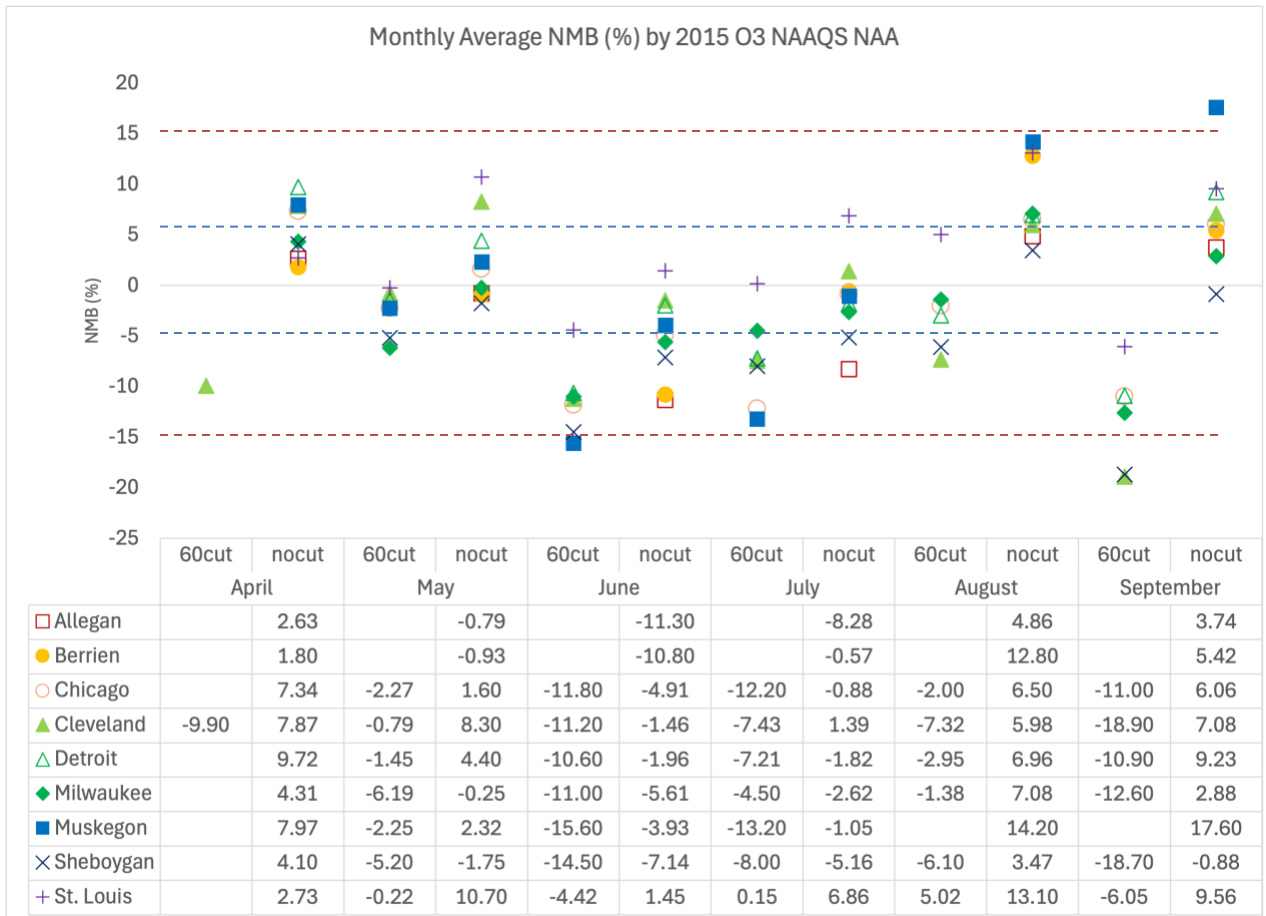
### 5.2.3. Performance Evaluation by Ozone Nonattainment Area

This section presents the 2022 LADCO 4-km CAMx model performance evaluation results by month averaged across all the monitors in different urban areas and NAAs in the region, including all the 2015 O<sub>3</sub> NAAQS NAAs. The statistics in the plots and tables described in this section indicate the skill of the model at simulating MDA8 O<sub>3</sub> on all

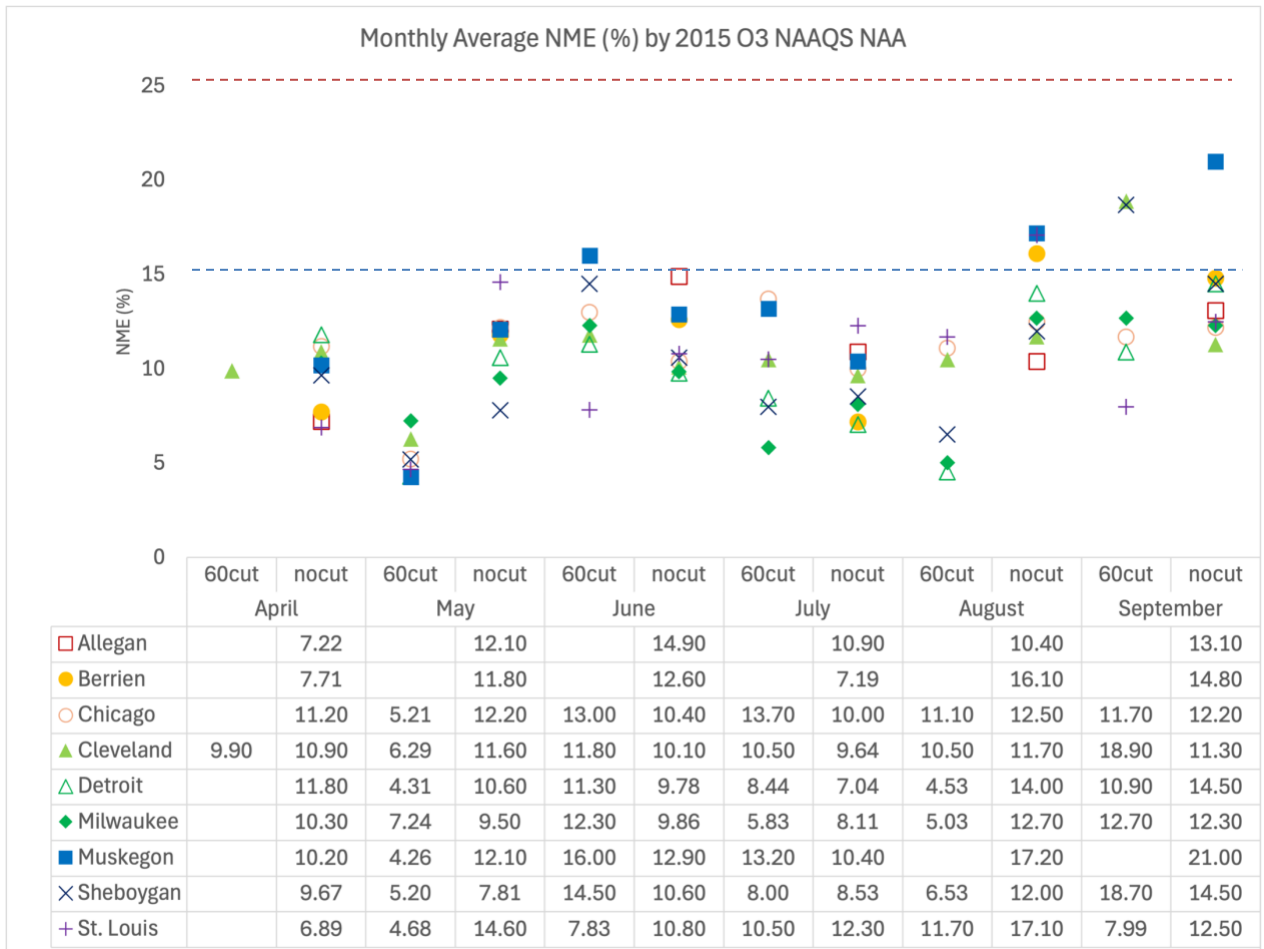
days and on high concentrations days (observed MDA8 concentrations > 60 ppb) at the small set of monitors contained within each NAA boundary. In some cases, these performance results are based on a single monitor, particularly at the more rural, downwind NAAs.

Figure 5-10 and Figure 5-11 show the average percent NMB and NME for MDA8 O<sub>3</sub>, respectively, at each NAA by month. The blue dashed lines in these figures show the levels of the Emery et al (2017) MPE goal, and the red dashed lines show the MPE benchmark. Figure 5-10 shows that for the monitors in the region's urban areas, with only a few exceptions, the model meets the less stringent performance criteria both for all days and high concentration days. The exception is for a few of the NAAs that fall outside of the NMB performance criteria in September. The LADCO 2022 CAMx model underestimates MDA8 O<sub>3</sub> on high concentration days in all NAAs with few exceptions. The best performance across all locations is for the high concentration days in May and August. The worse performance is for the high concentration days in June and for all days in August and September.

The NME plot in Figure 5-11 shows that the model performance varies across the year. The model meets the MDA8 O<sub>3</sub> NME performance criteria (25%) for all NAAs and all months, and meets the more stringent performance goal (15%) for most monitors and months. The lowest NME values are for the high concentration days in May and August, the highest NME values are for all days in August and September.



**Figure 5-10. MDA8 O<sub>3</sub> average normalized mean bias by month and nonattainment area with and without a 60 ppb concentration cutoff; dashed lines indicate model performance benchmarks**



**Figure 5-11. MDA8 O<sub>3</sub> average normalized mean error by month and nonattainment area with and without a 60 ppb concentration cutoff; dashed lines indicate model performance benchmarks**

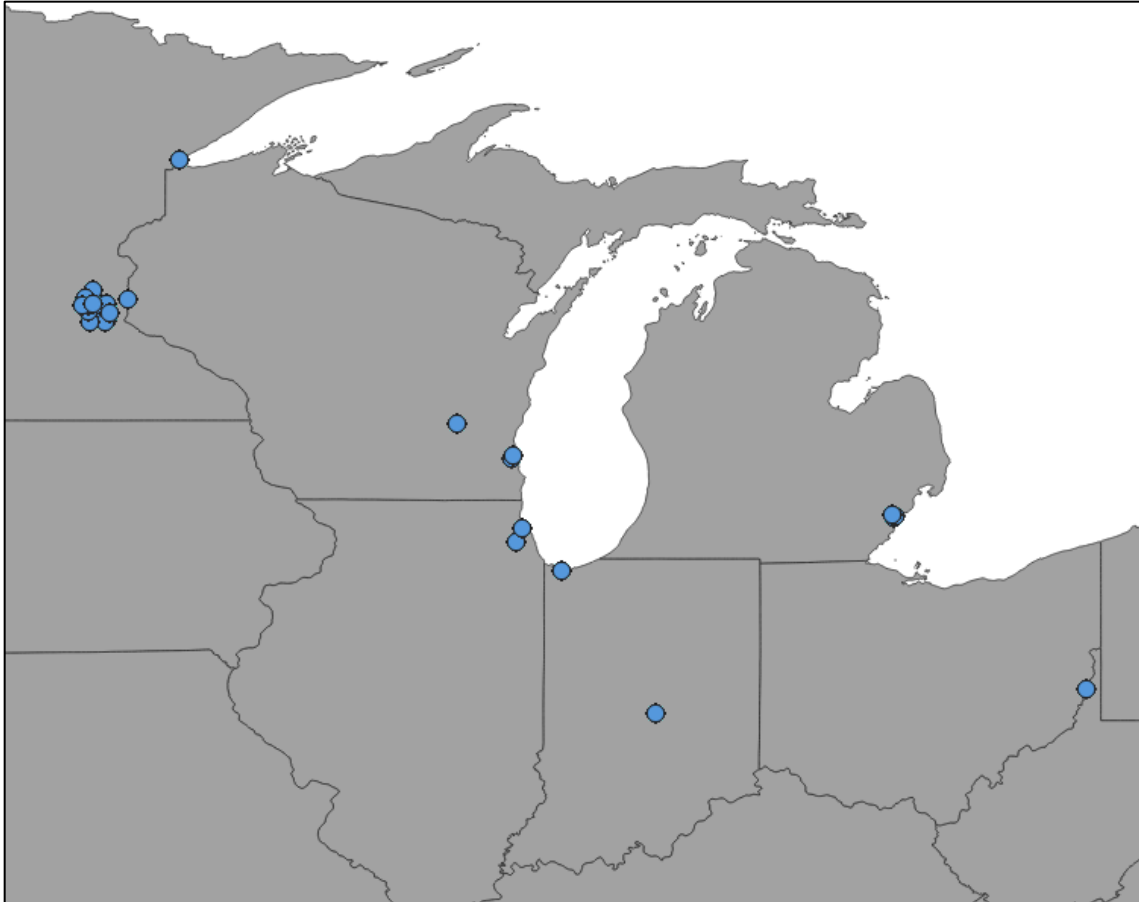
The Supplement to this TSD includes additional MDA8 O<sub>3</sub> model performance results for the 2015 O<sub>3</sub> NAAQS NAAs in the LADCO region. Tables of monthly NMB, NME, and correlation coefficients are shaded (green = better than the performance goal; orange = worse than the performance criteria) to indicate how well CAMx simulates MDA8 O<sub>3</sub> on all days and on high concentration days.

Table S 1 in the Supplementary Materials lists LADCO 2022 CAMx 4-km simulation performance statistics for all monitors in each of the 2015 O<sub>3</sub> NAAQS NAAs. The value of including the NAA-specific performance data in this TSD is to demonstrate the validity of

the LADCO 2022-based CAMx model to O<sub>3</sub> planning applications and attainment testing for the NAAs in the region.

### **5.3. CAMx 2022 Ozone Precursor Modeling Performance Evaluation**

LADCO calculated performance statistics for O<sub>3</sub> precursor pollutants with 2022 observations from the AQS network. The LADCO CAMx 2022 4-km simulation is evaluated against hourly NO<sub>2</sub> and CO AQS observations, and 1-in-6 day 24-hour average formaldehyde, acetaldehyde, ethylene, isoprene, and toluene observations from Photochemical Assessment Monitoring Station (PAMS) locations in the region. Figure 3-2 shows the locations of the AQS NO<sub>2</sub> (and CO) monitors and Figure 5-12 shows the locations of the PAMS monitors that collected the 2022 data used in the statistics presented here. The CAMx 4-km model results are paired in space and time with the AQS observations for the model grid cell in which each monitor is located.



**Figure 5-12. Locations of PAMs monitors with VOC observations for 2022 in the LADCO region**

Table 5-8 summarizes the ozone season (April - September) 4-km domain average CAMx performance statistics for ozone precursor species estimated by the LADCO 2022 CAMx 4-km simulation. The model underestimates (NMB < 0) for all reported O<sub>3</sub> precursor species except for ethylene, isoprene, and toluene. Table 5-9 shows the state-averaged ozone season NMB and NME from the LADCO 2022 CAMx 4-km simulation for NO<sub>2</sub>, CO, formaldehyde, and isoprene. The state-averaged results mirror the regional-average results in which the CAMx simulation underestimates NO<sub>2</sub>, CO, and formaldehyde but overestimates isoprene.

Figure 5-13 expands on these tables and shows state-averaged monthly NMB for April – September for select O<sub>3</sub> precursor species for the LADCO CAMx 2022 4-km simulation. The LADCO CAMx simulation underestimates (NMB < 0) most of the precursor species in most months during that period. The CAMx simulation significantly

overestimates (NMB > 0) isoprene in Illinois in April and May, likely related to mischaracterization of the biogenic emissions during that period. There are an insufficient number of O<sub>3</sub> precursor species monitoring stations to estimate performance statistics by nonattainment area.

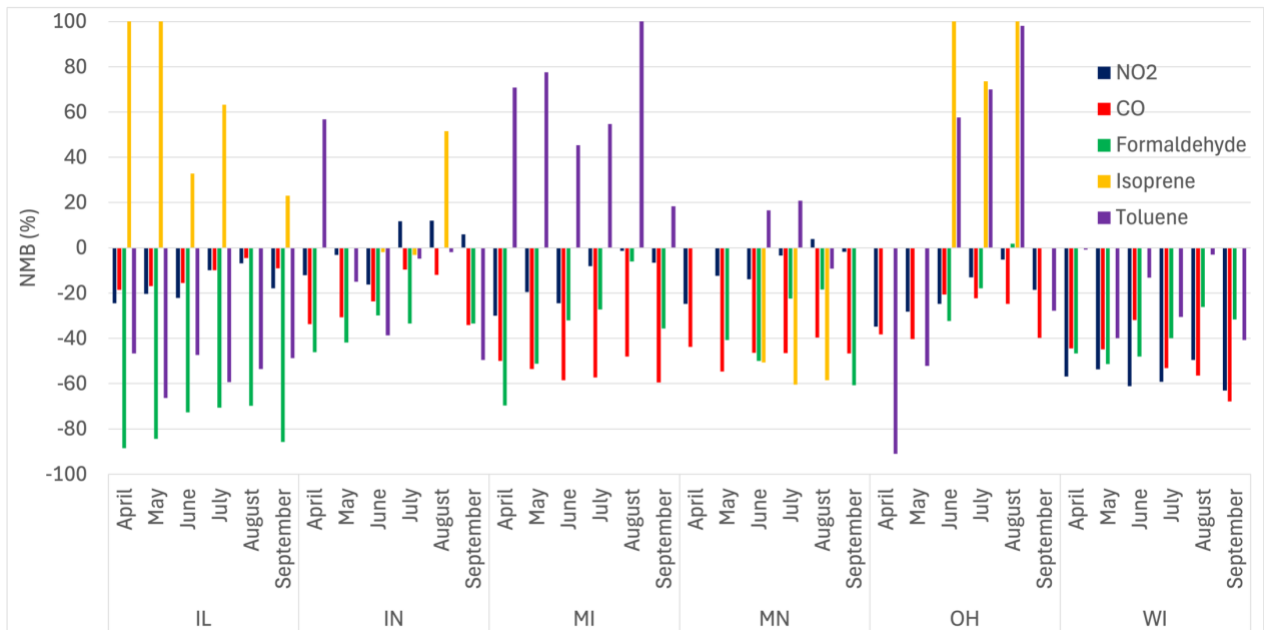
While the LADCO 2022 modeling seems to be generally underestimating most of the O<sub>3</sub> precursor species, the relatively sparse observations, particularly from the AQS daily measurements, makes it challenging to infer the model skill in estimating these pollutants. The LADCO 2022 model performance for the O<sub>3</sub> precursors is like those reported from the LADCO 2016 CAMx modeling (LADCO, 2022b).

**Table 5-8. LADCO CAMx 2022 4-km April - September average ozone precursor model performance statistics**

Pollutant	CAMx Avg (ppb)	Obs Avg (ppb)	NMB (%)	NME (%)	RMSE (ppb)	r	# obs
NO <sub>2</sub>	5.98	7.63	-19.83	52.83	5.89	0.72	141641
CO	143.80	238.94	-36.31	50.81	174.97	0.51	108506
Formaldehyde	1.74	3.70	-42.59	47.20	2.64	0.58	743
Acetaldehyde	0.47	1.18	-49.74	53.75	0.97	0.48	742
Ethylene	0.68	0.90	337.03	385.10	1.31	0.26	443
Isoprene	0.34	0.35	38.25	75.00	0.32	0.57	352
Toluene	0.32	0.44	0.03	60.72	0.55	0.54	1038

**Table 5-9. LADCO CAMx 2016 4-km April - September average ozone precursor model performance statistics by state**

State	NO <sub>2</sub>		CO		Formaldehyde		Isoprene	
	NMB	NME	NMB	NME	NMB	NME	NMB	NME
IL	-16.93	41.22	-12.41	37.80	-78.62	78.68	75.40	75.40
IN	-0.29	55.28	-23.94	42.95	-30.80	35.65	15.48	56.57
MI	-15.03	48.72	-54.47	60.55	-36.97	41.22		
MN	-8.71	57.62	-46.30	52.15	-38.46	42.78	-56.50	62.03
OH	-20.78	51.60	-30.98	55.50	-16.18	33.97	93.87	105.73
WI	-57.25	62.55	-49.78	55.90	-40.65	43.55		



**Figure 5-13. Monthly state average LADCO CAMx 2022 4km ozone precursor NMB**

#### 5.4. CAMx Model Performance Discussion

The LADCO 2022 CAMx modeling reported here falls within the range of CAMx operational performance reported by several recent regulatory CAMx modeling studies (US EPA, 2022; LADCO, 2022b; LADCO, 2020). At the time of release of this report, there are no other publicly available reports of model performance using the 2022v1 emissions modeling platform to use for comparison with the results shown here.

The O<sub>3</sub> performance evaluation by nonattainment area reveals that the LADCO CAMx 4-km simulation met the model performance benchmarks averaged across the high concentration days (> 60 ppb).

The LADCO CAMx 4-km simulation underestimated several of the available O<sub>3</sub> precursor species, including NO<sub>2</sub>, CO, and formaldehyde in most months and locations; on average the model overestimated ethylene and isoprene.

The statistics and model performance metrics presented in this section demonstrate that the LADCO CAMx 2022 O<sub>3</sub> model performance is within conventional and accepted model performance benchmarks, and is a valid model for use in regulatory applications.

## 6. LADCO 2026 Air Quality Projections

### 6.1. Attainment Test Methods

LADCO followed the U.S. EPA Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM<sub>2.5</sub>, and Regional Haze (US EPA, 2018) to calculate future-year design values in 2026 (DVF<sub>2026</sub>) for monitors in IL, IN, MI, OH, and WI<sup>13</sup>. As we used the base year of 2022, we estimated the base year design values using surface observations for the years 2020-2024 (DVB<sub>2020-2024</sub>). LADCO estimated the DVF<sub>2026</sub> with version 2.1 of the Software for Modeled Attainment Test Community Edition (SMAT-CE)<sup>14</sup>. SMAT-CE was configured to use the daily max average 8-hr (MDA8) O<sub>3</sub> concentration above 60 ppb in a 3x3 matrix around each monitor across for the 10 highest modeled days, per the U.S. EPA Guidance. If there are less than 10 days with MDA8 O<sub>3</sub> greater than 60 ppb, SMAT-CE uses all days, if there are at least 5 days that meet the minimum threshold criteria<sup>15</sup>.

Consistent with U.S. EPA modeling guidance (US EPA, 2018), SMAT-CE uses a multi-step process to estimate DVF<sub>2026</sub>:

1. Calculate DVB<sub>2020-2024</sub> for each monitor
  - The O<sub>3</sub> design value is a three-year average of the 4<sup>th</sup> highest daily maximum 8 hour average O<sub>3</sub> (MDA8<sub>4</sub>):

$$DV_{2022} = (MDA8_{4,2020} + MDA8_{4,2021} + MDA8_{4,2022})/3$$

$$DV_{2023} = (MDA8_{4,2021} + MDA8_{4,2022} + MDA8_{4,2023})/3$$

$$DV_{2024} = (MDA8_{4,2022} + MDA8_{4,2023} + MDA8_{4,2024})/3$$

2. Weighted 5-year average of design values centered on the base model year (2022):

$$DVB_{2020-2024} = (DV_{2022} + DV_{2023} + DV_{2024})/3$$

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<sup>13</sup> MN is not included because there are no 2015 O<sub>3</sub> NAAQS nonattainment or maintenance areas in the state

<sup>14</sup> <https://www.epa.gov/scram/photochemical-modeling-tools>

<sup>15</sup> 26 sites dropped out of the SMAT-CE design value calculation because their data did not meet the threshold criteria; none of these sites are in 2015 O<sub>3</sub> NAAQS nonattainment or maintenance areas

3. Find highest base year modeled days surrounding each monitor
  - Find ten days with the highest base year modeled MDA8 from within a 3x3 matrix of grid cells surrounding each monitor
  - At least 5 days with modeled MDA8  $\geq$  60 ppb are needed to retain the monitor for the future year DV calculation
4. Calculate relative response factor (RRF) for each monitor
  - Calculate multi-day average MDA8 for the base and future years from the maximum paired in space values in the 3x3 matrix
  - Calculate the RRF as the ratio of the multi-day average future to multi-day average base year MDA8:

$$RRF = MDA8_{2026,avg} / MDA8_{2022,avg}$$

5. Calculate DVF<sub>2026</sub> for each monitor

$$DVF_{2026} = RRF * DVB_{2020-2024}$$

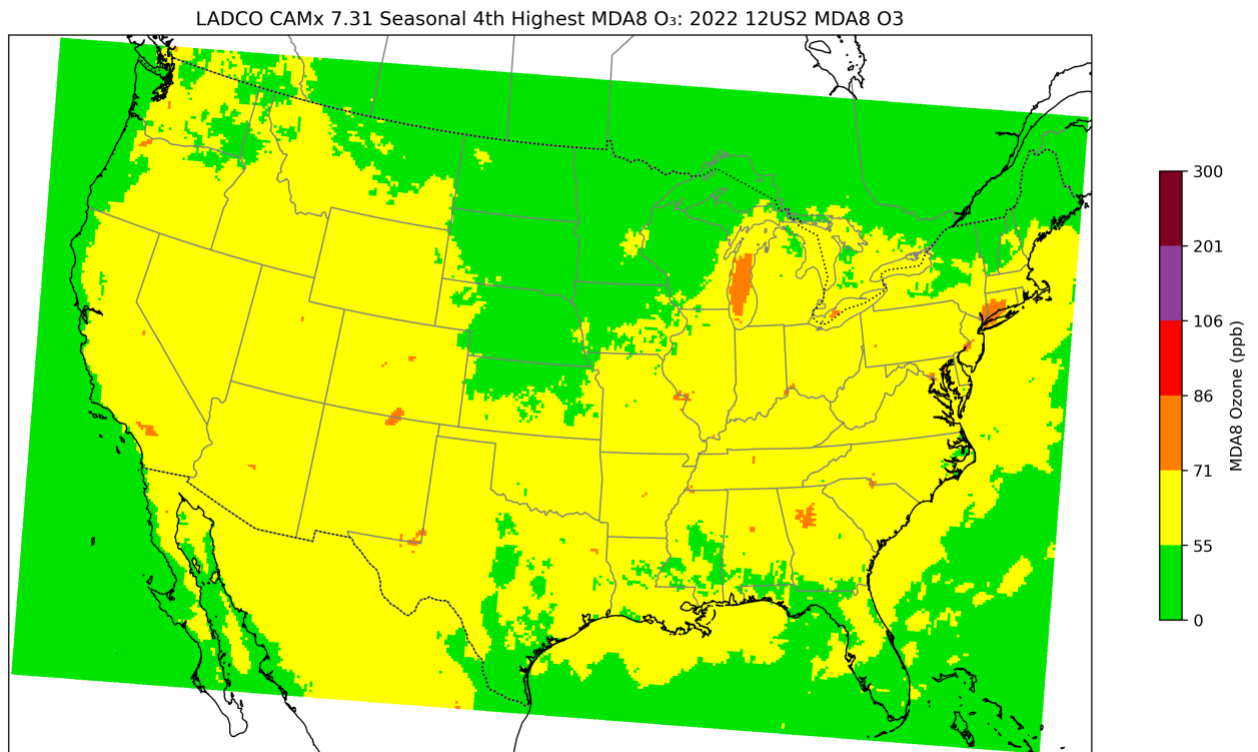
LADCO used the DVF<sub>2026</sub> to identify nonattainment sites in 2026 using the 5-year weighted average baseline design values (2020-2024) per U.S. EPA (2018). Under this methodology, sites with an average DVF<sub>2026</sub> that exceeds the 2015 O<sub>3</sub> NAAQS (71.0 ppb or greater) would be considered nonattainment in 2026.

## 6.2. 2026 CAMx Modeling Results

LADCO modified the emissions in the U.S. EPA 2022hc CAMx modeling platform to create a LADCO 2022 modeling platform with a projection year to 2026 (see Section 3.4). The LADCO 2026 CAMx simulation forecasted air quality on two nested modeling domains, including EGU emissions forecasts from the ERTAC 22.1 model. Figure 6-1 and Figure 6-2 show April through September 2022 4<sup>th</sup> highest MDA8 O<sub>3</sub> for the LADCO 2022 and 2026 CAMx simulations, respectively, on the 12US2 modeling domain. Figure 6-3 shows the difference (2026-2022) in O<sub>3</sub> season maximum MDA8 O<sub>3</sub> between the two simulations. Cool colors indicate that the 2026 simulation forecasted lower O<sub>3</sub> than the 2022 simulations; warm colors indicate higher O<sub>3</sub> in the 2026 forecasts. Figure 6-3 is a plot of the difference of the O<sub>3</sub> season 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations between

2022 and 2026 and illustrates the extent to which the O<sub>3</sub> concentrations are forecast to change in 2026.

The LADCO 2026 CAMx 12-km simulation predicted lower seasonal 4<sup>th</sup> highest O<sub>3</sub> concentrations across much of the modeling domain, with the largest reductions occurring in the eastern half of the U.S., and along the I-5 corridor in the Pacific Northwest. Note that the concentration changes shown in these figures mask finer temporal resolution features (i.e., hourly and daily) that also exist between the base and future year simulations.



**Figure 6-1. LADCO CAMx 12-km April - September 2022 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations**

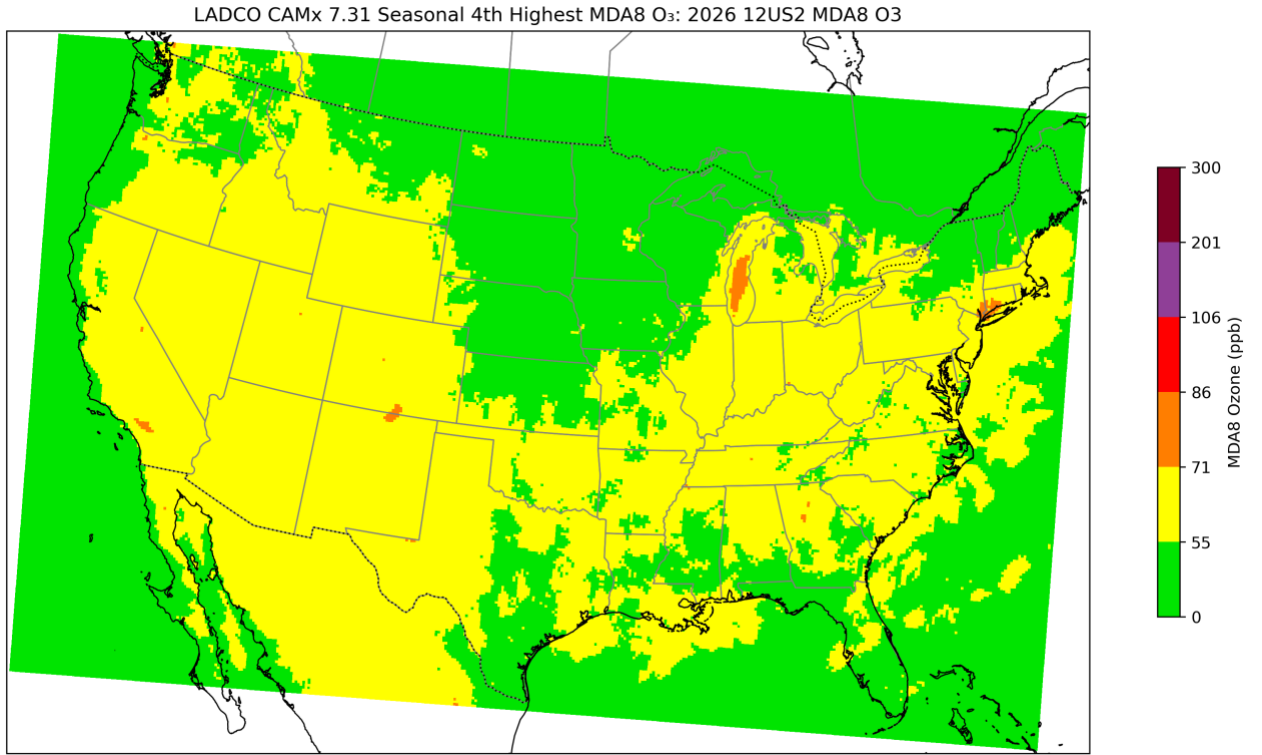
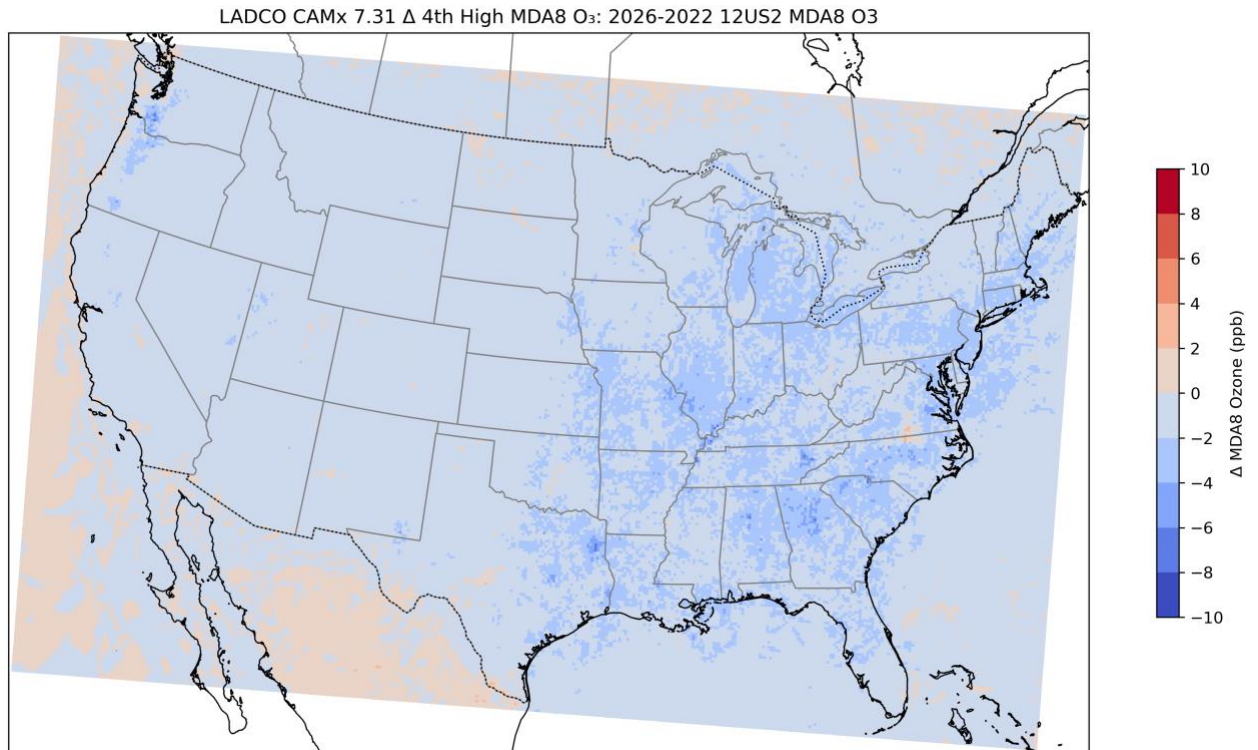
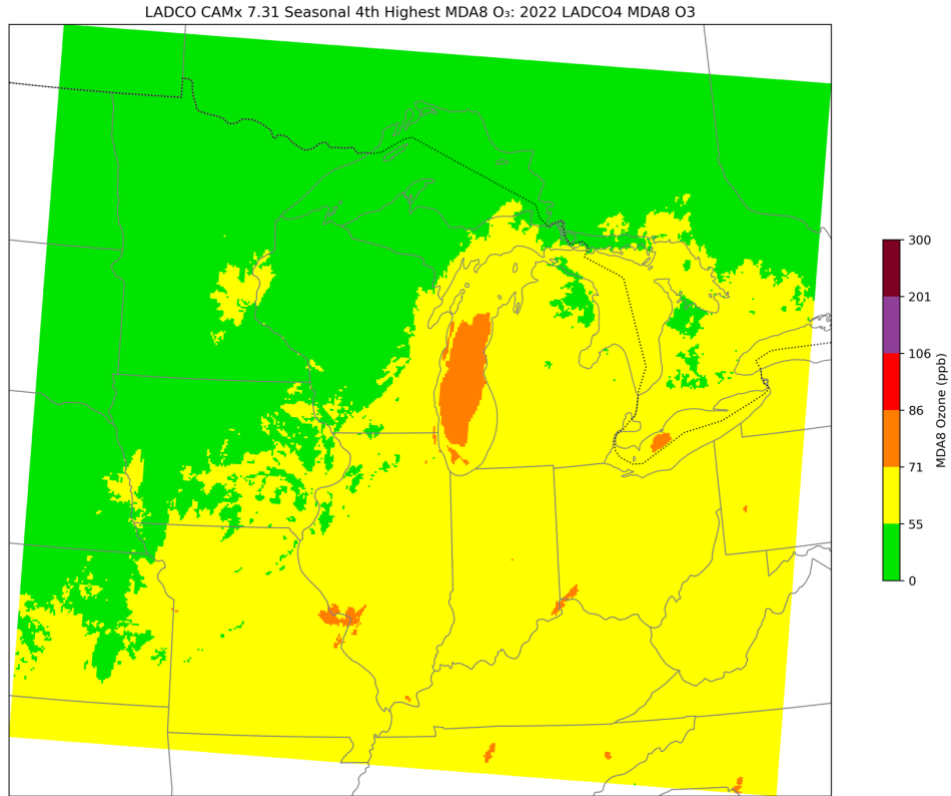


Figure 6-2. LADCO CAMx 12-km April - September 2026 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations

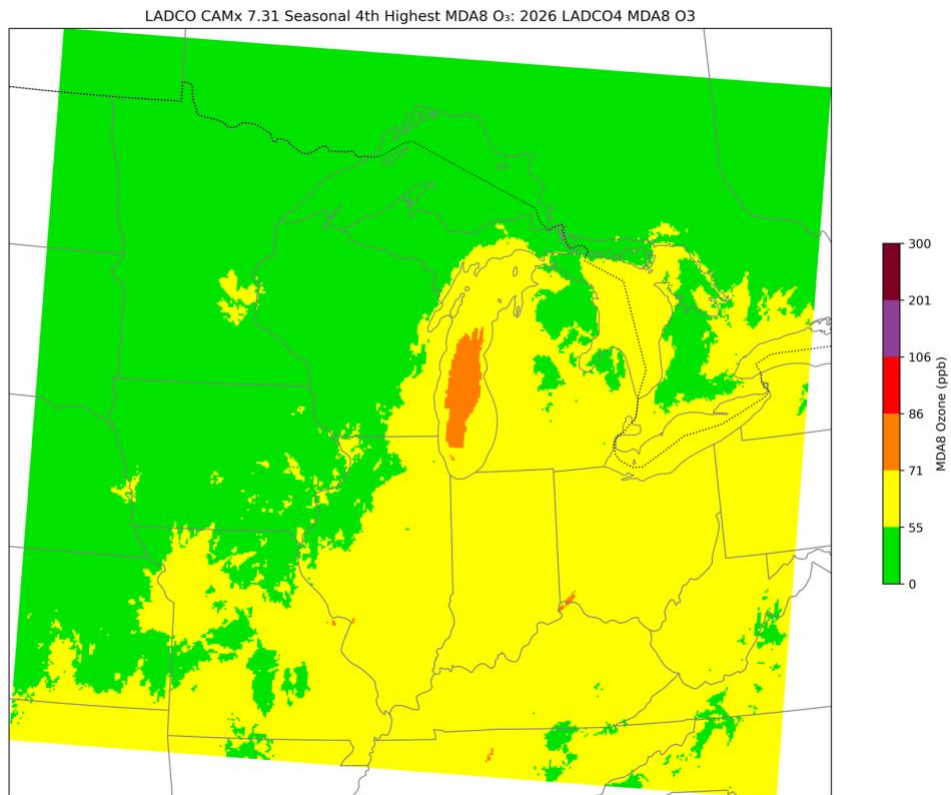


**Figure 6-3. LADCO CAMx 12-km difference (2026-2022) in April - September 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations**

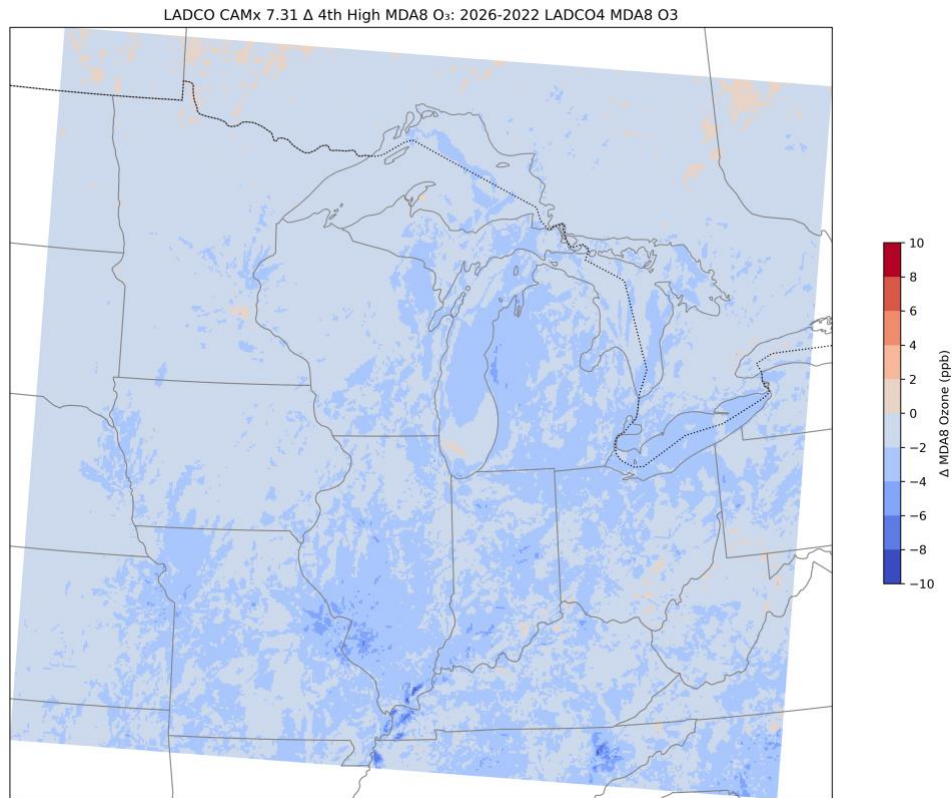
Figure 6-4 and Figure 6-5 show April through September 2022 4<sup>th</sup> highest MDA8 O<sub>3</sub> for the LADCO 2022 and 2026 CAMx simulations, respectively, on the LADCO 4-km modeling domain. Figure 6-6 shows the difference (2026-2022) in O<sub>3</sub> season 4<sup>th</sup> highest MDA8 O<sub>3</sub> between the two simulations. The LADCO simulation forecasts a 2-4 ppb decrease in seasonal 4<sup>th</sup> highest MDA8 O<sub>3</sub> across much of the domain in 2026. The largest concentration decreases (4-6 ppb) in 2026 are on the outskirts of St. Louis and in Southern Illinois/Western Kentucky. CAMx predicted concentration decreases in the range of 1-4 ppb over Lakes Michigan and Erie.



**Figure 6-4. LADCO CAMx 4-km April - September 2022 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations**



**Figure 6-5. LADCO CAMx 4-km April – September 2026 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations**



**Figure 6-6. LADCO CAMx 4-km difference (2026-2022) in April - September 4<sup>th</sup> highest MDA8 O<sub>3</sub> concentrations**

### 6.3. 2026 O<sub>3</sub> Design Values

Figure 6-7 shows the O<sub>3</sub> DVF<sub>2026</sub> values from the LADCO 2026 4-km CAMx simulation. Figure 6-8 is a map of the SMAT-CE 2026 relative response factors (RRFs) from the LADCO CAMx 4-km modeling. LADCO generated these results with SMAT-CE using the standard U.S. EPA attainment test configuration (top 10 modeled days, 3x3 cell matrix around the monitor, including water cells). We are showing the DVF<sub>2026</sub> calculated from the 4-km CAMx simulation because the domain encompasses the entire LADCO region, and it presents an optimized model configuration relative to the 12-km domain. As described previously in this TSD, the CAMx two-way nesting configuration used by LADCO propagates the fine grid model solution upward to the parent grids. The solution for the model grid cells in the 12-km modeling domain that includes the 4-km nested

domain is primarily from the 4-km simulation. The LADCO O<sub>3</sub> DVF<sub>2026</sub> values presented here used observational data completeness criteria based on the 2015 O<sub>3</sub> NAAQS. The completeness criteria are tied to the level of the standard in cases in which the number of valid observations falls below a statutory threshold but when at least one of the valid observations is greater than the NAAQS (see 40 CFR Part 50 Appendix U, Section 3(d)). By using the 2015 O<sub>3</sub> NAAQS for determining completeness, LADCO includes more available data points in the DV calculations than if we had used the 2008 O<sub>3</sub> NAAQS completeness criteria because the lower standard is more inclusive of the available monitoring data (i.e., there are more MDA8 O<sub>3</sub> observations  $\geq$  70 ppb than there are observations  $\geq$  75 ppb). Per U.S. EPA modeling guidance (U.S. EPA, 2018), LADCO truncated the SMAT-CE average DVF<sub>2026</sub> values to integer numbers.

The LADCO 2026 CAMx simulation predicts that only monitors bordering Lake Michigan will have an average DVF<sub>2026</sub> that exceeds the 2015 O<sub>3</sub> NAAQS; monitors in all the other nonattainment and maintenance areas in the region are projected to meet the 70 ppb standard. The RRF plot shows that the LADCO CAMx modeling projects all the monitors in the region to have  $<$ 5% reductions in their design values between 2022 and 2026 (RRFs = 0.96-1.0). The unfilled circles in the RRF plot indicate monitors that did not meet the attainment test completeness criteria.

Table 6-1 presents the average DVF<sub>2026</sub> values for monitors in the 2015 O<sub>3</sub> NAAQS NAA and maintenance areas in the region. As with the DVF<sub>2026</sub> and RRF figures in this section, this table presents the DVF<sub>2026</sub> values calculated from the LADCO 4-km CAMx modeling using a matrix of 3x3 grid cells surrounding each monitor and including water cells in the calculation. The monitors with average DVF<sub>2026</sub> values  $>$  71 ppb are highlighted. The 2022 DVs in this table are the truncated DVB<sub>2020-2024</sub> metric described in Section 6.1.

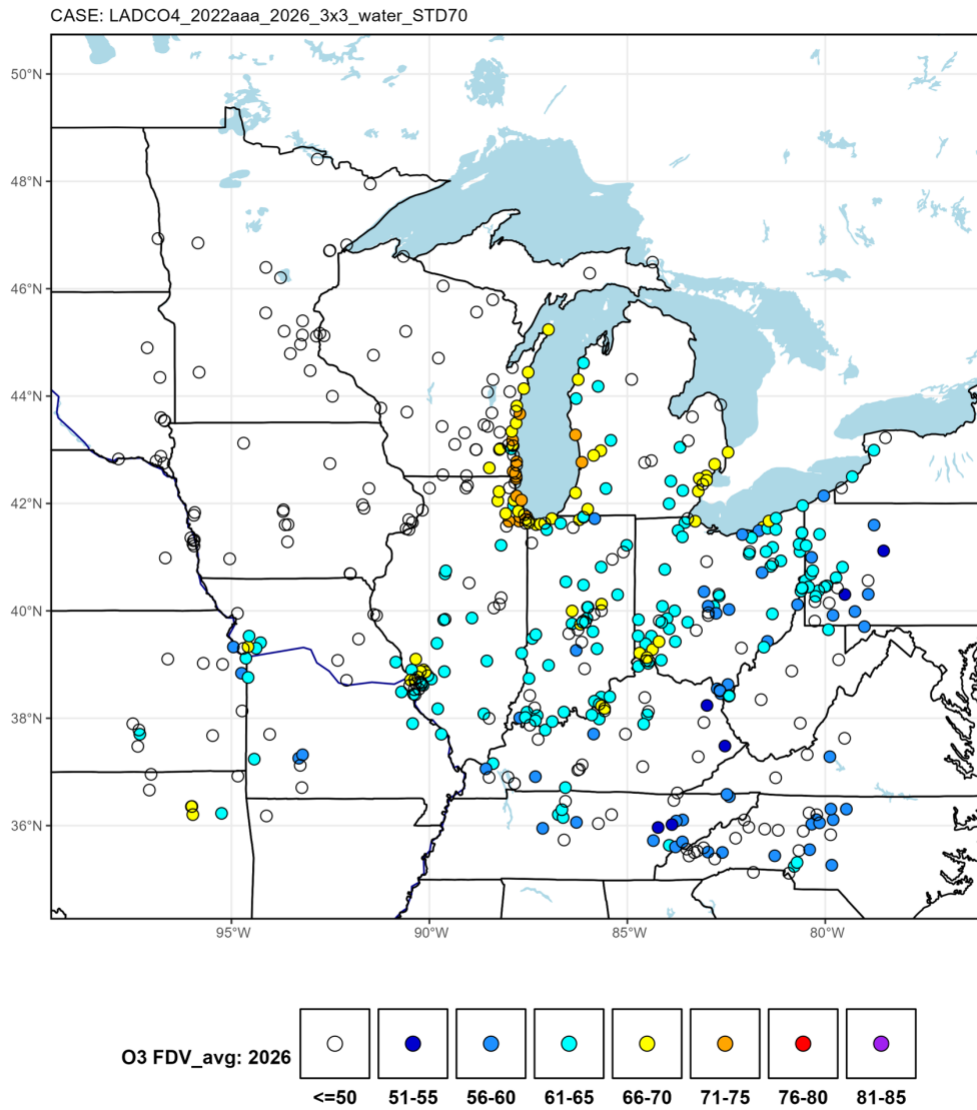


Figure 6-7. DVF<sub>2026</sub> O<sub>3</sub> design values calculated with water cells included from the LADCO 2026 4-km CAMx simulation.

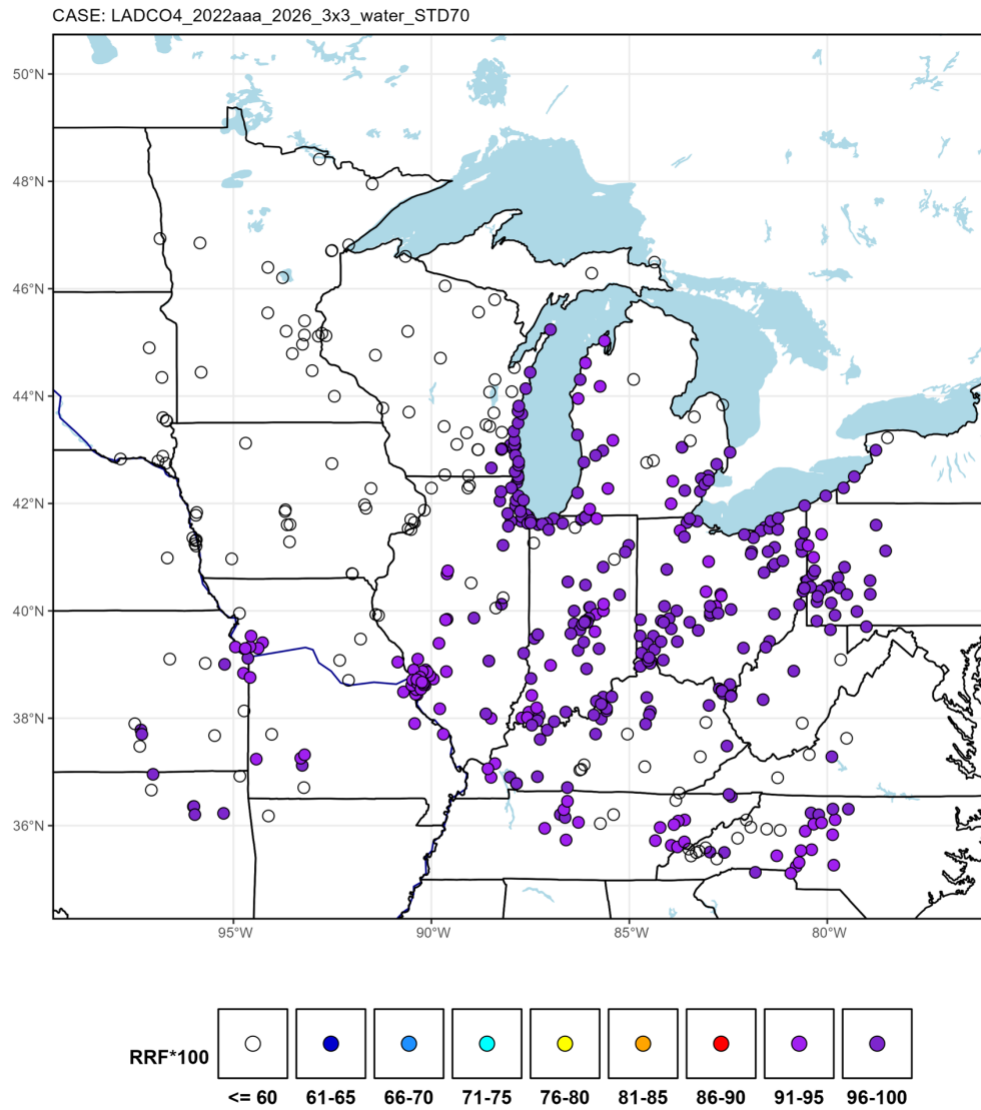


Figure 6-8. 2026 RRFs calculated with water cells included from the LADCO 2026 4-km CAMx simulation.

**Table 6-1. 2026 O<sub>3</sub> design values at each monitor in the 2015 O<sub>3</sub> NAAQS NAA and maintenance areas in the LADCO region; calculated from the LADCO 4-km CAMx modeling with water cells included in the 3x3 matrix surrounding the monitor**

State	Area	AQS Site ID	Site Name	2022 DV	2026 DV	RRF
Michigan	Allegan County, MI	260050003	HOLLAND	74	72.1	0.9664
Michigan	Berrien County, MI	260210014	COLOMA	72	70.2	0.9662
Michigan	Muskegon County, MI	261210039	MUSKEGON	77	74.6	0.9654
Illinois	Chicago, IL-IN-WI	170310001	Alsip	73	71.8	0.9798
Illinois	Chicago, IL-IN-WI	170310032	Chicago SWFP	75	73.1	0.9757
Illinois	Chicago, IL-IN-WI	170310076	Chicago Com Ed	73	71.4	0.9782
Illinois	Chicago, IL-IN-WI	170311003	Chicago Taft HS	70	69.0	0.9763
Illinois	Chicago, IL-IN-WI	170311601	Lemont	73	71.2	0.9717
Illinois	Chicago, IL-IN-WI	170313103	SHILPRK	66	64.8	0.9779
Illinois	Chicago, IL-IN-WI	170314002	Cicero	71	69.6	0.9805
Illinois	Chicago, IL-IN-WI	170314007	Des Plaines	72	70.8	0.9745
Illinois	Chicago, IL-IN-WI	170314201	Northbrook	75	73.7	0.9788
Illinois	Chicago, IL-IN-WI	170317002	Evanston	75	73.4	0.9748
Illinois	Chicago, IL-IN-WI	170436001	Lisle	71	69.0	0.9719
Illinois	Chicago, IL-IN-WI	170890005	Elgin	72	70.2	0.9721
Illinois	Chicago, IL-IN-WI	170971007	Zion	75	73.6	0.9786
Illinois	Chicago, IL-IN-WI	171110001	Cary	72	70.6	0.9713
Illinois	Chicago, IL-IN-WI	171971011	Braidwood	67	65.0	0.9670
Indiana	Chicago, IL-IN-WI	180890022	Gary-IITRI	71	69.4	0.9681
Indiana	Chicago, IL-IN-WI	180892008	Hammond	69	68.0	0.9759
Indiana	Chicago, IL-IN-WI	181270024	Ogden Dunes	73	70.6	0.9637
Indiana	Chicago, IL-IN-WI	181270026	Valparaiso	67	65.2	0.9694
Wisconsin	Chicago, IL-IN-WI	550590019	CHIWAUKEE	76	74.8	0.9761
Wisconsin	Chicago, IL-IN-WI	550590025	Kenosha WT	73	71.7	0.9738
Ohio	Cincinnati, OH-KY	390170018	Middletown	67	64.9	0.9658
Ohio	Cincinnati, OH-KY	390170023	Crawford Woods	67	65.9	0.9736
Ohio	Cincinnati, OH-KY	390179991	Oxford	65	63.3	0.9640
Ohio	Cincinnati, OH-KY	390250022	Batavia	65	62.4	0.9605
Ohio	Cincinnati, OH-KY	390610006	Sycamore	70	67.9	0.9714
Ohio	Cincinnati, OH-KY	390610010	Colerain	68	66.4	0.9730
Ohio	Cincinnati, OH-KY	390610040	Taft	69	68.2	0.9797
Ohio	Cincinnati, OH-KY	391650007	Lebanon	70	67.8	0.9650
Ohio	Cleveland, OH	390350034	District 6	71	68.8	0.9608
Ohio	Cleveland, OH	390350060	GT Craig	62	59.7	0.9630
Ohio	Cleveland, OH	390350064	Berea BOE	67	65.0	0.9615
Ohio	Cleveland, OH	390355002	Mayfield	68	65.2	0.9593

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Ohio	Cleveland, OH	390550004	Notre Dame	65	62.4	0.9601
Ohio	Cleveland, OH	390850003	Eastlake	73	70.3	0.9596
Ohio	Cleveland, OH	390850007	Painesville	66	63.4	0.9614
Ohio	Cleveland, OH	390930018	Elyria-Sheffield	61	58.8	0.9605
Ohio	Cleveland, OH	391030004	Chippewa Lake	67	64.6	0.9645
Ohio	Cleveland, OH	391331001	Lake Rockwell	68	65.5	0.9596
Michigan	Detroit, MI	260990009	New Haven	68	66.1	0.9629
Michigan	Detroit, MI	260991003	Warren	68	66.1	0.9623
Michigan	Detroit, MI	261250001	Oak Park	69	66.5	0.9649
Michigan	Detroit, MI	261470005	Port Huron	69	66.7	0.9633
Michigan	Detroit, MI	261610008	Ypsilanti	68	65.4	0.9624
Michigan	Detroit, MI	261619991	Dexter	66	63.1	0.9571
Michigan	Detroit, MI	261630001	Allen Park	70	68.0	0.9680
Michigan	Detroit, MI	261630019	Detroit-E 7 Mile	70	67.8	0.9654
Indiana	Louisville, KY-IN	180190008	Charlestown	66	63.6	0.9648
Kentucky	Louisville, KY-IN	210290006	SHEPHERDSVILLE	66	63.6	0.9648
Kentucky	Louisville, KY-IN	211110051	Watson Lane	67	65.0	0.9705
Kentucky	Louisville, KY-IN	211110067	CANNONS LANE	72	70.2	0.9713
Kentucky	Louisville, KY-IN	211110080	Carrithers	69	67.5	0.9693
Kentucky	Louisville, KY-IN	211850004	BUCKNER	65	62.6	0.9643
Wisconsin	Milwaukee, WI	550790010	Milw-16th St	64	62.7	0.9754
Wisconsin	Milwaukee, WI	550790068	Milw-UWM	71	69.4	0.9747
Wisconsin	Milwaukee, WI	550790085	Bayside	73	71.8	0.9745
Wisconsin	Milwaukee, WI	550890008	Grafton	73	70.9	0.9719
Wisconsin	Milwaukee, WI	550890009	Harrington Beach	72	70.5	0.9706
Wisconsin	Milwaukee, WI	551010020	Racine-P&D	74	72.5	0.9758
Wisconsin	Milwaukee, WI	551330027	Waukesha	70	68.2	0.9652
Wisconsin	Sheboygan County, WI	551170006	SHEBOYGAN	76	74.4	0.9701
Wisconsin	Sheboygan County, WI	551170009	Sheboygan-Haven	69	67.5	0.9690
Illinois	St. Louis, MO-IL	171193007	Wood River	71	67.7	0.9449
Illinois	St. Louis, MO-IL	171199991	Alhambra	67	63.4	0.9465
Illinois	St. Louis, MO-IL	171630010	East St. Louis	68	64.7	0.9475
Missouri	St. Louis, MO-IL	290990019	Arnold West	69	65.4	0.9440
Missouri	St. Louis, MO-IL	291831002	West Alton	71	67.4	0.9460
Missouri	St. Louis, MO-IL	291831004	Orchard Farm	67	63.9	0.9500
Missouri	St. Louis, MO-IL	291890005	Pacific	65	62.3	0.9497
Missouri	St. Louis, MO-IL	291890014	Maryland Heights	70	66.3	0.9475
Missouri	St. Louis, MO-IL	295100085	Blair Street	69	65.7	0.9494

### **6.3.1. Alternative DVF<sub>2026</sub> Results**

Confidence in the ability of photochemical models to accurately estimate O<sub>3</sub> over water is a persistent concern with the use of the models for air quality planning. This concern prompted measurement campaigns in the Eastern U.S. to address the issue (see the 2017 Lake Michigan Ozone Study, Long Island Sound Tropospheric Ozone Study, OWLETS, and the AGES+ campaign). The meteorology and chemistry processes in model grid cells that are dominated by water (> 50% land use area) are a challenge to simulate because the conventional technical formulations of the models were not optimized for water cells. Even with the introduction of new algorithms to simulate the dynamical and chemical features of water cells, a lack of over-water observations hinders our ability to verify the accuracy of the models in simulating these conditions.

In consideration that the models may not perform well in simulating water cells, U.S. EPA and others have presented alternative DVF calculation approaches that exclude water cells (US EPA, 2017; US EPA, 2018b). Per U.S. EPA (2018, pg. 109), when appropriate there may be cases where certain cells along the periphery of the 3 x 3 model grid cell matrix have different modeled responses than what would be expected at the monitor location at the center of a matrix due to a specific local topographic or geographical feature (e.g., a large water body or a significant elevation change). A potential example of this situation would be a matrix of grid cells where several grid cells are over water and where the meteorological conditions and relevant emissions sources differ substantially from the land-based monitor location. Again, in these types of cases and with appropriate justification, air agencies could consider removing the unrepresentative cells from the calculation.

Section 4.2.2 of the U.S EPA (2018) modeling guidance states, “In cases in which the spatial representativeness of a monitoring location is much smaller or larger than the area covered by the 3x3 array of cells, air agencies may consider assessing site-specific model response over an alternative grid cell array as part of corroborative analyses that inform the aggregate weight of evidence determination. Additionally, there may be cases where certain cells along the periphery of the 3 x 3 array have different modeled

responses than what would be expected at the monitor location at the center of array due to a specific local topographic or geographical feature (e.g., a large water body or a significant elevation change). “

Factoring in the impact of water cells on the DVF calculation does not require additional CAMx simulations. It is implemented through a postprocessing sequence per U.S. EPA (2018b) in which model grid cells that are dominated by water (> 50% land use area) are removed from the 3x3 matrix in the RRF and DVF calculation. One important modification to this process is to override the exclusion condition for cells that contain monitors; in other words, grid cells that contain monitors will be included in the 3x3 matrix regardless of the amount of water coverage in the cell.

Adjustments to the size of the grid cell matrix used in the DVF calculation is a configuration that can be adjusted in SMAT-CE. The program gives users the option to calculate DVs using only the model grid cell that contains a monitor, or matrices of 3x3, 5x5, or 7x7 cells around a monitor location. LADCO’s 2022 CAMx modeling platform used a 3:1 nesting ratio to simulate air quality at 12-km and 4-km resolutions. To normalize the area around a monitor used for calculating DVFs, the size of the matrix surrounding a monitor can be increased at finer grid resolutions.

LADCO conducted a series of attainment test experiments to understand the impacts on DVFs of excluding water cells or changing the size of the grid cell matrix. Table 6-2 shows the results of attainment test experiments for controlling<sup>16</sup> monitors at the lakeshore NAA and maintenance areas in the region. The results in this table compare DVF<sub>2026</sub> values for SMAT-CE configurations that include/exclude water cells and use different matrix sizes around the monitor. The range of DVF<sub>2026</sub> values at a monitor resulting from the different configurations presented in the table averages about 0.1 ppb.

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<sup>16</sup> The controlling monitor is the monitor location in the area with the highest base year design value

**Table 6-2. Comparison of LADCO 2026 4-km O<sub>3</sub> design values at shoreline nonattainment and maintenance area monitors in the region**

NAA	AQS Site ID	3x3		5x5		7x7	
		Water	No Water	Water	No Water	Water	No Water
Allegan County, MI	260050003	72.1	72.1	72.3	72.2	72.3	72.2
Berrien County, MI	260210014	70.2	70.2	70.2	70.3	70.1	70.3
Muskegon County, MI	261210039	74.6	74.6	74.8	74.8	74.7	74.7
Chicago, IL-IN-WI	550590019	74.8	74.6	74.8	74.6	74.7	74.6
Cleveland, OH	390850003	70.3	70.3	70.3	70.3	70.4	70.3
Detroit, MI	261630019	67.8	67.8	67.8	67.8	67.7	67.6
Milwaukee, WI	551010020	72.5	72.3	72.3	72.3	72.3	72.3
Sheboygan County, WI	551170006	74.4	74.3	74.4	74.3	74.4	74.3

LADCO’s CAMx DVF estimates are available in supporting materials to this TSD in the following spreadsheet. The spreadsheet includes tables and figures of DVF<sub>2026</sub> values calculated from the LADCO 12-km and 4-km CAMx modeling that use the different SMAT-CE configurations presented here.

[LADCO 2022-based 2026 Design Value Forecasts](#) (13 MB; XLSX)

## 7. Conclusions and Significant Findings

LADCO presents in this TSD a regional air quality modeling platform for quantifying and evaluating future year O<sub>3</sub> concentrations pursuant to testing attainment of the 2015 O<sub>3</sub> NAAQS serious area designations for receptors at nonattainment and maintenance areas throughout the Great Lakes Basin. After establishing that the LADCO 2022-based modeling platform is an acceptable tool for simulating regional O<sub>3</sub> concentrations, we presented the results from projections of future O<sub>3</sub> concentrations and for calculating O<sub>3</sub> design values in 2026. A summary of the significant findings from the LADCO modeling follows.

- Finding 1: While the LADCO 2022v1-based CAMx modeling platform has an underprediction bias for high O<sub>3</sub> concentrations, the LADCO platform skill is the same or better than the LADCO and U.S. EPA 2016 modeling platforms which were used to support recent O<sub>3</sub> regulatory actions.
- Finding 2: The LADCO 2026 CAMx simulation predicts that fourteen monitors in the LADCO region will have an average DV<sub>2026</sub> that exceeds the 2015 O<sub>3</sub> NAAQS.
- Finding 3: Excluding water cells in the attainment test calculation results in slightly lower DVs<sub>2026</sub> for some of the lakeshore monitors in the LADCO region.

As with all regional air quality modeling applications, there are uncertainties in the model inputs and in the model formulation that produce biases in the results presented here. LADCO determined that when the modeling for this application was started in Fall 2024 the LADCO 2022 WRF meteorology, U.S. EPA 2022hc emissions modeling platform, and the ERTAC EGU 22.1 emissions were the best available data for forecasting 2026 air quality for the LADCO member states.

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