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Conceptual Model of Ozone Formation in New Mexico with a Focus on the Permian Basin



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ACRONYMS AND ABBREVIATIONS

§179B	CAA §179B demonstration “but for” international impacts
AEO	Annual Emissions Outlook
AQS	Air Quality System
BC	Boundary Condition
BLM	Bureau of Land Management
CAA	Clean Air Act
CFO	Carlsbad Field Office
CAMx	Comprehensive Air-quality Model with extensions
CarCavAQS	Carlsbad Caverns Air Quality Study
CASTNet	Clean Air Status and Trends Network
CSN	Chemical Speciation Network
CSU	Colorado State University
DV	Design Value
DVB	Base Year Design Value
DVF	Future Year Design Value
EGU	Electrical Generating Units
EIA	U.S. Energy Information Administration
EMP	Emissions Modeling Platform
EPA	Environmental Protection Agency
ESA	European Space Agency
FCAQG	Four Corners Air Quality Group
FCAQTF	Four Corners Air Quality Task Force
FEM	Federal Equivalent Monitor
FNR	Formaldehyde to NO _x ratio
FRM	Federal Reference Monitor
FY	Fiscal year
GA	Gradient Adjusted
GHG	Green House Gas
HAQAST	NASA’s Health and Air Quality Applied Science Team
HCHO	Formaldehyde
HMS	Hazard Mapping System
HNO ₃	Nitric acid

HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
IMPROVE	Interagency Monitoring of Protected Visual Environments
IQR	Interquantile Range
km	Kilometer
L3	Level 3 (Satellite Data Processing Level)
LNOx	Lightning NOx emissions
m	Meter
mb	Millibar
MDA8	Maximum Daily 8-hour Average
NAA	Nonattainment Area
NAAQS	National Ambient Air Quality Standards
NARR	North American Regional Reanalysis
NEI	National Emissions Inventory
NM	New Mexico
NMB	Normalized Mean Bias
NME	Normalized Mean Error
NMED	New Mexico Environmental Department
NM-Cen	Central New Mexico
NM-PB	New Mexico Permian Basin
NM-S	New Mexico Doña Ana County
NM-SSJ	Northwest New Mexico –[South] San Juan Basin
NPS	National Park Service
SNMOS	Southern New Mexico Ozone Study
NEC	National Emissions Collaborative
NO	Nitric Oxide
NOAA	National Oceanic and Atmospheric Administration
NO ₂	Nitrogen Dioxide
NOx	Oxides of Nitrogen
NOy	Total reactive nitrogen (<i>e.g.</i> NOx + HNO ₃ + PAN + others)
NPS	National Park Service
O ₃	Ozone
O&G	Oil and Gas
OAI	Ozone Attainment Initiative
OMI	Ozone Monitoring Instrument
PAN	Peroxyacetyl nitrate

PGM	Photochemical Grid Model
PM	Particulate Matter
PMF	Positive Matrix Factorization
PPN	peroxypropionyl nitrate
QA	Quality Assurance
RCP	Representative Concentration Pathway
RFD	Reasonably Foreseeable Development
RMP	Resource Management Plan
SA	Source Apportionment
SIP	State Implementation Plan
SMAT	Software for the Modeled Attainment Test
TCEQ	Texas Commission on Environmental Quality
TPD	Tons per day
TPY	Tons per year
TROPOMI	Tropospheric Monitoring Instrument
TX	Texas
UAA	Unmonitored Area Analysis
VOC	Volatile Organic Compound
WS	Wind Speed

EXECUTIVE SUMMARY

EPA designated ozone nonattainment areas (NAAs) under the 70 parts per billion (ppb) 2015 ozone National Ambient Air Quality Standard (NAAQS) based on 2014-2016 observed ozone Design Values (DVs¹). The Sunland Park area in southern Doña Ana County adjacent to El Paso, Texas and Mexico was the only area in New Mexico with 2014-2016 ozone DVs above 70 ppb and was designated a Marginal ozone NAA. The Sunland Park NAA failed to attain the 2015 ozone NAAQS by August 2021 as required for a Marginal NAA. The New Mexico Environmental Department (NMED) prepared a Clean Air Act (CAA) §179B demonstration that was approved by EPA showing that the Sunland Park NAA would have attained the 2015 ozone NAAQS in 2021 but for international anthropogenic emissions. Consequently, the Sunland Park NAA was not redesignated as a Moderate NAA and remains a Marginal ozone NAA under the 2015 ozone NAAQS.

Since the 2015 ozone NAAQS NAA designations, oil and gas (O&G) production and related activities in the Permian Basin in southeast New Mexico (e.g., Eddy and Lea Counties) and nearby areas in Texas, have increased dramatically. The Permian Basin has become the most productive oil and gas basin in the U.S. Since 2018, observed ozone DVs in New Mexico portion of the Permian Basin have exceeded the 2015 ozone NAAQS of 70 ppb and even exceed the 75 ppb 2008 ozone NAAQS since 2019.

The NMED contracted with Ramboll to conduct future year ozone source apportionment modeling to identify the causes of high ozone concentrations in New Mexico and, in particular, within the Permian Basin O&G producing area of southeast New Mexico. Under Phase I of the NMED ozone source apportionment study that was performed during the 2024-2025 fiscal year (FY), Ramboll conducted 2026 ozone source apportionment modeling using the EPA 2022v1 CAMx 2026 12 km grid resolution photochemical grid model (PGM) modeling platform that was completed by June 30, 2025. Under Phase II during FY2025-2026, Ramboll is developing a higher grid resolution CAMx 2022v2 4 km PGM modeling platform for New Mexico and conducting CAMx 2032 12/4 km ozone source apportionment modeling. As an initial task for the Phase II work effort, Ramboll has prepared this Conceptual Model of ozone formation in New Mexico with an emphasis on the Permian Basin region.

Summary of Conceptual Model

The Conceptual Model development includes ozone and precursor trends using surface ambient measurements and satellite data, emissions trends, relationship of elevated ozone and meteorology, weekend ozone analysis (indicator of NO_x/VOC ozone formation sensitivity), climate anomalies, effects of wildfire smoke on ozone, analysis of past ozone modeling studies, analysis of special field study measurements in the Permian Basin, and other analysis.

The factors that affect ozone pollution across the New Mexico vary geographically. Ambient ozone trend analyses and satellite trends of ozone precursors reveal distinct regional

¹ An ozone Design Value is defined as the three-year average of the fourth highest Maximum Daily Average 8-hour (MDA8) ozone concentration.

patterns. The analysis in this document is organized by region with a focus on the Permian Basin. In the portion of the Permian Basin in New Mexico, observed ozone concentrations have increased by at least five ppb over the last two decades, which has resulted in substantially more ozone exceedance days at the Carlsbad City monitor; from fewer than six days per year from 2007 to 2016 to more than seventeen days per year for 2018 to 2024 (excluding 2020). Ambient surface NO₂ concentrations (i.e., an ozone precursor) at Carlsbad City have increased rapidly since 2017, which is corroborated by satellite NO₂ observations.

Figure ES-1 presents trends in Carlsbad City ozone design values as well as Permian Basin oil and gas production² and New Mexico O&G ozone precursor emissions (NO_x and VOC).³ The production estimates and precursor emissions are all normalized with respect to their 2017 values, therefore, values for 2017 are all 100%; years prior to 2017 are generally a smaller percentage, and the later years are generally a larger percentage. As shown in this report, 2017 was a pivotal year in terms of oil and gas production increases in the Permian Basin and Figure ES-1 illustrates the impact on New Mexico ozone precursor emissions and the ozone design value at Carlsbad City, which is in close proximity to the Permian Basin oil and gas development area. This figure provides circumstantial evidence that the increase in ozone concentrations in the New Mexico portion of the Permian Basin is related to the increase in oil and gas production.

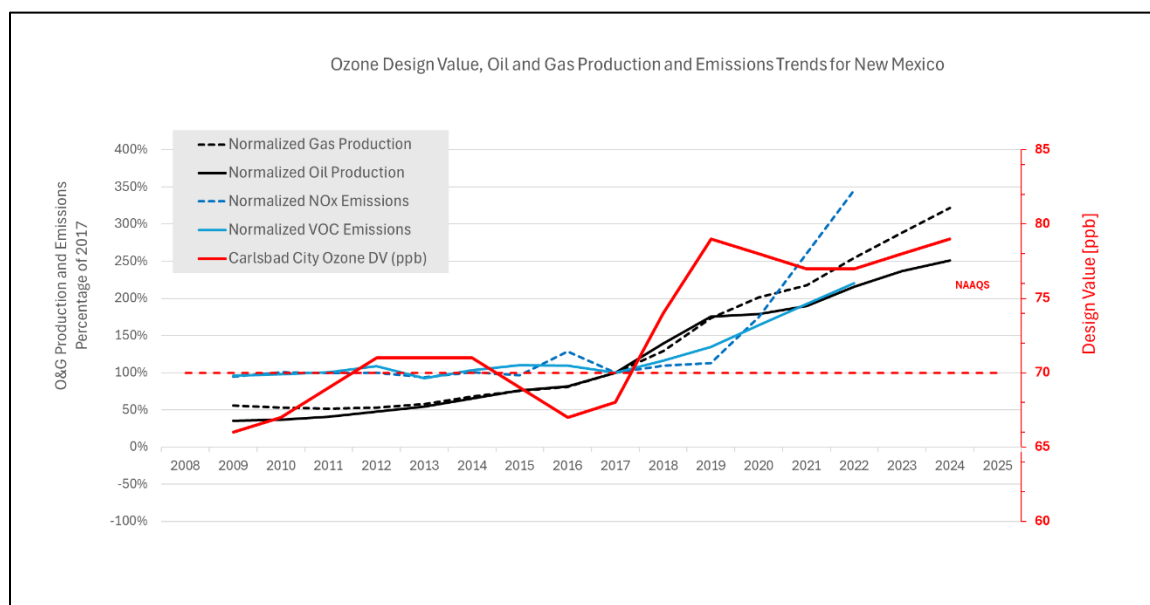


Figure ES-1. Trends in Carlsbad City design value (red scaled by right y-axis) and Permian Basin O&G production and New Mexico O&G ozone precursor emissions (left axis normalized to 100% in 2017).

² From U.S. Energy Information Administration: Crude Oil Production: Permian million barrels per day and Marketed (Wet) Natural Gas Production: Permian billion cubic feet per day

³ 2009 through 2020 estimates from EPA Trends, 2022 estimate from EMP OG emissions, 2021 interpolated between 2020 and 2022.

Per the Bureau of Land Management's Carlsbad Field Office oil and gas emissions projections, emissions are expected to remain high through 2032 for all potential scenarios. Previous photochemical grid modeling for the Permian Basin region underestimated peak ozone concentrations, the reasons for which are unknown. The last few years have seen air quality measurement field campaigns in the region that have acquired invaluable data that will be used to investigate and improve model performance for Phase II modeling. This should improve the fidelity of the modeling platform and lead to a deeper understanding of the causes and conditions for ozone pollution in the Permian Basin region and inform more effective mitigation strategies.

1.0 INTRODUCTION

The New Mexico Environmental Department (NMED) has contracted with Ramboll to conduct future year ozone source apportionment modeling to identify the causes of high ozone concentrations in New Mexico and, in particular, within the Permian Basin oil and gas (O&G) producing area of New Mexico. Based on 2014-2016 observed ozone Design Values (DV⁴), the Permian Basin area in southeast New Mexico was designated attainment of the 70 ppb 2015 ozone National Ambient Air Quality Standard (NAAQS). However, since 2018 the ozone DV at the Carlsbad City site has exceeded the 2015 ozone NAAQS. The Ramboll New Mexico ozone modeling work is divided into two Phases:

- Phase I was performed during FY2024-2025 covering the period of April 17, 2025, to June 30, 2025. Phase I conducted 2026 ozone source apportionment modeling using the EPA 2022v1 12 km modeling platform and begin developing a higher resolution 4 km 2022 ozone modeling platform for New Mexico.
- Phase II is being performed during FY2025-2026 starting after July 1, 2025. Phase II will finish the development of the New Mexico 4 km grid resolution summer 2022 platform and perform additional future year ozone source apportionment modeling and other analysis to identify the sources of elevated ozone concentrations in New Mexico, including the Permian Basin.

Phase II includes multiple Tasks as outlined in the Scope of Work (Ramboll, 2025a). The first task is to develop a Conceptual Model of Ozone Formation for New Mexico with a focus on the Permian Basin region (this document). The other tasks are the continued development of the CAMx 2022 4 km modeling platform to model and assess impacts on ozone from different emissions source regions and source sectors for the 2022 base year and 2032 future year scenarios.

This Conceptual Model analyzes the causes of elevated ozone for four areas in New Mexico:

- Permian Basin (e.g., Eddy and Lea Counties).
- Doña Ana County (and El Paso).
- Northwest New Mexico (San Juan Basin).
- Central New Mexico (Albuquerque and vicinity).

The Conceptual Model development includes ozone and precursor trends using surface ambient measurements and satellite data, emissions trends, relationship of elevated ozone and meteorology, weekend ozone analysis (indicator of NO_x/VOC ozone formation sensitivity), climate anomalies, effects of wildfire smoke on ozone, analysis of past ozone modeling studies, analysis of special field study measurements in the Permian Basin, and other analysis.

Based on 2014-2016 observations, the Sunland Park area in southern Doña Ana County was designated nonattainment of the 2015 ozone NAAQS. The NMED conducted a retrospective §179B demonstration that provided evidence that the area would have attained the 2015

⁴ A Design Value (DV) is defined as the three-year average of the fourth highest Maximum Daily Average 8-hour (MDA8) ozone concentrations.

ozone NAAQS but for international emissions. The NMED §179B demonstration included a conceptual model of ozone formation that was contained in a June 2021 report (NMED, 2021). The Texas Commission on Environmental Quality (TCEQ) released a §179B demonstration for the El Paso portion of the El Paso – Las Cruces ozone nonattainment area in February 2022 (Ramboll, 2022). Pertinent results from these reports are excerpted and included in this conceptual model report.

Additional analysis was conducted in developing the conceptual modeling ozone formation in the New Mexico portion of the Permian Basin. This included analysis of data from the Carlsbad Caverns Air Quality Study (CarCavAQS) field study measurements during summer 2019 that were analyzed in several publications.⁵ A second field study collected measurements at Carlsbad Caverns in summer 2021. BoulderAir also collected ozone, NO_x and VOC measurements in Loving, New Mexico during April 2023 – March 2024 that was reviewed and incorporated into this conceptual model report.⁶

1.1 Purpose of the Conceptual Model

Prior to performing a photochemical modeling study it is good practice to develop a conceptual model of ozone formation. For ozone, PM_{2.5} and regional haze SIP modeling, EPA provides guidance for developing a conceptual model that they describe as follows (EPA, 2018, p. 12):

"Conceptual descriptions, which are also referred to as conceptual models, are comprehensive summaries of the 'state of the knowledge' regarding the influence of emissions, meteorology, transport, and other relevant atmospheric processes on air quality in the area (Vickery, 2004). For a conceptual description to be informative, it should identify what processes and sources, in the generic sense, are most responsible for the air quality issue being simulated. Well-constructed conceptual models can substantially inform the design of the attainment demonstration modeling (e.g., episode selection, choice of domain, emissions priorities, evaluation focus) and should be conducted in advance of the development of a modeling protocol."

EPA identified the following building blocks for a Conceptual Model:

- Introduce the general nature of the air quality problem addressed by the conceptual model:
 - What are the pollutants of concern in the area?
 - What are the current air quality levels in the area?
 - What is the attainment/nonattainment status of the area?
 - What is the geographical scope of poor air quality?
 - What is the temporal scope of poor air quality?
 - What are the air quality trends in the area?
 - Is the problem getting better or worse?

⁵ <https://mountainscholar.org/items/f2008153-3093-457d-a250-fc9004aa03b9>

⁶ <https://www.bouldair.com/loving.htm>

- What are the suspected mechanisms for formation of poor air quality levels?
- What are the sources of emissions that may contribute to poor air quality?
- Are there unique meteorological influences on local air quality levels?
- Describe the ambient monitoring network used for the conceptual model:
 - Develop a map of monitor sites and types (e.g., FRM, FEM, CSN, IMPROVE, CASTNET, etc.).
 - Describe characteristics of individual monitoring sites (scale, frequency, etc.).
- Describe the status and trends of air quality in the area:
 - Summarize the relevant monitoring data for the air quality problem being studied.
 - Identify locations that are in violation of the NAAQS.
 - Describe the spatial pattern in pollutant and precursor pollutant levels.
 - Describe the temporal pattern in pollutant and precursor pollutant levels.
 - Describe the annual trends in concentrations over the period of interest.
 - If appropriate, develop fused ambient/model surfaces to fill any gaps within the monitoring network.
- Investigate possible relationships between emissions and air quality:
 - Examine emissions estimates for the main sector/source categories.
 - Compare emission trends for annual and or seasonal/episodic periods to corresponding air quality trends.
 - Identify key emission sources or source categories.
 - Assess the historical effectiveness of control programs.
 - Consider how future emissions growth or reductions may affect air quality.
 - List control programs that are in place, or will soon be implemented, that may impact emissions sources in the area.
- Investigate possible relationships between meteorology and air quality:
 - Describe meteorological characteristics on poor air quality days (e.g., wind speed/direction, temperatures, relative humidity levels, inversion indicators, etc.).
 - Identify any distinct meteorological phenomena that coincide with poor air quality days.
 - Prepare pollution roses, Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) back-trajectories (Draxler, 1998), or any other relevant analysis needed to link poor air quality days to specific meteorological patterns and sources of transported pollutants.
 - Assess the impact from pollutant transport into area based on meteorological data and ambient air quality data.
- Synthesize all the relevant information into a detailed conceptual model:
 - Aggregate all elements of the conceptual model and provide the key findings resulting from the analyses completed.

- Characterize the potential factors that influence air quality in the area and, where possible, rank the importance of those influences.
- Identify issues that require further investigation, either in terms of data collection or chemical transport modeling.
- Discuss how the subsequent SIP modeling and associated protocol is impacted by this conceptual description.

The NMED Phase II FY2025-2026 ozone modeling work effort is not a formal SIP demonstration, however, most of the EPA listed elements are relevant and are presented in this conceptual model report.

1.2 Existing Conceptual Models

1.2.1 NMED Phase I Ozone Source Apportionment Modeling Study

In the NMED Phase I FY2024-2025 study, Ramboll identified the same four geographic regions of New Mexico as having unique ozone formation attributes as identified for this (i.e., Phase II) work (Ramboll, 2025b). For Phase I, the regions were abbreviated as: NM-PB (Permian Basin), NM-S (Doña Ana County), NM-Cen (Central New Mexico) and NM-SSJ (Northwest New Mexico – [South] San Juan Basin). Phase I provided a brief conceptual model of ozone as follows:

All four of the New Mexico geographic regions with ozone monitors share a common attribute that ozone transport dominates ozone concentrations on all days. Days with the highest local ozone formation are typically hot summer days with a high pressure system or ridge that slows the synoptic westerly winds without an excessive amount of precipitation (summer monsoon). The highest ozone in the southern New Mexico Doña Ana County and vicinity area (NM-S) occurs during transport from the south including contributions from El Paso, Texas, Juarez, Mexico and other international emissions. The Eddy and Lea Counties portion of southeastern New Mexico (NM-PB) also has ozone contributions from O&G emissions in the Permian Basin added to the transported ozone. Ozone concentrations in Northwestern New Mexico (NM-SSJ) are affected by O&G emissions from the San Juan Basin in addition to transport. Ozone at sites in Bernalillo and adjacent counties (NM-Cen) are affected by emissions from Albuquerque, which is New Mexico's largest city, in addition to transport.

Some of these findings were derived from the Phase I source apportionment modeling that is described in more detail and with results in Section 7.5.

1.2.2 Sunland Park §179B demonstration

The Sunland Park §179B retrospective demonstration (NMED, 2021) provides a conceptual model of ozone formation for the "binational, tri-state shared airshed known as the Paso del Norte (PdN), which consists of the City of Sunland Park, the City of El Paso, and Ciudad Juárez, Mexico along the U.S./Mexico border."

The conceptual model discusses the regional topography, meteorology, and emissions sources of the region as well as conditions for high ozone to occur as follows:

Research continues to support that when the atmosphere is stable and the planetary boundary layer is low (caused by high-pressure ridge systems centered over the PdN), the potential for pollutant accumulation at ground level on exceedance days is

high due to the lack of vertical mixing; unlike when unstable low-pressure systems prevent the accumulation of pollutants near ground level on non-exceedance days due to increased vertical mixing through unstable windy conditions. O₃ concentrations typically peak in the summer months on weekday afternoon hours, lasting into the evening when the angle and distance of the sun is the most intense and the accumulation of precursors for efficient O₃ photosynthetic production are at peak concentrations to occur quickly. High exceedance days can also occur on weekends in the PdN, if the previous day's pollutants have not been dispersed and immediately start the photochemical reaction the following day. There is a correlation of high exceedance days occurring before or after a precipitation event, indicating an increase of relative humidity is needed for efficient O₃ production, and supports higher exceedances occurring during the monsoon season of July and August that falls within the peak O₃ season. The calm conditions that precede or follow a synoptic mesoscale event are perfect conditions for the accumulation and production of O₃ as the humidity increases with localized stable conditions.

The Sunland Park §179B demonstration also discusses atmospheric transport directions using windrose diagrams, pollution rose diagrams, and HYSPLIT back-trajectory analyses to provide a “weight of evidence demonstration to show the impact of the urban emissions from Ciudad Juárez, Mexico on air quality in New Mexico”, and to concluded “that international emissions significantly contribute to high O₃ levels at the Desert View monitoring site and the state’s ability to comply with the NAAQS”.

2.0 OBSERVED OZONE CONCENTRATIONS

2.1 Ozone Monitors in New Mexico

As described in the introduction, this conceptual model of ozone formation encompasses all of New Mexico but focuses on the southeast region of New Mexico that is within or near the Permian Basin Oil and Gas development region that has seen large increases in ozone air pollution in recent years. Figure 2-1 displays the ozone monitors within New Mexico and indicates additional pollutants and/or meteorological monitoring with color-code monitor icons. The monitors can be grouped into one of the four distinct geographic regions listed below:

- Permian Basin (e.g., Eddy and Lea County)
- Doña Ana County (and El Paso)
- Northwest New Mexico (San Juan Basin)
- Central New Mexico (Albuquerque and vicinity)

Table 2-1 specifies the regional grouping of the New Mexico monitors as well as additional monitor specific information.

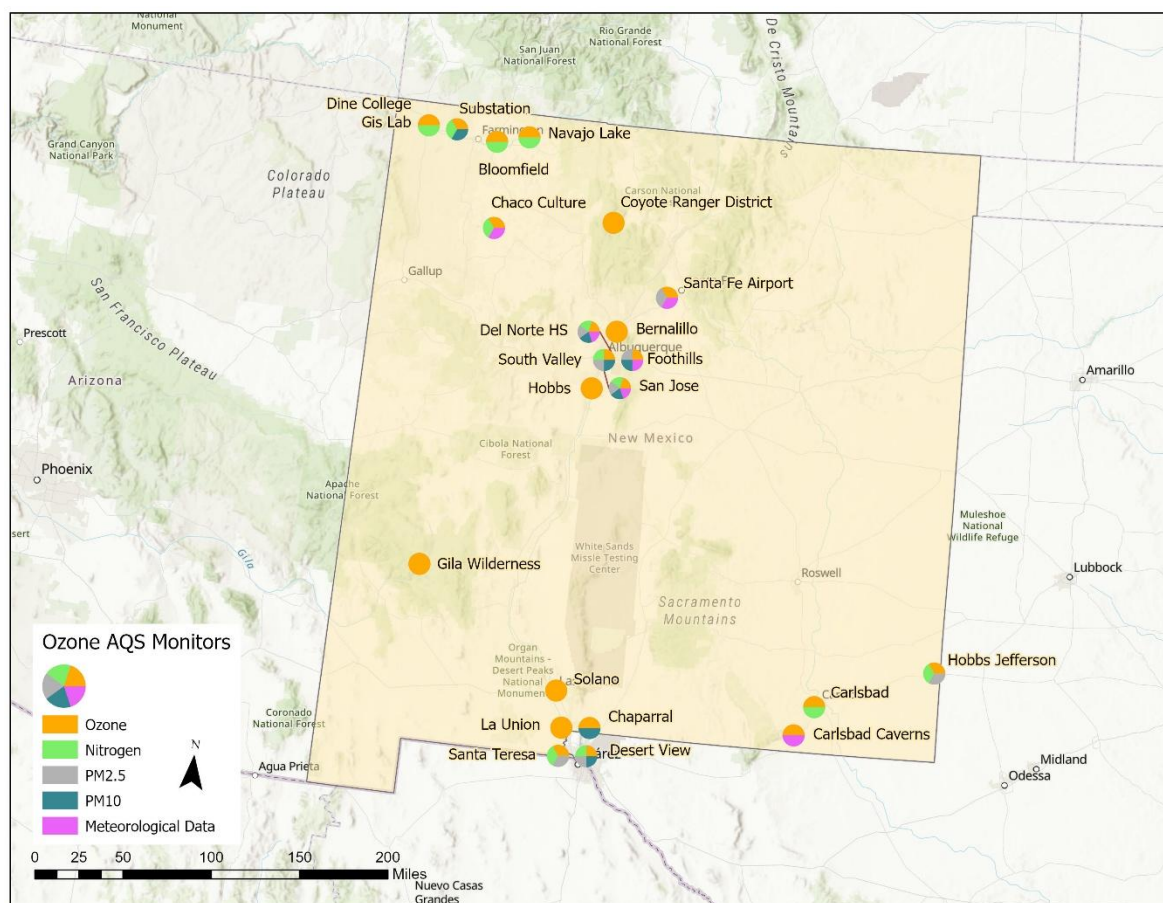


Figure 2-1. Map of New Mexico monitoring stations with monitored pollutants indicated.

Table 2-1. New Mexico Air Quality Monitors.

AQS Site ID	County Name	Local Site Name	Monitor Begin Date	Reporting Agency	Region
350010023	Bernalillo	Del Norte HS	1/1/1986	Albuquerque EHD-AQD	Central New Mexico
350010029	Bernalillo	South Valley	7/1/2002	Albuquerque EHD-AQD	Central New Mexico
350011012	Bernalillo	Foothills	2/13/2007	Albuquerque EHD-AQD	Central New Mexico
350012022	Bernalillo	San Jose	10/11/2022	Albuquerque EHD-AQD	Central New Mexico
350037501	Catron	Gila Wilderness	6/20/2024	US Forest Service	---
350130008	Doña Ana	La Union	1/1/1979	NMED	Doña Ana County
350130020	Doña Ana	Chaparral	2/14/1996	NMED	Doña Ana County
350130021	Doña Ana	Desert View	2/13/1996	NMED	Doña Ana County
350130022	Doña Ana	Santa Teresa	1/24/1996	NMED	Doña Ana County
350130023	Doña Ana	Solano	5/18/2004	NMED	Doña Ana County
350150010	Eddy	Carlsbad Caverns	7/17/2019	National Park Service	Permian Basin
350151005	Eddy	Carlsbad (City)	8/13/1997	NMED	Permian Basin
350250008	Lea	Hobbs Jefferson	8/20/2004	NMED	Permian Basin
350431001	Sandoval	Bernalillo	1/1/1981	NMED	Central New Mexico
350450009	San Juan	Bloomfield	6/7/2000	NMED	Northwest New Mexico
350450018	San Juan	Navajo Lake	3/23/2006	NMED	Northwest New Mexico
350450020	San Juan	Chaco Culture	2/23/2017	National Park Service	Northwest New Mexico
350451005	San Juan	Substation	5/8/1997	NMED	Northwest New Mexico
350451233	San Juan	Dine College Gis Lab	1/1/2003	Navajo Nation, AZ, NM, UT	Northwest New Mexico
350490021	Santa Fe	Sante Fe Airport	7/2/2007	NMED	Central New Mexico
350610008	Valencia	Hobbs	6/11/2009	NMED	Central New Mexico
350390026	Rio Arriba	Coyote Ranger District	3/14/2013	NMED	Northwest New Mexico

2.2 Ozone Design Value Trends at New Mexico Monitors

To gain insight into ozone trends we first consider trends in ozone design value. The ozone design value is the key statistic that describes the air quality status of a given location relative to the level of the National Ambient Air Quality Standards (NAAQS). EPA publishes official design value files annually which include 10-year trends.⁷ The following plots are based on EPA's design value data and are grouped into the four geographic New Mexico regions and compared against the 70 ppb 2015 NAAQS.

Figure 2-2 through 2-5 depict trends in ozone design values for the Permian Basin, Northwest New Mexico (South San Juan Basin), Central New Mexico (Albuquerque Region), and Doña Ana County monitors. Figure 2-2 shows that the Permian Basin ozone design values include the Carlsbad City monitor that exhibits an upward trend, that surpassed and remains above the 70 ppb NAAQS after the 2015-2017 design value period that is in contrast to the Hobbs Jefferson monitor ozone design value trend that has a less pronounced upwind trend over the 2017-2024 period than Carlsbad City. The South San Juan Basin monitors experienced consistent ozone design values fluctuating between 72 to 60 ppb across the five monitors as depicted in Figure 2-3, only surpassing the NAAQS in the earlier analyzed years. The Albuquerque and Doña Ana Regions, represented by Figure 2-4 and Figure 2-5, similarly experience relatively consistent observed ozone design values with larger value fluctuations ranging from 80 to 60 ppb. La Union monitor in the Don Ana Region does experience a subtle, yet consistent increasing trend whereas all other monitors fluctuate with design values relative dips in 2009-2011 and 2014-16 and peaks in 2011-2013 and 2019-2021. Multiple Doña Ana monitors have design values that exceeded the 2015 NAAQS over the period.

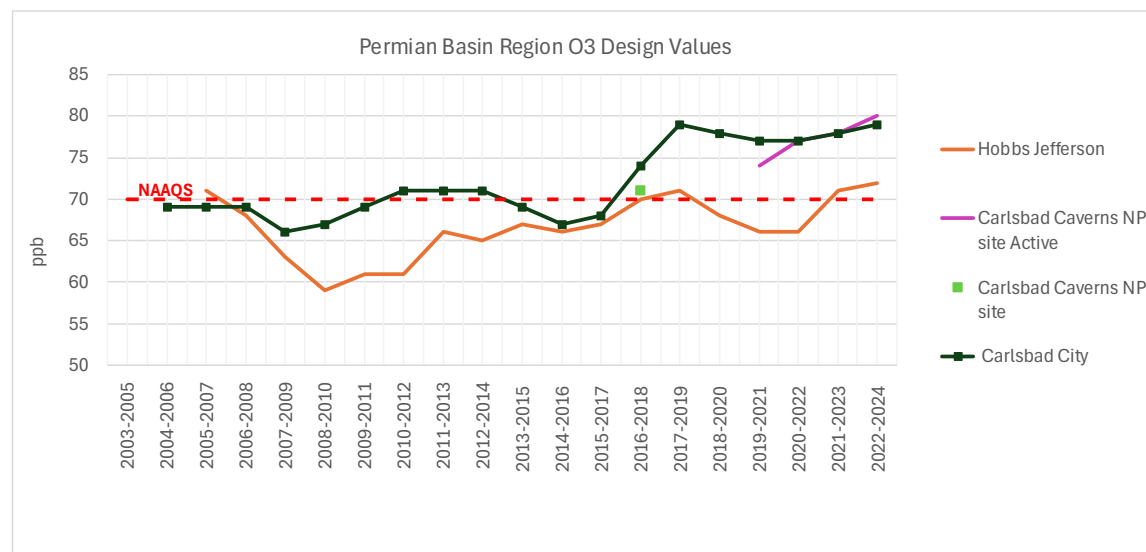


Figure 2-2. Ozone design value trends for the Permian Basin region monitors.

⁷ <https://www.epa.gov/air-trends/air-quality-design-values>

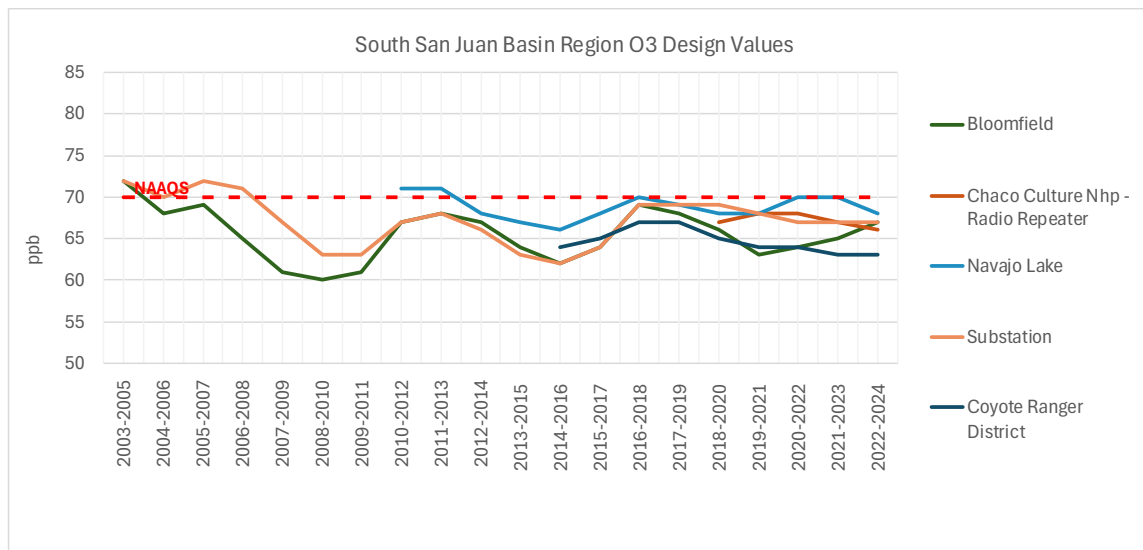


Figure 2-3. Ozone design value trends for the South San Juan Basin region monitors.

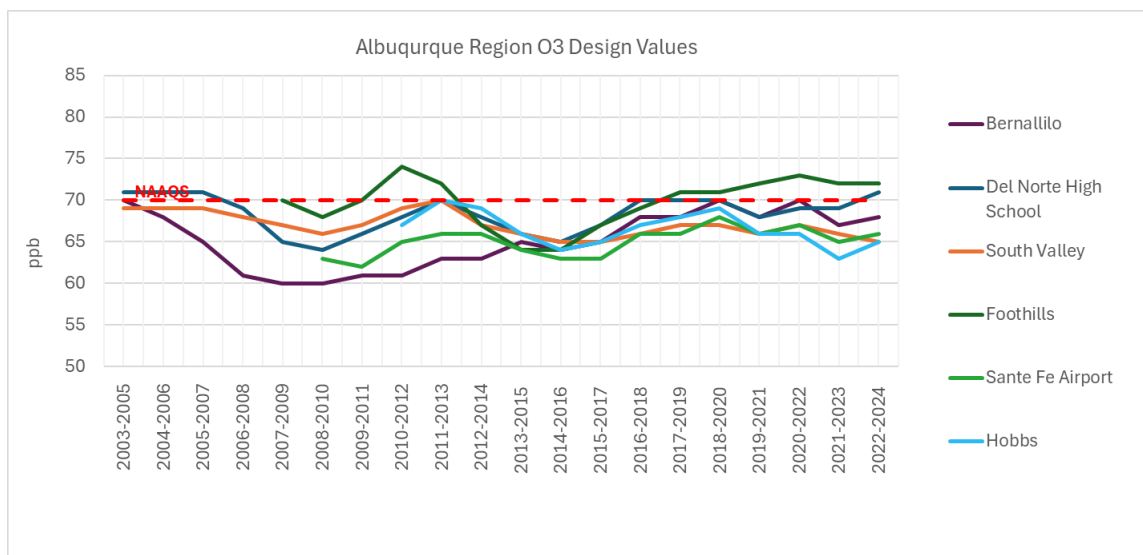


Figure 2-4. Ozone design value trends for the Albuquerque region monitors.

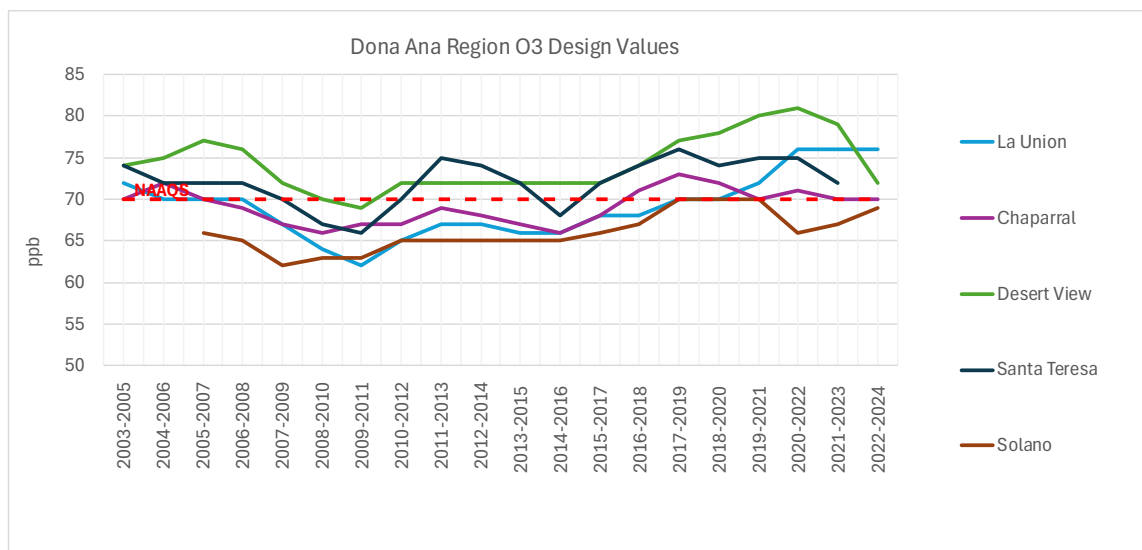


Figure 2-5. Ozone design value trends for the Doña Ana region monitors.

2.3 Permian Basin Ozone Trends

Given the recent increases in ozone in the southeast corner of New Mexico, we provide a more in-depth evaluation of ozone trends for that region. These monitors are within or in close proximity to the Permian Basin Oil and Gas development region, and previous studies have established air quality impacts from emissions from the Permian Basin (Benedict et al., 2020). Note that the current National Park Service (NPS) monitor at Carlsbad Caverns (AQS ID = 350150010) has been active since 2019. Prior to commencement of the current Carlsbad Caverns monitor, there was another monitor at the same Carlsbad Caverns location (AQS ID = 350153001) that measured ozone from 2006 to 2018. For the following analysis we combine the two Carlsbad Caverns datasets. Table 2-2 provides details on the Permian Basin region monitors.

Table 2-2. New Mexico Permian Basin Monitoring.

AQS Site ID	County Name	Local Site Name	Monitor Begin Date	Monitor End Date	Pollutants Monitored	Reporting Agency
350150010	Eddy	Carlsbad Caverns	7/17/2019	NA	O ₃ , met	NPS
350153001	Eddy	Carlsbad Caverns (Inactive)	6/15/2006	10/31/2018	O ₃ , met	NPS
350151005	Eddy	Carlsbad City	8/13/1997	NA	O ₃ , NO, NO ₂	NMED
350250008	Lea	Hobbs Jefferson	8/20/2004	NA	O ₃ , NO, NO ₂	NMED

2.3.1 Distributions of Ozone Exceedances

The first set of analyses considers the number of exceedance days that occurred at the three Permian Basin region monitors. An exceedance is defined as a day for which the maximum daily 8-hour average (MDA8) ozone concentration exceeded 70 ppb which is the 2015 ozone NAAQS (i.e., the measured MDA8 ozone concentration is 71.0 ppb or higher).

Figure 2-6 to Figure 2-8 display the frequency of ozone exceedances by year, month, and day-of-the-week for the three monitors in the Permian Basin. Figure 2-6 shows a sharp upward trend in the number of ozone exceedances that coincides with rapid increase in the Permian Basin O&G production starting in 2017. There are fewer exceedances in 2020 that coincides with O&G activity reductions due to the COVID-19 pandemic. Carlsbad City and Carlsbad Caverns consistently experience more exceedance than Hobbs Jefferson, which is located farther east near the Texas border. Figure 2-7 depicts occurrences of exceedances from May to August with values peaking in July as to be expected with warmer months. Lastly, Figure 2-8 represents a relatively consistent distribution of ozone exceedances by day-of-the-week with a slightly lower frequency on Sundays and Mondays and with an outlier of substantially more exceedance days on Thursdays at Carlsbad City. The reason for more exceedances on Thursdays at Carlsbad City is unknown.

The differences in ozone between weekdays and weekend days has been used to infer whether ozone formation is more NO_x- or VOC-sensitive with higher ozone on weekend days indicating more VOC-sensitivity as the lower morning NO_x emissions on weekend days causes increases in ozone (the “weekend effect”). For Carlsbad Cavern, the average number of exceedance days on the weekend (14.5) is identical to the average on a weekday (14.6). For both Carlsbad City and Hobbs, the average number of exceedance days on weekdays (23.4 and 6.2) are greater than on the weekend (20.0 and 3.5) suggesting more NO_x-sensitive ozone formation conditions.

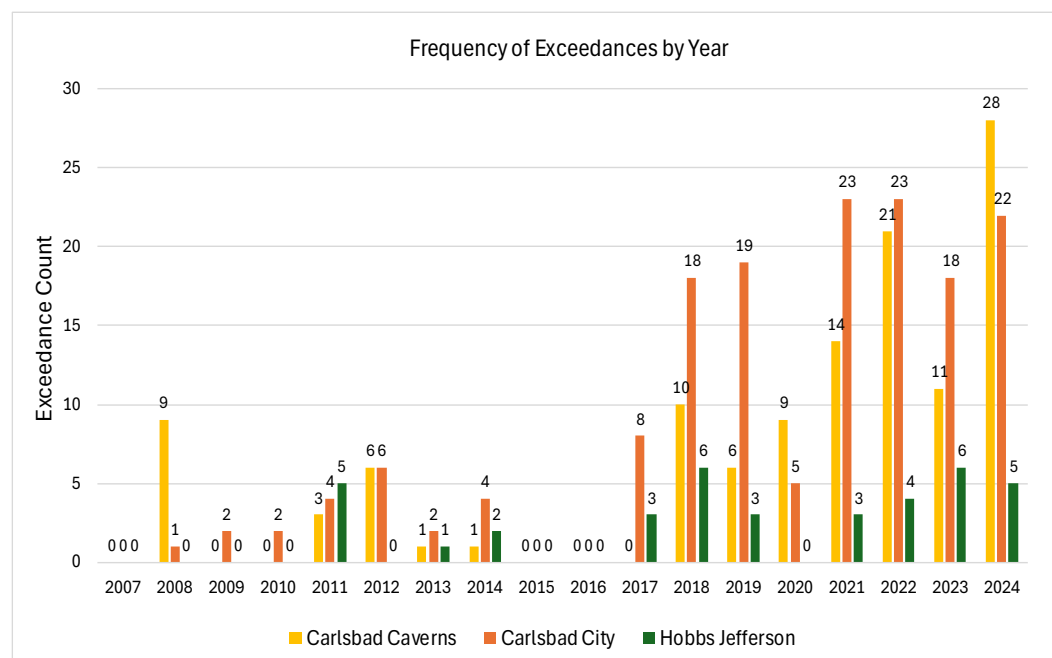


Figure 2-6. 2007 to 2024 trends in ozone exceedances.

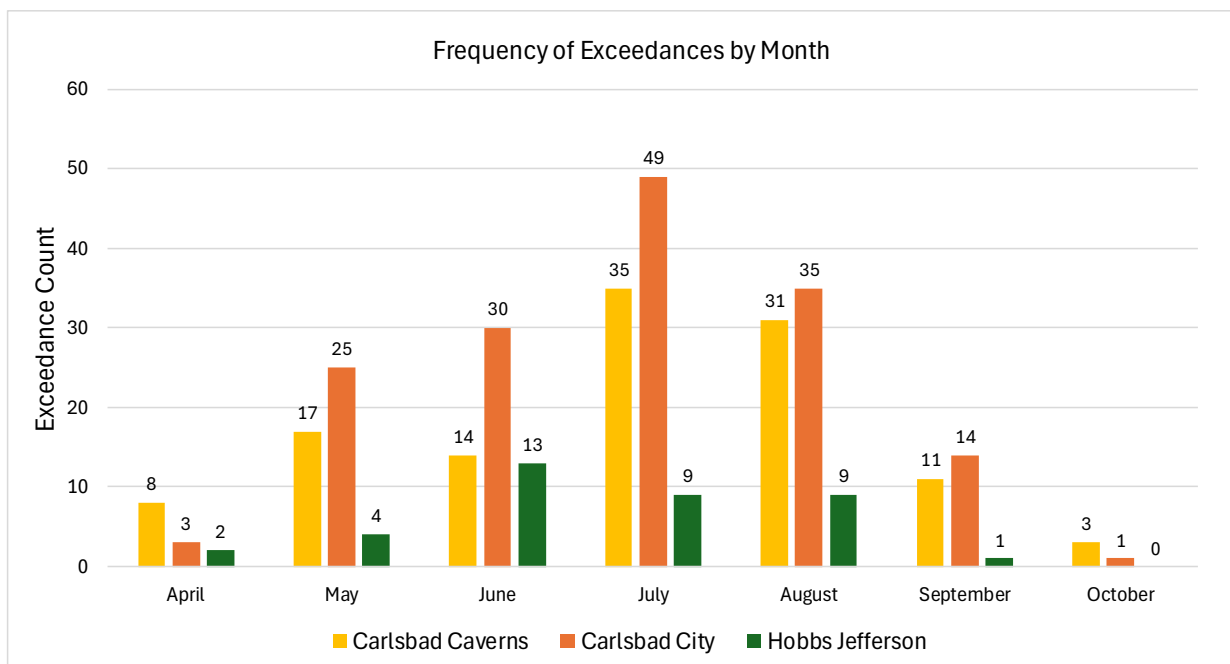


Figure 2-7. Ozone exceedances by month from April through October during 2007 to 2024.

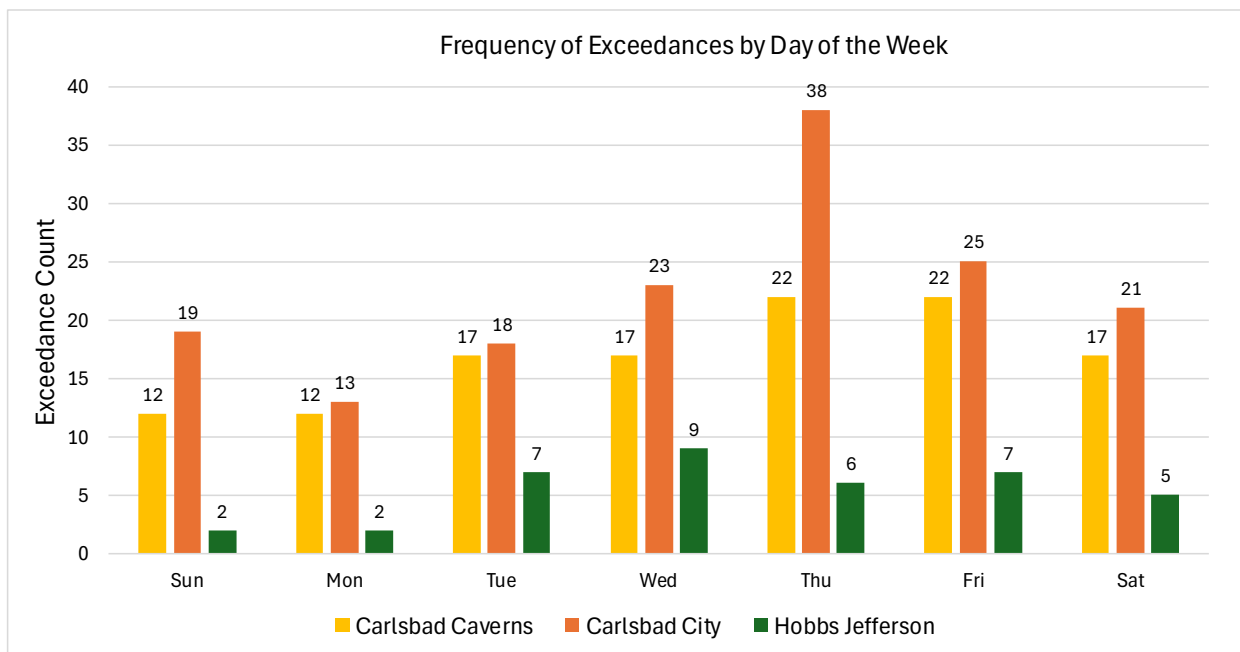


Figure 2-8. Ozone exceedances by day-of-week during 2007 to 2024.

Figure 2-9 focuses on ozone exceedances at the Carlsbad City monitor to investigate the possible cause of the fewer exceedances in 2020 compared to other years since 2017. Per the Energy Information Agency (EIA), trends of Permian basin oil and gas production and the number of new wells (“spuds”) per year are displayed. While there was no material decrease in oil or gas production in 2020, EIA data estimates that there were substantially fewer spuds in 2020, which suggests fewer emissions which could have contributed to fewer exceedances in 2020. Additional analysis would be required to assess emission differences between years to test this hypothesis more robustly.

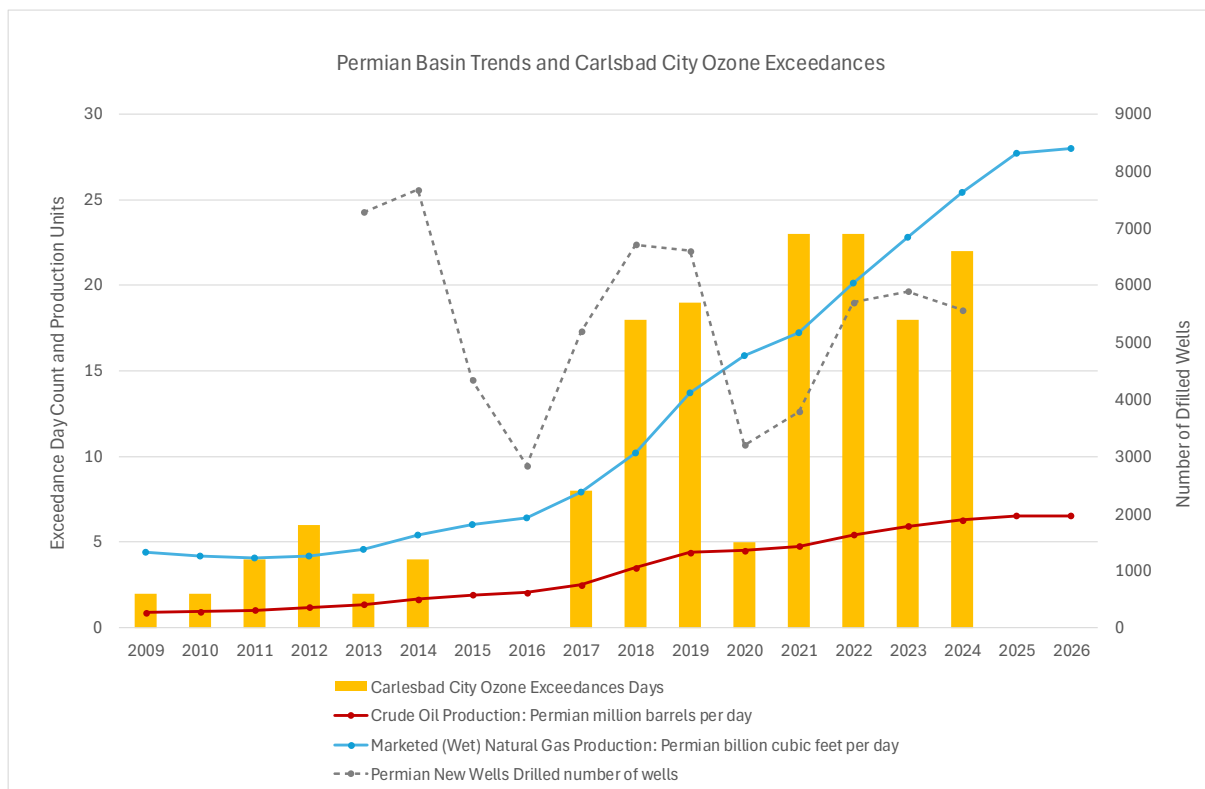


Figure 2-9. 2009 to 2024 ozone exceedances at Carlsbad City compared with Permian Basin oil and gas activities.

2.3.2 EPA’s Meteorologically-Adjusted Ozone Trends

The EPA annually releases a meteorologically-adjusted ozone trend analysis.⁸ The purpose of the meteorological-adjustment is to account for variations in weather conditions since they play a key role in determining ozone concentrations. EPA uses a statistical model to adjust for weather-based variability in seasonal ozone concentrations to provide a more accurate assessment of the underlying trend in ozone caused by emissions.

EPA’s observed and meteorologically-adjusted MDA8 ozone trends averaged over all 974 national monitors from May through September for seasonal mean, 90th percentile and 98th percentile from 2000 to 2023 are presented in Figure 2-10. The average national trends show substantial decreases for the mean, 90th percentile and 98th percentile MDA8 ozone for both unadjusted and adjusted trends. The rate of ozone reduction over the first decade (i.e., 2000-2010) is greater than the second decade, the downward trend continued at a slower rate from 2010 to the early 2020’s and there was a notable uptick in 2023. The difference between the adjusted and unadjusted values in recent years is minimal which indicates non-extreme meteorological conditions in those years when averaged across the entire U.S.

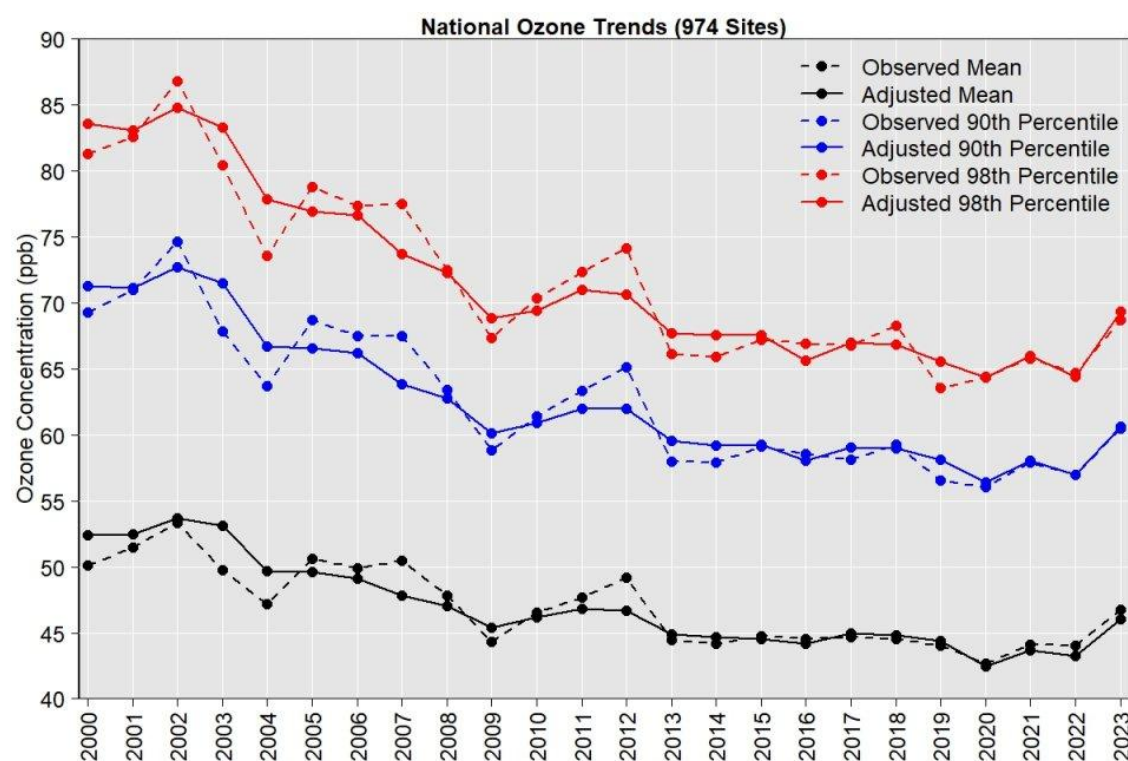


Figure 2-10. EPA MDA8 ozone (solid) and meteorologically-adjusted MDA8 ozone (dashed) trends (2000 – 2023) averaged over all U.S. sites. Seasonal means (black), 90th percentiles (blue) and 98th percentiles (orange).⁹

⁸ <https://www.epa.gov/air-trends/trends-ozone-adjusted-weather-conditions>

⁹ <https://www.epa.gov/air-trends/trends-ozone-adjusted-weather-conditions#:~:text=Nationally%2C%20after%20adjusting%20for%20the,in%202023%20compared%20to%202022.>

EPA’s meteorologically-adjusted trends for the Carlsbad City and Hobbs-Jefferson monitors are presented in Figure 2-11 and 2-12, respectively. The Carlsbad City trends show increases that started in 2017 for each MDA8 metric and a distinct dip in 2020 that aligns with the COVID-19 shutdown period. The Hobbs-Jefferson trend exhibits interannual variations and a large dip in 2020 but no clear trend over the full period. Meteorological adjustments are generally modest except for a few years at the 98th percentile level. The last 5 years have had modest meteorological adjustments at all three percentile levels that indicates that meteorology was fairly typical.

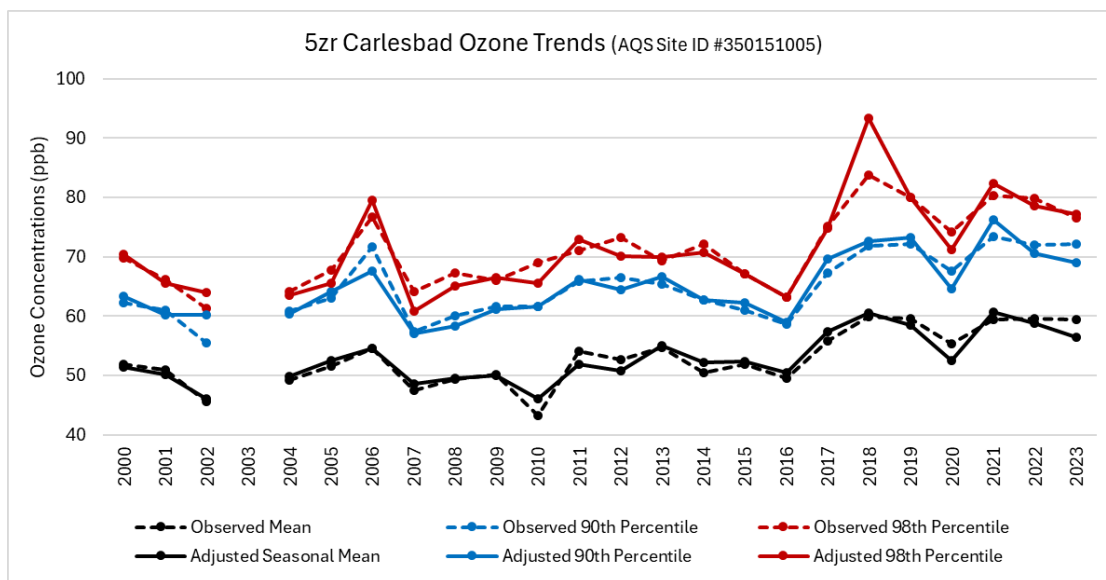


Figure 2-11. EPA MDA8 ozone (solid) and meteorologically-adjusted MDA8 ozone (dashed) trends (2000 – 2023) at the Carlsbad monitor.

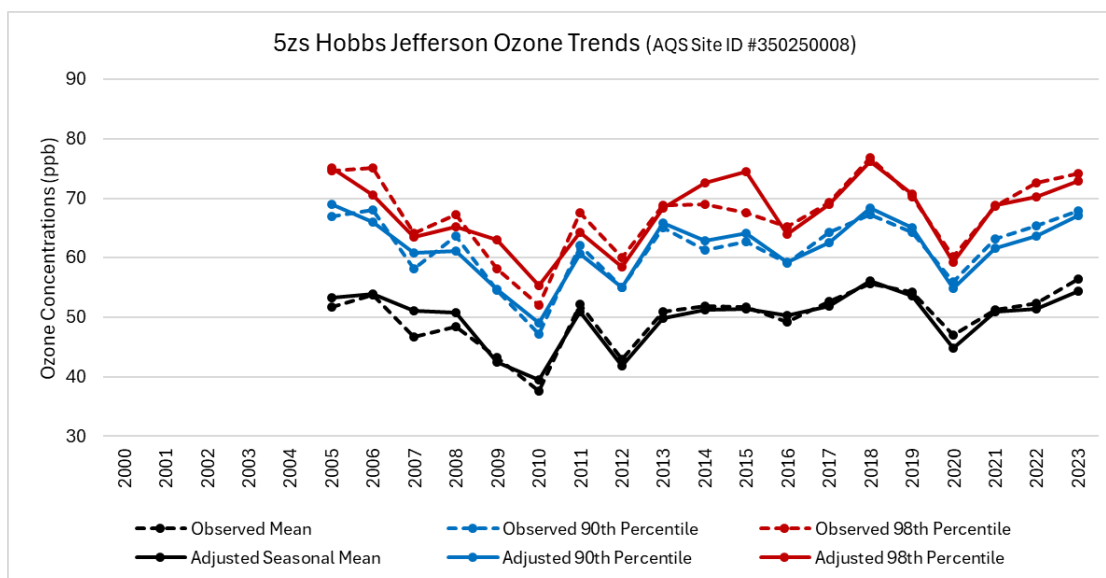


Figure 2-12. EPA MDA8 ozone (solid) and meteorologically-adjusted MDA8 ozone (dashed) trends (2005 – 2023) at the Hobbs-Jefferson monitor.

2.3.3 Additional Ozone Trends

The next analysis considers the correlation between daily maximum 1-hr temperature and MDA8 ozone for the three Permian Basin region monitors. The results are presented for two eight-year periods, an early period (2007 – 2014) and a more recent period (2017-2024) to assess changes that may have occurred between those periods. Temperature is only measured at the Carlsbad Caverns site, so we assume the same daily maximum temperatures for all three sites, since they are located in relatively close proximity and there would not likely be significant variations in temperatures between them.

Figure 2-13 presents scatter plots of daily maximum temperature versus MDA8 ozone for all days in May through September for the two periods. The analysis shows that daily maximum temperatures are most often warmer than 25 degrees Celsius (77 degrees Fahrenheit) and there is not a strong correlation between daily maximum temperature and high ozone. Exceedances tend to occur for most of the daily maximum temperature range except the coolest days (< 18 degrees Celsius; < 64 degrees Fahrenheit) and, interestingly, the warmest days (~ 40 degrees Celsius; 104 degrees Fahrenheit) tend to not be exceedance days. This is in contrast to other locations in the U.S. that often only have ozone exceedances on relatively infrequent warm days. Given the consistently warm climate in this region, high daily maximum temperature is not a necessary condition for high ozone and other factors such as wind speed and direction, humidity, precipitation, and vertical mixing may play a larger role. As in Texas, when highest ozone concentration days frequently occur during the shoulder seasons, very high temperatures are likely causing a lot of surface heating and increasing vertical mixing that dilutes the ozone precursor emissions.

Figure 2-14 and Figure 2-15 present daily maximum temperature and MDA8 ozone distributions for the early period and recent period using box and whisker plots. Box and whisker plots have a box representing the 25th and 75th percentiles (i.e., the middle 50% which is also referred to as the interquartile range [IQR]). The whiskers represent the minimum and maximum values provided they do not exceed 1.5 times the IQR. Values that exceed 1.5 times the IQR are considered outliers and are represented as points. The median value is displayed as a line within the box. The median and 75th percentile of the daily maximum temperature has increased by approximately 1 degree Celsius over the 10-year time period, while the median MDA8 and IQR of the MDA8 ozone has increased by approximately 5 ppb over the same period. The recent period also has many higher outlier values than the early period; many of these days have ozone exceedances and drive the much higher ozone design values seen in recent years.



Figure 2-13. Scatter plots of daily maximum temperature and MDA8 ozone for 2007 to 2014 (left) and 2017-2024 (right), for Carlsbad Caverns (top), Hobbs Jefferson (middle) and Carlsbad City (bottom).

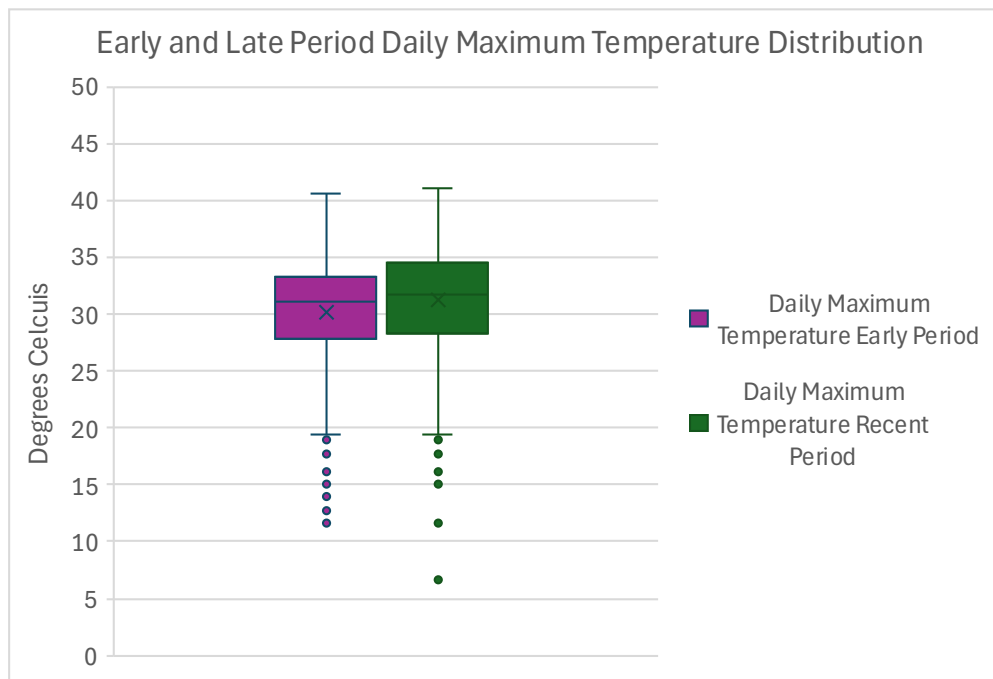


Figure 2-14. Temperature distribution at Carlsbad City for the early (2007-2014) and recent (2017-2024) periods.

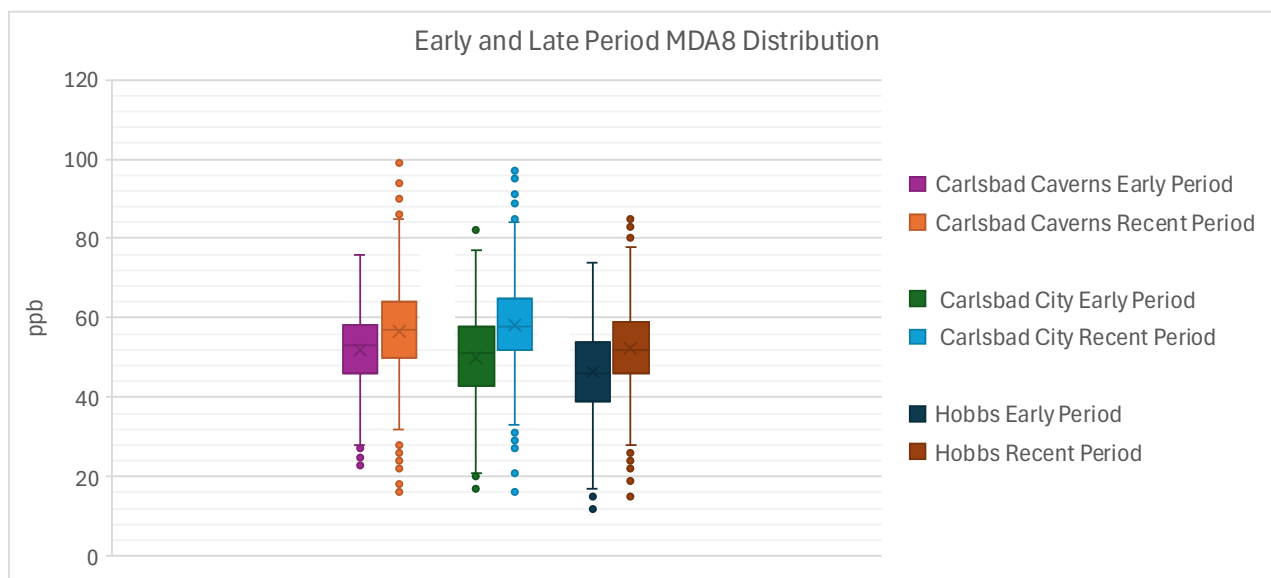


Figure 2-15. MDA8 distribution for the early (2007-2014) and recent (2017-2024) periods.

3.0 OZONE PRECURSOR TRENDS

3.1 Surface NO₂ Trends

The Carlsbad City and Hobbs Jefferson monitors both have long-term records of NO₂ measurements. Daily NO₂ arithmetic mean concentrations and daily 1-hour maximum concentrations were obtained from the Air Quality System (AQS) for 2007 through 2024 and plotted in Figure 3-1.¹⁰ Carlsbad City monitor observed rapid increases in annual average ozone concentrations for both metrics starting in 2017. At the Hobbs Jefferson monitor, NO₂ concentrations generally decreased from 2007 to 2017 with a minimum in 2021 and increases since then.

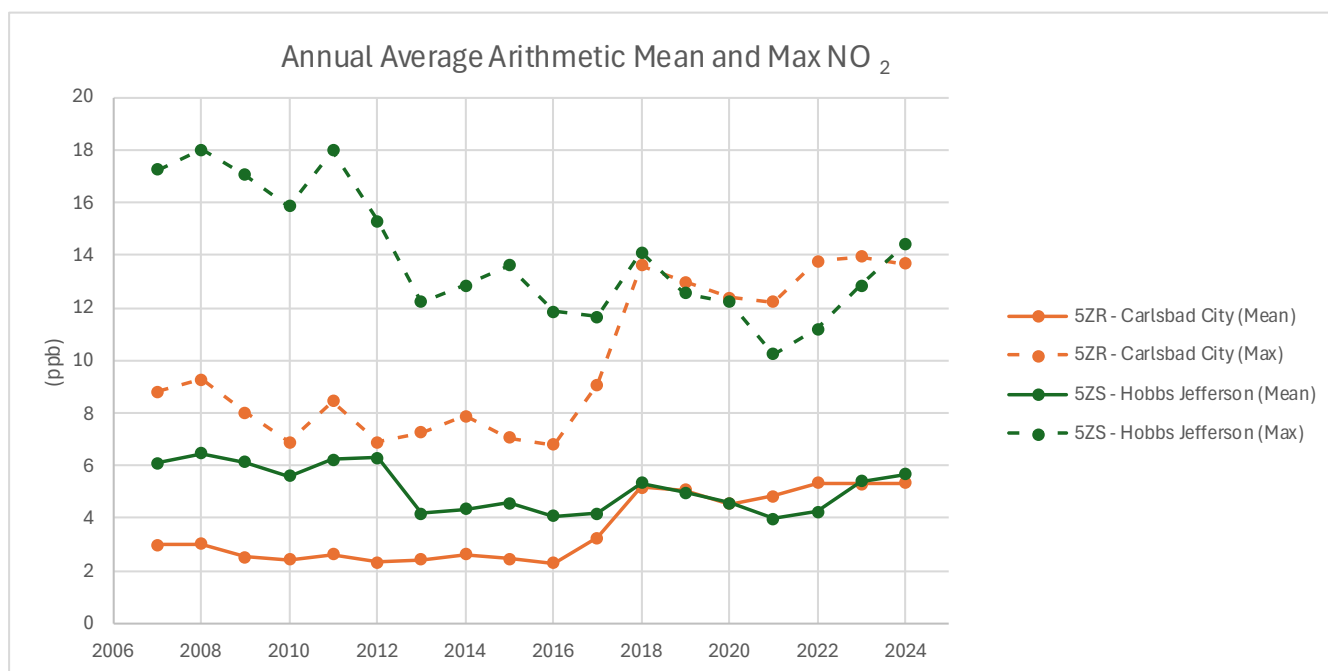


Figure 3-1. 2007 to 2024 trends in annual NO₂ concentrations.

Figure 3-4 presents NO₂ concentrations by day-of-the-week and by early period (2007 to 2014) and recent period (2017 to 2024) for the Carlsbad City and Hobbs Jefferson monitors. Comparing the early and recent periods for Hobbs Jefferson shows a decrease of approximately 1 ppb over the two periods and distinctly lower NO₂ concentrations on weekend days compared to weekdays, which appears to be more defined in the early period compared to the recent period. For Carlsbad City, the NO₂ concentrations have increased dramatically (approximately doubled) from the early period to the recent period and are very comparable in magnitude to Hobbs-Jefferson concentration in the recent period.

¹⁰ https://aqs.epa.gov/aqsweb/airdata/download_files.html

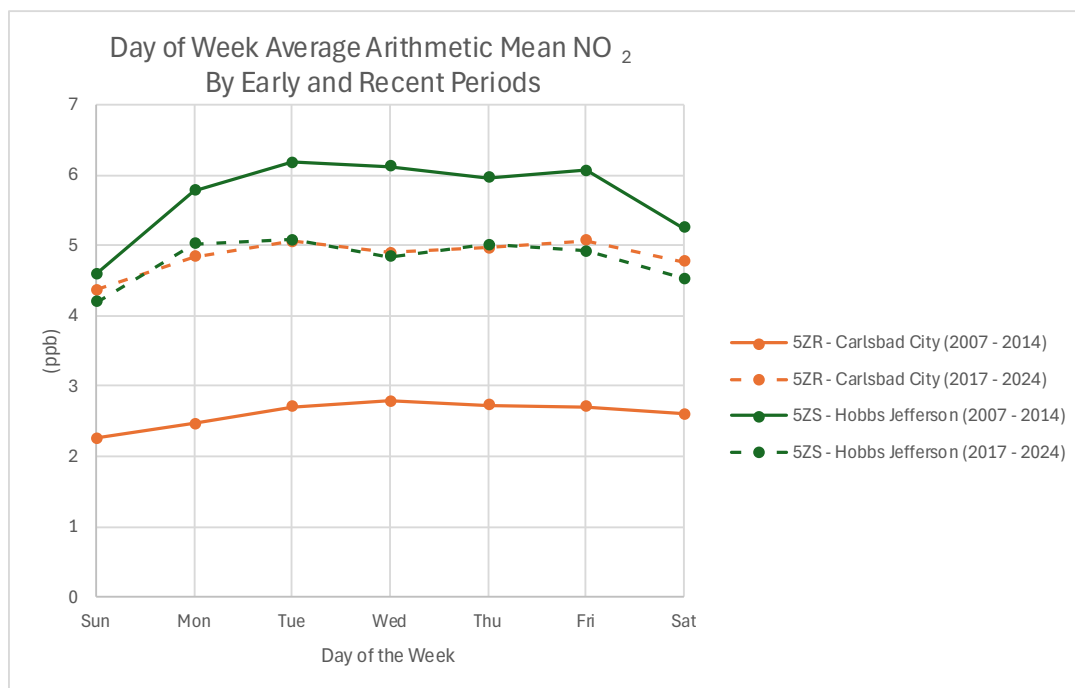


Figure 3-2. Day-of-week annual average NO₂ concentration for 2007-2014 and 2017-2024 periods.

Figure 3-3 depicts the time of day when peak 1-hr NO₂ concentrations occur by early and recent periods. There is minor change in the timing of peak 1-hour NO₂ concentrations between the two different periods. Peak 1-hr NO₂ concentrations occur most frequently at 5 and 6 am, when the boundary layer is most stable and there is little dispersion and also no photochemistry. It is very unlikely to observe peak 1-hr NO₂ during the hours of 10 am to approximately 4 pm when there is more vertical mixing. At the Hobbs Jefferson monitor, the evening hours may have peak 1-hr NO₂ concentrations while that is less likely to be the case at the Carlsbad City monitor location. Figure 3-4 presents peak 1-hr NO₂ concentrations by time of day for early and recent periods. Peak 1-hr NO₂ concentrations are highest throughout the morning and evening at the Hobbs Jefferson monitor, while Carlsbad does not have a strong diurnal variation in NO₂ concentrations.

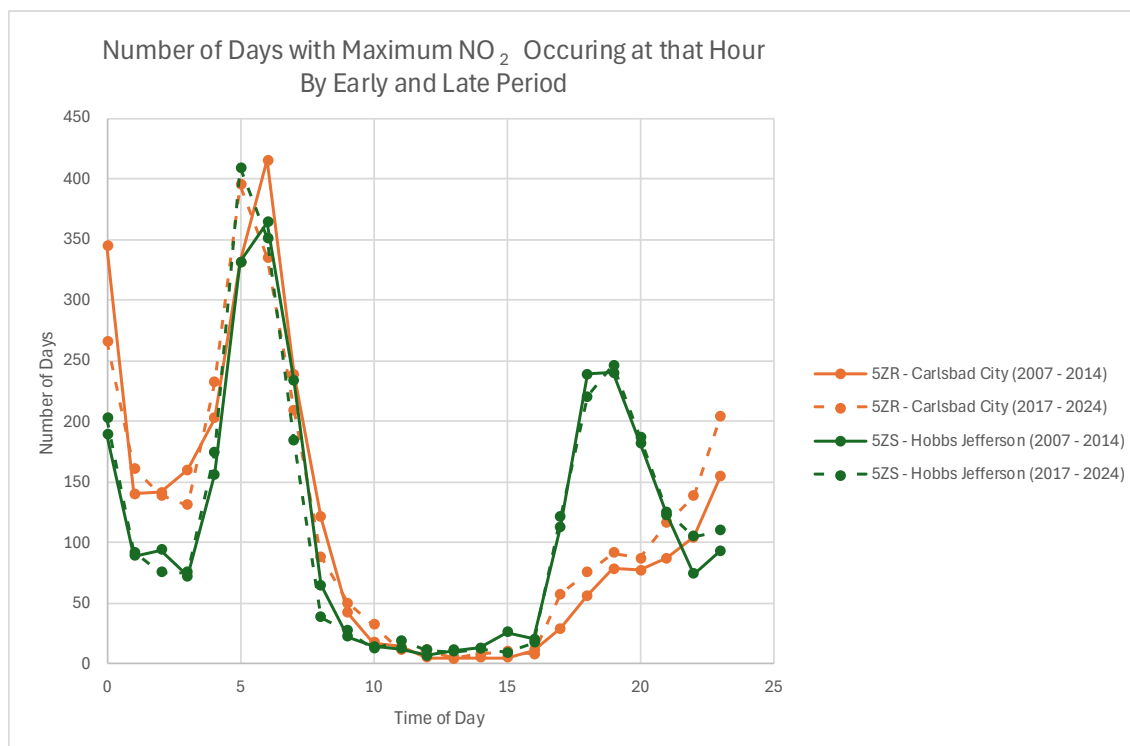


Figure 3-3. Frequency of peak 1-hr NO₂ concentration by time-of-day for 2007-2014 and 2017-2024 periods.

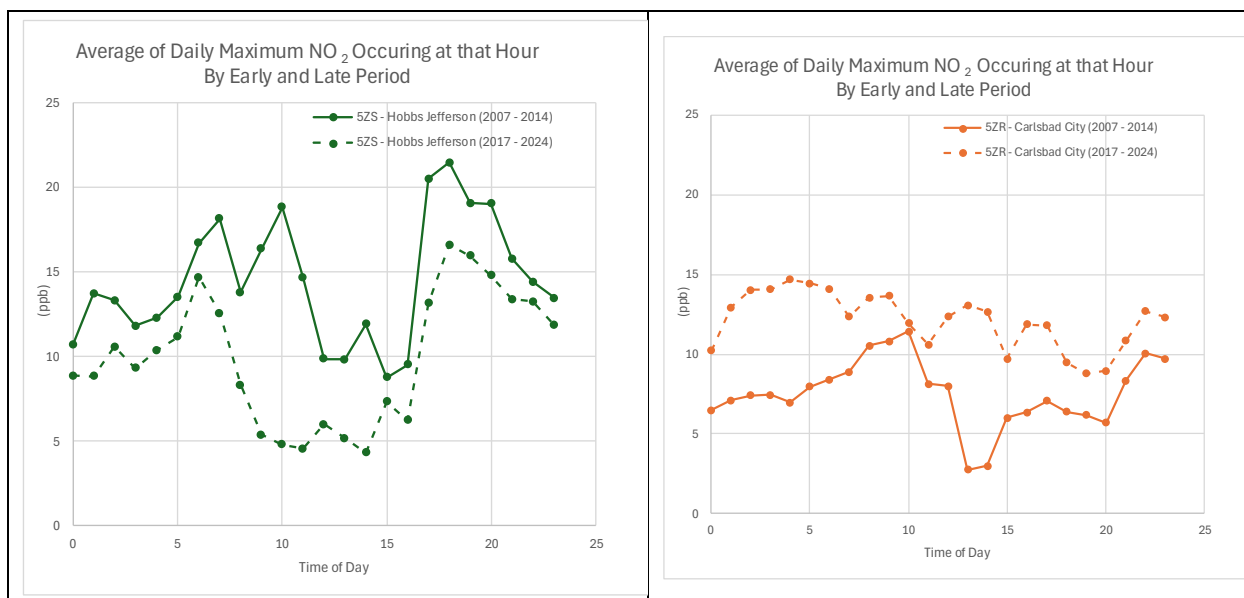


Figure 3-4. Peak 1-hr NO₂ concentration by time of day 2007-2014 and 2017-2024 periods for Hobbs (left) and Carlsbad City (right).

3.2 Satellite Tropospheric NO₂ Columns Trends

Trends in satellite measurements of tropospheric NO₂ are presented in this section. Tropospheric NO₂ is a column product which estimates the number of molecules of NO₂ in an atmospheric column from the Earth's surface to the top of the troposphere (~10 km). The measurements are based on molecular absorption of backscattered sunlight in the visible and ultraviolet wavelengths and are processed to remove the contribution from the upper atmosphere (i.e., above the troposphere).

This analysis is based on the tropospheric NO₂ column product from NASA's Ozone Monitoring Instrument (OMI) which began collecting data in 2006 and is still operational. Level 3 OMI data (v004) were downloaded and tropospheric NO₂ column values for the nearest grid cell to the monitor were extracted for each day in April through September 2006 to 2023.¹¹ The spatial resolution of OMI L3 grid cells is 0.25 x 0.25 degrees which is approximately 25 km.

In addition to OMI, the Tropospheric Monitoring Instrument (TROPOMI) on the European Space Agency's (ESA) Sentinel-5 satellite also measures tropospheric NO₂. The TROPOMI instrument acquires tropospheric NO₂ column contents from low Earth orbit (~824 km above ground level) once per day globally at approximately 13:30 local standard time. Data is available from May 2018 to present. Level 3, monthly TROPOMI data were obtained and the same monitor grid cell NO₂ columns were extracted.¹² The spatial resolution of the TROPOMI L3 grid cells is 0.01 x 0.01 degrees which is approximately 1 km.

Figure 3-5 displays the satellite tropospheric NO₂ column trends for the Permian Basin monitor grid cells from OMI (2005 to 2023; dashed lines) and TROPOMI (2018 to 2024; solid lines). Prior to 2018, tropospheric NO₂ is consistently higher at the Hobbs Jefferson location compared to the Carlsbad locations. Around 2018 (when TROPOMI came online), both satellites suggest that the Carlsbad City location has the highest tropospheric NO₂ of the three monitoring site locations in the Permian Basin region. 2020 tropospheric NO₂ tended to be lower than the two years prior and the years after 2020, most likely due COVID-19 impacts on changes in activities.

¹¹ https://data.gesdisc.earthdata.nasa.gov/data/Aura_OMI_Level3/OMNO2d.004/2023/OMI-Aura_L3-OMNO2d_2023m0930_v004-2025m0120t142728.he5

¹²https://data.gesdisc.earthdata.nasa.gov/data/HAQAST/HAQ_TROPOMI_NO2_CONUS_M_L3.2.4/2024/HAQ_TROPOMI_NO2_CONUS_QA75_L3_Monthly_092024_V2.4_20250115.nc4

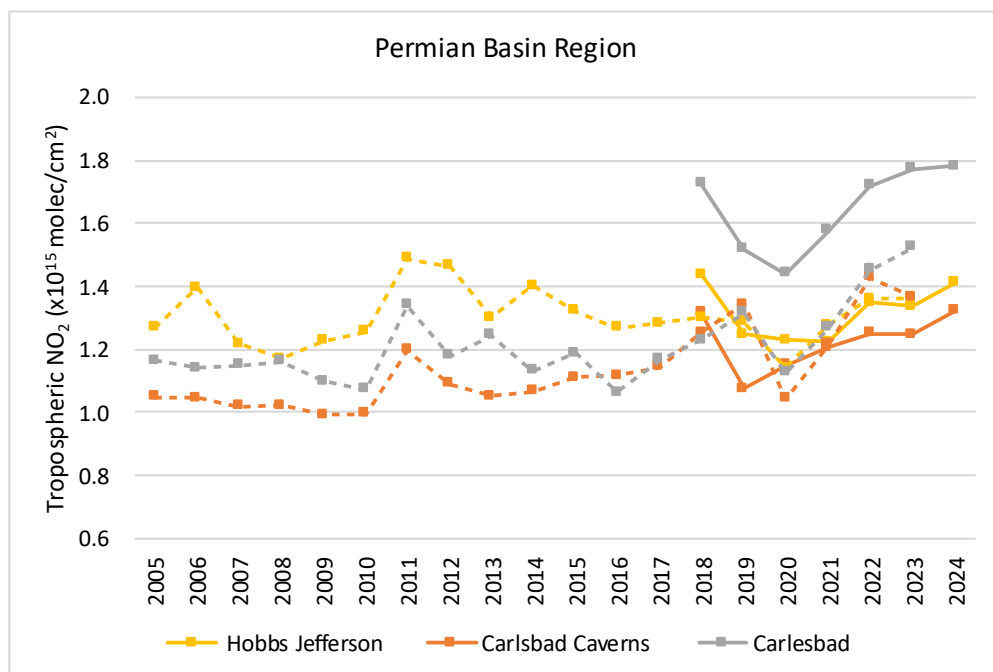


Figure 3-5. Satellite tropospheric NO₂ column trends for the Permian Basin Region. OMI has dashed lines; TROPOMI has solid lines.

Figure 3-6 displays the satellite tropospheric NO₂ column trends for the South San Juan Basin monitor grid cells. The figure reveals rapidly declining tropospheric NO₂ in the San Juan Basin, with the most noticeable reduction observed at the Substation site. Chaco Culture and 3CRD Coyote Ranger District experience the smallest changes, starting and ending around 1.0 x10¹⁵ molecules/cm². OMI data, represented by dashed lines, aligns closely with the solid lines from TROPOMI data, supporting the observed downward trend across various sites such as Bloomfield, Navajo Lake, and Coyote Ranger District.

The satellite tropospheric NO₂ column trends for the Albuquerque Region shown in Figure 3-7 depict slight reductions over the full time period but relative flat trends since 2017. TROPOMI estimates tend to be higher than OMI estimates for most monitor locations in this region. Figure displays tropospheric NO₂ trends for the Doña Ana Region monitors. The trend patterns are similar to those in the Albuquerque Region, with slight decreases over the full time period but relatively flat trends since 2017 and TROPOMI being higher than OMI.

TROPOMI estimates are generally higher than OMI estimates but exhibit similar year-to-year changes over the period of overlap. The reason for the higher TROPOMI estimates compared to OMI is that TROPOMI uses a different cloud retrieval and a surface reflectance correction that results in larger tropospheric NO₂ columns over polluted areas.

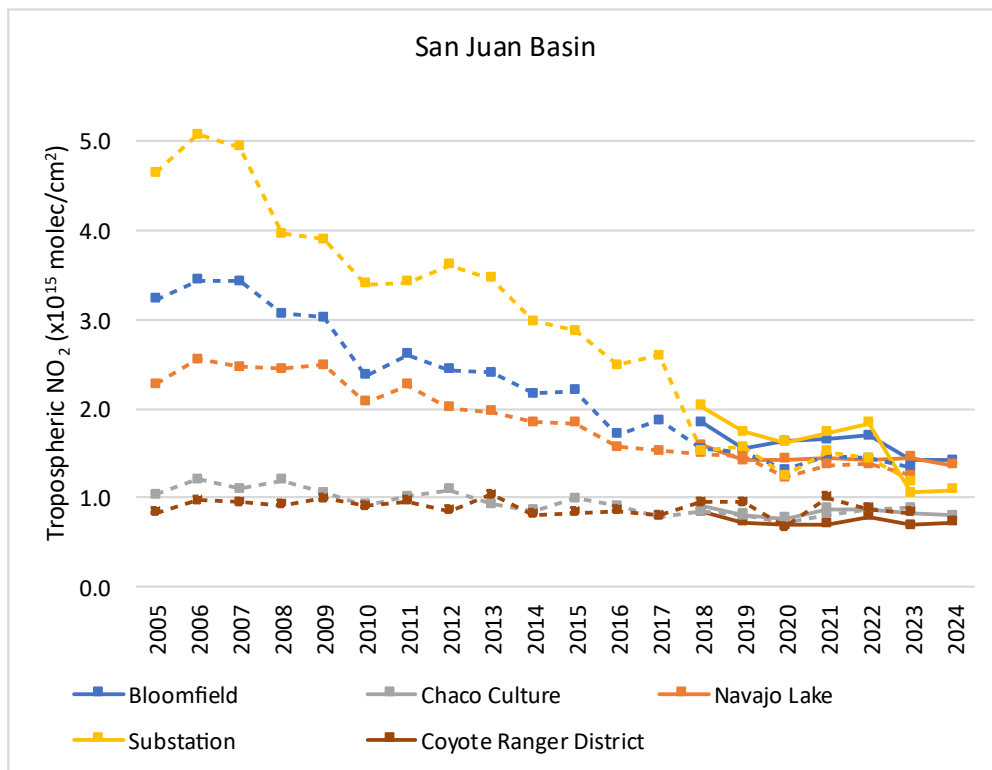


Figure 3-6. Satellite tropospheric NO₂ column trends for the San Juan Basin Region. OMI has dashed lines; TROPOMI has solid lines.

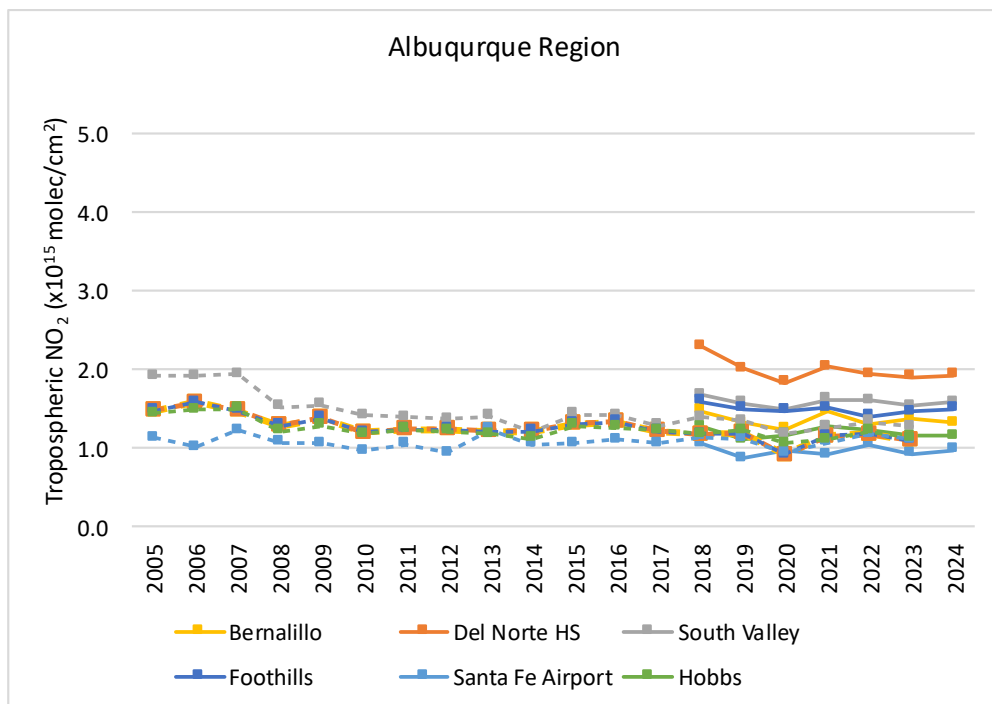


Figure 3-7. Satellite tropospheric NO₂ column trends for the Albuquerque Region. OMI has dashed lines; TROPOMI has solid lines.

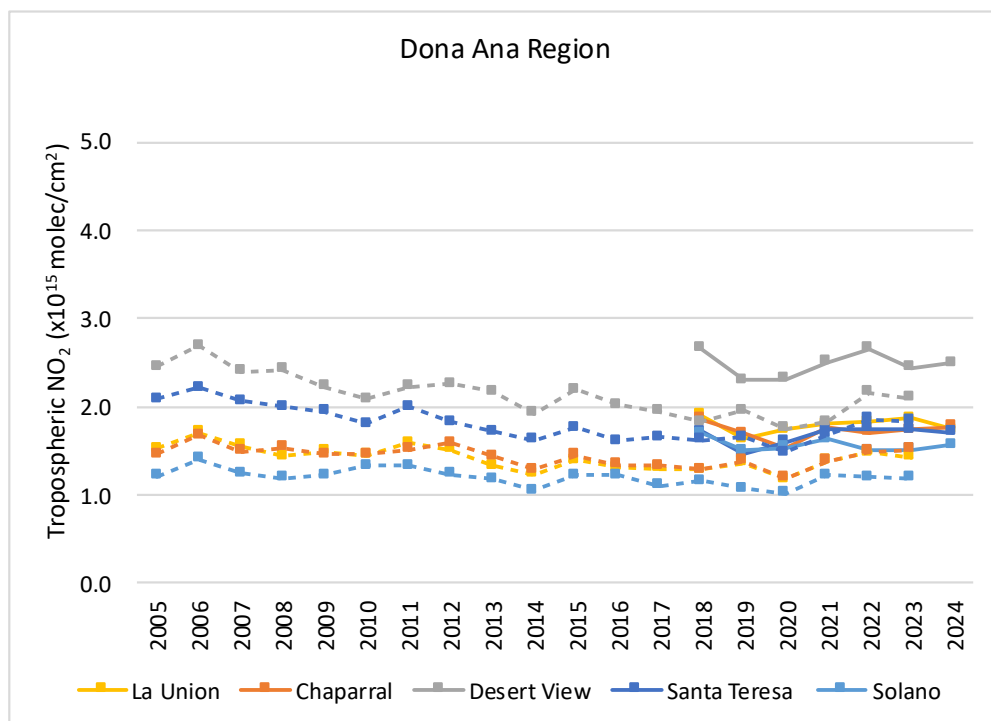


Figure 3-8. Satellite tropospheric NO₂ column trends for the Doña Ana Region. OMI has dashed lines; TROPOMI has solid lines.

3.3 Spatial Maps of TROPOMI NO₂, HCHO, and HCHO to NO₂ Ratios

Figure 3-9, 3-10 and 3-11 present TROPOMI tropospheric columns for 2022 averaged over all days during May through September for NO₂, HCHO (Formaldehyde), and Formaldehyde to NO_x ratios (FNR), respectively.

The TROPOMI site describes the NO₂ and HCHO products as follows:¹³

TROPOMI Nitrogen Dioxide (NO₂):

Nitrogen Dioxide (NO₂) plays a crucial role as a precursor to anthropogenic ozone and is a primary factor in generating various airborne compounds, such as nitric acid, fine particles, peroxyacetyl nitrate, nitrosamines, and nitro-polycyclic aromatic hydrocarbons. The TROPOMI instrument on Sentinel-5 Precursor retrieves tropospheric and stratospheric NO₂ column products. It distinguishes stratospheric and tropospheric contributions, calculating air-mass factors for accurate conversion. TROPOMI NO₂ data comes in various timeliness levels, including Near Real Time (NRTI), Offline (OFFL), and Reprocessed (RPRO) products. Each level corresponds to different processing baselines, ensuring users have access to timely information, long-term datasets, and improved accuracy through continuous updates and refinements. The OFFL and RPRO products, with distinct identifiers and DOIs, offer comprehensive information on tropospheric NO₂ columns, precision estimates, and quality values, supporting diverse applications and research needs. Note that the data file contains tropospheric NO₂ column, precision estimates, and a quality

¹³ <https://www.tropomi.eu/data-products>

assurance value (qa_value) for interpreting data quality. Recommendations suggest using pixels with qa_value above 0.75 (or 0.5 for cloud-covered scenes).

TROPOMI Formaldehyde (HCHO):

Long term satellite observations of tropospheric formaldehyde (HCHO) are essential to support air quality and chemistry-climate related studies from the regional to the global scale. Formaldehyde is an intermediate gas in almost all oxidation chains of non-methane volatile organic compounds (NMVOC), leading eventually to CO₂. Non-Methane Volatile Organic Compounds (NMVOCs) are, together with NO_x, CO and CH₄, among the most important precursors of tropospheric O₃. The major HCHO source in the remote atmosphere is CH₄ oxidation. Over the continents, the oxidation of higher NMVOCs emitted from vegetation, fires, traffic and industrial sources results in important and localized enhancements of the HCHO levels. The seasonal and inter-annual variations of the formaldehyde distribution are principally related to temperature changes and fire events, but also to changes in anthropogenic activities. Its lifetime being of the order of a few hours, HCHO concentrations in the boundary layer can be directly related to the release of short-lived hydrocarbons, which mostly cannot be observed directly from space. The excellent signal-to-noise ratio of TROPOMI yields stunning images of HCHO.

Ramboll used Google Earth Engine to obtain, process, and visualize the NO₂, HCHO and FNR data.¹⁴ The formaldehyde to NO₂ ratio (FNR) is a proxy for ozone formation chemistry.¹⁵ A high FNR indicates a more NO_x-sensitive ozone formation chemical regime where decreases in NO_x emissions would reduce ozone, while a low FNR indicates a VOC-sensitive ozone formation regime where decreases in VOC emissions would decrease ozone concentrations. There are also transitional regimes where ozone chemistry could be sensitive to changes in NO_x and/or VOCs. In VOC-sensitive or transitional regimes, decreases in NO_x emissions could potentially lead to increases in ozone concentrations.

Figure 3-9 presents TROPOMI NO₂ columns in New Mexico and adjacent states. Localized regions of higher NO₂ columns (yellow to red) are observed over major cities, including Phoenix, AZ, El Paso, TX, Denver, CO and other cities in Texas. Most of New Mexico is colored dark blue that indicates relatively low NO₂ columns. There are, however, regions of cyan that indicate relatively higher NO₂, including San Juan County in northwest of New Mexico, the Albuquerque region, and the southeast region of New Mexico (i.e., Permian Basin region).

¹⁴ <https://earthengine.google.com/>

¹⁵ Jin, X. et. al. "Inferring Changes in Summertime Surface Ozone-NO_x-VOC Chemistry over U.S. Urban Areas from Two Decades of Satellite and Ground-Based Observations." *Environmental Science & Technology* 54, no. 11 (April 29, 2020): 6518–6529.
<https://doi.org/10.1021/acs.est.9b07785>.

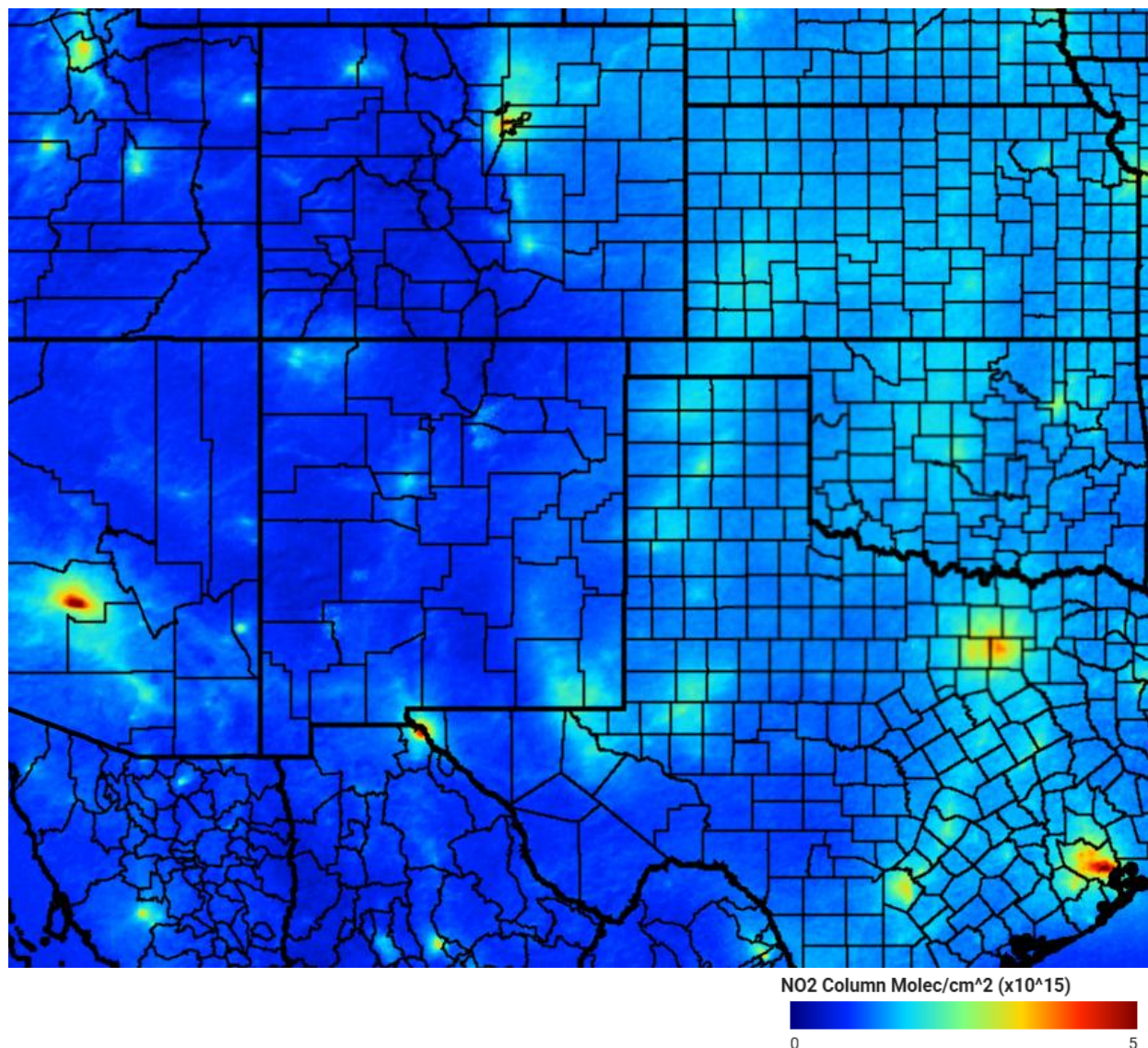


Figure 3-9. TROPOMI tropospheric NO₂ columns for New Mexico and surrounding states for May through September 2022.

Figure 3-10 presents HCHO columns which exhibit a quite different spatial pattern than NO₂. HCHO columns are highest over eastern Texas and Oklahoma and there is a general spatial gradient from east to west, with higher values in the east and lower values in the west. The same spatial gradient exists within New Mexico, and the Permian Basin is a region of higher HCHO within New Mexico. Biogenic isoprene is a major precursor to HCHO.

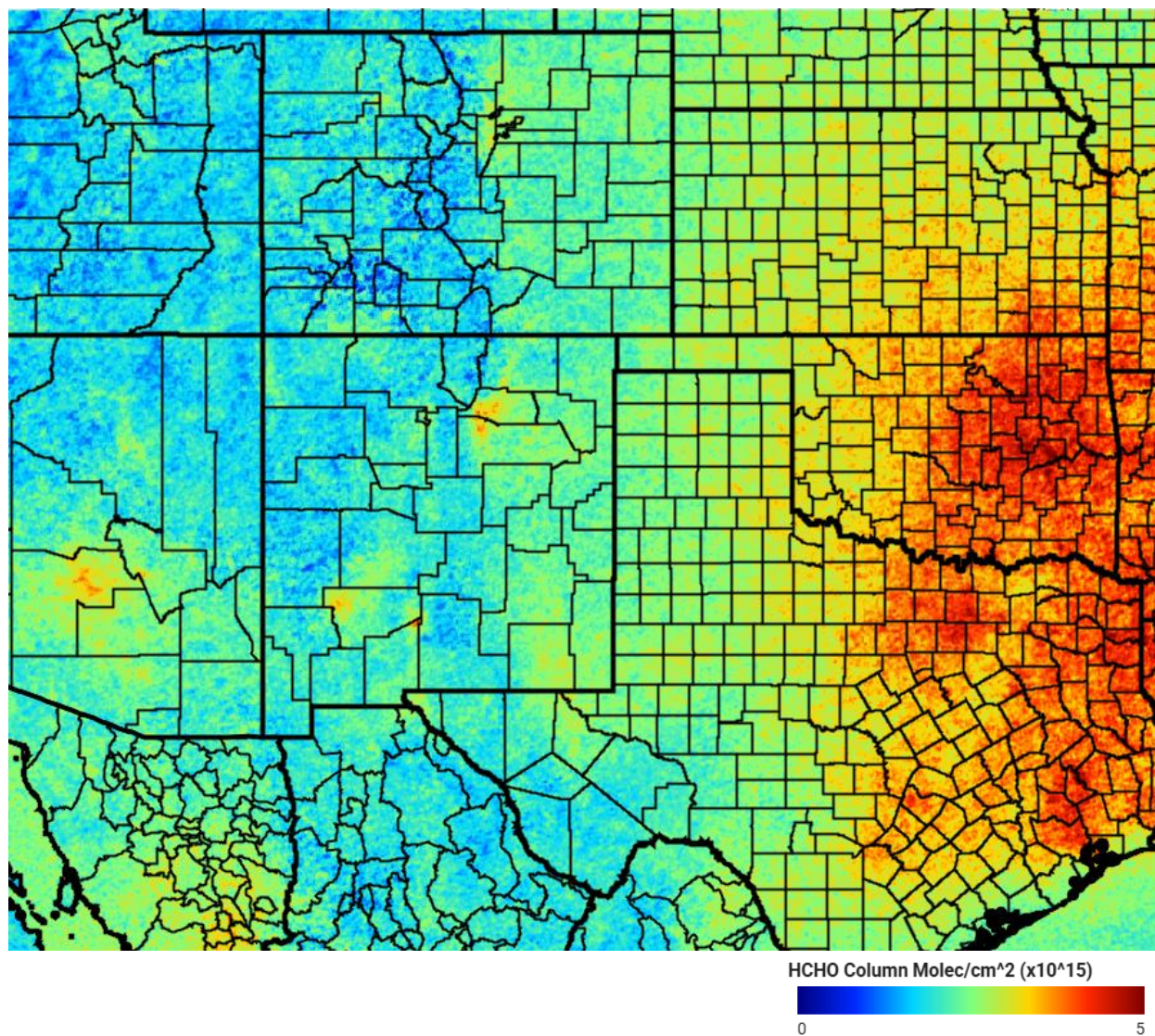


Figure 3-10. TROPOMI tropospheric HCHO columns for New Mexico and surrounding states for May through September 2022.

Figure 3-11 presents FNR which is an indicator of ozone formation chemistry NO_x - versus VOC-sensitive formation regimes. Souri and co-workers (2020) suggest the following ozone formation regimes based on FNR:

- $\text{FNR} < 1.0$ implies VOC-sensitive ozone formation regime;
- $1 < \text{FNR} < 4$ implies transitional ozone formation regime; and
- $\text{FNR} > 4$ implies NO_x -sensitive ozone formation regime.

Most of the region is colored red ($\text{FNR} > 8$) which indicates NO_x -sensitive ozone formation chemistry. There are small regions of cooler colors (blue, purple) that indicate transitional and/or VOC-sensitive ozone formation conditions. All of New Mexico is in the NO_x -sensitive ozone formation regimes, except for small areas in San Juan County, Eddy and Lea Counties (San Juan and Permian Basin O&G production regions) and Bernalillo County (Albuquerque City) that are more transitional or VOC-sensitive.

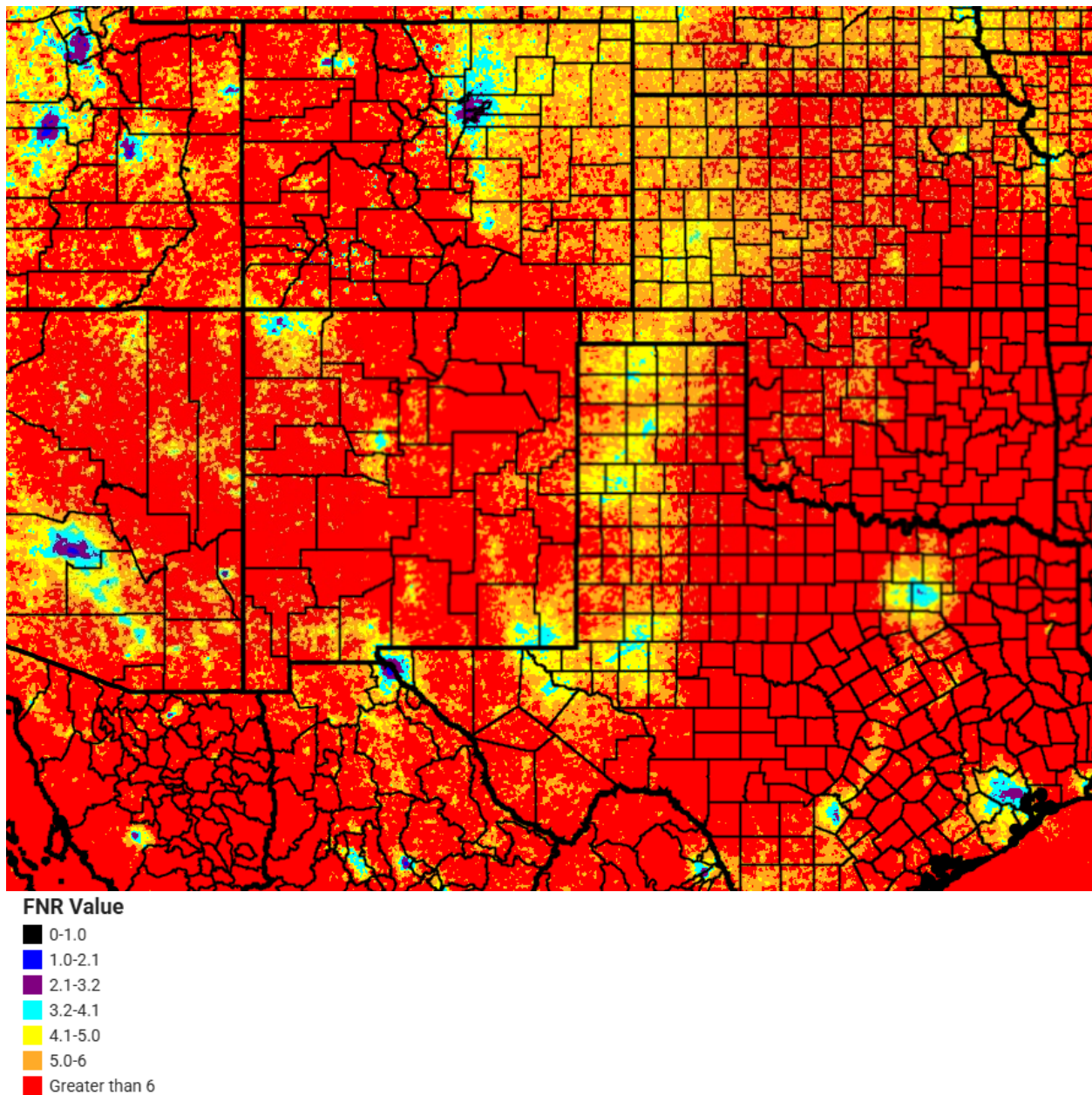


Figure 3-11. TROPOMI tropospheric formaldehyde to NO₂ ratios (FNR) columns for New Mexico and surrounding states for May through September 2022.

4.0 METEOROLOGICAL ANALYSIS

4.1 Wind Patterns

Figure 4-1 depicts monthly average surface wind vectors that identify surface wind and air transport patterns for June through September based on 2015 through 2024 climatology. For all four months and the Permian Basin region of New Mexico, the winds are southeasterly (i.e. air transport is from the southeast), from the Permian Basin region of Texas.

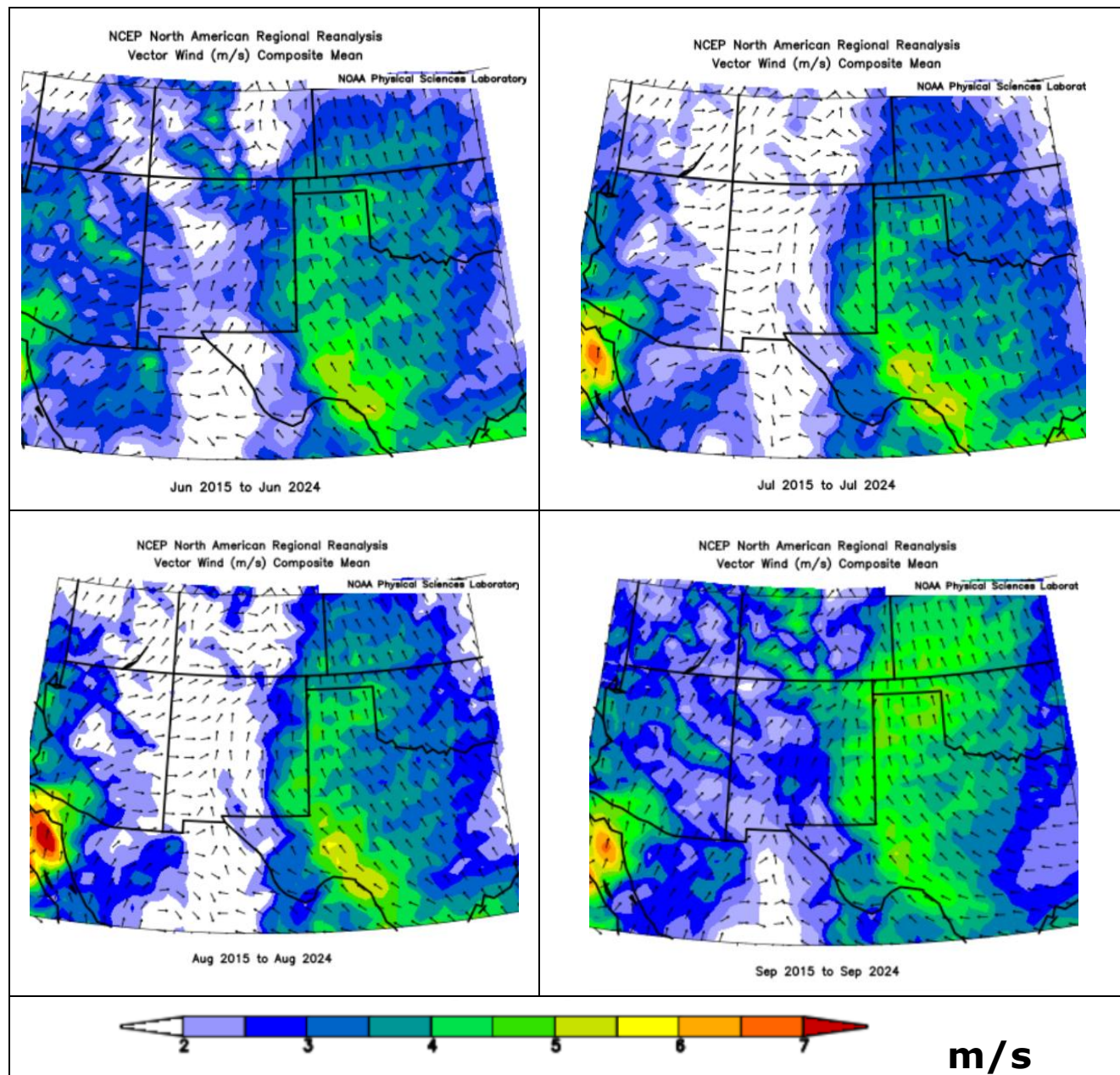


Figure 4-1. Monthly average surface wind vectors for New Mexico and surrounding states.

4.2 Climate Anomaly Analysis by Month for 2020-2023

This section examines monthly climate anomalies from the North American Regional Reanalysis (NARR) project¹⁶ by month for June – August and 2020 – 2023. Results for May and September are contained in Appendix C and the discussion below is for June – August when the majority of the ozone exceedances occur. The top panels in the figures show the average monthly climatology for 1981-2010 (i.e., typical, or normal conditions) for the given parameter and the lower panels show the anomalies for the given year and month (i.e., the differences of the specified year from the climatological average). Figure 4-2 presents air temperature, Figure 4-3 presents average total precipitation at the surface, and Figure 4-4 presents 500 mb geopotential heights. 2020 had slightly higher temperatures than normal and was slightly drier, especially in August 2021. July 2021 was much cooler and wetter than normal, as discussed later, this was during an intensive field study at Carlsbad Caverns. 2022 was slightly warmer in June and July and cooler in August with fairly typical precipitation. And summer 2023 was mostly warmer and drier than typical. With the exception of June 2023, the monthly 500 mb heights in 2020-2023 were higher than the 1981-2010 climatological average. Higher 500 mb heights produce slower wind speeds and warmer temperatures resulting in more favorable ozone formation meteorological conditions, these results could suggest that on more recent years climate change is producing meteorological conditions more favorable to ozone formation in the western states including New Mexico. This analysis shows that fairly typical conditions were present in the 2022 modeling year in New Mexico and nationally.

¹⁶ "The NARR project is an extension of the NCEP Global Reanalysis which is run over the North American Region. The NARR model uses the very high resolution NCEP Eta Model (32km/45 layer) together with the Regional Data Assimilation System (RDAS) which, significantly, assimilates precipitation along with other variables. The improvements in the model/assimilation have resulted in a dataset with substantial improvements in the accuracy of temperature, winds and precipitation compared to the NCEP-DOE Global Reanalysis. For a list of complete list of variables see. [narr_archive_contents.pdf \(noaa.gov\)](https://www.narr.ncep.noaa.gov/narr_archive_contents.pdf)

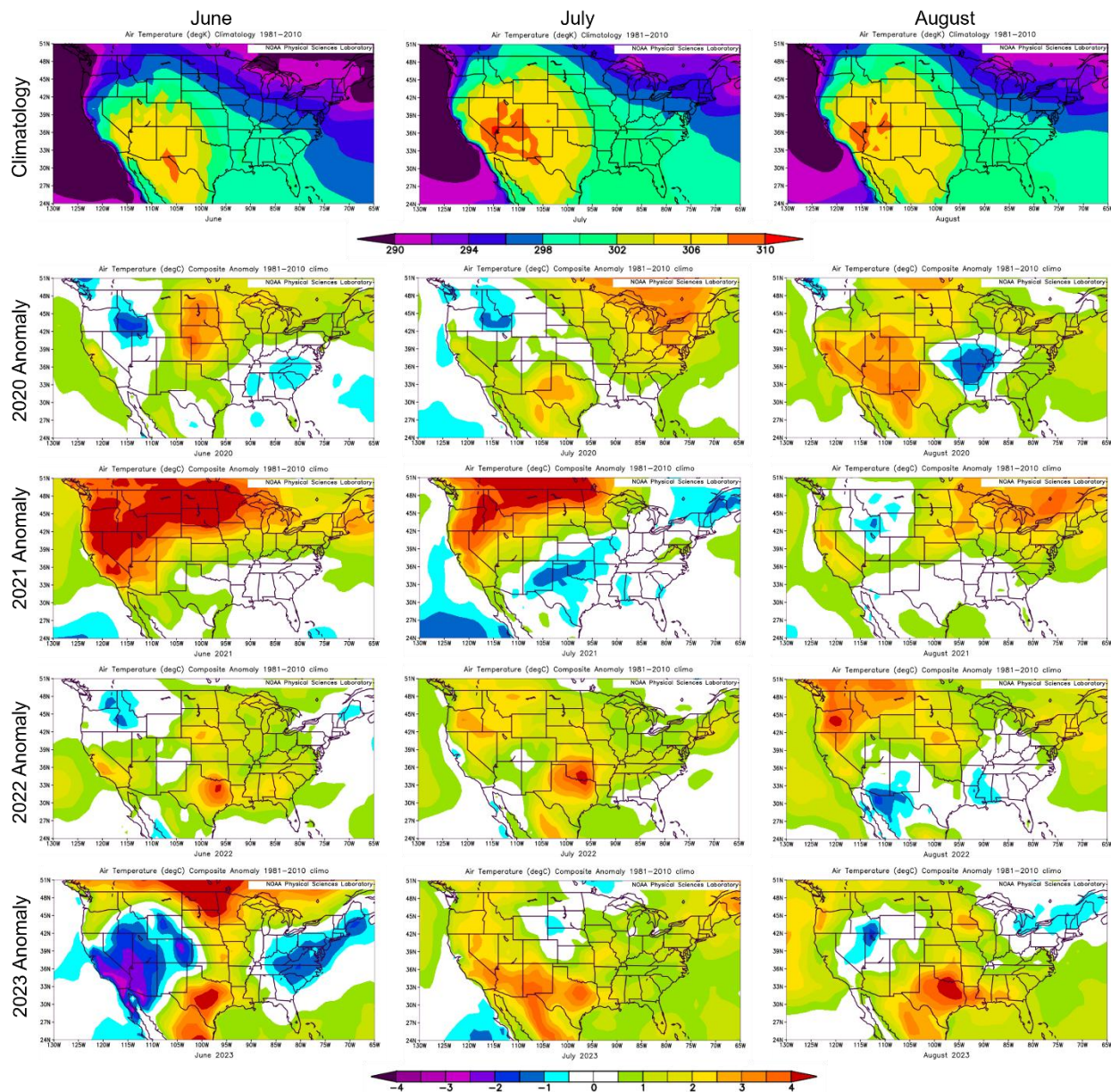


Figure 4-2. Air temperature climatology (1981-2010; top panels) and anomalies (in 2020-2023) for June, July, and August.

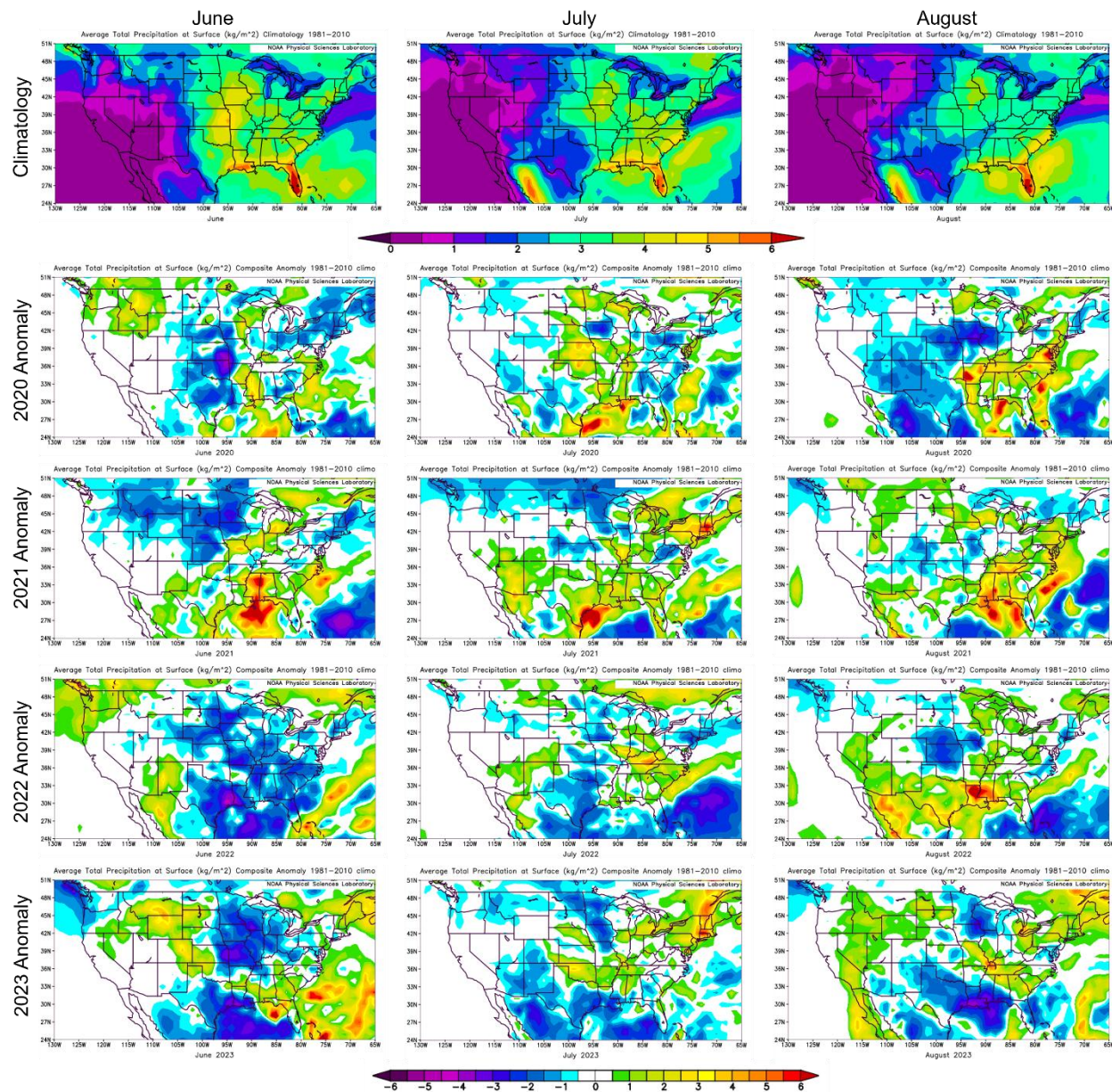


Figure 4-3. Average total precipitation at surface climatology (1981-2010) and anomalies (in 2020-2023) for June, July, and August.

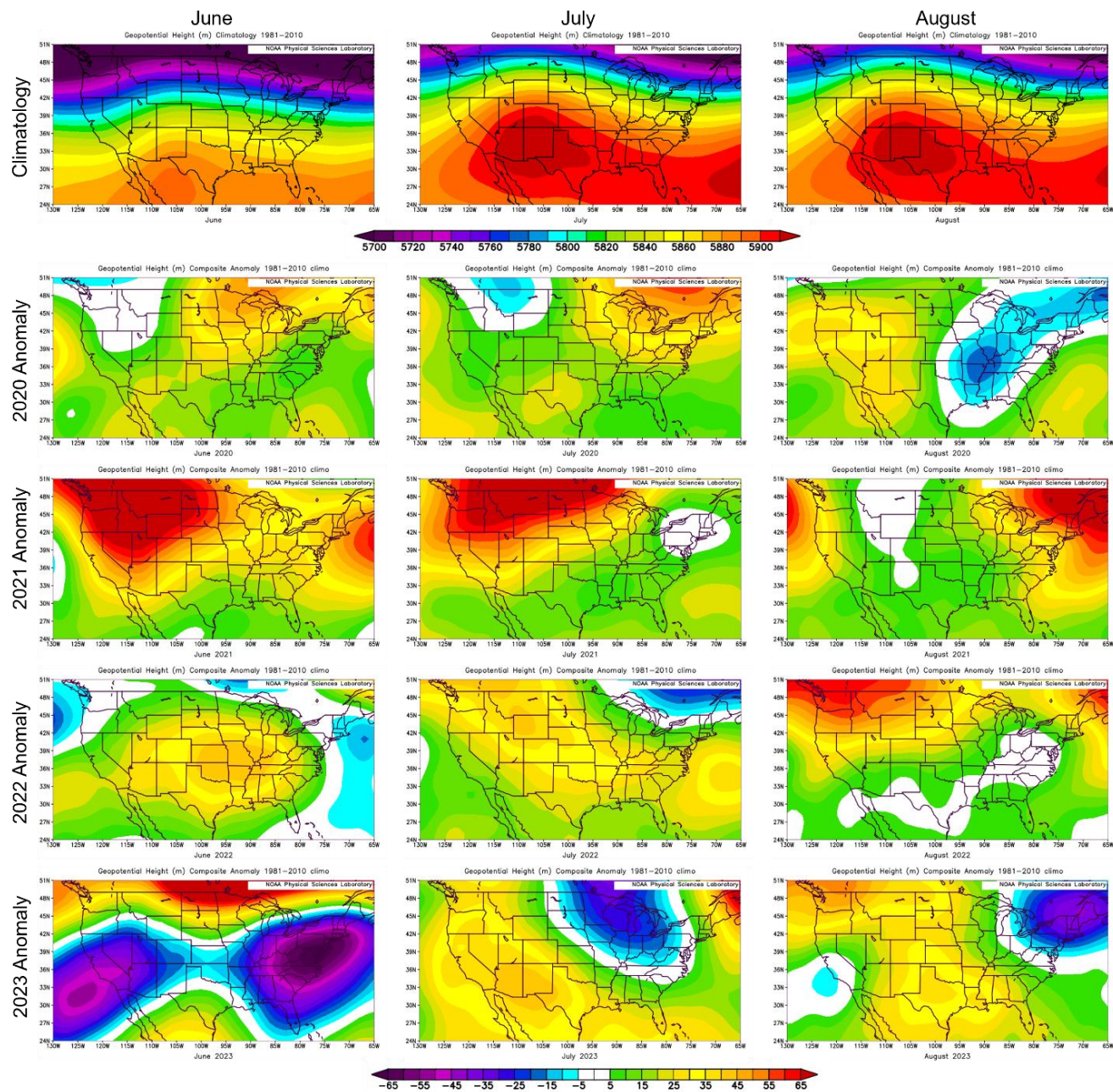


Figure 4-4. 500 mb geopotential height climatology (1981 to 2010) and anomalies (in 2020-2023) for June, July, August.

4.3 Effects of Climate Change on Ozone Concentrations

Climate change is expected to worsen ozone and PM_{2.5} air quality in some areas of the U.S. The Fifth National Climate Assessment (NCA5) summarizes the effect climate change may have on air quality with expected confidence as follows (USGCRP, 2023):

"Climate change is projected to worsen air quality in many US regions (medium confidence), thereby harming human health and increasing premature death (very likely, high confidence). Extreme heat events, which can lead to high concentrations of air pollution, are projected to increase in severity and frequency (very likely, very high confidence), and the risk of exposure to airborne dust and wildfire smoke will increase with warmer and drier conditions in some regions (very likely, high confidence)."

More specifically, higher temperatures resulting from climate change speed up many photochemical reactions that form ozone. Higher temperatures also increase biogenic volatile organic compound (VOC) and evaporative VOC emissions that are precursors to ozone. Climate change is causing longer and hotter summers, the season when most areas experience high ozone formation. Climate change is also expected to result in more extreme meteorological events, including conditions conducive to ozone formation. Extended drought periods and hotter conditions are also conducive to more wildfires that generate ozone precursor emissions including VOCs and nitrogen oxides (NO_x). Wildfires have been especially prevalent in many recent years in the Western U.S. Other aspects of climate change may reduce conditions conducive to ozone formation, such as higher humidity and increased convective activity (enhanced dispersion) and precipitation (more wet deposition). Figure 1-2 from NCA5 (West et al., 2023) summarizes several effects of climate change that can affect ozone and PM_{2.5} concentrations.

In the absence of methane increases, which act to increase background ozone (described further below), climate change will likely reduce ozone in currently unpolluted regions but possibly increase it in polluted areas (Schnell et al. 2016; Zanis et al. 2022). Projected increases in temperatures lead to increased atmospheric water vapor concentrations. Since the photolysis of ozone produces lone oxygen atoms, the increased reactions of water vapor with these oxygen atoms further drives the destruction of ozone. Thus, in unpolluted regions, particularly over the oceans, climate change will likely reduce ozone (Johnson et al. 1999; Zanis et al. 2022). In regions with significant pollution levels, such as ozone nonattainment areas (e.g., El Paso-Las Cruces, TX-NM NAA), warmer temperatures speed up the chemical reactions that produce ozone, as well as increase biogenic emissions of VOCs.

Several studies show, in experiments holding anthropogenic precursor emissions fixed (e.g., at year-2000 levels), that ozone will increase in regions with high historical emissions, including the northeast U.S. (excluding New England), the Ohio Valley, Colorado, and southern California. These regions closely align with the EPA's 8-Hour Ozone Nonattainment Areas. For example, Shen et al. (2016) projected an increase of 3-12 ozone episode days (which they defined as days with Maximum Daily Average 8-hour [MDA8] ozone concentrations greater than 75 ppb, the 2008 ozone NAAQS) in these regions from the 2000s to the 2050s under representative concentration pathway (RCP) 4.5, an intermediate greenhouse gas (GHG) scenario. Nolte et al. (2018) investigated changes in fourth-highest annual values of MDA8 ozone from 2000 to 2030 under three RCP scenarios. They found statistically significant increases (ranging from 1-4 ppb in RCP 4.5 to 3-8 ppb in RCP 8.5, a

high GHG scenario) in the aforementioned regions, in addition to the upper Midwest (Minnesota, Iowa). The projected changes for New Mexico in Shen et al. (2016) and Nolte et al, (2018) are relatively minimal but climate change is still estimated to produce increased ozone concentrations (i.e., approximately less than 2 more exceedance days, and less than 1-2 ppb increases in ozone concentrations).

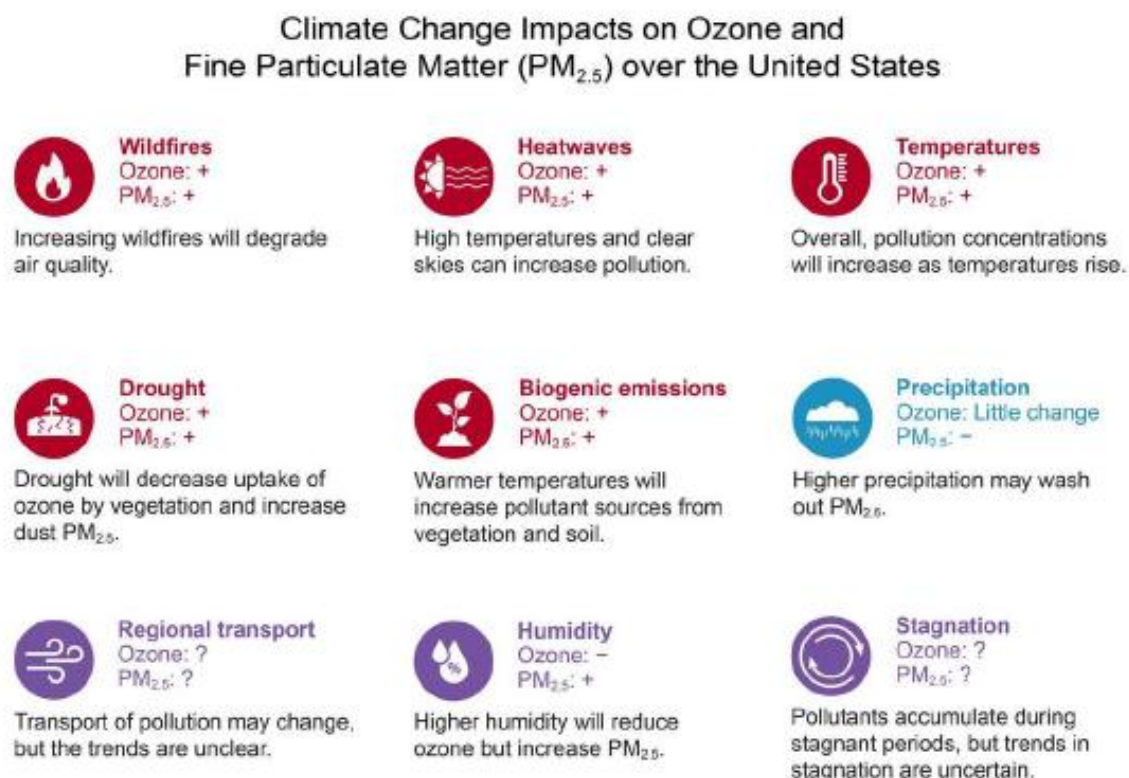


Figure 4-5. Expected climate change effects on ozone and PM_{2.5} concentrations with red indicating concentration increases, blue indicating concentration decreases and purple indicating uncertain direction of change. Image from NCA5 (West et al., 2023).

In summary, without considering emissions changes, climate change will likely act to reduce ozone in historically non-polluted regions via an intensification of the chemical reactions governing ozone destruction due to higher humidity (i.e., water vapor). In polluted regions, climate change is expected to increase ozone concentrations due to higher temperatures that increase biogenic VOC emissions and generally speed up the chemical reactions governing ozone production. It is unclear whether climate change will have a significant impact on ozone concentrations for New Mexico.

5.0 EMISSIONS

This section compiles emission inventory summaries and trends from sources including EPA's Air Pollutant Trend Analyses for National and State level trends¹⁷ and Permian Basin Emissions Trends.

5.1 EPA's National and New Mexico Emissions Trends

EPA provides annual emissions summaries for criteria pollutants by state in an [Air Pollutant Trend Analyses](#). It is described as follows:

"The latest version of the 1970 - 2024 data show the trends for Tier 1 categories which distinguish pollutant emission contributions among major source types. Improvements to the methods used to estimate emissions for the years 2002-2019 were introduced for the trends summaries released in 2023, and are retained for the current February 2025 update of these data. These updated procedures minimize the effects of method changes on emissions over this time frame. In addition, 2020 is represented by the 2020 NEI data, and 2021 and 2022 are based on the emissions modeling platform data with the 2020 NEI used where newer information for 2021 and 2022 was not available. Year 2023 data was updated for this release but is limited to information on electric generating units, mobile sources, and draft wildfires and agricultural field burning with 2022 estimates carried forward for all other data points. Year 2024 data is introduced in this updated trends release, but is limited to NO_x and SO₂ from electric generating units and projected emissions for onroad and nonroad sources, with 2023 estimates carried forward for all other data points."

Figure 5-1 and 5-2 present, for the nation and New Mexico, respectively, the annual anthropogenic emissions trends for NO_x and VOC by major source category. National NO_x emissions exhibit steep declines overall that are primarily driven by reductions in the on-road mobile source sector with reductions in EGU NO_x also clearly present. National on-road mobile source VOC emissions also exhibit a downward trend for the beginning of the period that is driven by decreases in on-road mobile source VOC emissions, but there is high interannual variability in the total VOC emissions trends that is driven by emissions from fires with many recent years having higher fire VOC emissions than typical over the last two decades.

For New Mexico in particular, the overall NO_x emissions have trended downward with time, thanks to gradual decreases in emissions from mobile sources and EGUs. Industrial Process emissions, which include oil and gas production, have seen sharp rises since 2019, and the sector is almost entirely responsible for the overall rise in New Mexico NO_x and VOC emissions seen in Figure 5-2. Fires have also contributed significant and highly varying levels of VOC emissions, notably in 2022 when wildfires caused roughly the equivalent VOC emissions as all other source groups combined, about 400,000 tons per year. The assignment of sectors into source groups is shown in Table 5-2.

¹⁷ <https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data>

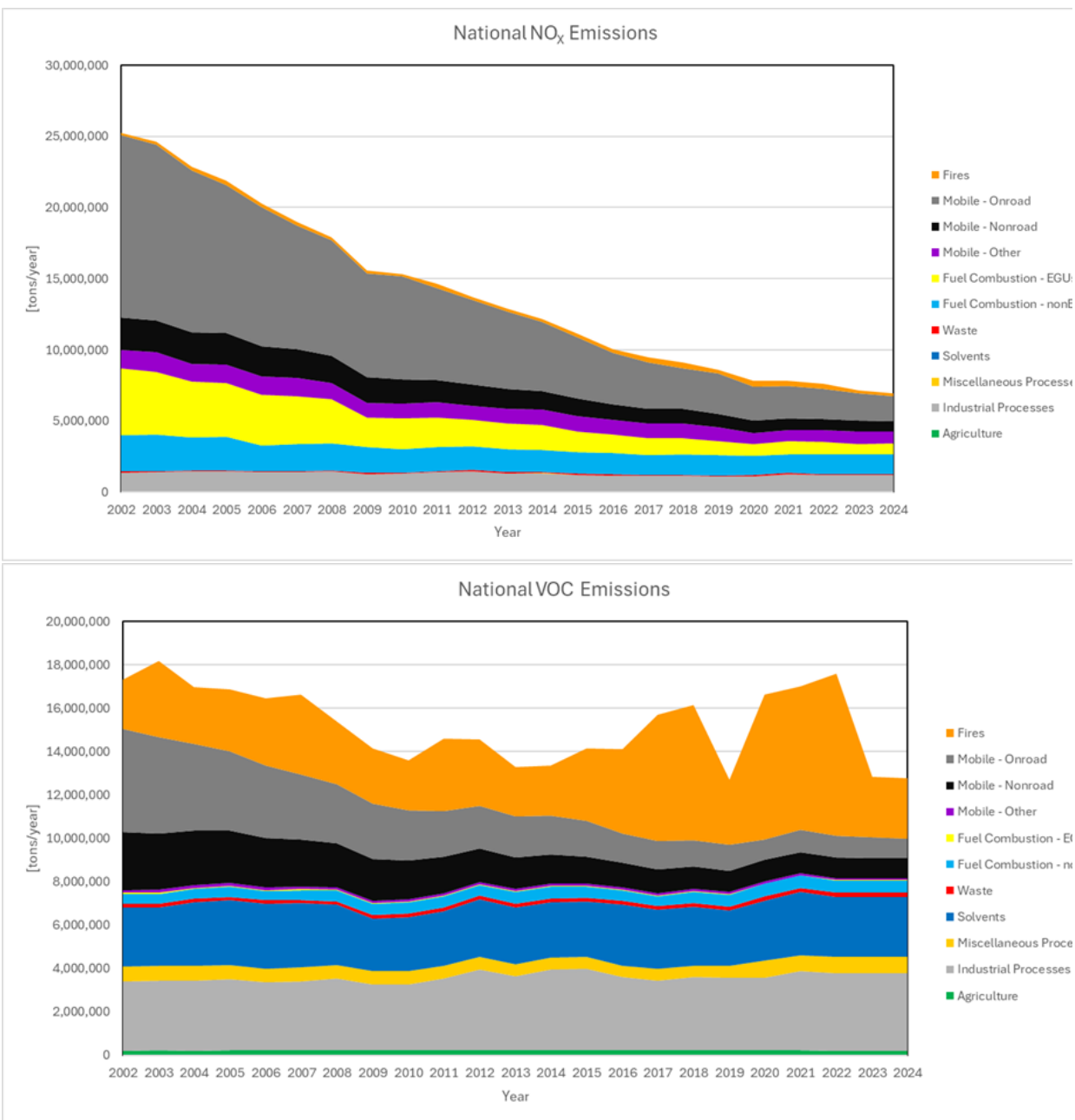


Figure 5-1. EPA National NO_x (top) and VOC (bottom) anthropogenic emission trends by source sector.

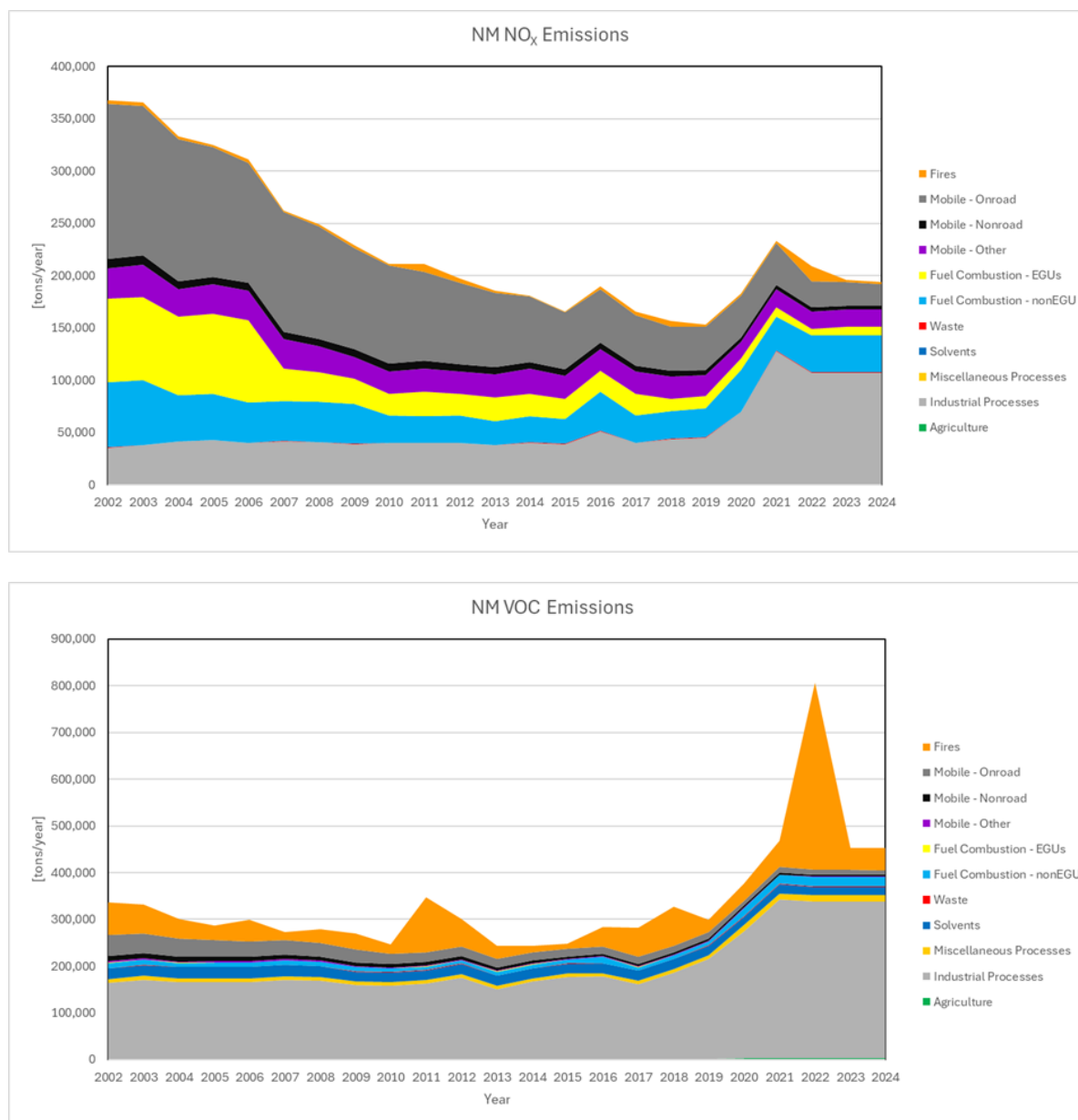


Figure 5-2. EPA New Mexico NO_x (top) and VOC (bottom) anthropogenic emissions trends by source sector.

Table 5-1. EPA emissions inventory subcategories.

Mobile – Onroad	Mobile – On-Road Diesel Heavy Duty Vehicles; Mobile – On-Road Diesel Light Duty Vehicles; Mobile – On-Road non-Diesel Heavy Duty Vehicles; Mobile – On-Road non-Diesel Light Duty Vehicles
Mobile – Nonroad	Mobile – Non-Road Equipment – Diesel; Mobile – Non-Road Equipment – Gasoline; Mobile – Non-Road Equipment – Other
Mobile – Other	Mobile – Aircraft; Mobile – Commercial Marine Vessels; Mobile – Locomotives
Fuel Combustion – EGUs	Fuel Comb – Electric Generation – Biomass; Fuel Comb – Electric Generation – Coal; Fuel Comb – Electric Generation – Natural Gas; Fuel Comb – Electric Generation – Oil; Fuel Comb – Electric Generation – Other
Fuel Combustion – nonEGU	Fuel Comb – Comm/Institutional – Biomass; Fuel Comb – Comm/Institutional – Coal; Fuel Comb – Comm/Institutional – Natural Gas; Fuel Comb – Comm/Institutional – Oil; Fuel Comb – Comm/Institutional – Other; Fuel Comb – Industrial Boilers, ICEs – Biomass; Fuel Comb – Industrial Boilers, ICEs – Coal; Fuel Comb – Industrial Boilers, ICEs – Natural Gas; Fuel Comb – Industrial Boilers, ICEs – Oil; Fuel Comb – Industrial Boilers, ICEs – Other; Fuel Comb – Residential – Natural Gas; Fuel Comb – Residential – Oil; Fuel Comb – Residential – Wood; Fuel Comb – Residential – Other
Waste	Waste Disposal
Solvents	Solvent – Consumer & Commercial Solvent Use; Solvent – Degreasing; Solvent – Dry Cleaning; Solvent – Graphic Arts; Solvent – Industrial Surface Coating & Solvent Use
Miscellaneous Processes	Bulk Gasoline Terminals; Commercial Cooking; Dust – Construction Dust; Gas Stations; Miscellaneous Non-Industrial NEC
Industrial Processes	Industrial Processes – Cement Manuf; Industrial Processes – Chemical Manuf; Industrial Processes – Ferrous Metals; Industrial Processes – Mining; Industrial Processes – NEC; Industrial Processes – Non-ferrous Metals; Industrial Processes – Oil & Gas Production; Industrial Processes – Pulp & Paper; Industrial Processes – Storage and Transfer
Fires	Fires – Agricultural Field Burning; Fires – Prescribed Fires; Fires – Wildfires
Agriculture	Agriculture – Crops & Livestock Dust; Agriculture – Livestock Waste

Figure 5-3 focuses on the years 2015-2024 and breaks out emissions from the Industrial Processes and Fires source sectors from Figure 5-2 into individual source categories to highlight the emissions trends for these two source sectors, which are predominantly driven by changes to emissions from, respectively, Oil & Gas Production and Wildfires. In the time period shown, emissions of both NO_x and VOC due to Oil & Gas Production have approximately doubled while all other source groups have remained mostly the same, and the extreme variability in emissions due to wildfires is demonstrated as well. Of particular note are the high wildfire emissions during the 2022 modeling year. Note that EPA's trends analysis held the Oil and Gas sector emissions for 2023 and 2024 constant at 2022 values and are likely not reflective of actual emissions for those most recent years.

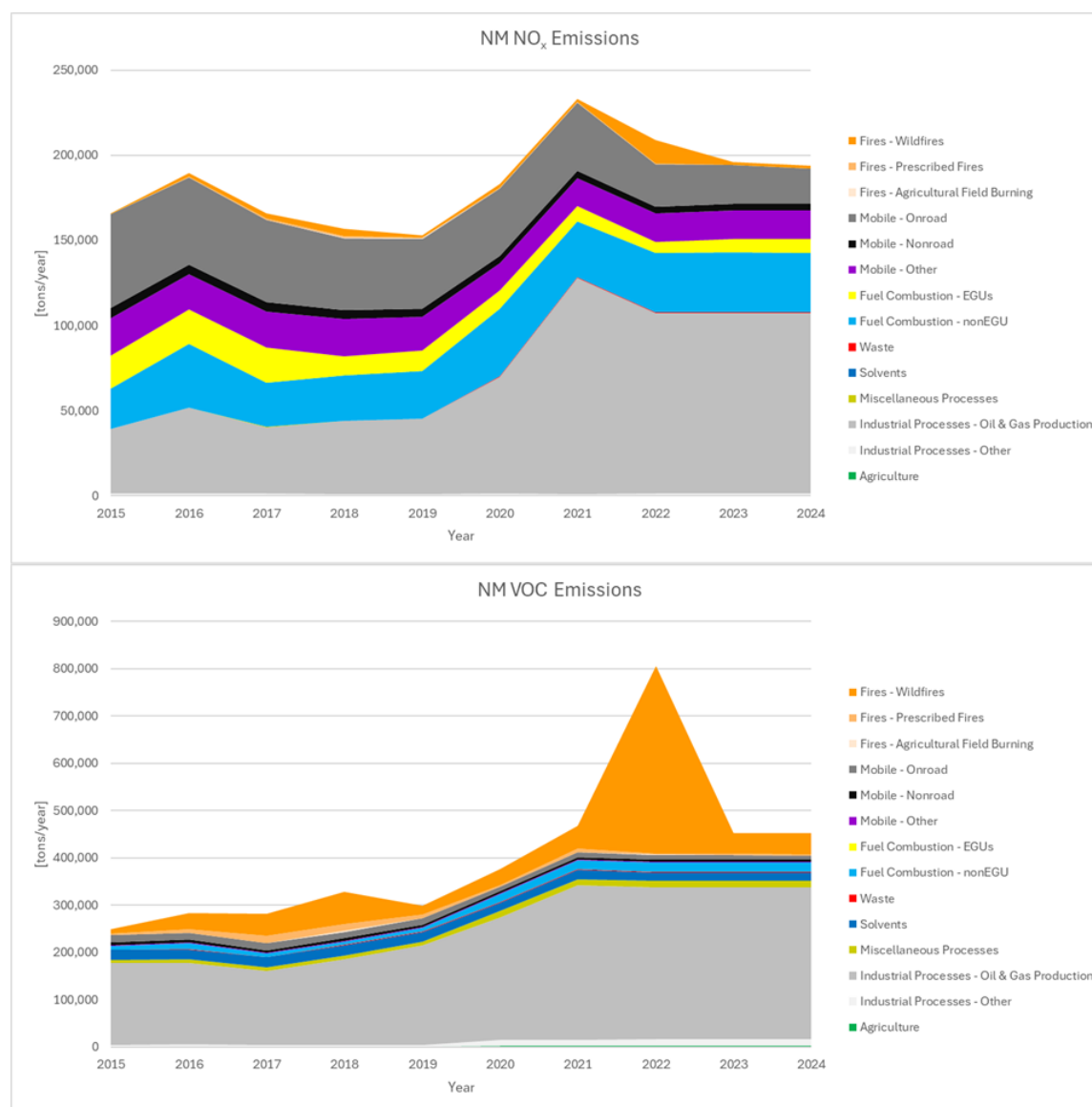


Figure 5-3. EPA New Mexico NO_x (top) and VOC (bottom) anthropogenic emissions trends by source sector. Detailed fires and industrial processes.

5.3 New Mexico 2022 and 2026 Emissions Estimates

Table 5-2 is excerpted from the NMED FY2024-2025 Phase I ozone source apportionment modeling study and presents a summary of 2022 and 2026 annual NO_x and VOC emissions for New Mexico from the 2022 EMP 2022v1. For NO_x, the largest anthropogenic source categories are O&G non-point, on-road mobile, O&G point, and rail; by 2026 rail NO_x is comparable to on-road. Natural sources of NO_x are relatively minor compared to anthropogenic sources. For VOCs, O&G emissions are the largest anthropogenic source and are comparable to wildfire and biogenic sources that each contribute approximately one third to the total VOC inventory in 2022. As noted previously, 2022 was an unusually high wildfire year for New Mexico.

The 2022 NO_x estimates shown in Table 5-2 generally agree with the EPA trends inventory for New Mexico for 2022 (Figure 5-3) that shows more than half of the NO_x emissions are due to O&G and a large fraction of NO_x is from on-road sources. The EPA-estimated 2022 NO_x has “Fuel Combustion – nonEGU” as an important category which is not the case for the 2022v1 inventory. The reason for the discrepancy is unclear, but is likely due to some engines in the O&G sector (e.g., midstream) being lumped in with the non-EGU combustion sources in the EPA trends inventory. For VOCs, wildfires and O&G emissions are comparable to EPA estimates for 2022 (biogenic emissions are not included in the EPA trends inventory).

Table 5-2. Summary of 2022 and 2026 annual VOC and NO_x emissions (average TPD) for New Mexico from the 2022 EMP 2022v1 modeling platform (Source: Phase I NMED Study).

New Mexico State-Wide Emission Summaries including Tribal Emissions						
Tons per Day (TPD)	NO _x			VOC		
Source Sector	2022	2026	%Diff	2022	2026	%Diff
Airports	1.6	1.7	6.0%	1.0	1.0	5.6%
Livestock				7.1	7.0	-1.3%
Non-Point	14.1	13.7	-2.7%	37.0	39.5	6.8%
Non-Road	11.0	9.0	-17.6%	12.3	11.7	-4.7%
O&G Non-Point	271.5	160.8	-40.8%	773.0	356.0	-53.9%
Solvents				47.7	50.0	4.8%
On-Road	67.9	45.4	-33.1%	27.8	21.8	-21.7%
Open Burn	0.7	0.7	0.0%	1.2	1.2	0.0%
O&G Point	95.8	97.6	1.9%	174.8	179.7	2.8%
Agriculture Fires	0.4	0.4	0.0%	1.4	1.4	0.0%
EGU	27.7	15.1	-45.5%	0.9	0.7	-24.0%
Non-EGU	7.0	6.7	-4.4%	5.4	5.5	1.0%
Rail	43.4	43.1	-0.8%	1.8	1.7	-0.8%
RWC	2.2	2.2	0.0%	23.4	23.4	0.0%
Total Anthropogenic	543.4	396.6	-27.0%	1,114.7	700.6	-37.1%
Biogenic	43.6	43.6	0.0%	923.3	923.3	0.0%
Prescribed Fires	0.5	0.5	0.0%	7.4	7.4	0.0%
Wildfires	37.9	37.9	0.0%	1,085.6	1,085.6	0.0%
Total Anthro + Natural	625.3	478.6	-23.5%	3,131.0	2,716.9	-13.2%

5.4 New Mexico 2022 Spatial Distribution of Emissions

The figures in this section are spatial maps of NO_x and VOC emissions for the 4 km NM modeling domain by sector to help understand how those emissions are distributed over the State. These emissions are from the Phase II 2022 EMP 2022v2 inventory. Each set of figures displays NO_x emissions on the top panel and VOC emissions on the bottom panel.

Figure 5-4 presents the non-point (left) and point O&G (right) sectors and highlights the San Juan Basin in northwest part of the State and the Permian Basin in the southeast corner of the State as having the highest NO_x and VOC emissions. The maximum grid cell emissions are in the Texas portion of the Permian Basin with emission rates of approximately five tons per day, and ninety-four tons per day of NO_x and VOC, respectively, for the non-point category

Figure 5-5 presents the on-road (left) and nonroad (right) sectors and highlights the highway and road networks throughout the state as well as the urban areas where nonroad equipment is primarily utilized. Figure 5-6 presents the rail (left) and biogenic (right) sectors and highlights the rail network throughout the state as well as the regions with higher biogenic emissions. For rail, VOC emissions are negligible, likewise, for biogenic NO_x emissions are negligible (both less than 0.05 tpd per 4 km grid cell).

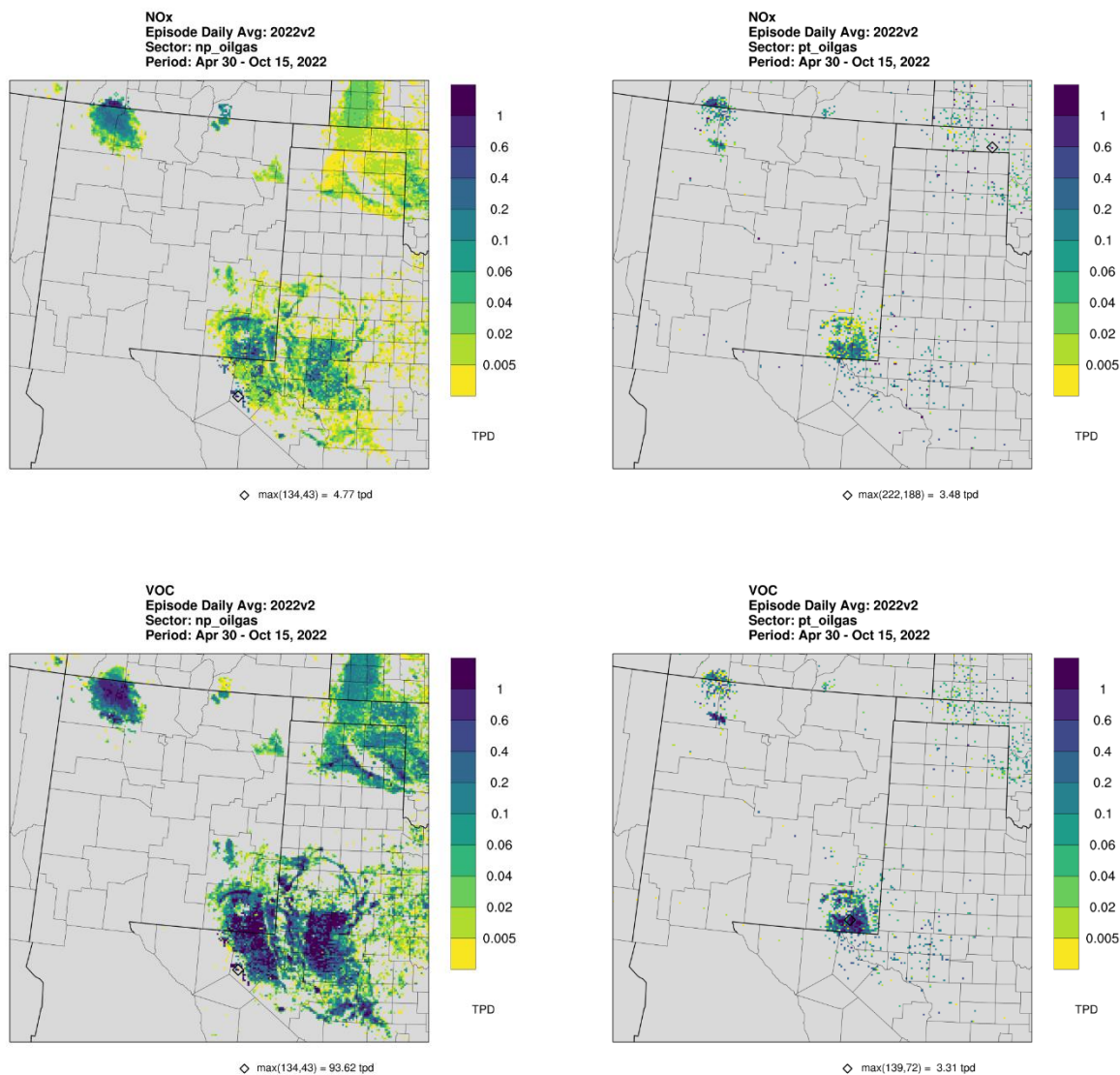


Figure 5-4. Modeled (Phase II) 2022v2 emissions for the 4 km modeling domain NO_x (top) and VOC (bottom) for non-point oil and gas (left), point oil and gas (right), in tons per day, per model grid cell.

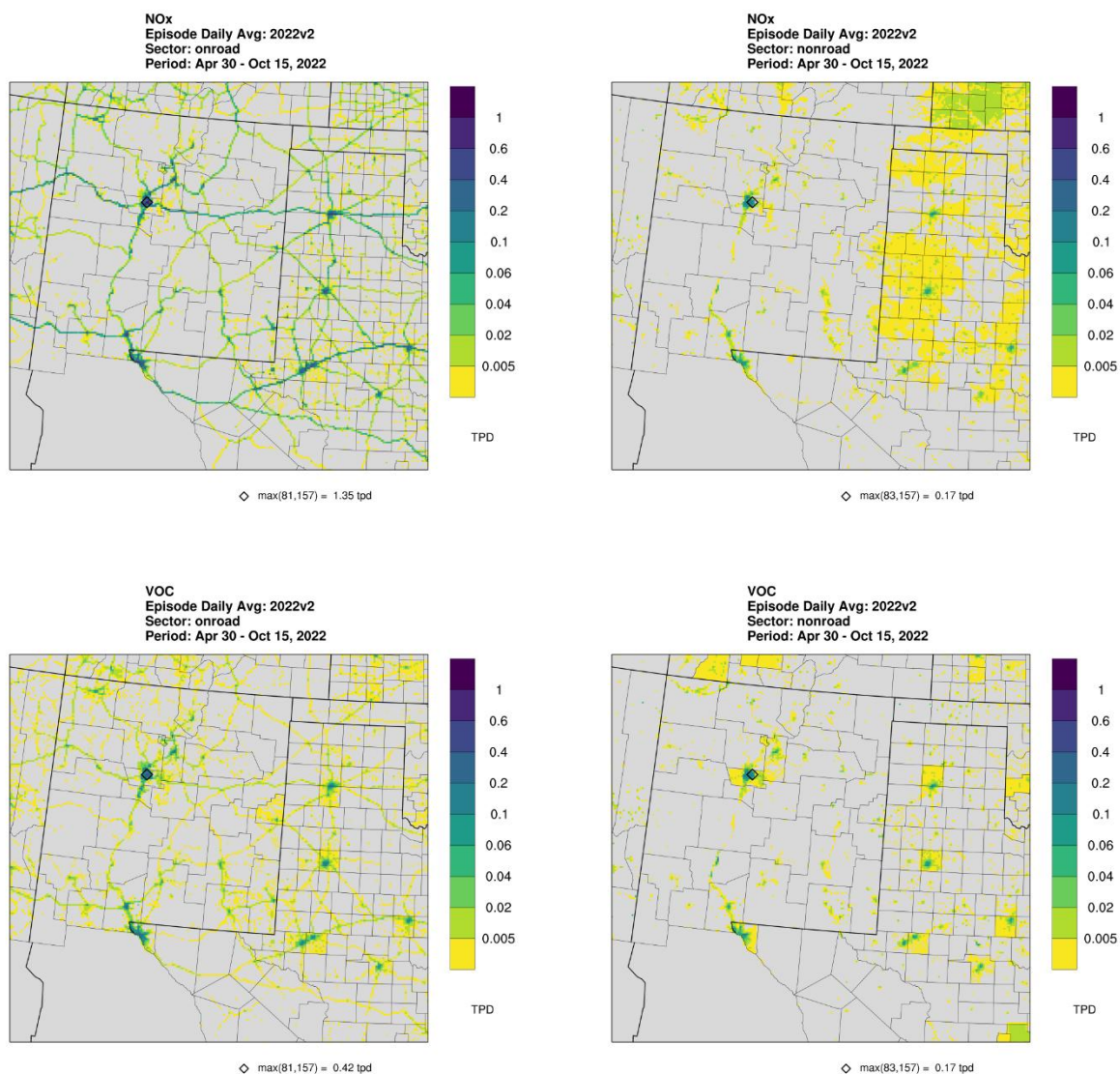


Figure 5-5. Modeled (Phase II) 2022v2 emissions for the 4 km modeling domain NO_x (top) and VOC (bottom) for onroad (left), nonroad (right), in tons per day, per model grid cell.

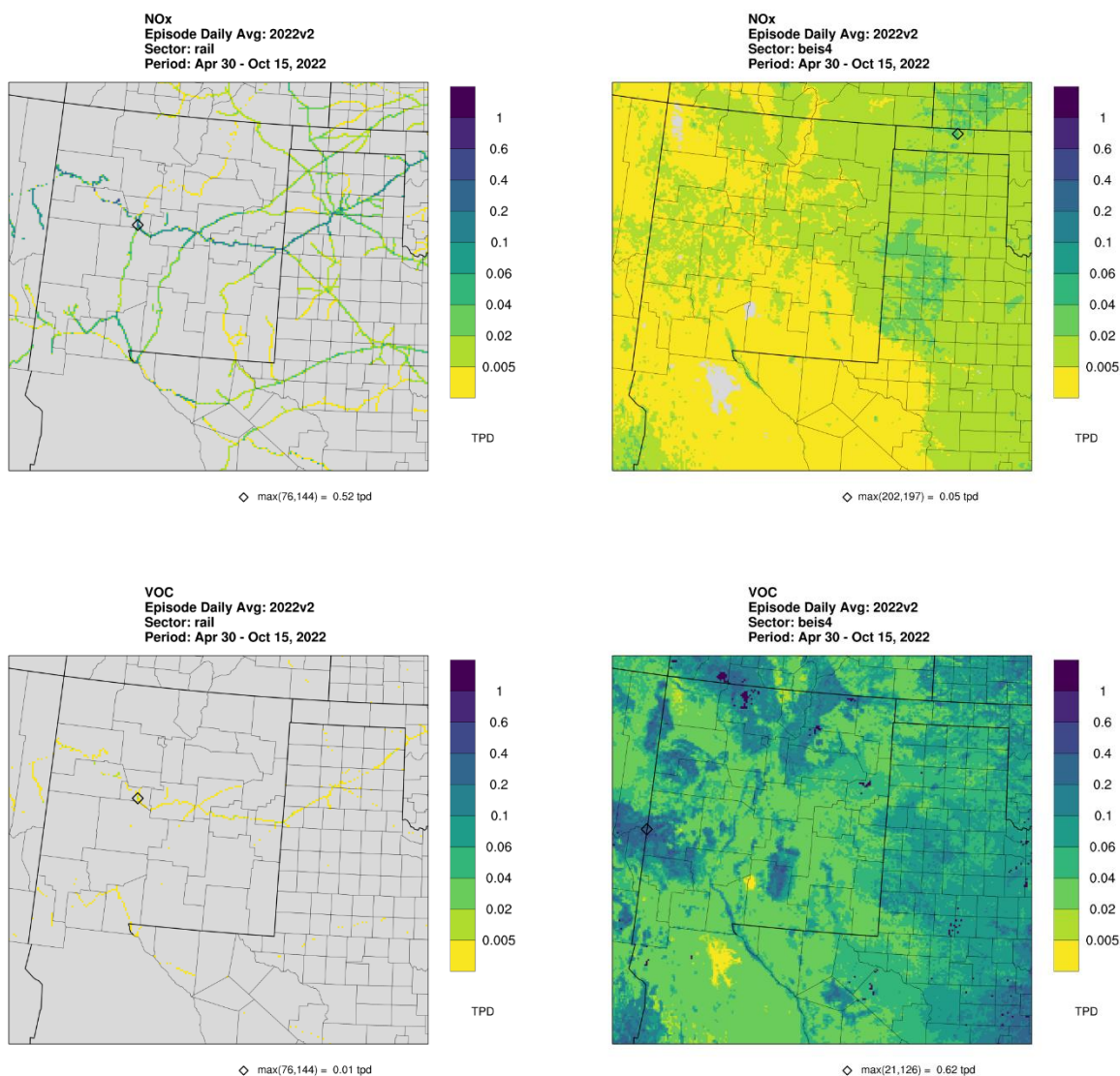


Figure 5-6. Modeled (Phase II) 2022v2 emissions for the 4 km modeling domain NO_x (top) and VOC (bottom) for rail (left), biogenic (right), in tons per day, per model grid cell.

5.5 Permian Basin Emissions

5.5.1 O&G Production Trends

As seen in the previous section, the O&G sector is the largest source of anthropogenic NO_x and VOC emissions in New Mexico. O&G emissions increased rapidly starting in approximately 2018 (Figure 5-2) which corresponds to the time of rapidly increasing oil production from the Permian Basin. Figure 5-7 presents crude oil production rate trends from the Permian Basin from 2010 to 2023 and Figure 5-8 extends the trend to 2024 and focuses on cumulative changes since 2020. These figures from the Energy Information Administration (EIA) report crude oil production rates from the entire Permian Basin as well as Lea and Eddy Counties in New Mexico. The EIA describes the recent (2020 to 2024) Permian Basin crude oil production trends as follows:

Between 2020 and 2024, total crude oil and lease condensate production in the United States grew by 1.9 million barrels per day (b/d), 93% of which was produced from just 10 counties in Texas and New Mexico. Production from the rest of the United States, including producing areas in offshore state or federal waters, grew by just 130,000 b/d. The 10 counties are all within the Permian Basin, a large geologic feature underlying 66 counties in New Mexico and Texas. Two of these counties, Lea and Eddy in New Mexico, accounted for nearly 1.0 million b/d of U.S. production growth (52%) between 2020 and 2024. Martin and Midland in Texas accounted for an additional 0.40 million b/d (21%). Six additional counties in Texas—Andrews, Glasscock, Howard, Loving, Reagan, and Ward—together grew by 0.36 million b/d (19%), based on county-level production data from Enverus. Crude oil and lease condensate production in these 10 counties averaged 4.8 million b/d in 2024, 37% of the U.S. total. Within these 10 counties, the primary geologic units responsible for this growth are the Bone Spring, Spraberry, and Wolfcamp formations. These geologic units have been the main sources of oil production growth across the Permian Basin and the United States at large since 2020.

This highlights the massive increases in oil production in Southeast New Mexico in recent years and corresponds with large increases in NO_x, VOC, greenhouse gas and other emissions and atmospheric ozone concentrations in the region.

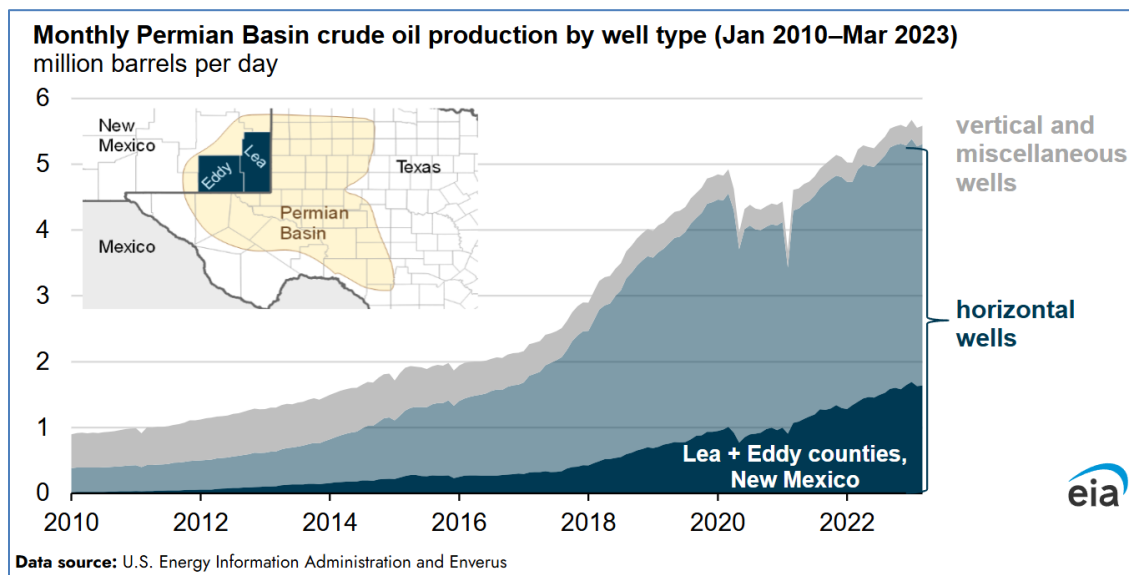


Figure 5-7. Crude oil production trends for the Permian Basin from 2010 to 2023. (Source: EIA¹⁸).

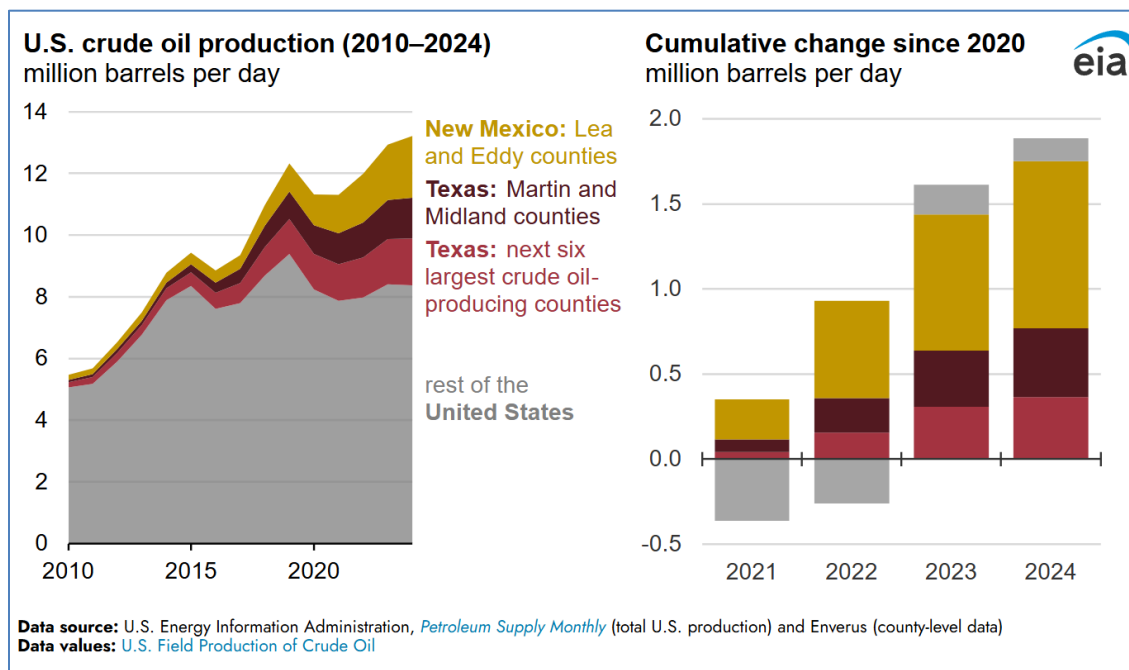


Figure 5-8. Crude oil production trends for the Permian Basin from 2010 to 2024 and a focus on changes between 2021 to 2024. (Source: EIA.¹⁹)

¹⁸ <https://www.eia.gov/todayinenergy/detail.php?id=57020>

¹⁹ <https://www.eia.gov/todayinenergy/index.php>

5.5.2 Estimated Permian Basin O&G Future Year Emissions

The BLM Carlsbad Field Office (CFO) recently performed photochemical modeling to assess the impacts of oil and gas development and other cumulative sources on air quality and air quality related values (BLM, 2025). The purpose of the modeling is to provide vital information to support a resource management plan (RMP) for future planning and the designated future year for which emissions were generated was 2032. Four different emission scenarios were modeled to consider the Reasonable Foreseeable Development (RFD), low and high potential oil and gas development and a 2032 Annual Energy Outlook (AEO) Southwest Forecast emissions scenario. Each scenario differed by oil and gas activity (oil production, gas production, and spud counts). For all scenarios, except for the AEO Southwest Forecast Scenario, BLM provided the oil and gas activity data.²⁰

Activity growth factors were developed for each county for various activities (e.g., oil production, natural gas production) for 2016 to 2032. These factors were used to project EPA's 2016v3 base year 2016 oil and gas emissions to 2032. Equipment control factors were also incorporated, and the details are documented in (BLM, 2025).

Table 5-3 reports the 2032 activity estimates by County and by scenario from the BLM CFO RMP modeling. The AEO forecast has the highest activity rates. All four scenarios exceed the current (circa 2024) oil production rate. Table 5-4 reports estimated criteria pollutant emissions from 2032 for the CFO (i.e., Eddy and Lea Counties) for each scenario. The NO_x and VOC emission estimates for the RFD scenario are approximately 70,000 TPY and 145,000 TPY which are slightly less than the entire New Mexico O&G 2026 estimates [NO_x: $(160.8 + 97.6) \times 365 = 94,300$ TPY; VOC $(356.0 + 179.7) \times 365 = 195,000$ TDY; Table 5-2]. For the higher AEO scenario, the estimated O&G emissions from Eddy and Lea Counties in 2032 is comparable to the current O&G emissions for all of New Mexico.

²⁰ Email from AECOM (Amy Cordle) to Ramboll (John Grant), March 20, 2023.

Table 5-3. BLM CFO-wide gas production, oil production and spud estimates for each 2032 activity scenario. Source: BLM (2025).

Scenario	County ¹	Gas Production (BCF/year)	Oil Production (MMBbl/year)	Spuds
RFD	Eddy	891	179	394
RFD	Lea	634	212	484
RFD (Scenario 1)	Subtotal	1,525	1,269	878
Low	Eddy	782	156	344
Low	Lea	556	185	422
Low (Scenario 2)	Subtotal	1,338	1,107	766
High	Eddy	1,041	209	461
High	Lea	741	247	566
High (Scenario 3)	Subtotal	1,782	1,483	1,027
AEO Southwest Forecast	Eddy	1,325	228	620
AEO Southwest Forecast	Lea	943	270	762
AEO Southwest Forecast (Scenario 4)	Subtotal	2,268	1,880	1,382

Table 5-4. Summary of the 2032 CFO-wide oil and gas emissions (short tons/year). Source: BLM (2025).

Pollutants	Scenario 1: RFD	Scenario 2: Low Development	Scenario 3: High Development	Scenario 4: AEO Southwest Forecast Scenario
Carbon Monoxide	88,276	77,221	103,157	117,991
Nitrogen Oxides	70,602	61,787	82,504	96,754
PM ₁₀ - Total	2,720	2,380	3,179	3,714
PM _{2.5} - Total	2,528	2,213	2,954	3,458
Sulfur Oxides	69,294	60,627	80,976	93,000
Volatile Organic Chemicals	146,448	128,091	171,135	195,125

6.0 WILDFIRES

In this chapter we examine wildfires in New Mexico during the 2022 modeling year. 2022 was the largest wildfire year on record in New Mexico, which is indicated by EPA's emissions trends in Figure 5-2. The New Mexico Calf Canyon/Hermits Peak Fire was the largest wildfire in 2022 in the contiguous U.S.

6.1 Wildfire in New Mexico During the 2022 Model Year

To examine wildfires in New Mexico during 2022, Ramboll obtained the 2022 fire emissions inventory for New Mexico from EPA's 2022v2 modeling platform.²¹ The fires are plotted by area burned and by month in Figure 6-1. The majority of fires, including the four largest in terms of areas burned, occurred in April through June with approximately two-thirds of the New Mexico 2022 wildfire NO_x and VOC emissions occurring in May. Total NO_x and VOC emissions by month are reported in Table 6-1. The total NO_x and VOC emissions from fires over the period are comparable to EPA's emissions trend analysis (Figure 5-2; NO_x = 14,140 TPY and VOC = 399,499 TPY).

Table 6-1. New Mexico 2022 fire emissions of NO_x and VOC by month.

Month	NO _x Emissions (tons)	VOC Emissions (tons)
January	31	398
February	49	763
March	113	1931
April	2076	52,957
May	9476	272,066
June	2197	69,728
July	23	495
August	7	133
September	13	207
October	3	41
November	5	87
December	7	126
2022	14,001	398,931

²¹ <https://gaftp.epa.gov/Air/emismod/2022/v2/2022emissions/fires/>



Figure 6-1. Maps of New Mexico fires by area burned by month for May to August 2022.

The total cumulative NO_x and VOC emissions for the largest five wildfires are shown in Table 6-2. The EPA 2022v2 modeling platform notes that the fire name can be inaccurate for large fires that use many different activity sources when reconciling. The second largest fire in the EPA 2022v2 modeling platform is listed as “Water” and cross-checking with Wikipedia suggests that this is also called the Black Fire.²²

Table 6-2. Burned area, NO_x, and VOC emissions from the four largest fires in New Mexico in 2022. Source: EPA’s 2022v2 modeling platform.

Fire Name	NO _x (TPY)	VOC (TPY)	Area (acres)	Counties	Dates
Calf Canyon/Hermits Peak Fire	7,065	224,426	343,350	San Miguel, Mora, Taos	April 6 - June 18, 2022
Water (Black Fire)	4,691	121,341	327,291	Catron, Grant, Sierra	April 28 - June 18, 2022
Cooks Peak	664	16,636	60,101	Mora, Colfax	April 17 - May 1, 2022
Cerro Pelado	489	12,560	44,252	Sandoval	April 22 - June 11, 2022
Bear Trap	467	11,872	38,178	Socora	May 1- June 4, 2022

²² https://en.wikipedia.org/wiki/2022_New_Mexico_wildfires

6.2 Daily HMS Smoke and PM_{2.5} Concentration Maps for 2022

To evaluate the atmospheric smoke conditions over New Mexico for the 2022 model year Ramboll downloaded the NOAA Hazard Mapping System (HMS) Fire and Smoke Product. The NOAA HMS Fire and Smoke Products use satellite detects of fires and trained NOAA staff to analyze satellite data to develop spatial polygons of light, medium and heavy smoke impacts in near real-time across North America.²³ Smoke detection relies on visual analysis using GOES-16 and GOES-17 imagery during daylight hours. Ramboll applies color scaling based on HMS smoke density: light (gray), medium (yellow), and heavy (brown). Note that the HMS smoke layers are displayed with transparency and multiple layers are superimposed upon each other which creates a daily integrated product with varying density of the gray, yellow and brown shading. The PM_{2.5} monitors 24-hr concentrations are also displayed on these maps which may indicate when smoke reached ground-level.

Ramboll generated daily smoke maps for all days from May to September 2022. The complete list of figures can be found in Appendix E. Figure 6-2 and Figure 6-23 illustrate a subset of the days and focus on a period in mid-May when there were active fires in New Mexico and a period in early August with minimal fires in New Mexico but light smoke plumes covering Texas and east New Mexico for most days. Smoke from the Calf Canyon/Hermits Peak fire in northeast New Mexico is clearly evident during May 10-15. By May 15, smoke from the Water/Black fire is seen in southwest New Mexico.

²³ National Oceanic & Atmospheric Administration (NOAA) Hazard Mapping Systems (HMS) Fire and Smoke Product - <https://www.ospo.noaa.gov/products/land/hms.html>

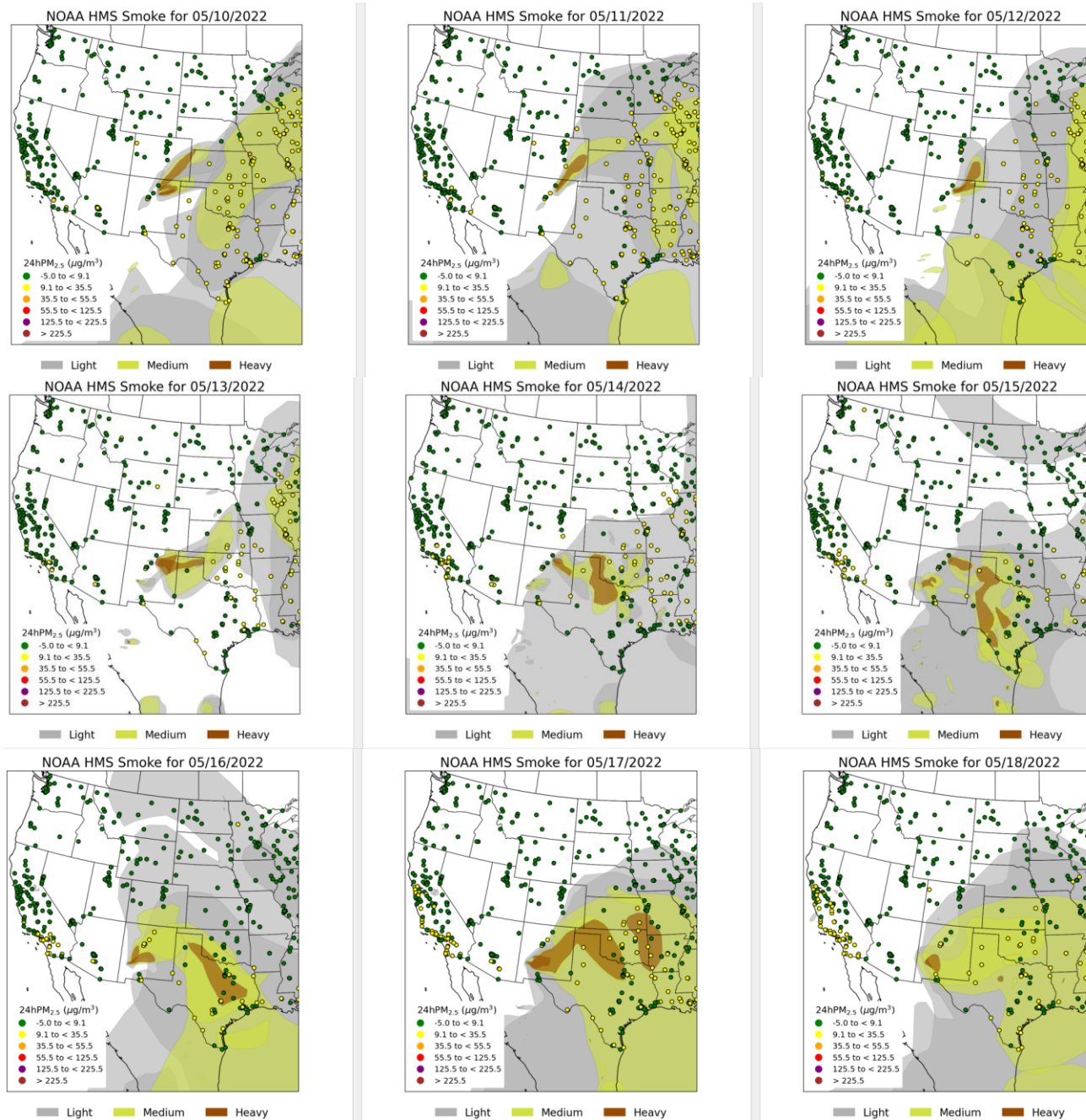


Figure 6-2. Daily Regional HMS smoke maps and monitored PM_{2.5} concentrations for May 10-18, 2022, period.

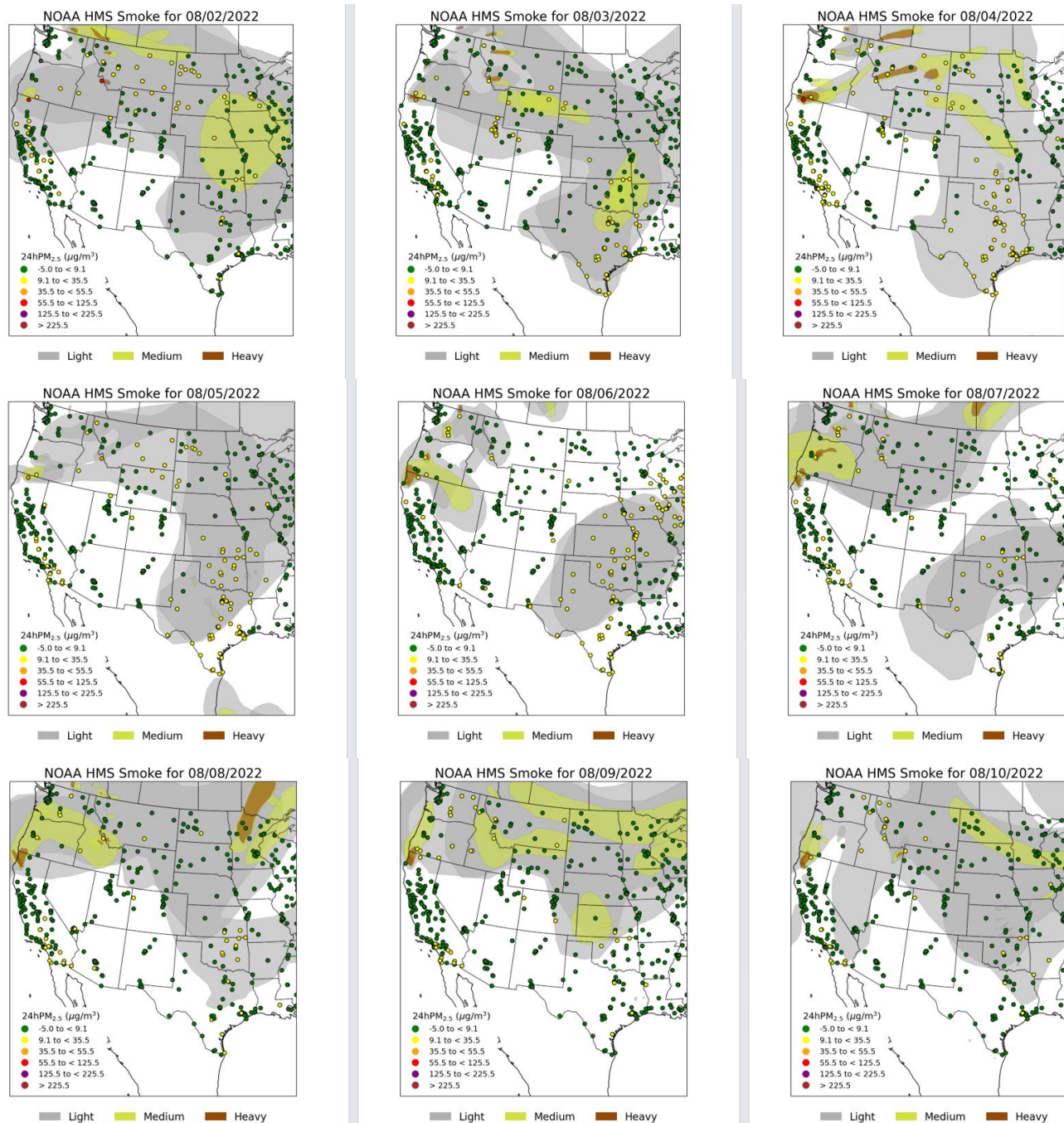


Figure 6-3. Daily Regional HMS smoke maps and monitored PM_{2.5} concentrations for August 2-10, 2022, period.

7.0 PREVIOUS OZONE SOURCE APPORTIONMENT RESULTS

There have been several previous ozone attribution studies of the sources of ozone concentrations in New Mexico. Below we briefly discuss the results from several such studies that looked at the contributions of both in-state and out-of-state sources to ozone concentrations in New Mexico. Additional information on the out-of-state ozone contributions can be found in EPA's Cross State Air Pollution Rule (CSAPR) website.²⁴

7.1 Four Corners Air Quality Task Force (FCAQTF)

The States of New Mexico and Colorado convened the Four Corners Air Quality Task Force (FCAQTF) in 2005 to address air quality issues in the Four Corners region and consider mitigation options for air pollution. Air pollutants considered were ozone (NO_x and VOC emissions), particulate matter (PM) and mercury. The FCAQTF had over 100 members from federal, state and local agencies, tribes, stakeholders and interested parties. Reports were published after two years (2005-2007) that discussed potential emission mitigation measures (FCAQTF, 2007), monitoring needs and air quality modeling results (Stoeckenius et al., 2007), and other issues. Although ozone transport was the largest contributor to ozone in the Four Corners region, the modeling found that for local sources reducing NO_x and VOC emissions from oil and gas and NO_x from power plants was the most effective local emissions ozone control strategy. Currently, the Four Corners air quality and other issues are being studied by the Four Corners Air Quality Group (FCAQG).²⁵

7.2 Southern New Mexico Ozone Study (SNMOS)

The Southern New Mexico Ozone Study (SNMOS; Ramboll, 2016) performed CAMx ozone modeling for a 2011 base and 2025 future year using a CAMx 12/4 km modeling platform; the 12/4 km modeling domains are shown in the right panel of Figure 7-1. The SNMOS found that a vast majority of ozone in southern New Mexico is due to ozone transport from outside of New Mexico. For example, the left panel in Figure 7-1 displays the 2011 and 2025 ozone contributions to the ozone Design Value (DV) at the Desert View monitoring site in southern Doña Ana County by geographic regions shown in the right panel in Figure 7-1. Only 3 percent of the 2011 ozone DV at the Desert View monitor in Doña Ana County is due to anthropogenic emissions from New Mexico, and New Mexico emissions contribute less than 2 percent of the projected 2025 ozone DV at Desert View. Note that the Texas and Mexico contributions to the 2021 and 2025 ozone DVs at Desert View in the left panel; of Figure 7-1 are only due to the in-domain emissions of those two regions (left panel in Figure 7-1) and their total contributions, some of whose contributions are part of the Boundary Conditions, would be larger.

²⁴ [Cross-State Air Pollution | US EPA](#)

²⁵ <https://www.env.nm.gov/air-quality/four-corners-air-quality-group/>

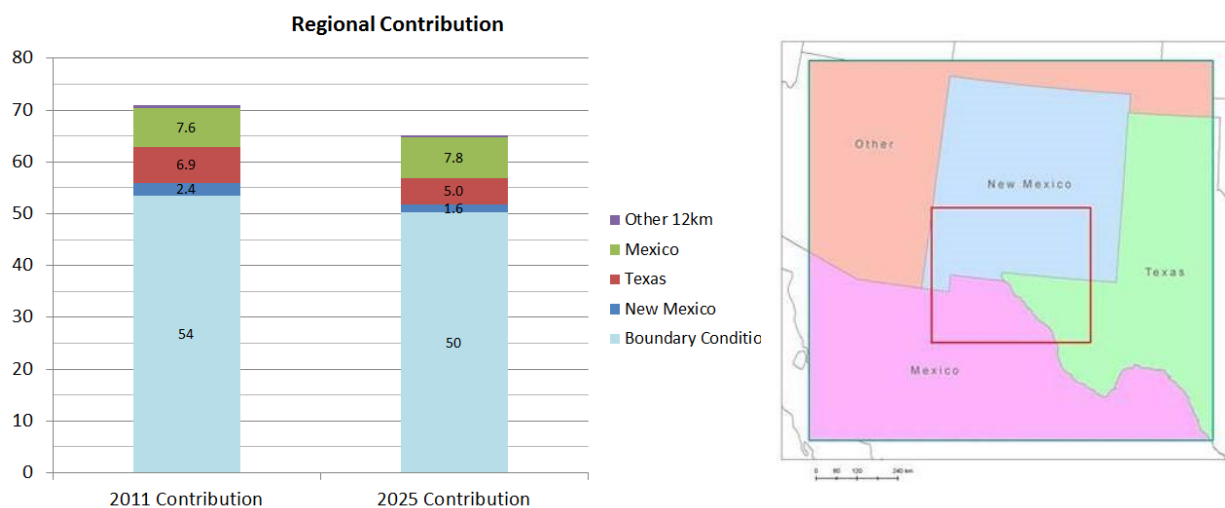


Figure 7-1. Contributions to the 2011 and 2025 ozone DVs at the Desert View monitoring site (left). Modeling domain and source regions used in the modeling (right). (Source: SNMOS, Ramboll, 2016).

The SNMOS 2011 and 2025 ozone source apportionment modeling also obtained contributions by source sector in addition to the four source regions depicted in the right panel of Figure 7-1. Figure 7-2 displays the source sector contributions to the 2011 and 2025 ozone DV at the Desert View monitor as well as the 10 highest source groups (i.e., source sector emissions from source regions) contributions. On-road mobile sources have the highest source sector contribution to ozone DVs in both 2011 and 2025 (Figure 7-2, top panel), but that is mainly due to on-road mobile source emissions in Texas and Mexico that are the two highest contributing source groups (Figure 7-2, bottom panel). On road emission contributions were projected to decrease, while oil and gas and EGU and non-EGU point source emission contributions were projected to increase.

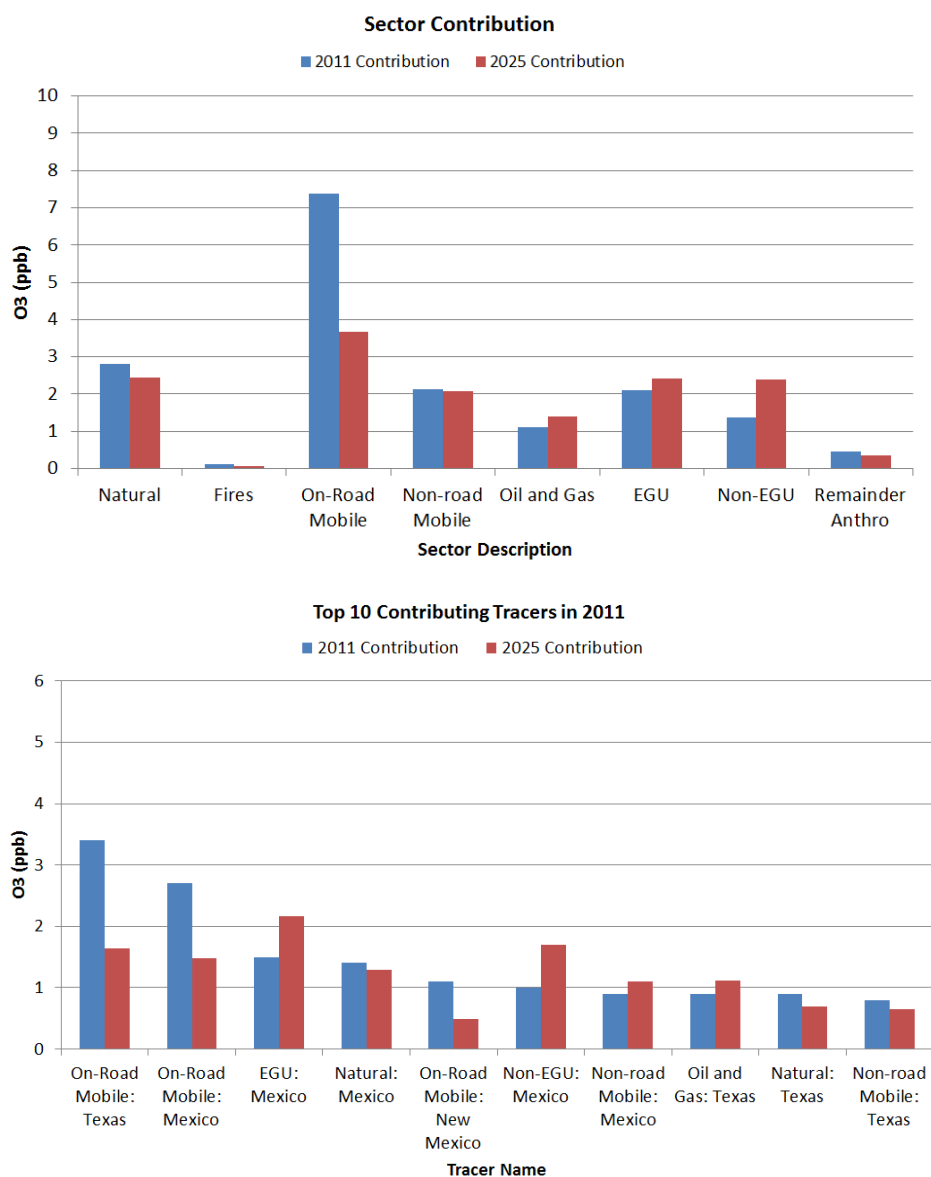


Figure 7-2. Contributions of source sector emissions to the 2011 and 2025 ozone DVs at the Desert View monitoring site (top). Top ten source group contributions (bottom). (Source: SNMOS, Ramboll, 2016).

7.3 New Mexico Ozone Attainment Initiative Modeling Study (NM OAI)

The New Mexico Air Quality Control Act (NMAQCA; 74-3-5.3, NMSA 1978²⁶) requires the NMED to develop a plan to address elevated ozone levels when air quality is within 95% of the ozone NAAQS (i.e., ozone DV of 67 ppb or higher for the 70 ppb 2015 ozone NAAQS). The maximum 2016-2018 ozone DV in Doña Ana (74 ppb), Eddy (74 ppb), San Juan (70 ppb), Lea (70 ppb) and Sandoval (68 ppb) Counties all were within 95% of the 70 ppb 2015 ozone NAAQS. During 2020-2021, NMED contracted with WESTAR, and their Subcontractor Ramboll, to perform the New Mexico Ozone Attainment Initiative (NM OAI) study to develop a 2014 CAMx photochemical modeling platform, make future year ozone DV projections, and conduct future year ozone source apportionment modeling. The NM OAI Study produced a Modeling Protocol (Ramboll and WESTAR, 2020a), 2014 base case modeling report (Ramboll and Wester, 2021a), and a 2028 future year modeling report (Ramboll and WESTAR, 2021b).

The left panel in Figure 7-3 displays the 36/12/4 km domain structure used in the NMED OAI Study. CAMx was run for the summer 2014 using one-way grid nesting between the 36 and 12 km domains and two-way grid nesting between the 12/4 km domains. Boundary Conditions (BCs) for the 36 km domain were based on a 2014 simulation of the GEOS-Chem global chemistry model, whereas BCs for the 12/4 km domains were based on the CAMx 36 km domain simulation. The right panel in Figure 7-3 shows the five source regions (NM, TX, CO, remainder U.S. and International) used in the CAMx 2028 future year 12/4 km ozone source apportionment modeling.

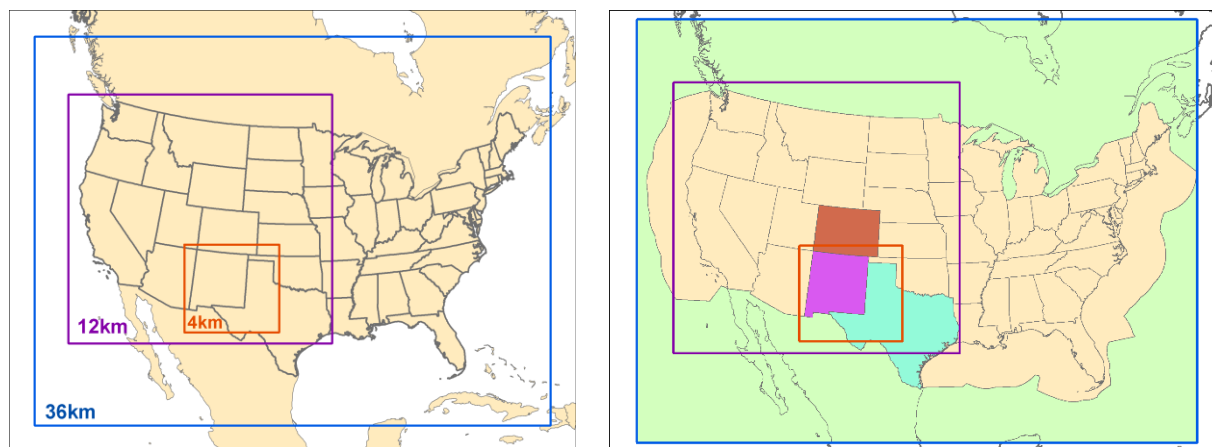


Figure 7-3. 36/12/4 km modeling domains used in the NM OAI (left) and five source regions used in the ozone source apportionment modeling (right). (Source: Ramboll and Wester, 2021b).

The source region ozone contributions for the 10 highest MDA8 ozone concentrations days at the Carlsbad monitor are shown in Figure 7-4. Boundary Conditions (i.e., concentrations from outside of the 12/4 km domains) are by far the largest contributor to 2028 ozone at the Carlsbad monitoring site. The next largest source region contributor is International

²⁶ <https://law.justia.com/codes/new-mexico/2017/chapter-74/article-2/section-74-2-5.3/>

emissions within the 12/4 km domain (i.e., Mexico), Remainder U.S., and usually Texas, although New Mexico can have a higher ozone contribution than Texas on some days.

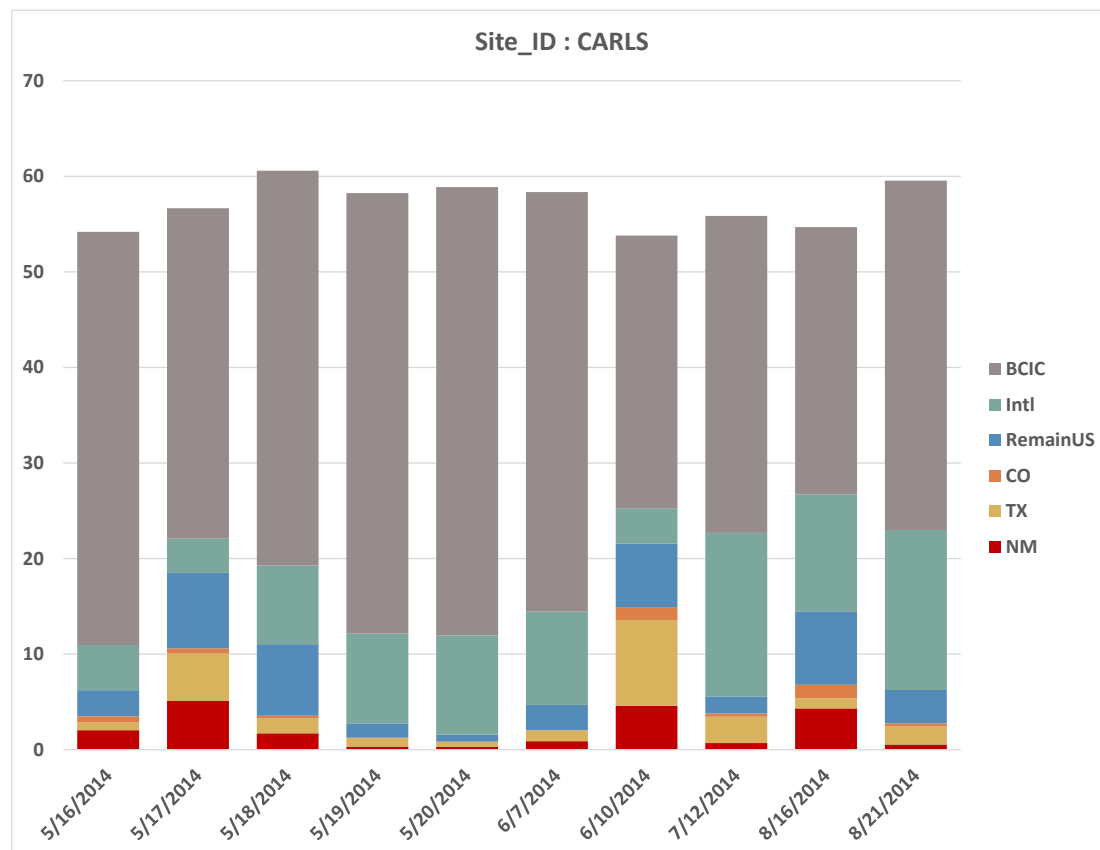


Figure 7-4. Contributions of source regions to the 10 highest 2028 MDA8 ozone concentrations at the Carlsbad monitor. (Source: Ramboll and Wester, 2021b).

Figure 7-5 displays the New Mexico source category contribution to the 2028 MDA8 ozone concentrations for the 10 highest modeled MDA8 ozone days at Carlsbad. The New Mexico ozone contribution ranges from approximately 0.2 to 5.0 ppb. The largest New Mexico source category to the 10 highest 2028 MDA8 ozone concentrations at Carlsbad is typically O&G (point plus non-point) followed by on-road mobile.

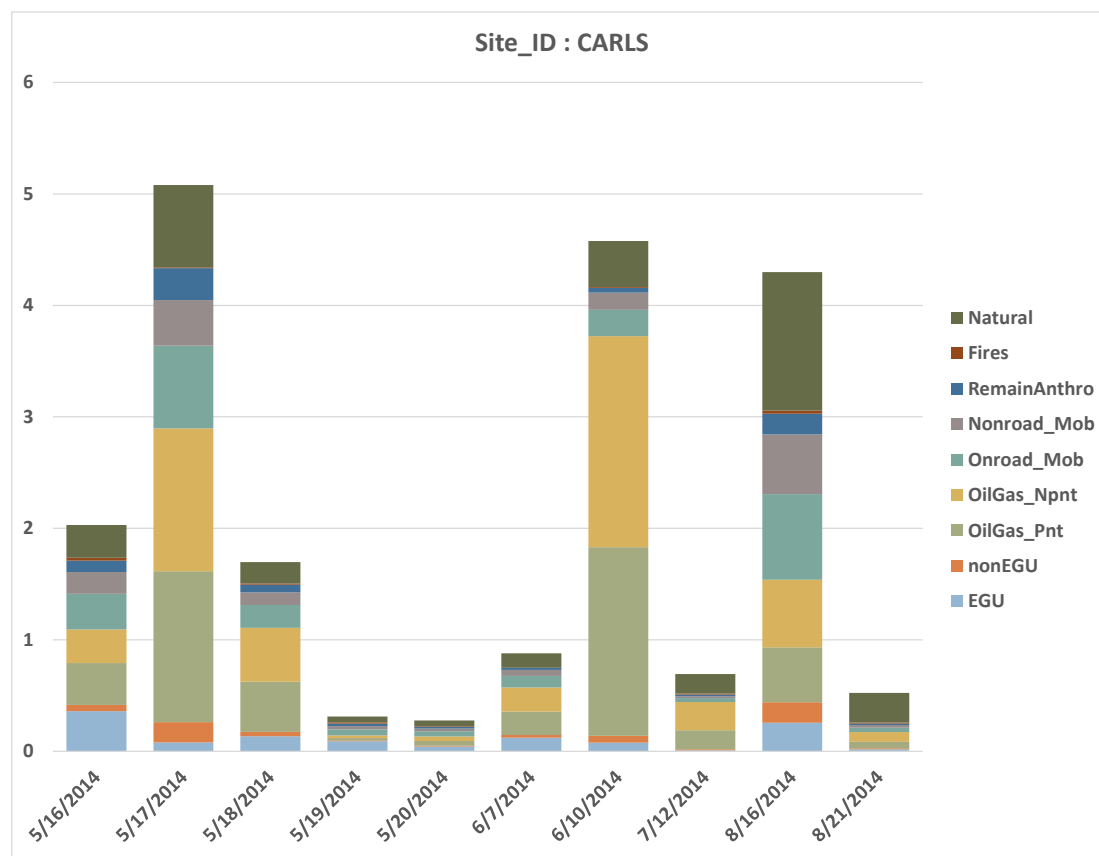


Figure 7-5. Contributions of New Mexico source categories to the 10 highest 2028 MDA8 ozone concentrations (ppb) at the Carlsbad monitoring site. [Source: Ramboll and Wester, 2021b].

7.4 New Mexico Section 179B Demonstration for Sunland Park Ozone Nonattainment Area

Based on 2014-2016 ozone DVs, the Sunland Park area in southern Doña Ana County, New Mexico was designated nonattainment of the 2015 ozone NAAQS. The NMED conducted a retrospective §179B(b) demonstration that the Sunland Park nonattainment area (NAA) would have attained the 2015 ozone NAAQS “but for” international anthropogenic emissions. The NMED §179B demonstration used the SNMOS and NM OAI ozone source apportionment modeling results to estimate the contributions of international anthropogenic emissions to ozone concentrations in the Sunland Park ozone NAA and demonstrate the area would have been in attainment of the 2015 ozone NAAQS without international anthropogenic emissions (NMED, 2021).²⁷ The Texas Commission on Environmental Quality (TCEQ) released a §179B demonstration for the El Paso portion of the El Paso – Las Cruces ozone nonattainment area in February 2022 (Ramboll, 2022).²⁸ The U.S. EPA agreed that the El Paso – Las Cruces ozone nonattainment area (that includes Sunland Park) would have attained the 2015 ozone NAAQS by the August 3, 2021 attainment date but for international

²⁷ <https://www.env.nm.gov/air-quality/wp-content/uploads/sites/2/2017/02/Sunland-Park-179B-Final.pdf>

²⁸ <https://www.tceq.texas.gov/airquality/airmod/docs/international-transport>

emissions and approved of NMED’s and TCEQ’s 179B(b) demonstrations (EPA, 2023). Thus, the El Paso – Las Cruces NAA remains a Marginal ozone NAA under the 2015 ozone NAAQS and was not redesignated as a Moderate ozone NAA.

7.5 NMED Phase I 2026 Ozone Source Apportionment Modeling Study

NMED contracted with Ramboll to perform an ozone source apportionment modeling study to determine the source of elevated ozone concentrations in New Mexico and, in particular, the Permian Basin portion of New Mexico that has measured violations of both the 70 ppb 2015 and 75 ppb 2008 ozone NAAQS since 2019. Phase I of the study was performed from April 17 to June 30, 2025 during FY2024-2025 and used the EPA 2022v1 12 km CAMx modeling platform to conduct CAMx 2022v1 12 km base case modeling and a model performance evaluation and future year 2026v1 12 km ozone source apportionment modeling. The 2022v1 and 2026v1 emissions were based on the National Emissions Collaborative (NEC) 2022v1 Emissions Modeling Platform (EMP).^{29,30}

The NMED Phase I ozone source apportionment modeling study generated results that include the following products:

- A report documenting the CAMx 2022v1 12 km base case modeling and modeling performance evaluation and the CAMx 2026v1 12 km ozone source apportionment modeling was published in June 2025 (Ramboll, 2025b).
- Three Excel Dashboards that allows the user to visualize the CAMx 2026v1 ozone source apportionment contributions at monitoring sites:
 - Contributions of the 6 Source Regions and 9 Source Categories to 2026v1 MDA8 ozone concentrations for combinations of day(s) including the 10 SMAT days used to make 2026 ozone DVF projections.
 - Contributions of regions/categories O3N and O3V tracers to 2026v1 MDA8 ozone concentrations providing an indication of NO_x vs. VOC ozone formation sensitivity; and
 - NO_x and VOC efficiency metrics by source region/category of MDA8 ozone formed divided by precursor emissions.

The observed 2020-2024 ozone Design Values (DVs) were projected to 2026 and were estimated to exceed the 70 ppb 2015 ozone NAAQS at sites in the Permian Basin and Sunland Park. Figure 7-6 shows the 2026 ozone DVFs across New Mexico calculated using the Speciated Modeled Attainment Test (SMAT) Unmonitored Area Analysis (UAA) using the CAMx 2022v1 and 2026v1 12 km modeling results. The red areas indicate projected 2026 ozone DVFs that exceed the 70 ppb NAAQS with a peak projected 2026 ozone DVF of 75.3 ppb in the New Mexico portion of the Permian Basin. SMAT UAA has an option to interpolate the DVB₂₀₂₀₋₂₀₂₄ across the domain with (UAA-GA) and without (UAA-NoGA) adjusting for modeled 2022 ozone concentration gradients, the UAA-GA spatial interpolation approach was used in the projected 2026 ozone DVFs shown in Figure 7-6. The SMAT-UAA using the GA ozone DVB interpolation procedure (UAA-GA) generated higher projected ozone DVFs downwind of the Water (Black) fire in southwest New Mexico.

²⁹ <https://views.cira.colostate.edu/wiki/SiteSettings/Wiki/Index/11209>

³⁰ <https://www.epa.gov/air-emissions-modeling/2022v1-emissions-modeling-platform>

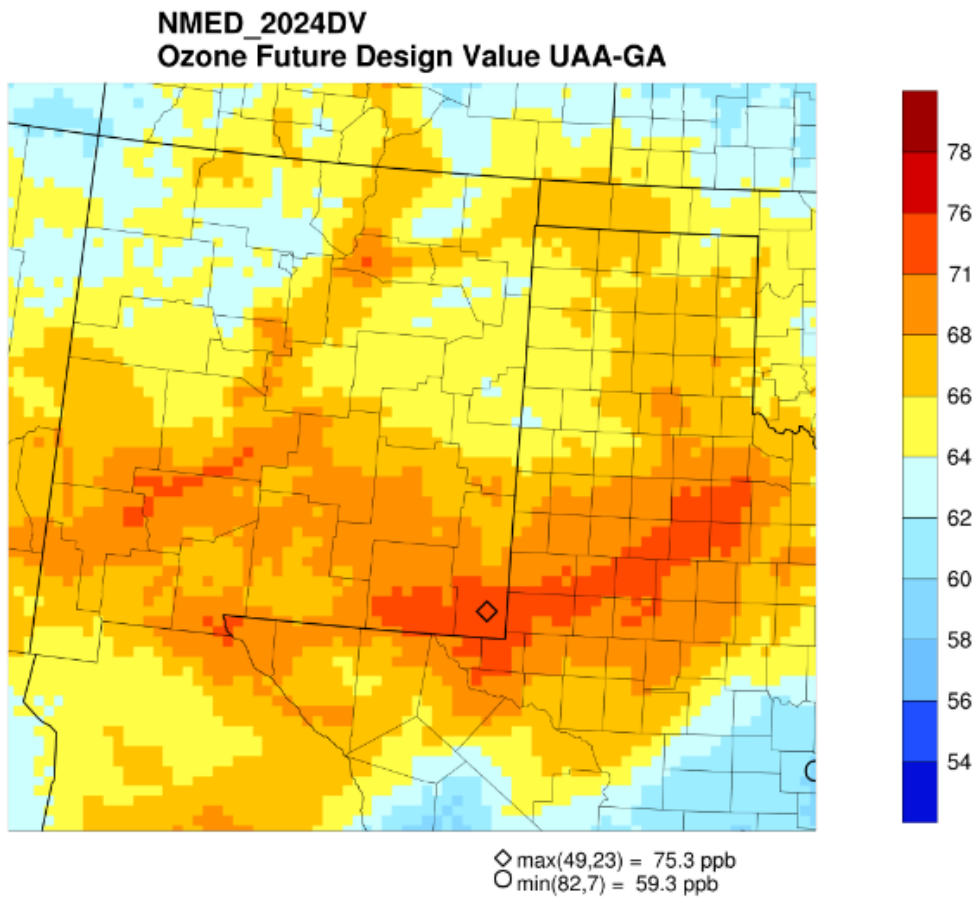


Figure 7-6. Projected 2026 ozone DVF across New Mexico using SMAT Unmonitored Area Analysis (UAA).

7.5.1 Contributions to 2026 Ozone DVF Across New Mexico using the SMAT UAA

The CAMx 2026v1 12 km ozone source apportionment modeling divided the 12 km CONUS domain into 6 source regions (see Figure 7-7) and obtained separate contributions for the 9 source categories as shown below. This results in 2026 ozone source apportionment being obtained for 56 source groups as Initial Concentrations (IC) and Boundary Conditions always have to be included as a source groups ($56 = 6 \times 9 + 2$).

Source Regions

1. Permian Basin portion of NM;
2. Remainder NM;
3. Permian Basin portion of TX;
4. Remainder TX;
5. Mexico; and
6. Remainder 12 km domain.

Source Categories

1. Natural (biogenic, lightning NO_x, oceanic);
2. Fires;
3. Oil and gas point sources;
4. Oil and gas non-point sources;
5. EGU point;
6. Non-EGU point;
7. On-road mobile;
8. Non-road mobile; and
9. Remainder anthropogenic.



Figure 7-7. Source regions used in the CAMx 2026v1 12 km ozone source apportionment simulation using the 2022 EMP 2022v1 12 km modeling platform.

Figure 7-8 displays the contributions to the SMAT UAA 2026 ozone DVF projections across New Mexico due to total anthropogenic emissions in New Mexico and Texas (each separately), New Mexico Permian Basin O&G emissions, and New Mexico plus Texas Permian Basin O&G emissions. The maximum New Mexico anthropogenic emissions contribution to the 2026 ozone DVF is 9.0 ppb that occurs in Eddy County near Carlsbad. O&G emissions in the New Mexico portion of the Permian Basin contribute 94% (8.5 ppb) of the 9.0 ppb total New Mexico anthropogenic emissions contribution. The combined NM+TX Permian Basin contribution at approximately the same location near Carlsbad is 12.0 ppb, thus the Texas Permian Basin O&G contribution is 3.5 ppb at this location.

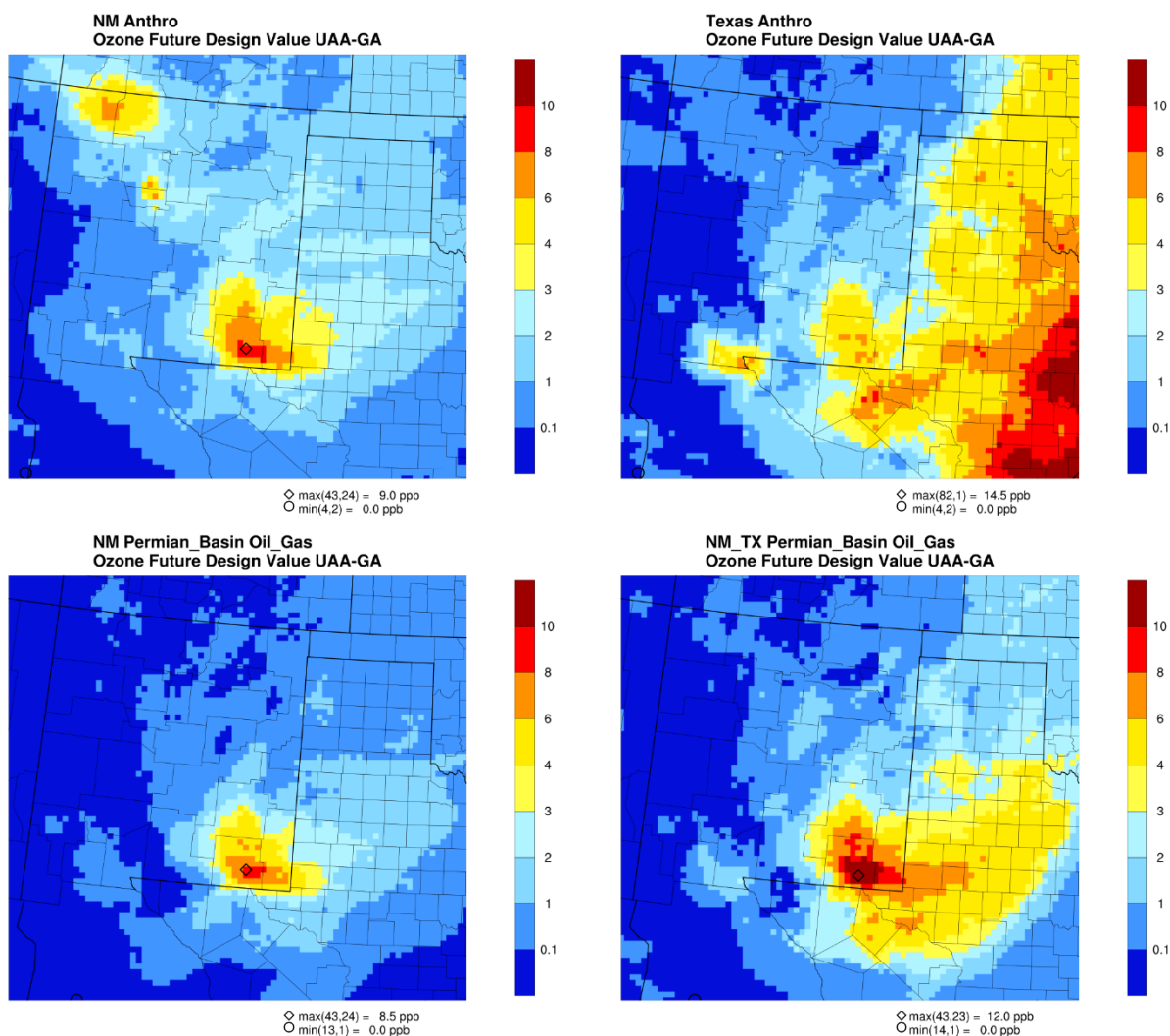


Figure 7-8. Contributions of anthropogenic emissions in New Mexico (top left) and Texas (top right), New Mexico Permian Basin oil and gas emissions (bottom left) and New Mexico plus Texas Permian Basin oil and gas emissions (bottom right) to the projected 2026 ozone DVFs.

7.5.2 Contributions of Source Regions and Sectors to 2026 MDA8 Ozone Concentrations

The CAMx 2026v1 ozone source apportionment modeling results at monitoring sites were loaded into Excel Dashboards that are used to obtain the contributions of the source regions/categories to modeled 2026 MDA8 ozone concentrations. When examining 2026 ozone concentrations across the 10 days used by SMAT to make 2026 ozone DVF projections, the contributions can be interpreted as the contributions to the projected 2026 ozone DVFs. Figure 7-9 displays the source sector contributions to 2026 MDA8 ozone at Carlsbad City monitor for the 10 SMAT days. The largest contribution to the average of the 2026 MDA8 ozone across the 10 SMAT days is 66% that is due to Boundary Conditions (BCs, labeled BCD in Figure 7-9) that are the concentration specified around the boundaries of the 12 km CONUS domain. With Natural (NAT) and Fire (FIR) contributing, respectively, 4% and 1% that leaves a 29% contribution due to anthropogenic emissions of which over half is due to oil and gas emissions. The BC contribution is greater for the four SMAT days in May (average of 97%) than the other six SMAT days (average of 51%).

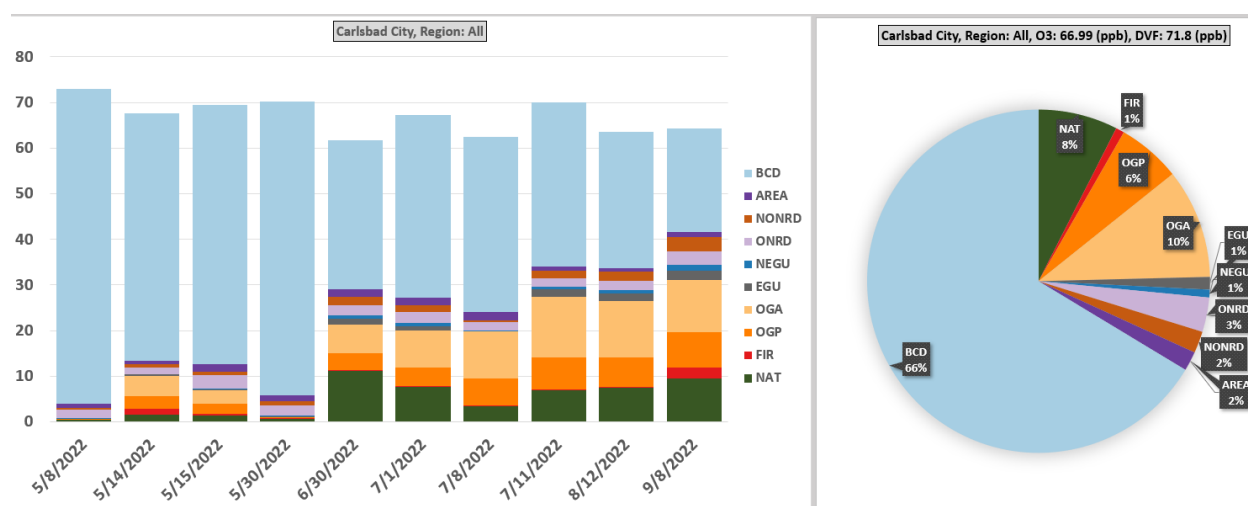


Figure 7-9. Contributions of Source Sectors to 2026 MDA8 ozone concentrations on the 10 days used by SMAT to make 2026 ozone DVF projections at the Carlsbad City monitoring site.

Figure 7-10 displays the contributions of source sectors to 2026 MDA8 ozone concentrations on the 10 SMAT days at the Desert View monitor in Doña Ana County. Like Carlsbad, BCs have the highest contribution to 2026 MDA8 ozone averaged across the 10 SMAT days (66%) with the BC contribution being greater for the May SMAT days (85-95%) than the non-May SMAT days (50-75%). On-road mobile sources is the largest anthropogenic emissions source sector contributor (11%), followed by area sources (6%), O&G (3%) and non-road mobile (2%).

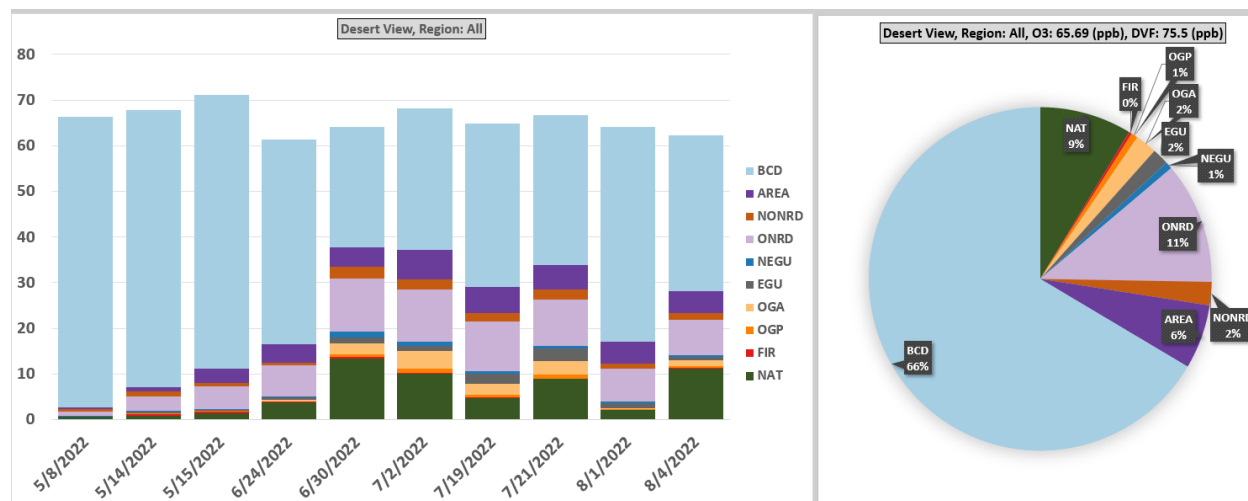


Figure 7-10. Contributions to the 2026 MDA8 ozone concentrations at Desert View for the 10 SMAT days.

The source sectors contributions to 2026 MDA8 ozone concentrations at the other New Mexico monitoring sites also show a majority of the contributions is due to BCs, with the BC contributions in May being much higher than the other months.

The analysis of the contributions of the O3N and O3V tracers to 2026 MDA8 ozone indicates that ozone formation that leads to elevated 2026 MDA8 ozone concentrations is more NO_x-sensitive than VOC-sensitive. This finding was confirmed by CAMx 2026 VOC and NO_x emission reduction sensitivity simulations (Ramboll, 2025c).

7.5.3 Mexico Zero-Out Anthropogenic Emissions Sensitivity Simulation

Including Carlsbad Caverns, which did not have three-years of data so the DV was based on two years, there were four sites in New Mexico with 2020-2024 ozone DVB that exceeded the 70 ppb 2015 ozone NAAQS: Carlsbad City (78.0 ppb), Carlsbad Caverns (78.3 ppb), Desert View (75.5 ppb), and La Union (76.0 ppb). When the ozone contribution to 2026 MDA8 ozone concentrations due to 2026 Mexico anthropogenic emissions within the 12 km CONUS domain are eliminated, the SMAT projected 2026 ozone DVF at all four sites are below the 2015 ozone NAAQS: Carlsbad City (70.2 ppb), Carlsbad Caverns (70.9 ppb), Desert View (64.9 ppb), and La Union (65.1 ppb). These results support the NMED Section 179B(b) demonstration for the El Paso-Las Cruces (Sunland Park) nonattainment area that it would have attained the 2015 ozone NAAQS if not for international anthropogenic emissions and a similar finding would occur for the Permian Basin. The projected 2026 ozone DVFs without all international anthropogenic emissions would be even lower than obtained by just eliminating Mexico anthropogenic emissions in the 12 km CONUS domain as a large portion of the BCs are due to international anthropogenic emissions.

8.0 2022 MODEL YEAR

The NMED Phase II 2026 ozone source apportionment modeling will use a 2022 base meteorological year and emissions data from the 2022 EMP 2022v2. In this chapter we briefly discuss the suitability of the 2022 base year for ozone source apportionment modeling.

The climate anomaly analysis in Section 4.2 revealed fairly typical meteorological conditions for the 2022 modelling year in New Mexico and nationally. Figure 8-1 corroborates fairly typical meteorology for New Mexico since EPA’s meteorological adjustments for the ozone trends analysis are not extreme.³¹ As noted in Section 6.0, the largest and second largest fires in New Mexico history occurred in 2022. However, they were most active in April through mid-June and likely did not greatly impact New Mexico ozone concentrations after that time. Typical light smoke conditions prevailed from the rest of the summer as shown in Appendix D. In summary, 2022 is a suitable year to select for modeling since it is the most recent year for which the EPA modeling platform is available and there were fairly typical meteorological conditions through New Mexico.

Table 8-1 provides a list of the exceedance days for Permian Basin monitors in 2022 color-coded by MDA8 with values higher than the 75 ppb 2008 ozone NAAQS shaded red, between the 70 ppb 2015 NAAQS and 75 ppb shaded yellow and between 65 and 70 ppb shaded green. Figure 8-1 displays the EPA meteorological adjustments for 2022 for different percentiles of ozone concentration. Since the magnitudes of the meteorological adjustment were moderate (i.e., denoted as light shades and not deep blues and reds), that suggests that meteorological impacts on ozone were fairly typical across New Mexico in 2022.

Despite 2022 being a high wildfire year for New Mexico, it appears to have fairly typical meteorological conditions, ozone concentrations, and oil and gas activity representative of recent years. Two-thirds of the New Mexico wildfire ozone precursor emissions occurred during May that needs to be accounted for in the interpretation of the modeling results.

³¹ ³¹ <https://www.epa.gov/air-trends/trends-ozone-adjusted-weather-conditions>

Table 8-1. MDA8 ozone exceedances at the Permian Basin monitors in 2022.

Local Name:	Carlsbad Caverns	Carlsbad City	Hobbs
County:	Eddy	Eddy	Lea
Date	35-015-0010	35-015-1005	35-025-0008
4/30/2022	70	73	53
5/3/2022	71	72	56
5/14/2022	64	71	63
5/15/2022	68	71	50
5/16/2022	71	79	55
5/26/2022	71	73	70
5/27/2022	60	74	59
5/30/2022	72	72	72
6/4/2022	51	59	74
6/9/2022	72	71	52
6/10/2022	71	69	54
6/29/2022	81	77	75
6/30/2022	69	71	69
7/1/2022	78	76	69
7/2/2022	72	75	68
7/8/2022	85	72	66
7/9/2022	71	71	62
7/10/2022	71	67	61
7/11/2022	83	79	65
7/13/2022	71	74	66
7/14/2022	71	71	68
7/15/2022	76	78	75
8/12/2022	86	84	70
8/13/2022	84	83	67
8/14/2022	78	80	62
8/24/2022	71	66	56
9/8/2022	83	0	68
10/13/2022	65	76	64

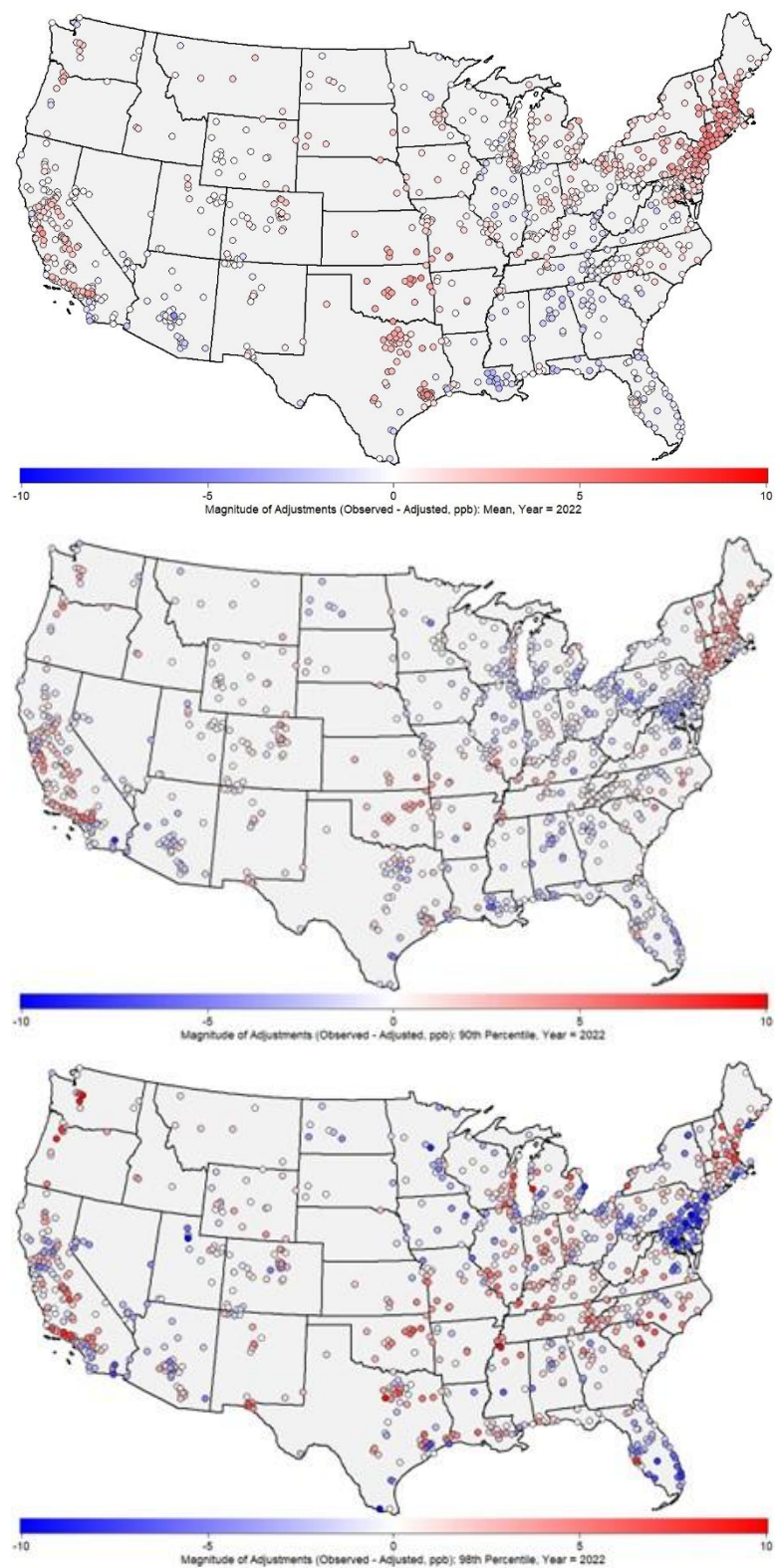


Figure 8-1. EPA's meteorological adjustments for ozone: mean (top), 90th percentile (middle) and 98th percentile (bottom).

9.0 SUMMARY OF AVAILABLE PERMIAN BASIN FIELD STUDY DATA

9.1 Air Quality Studies at Carlsbad Caverns

Figure 9-1 shows a timeline of the three Carlsbad Caverns Air Quality Studies (CarCavAQS) that were led by Colorado State University (CSU) and included other participants. An initial survey study was conducted in 2017, the primary study period was a 6 week period during the summer of 2019, and there was a follow-up 4-5 week study in the summer of 2021. Also shown in Figure 9-1 is the trend in ozone DVs at Carlsbad Caverns and oil production in the Permian Basin. The increase in ozone DVs starting in 2018 corresponds to an increase in oil production in the Permian Basin. Appendix D summarizes the results of several peer-review papers that documented the 2019 CarCavAQS with papers in preparation on the 2021 CarCavAQS.

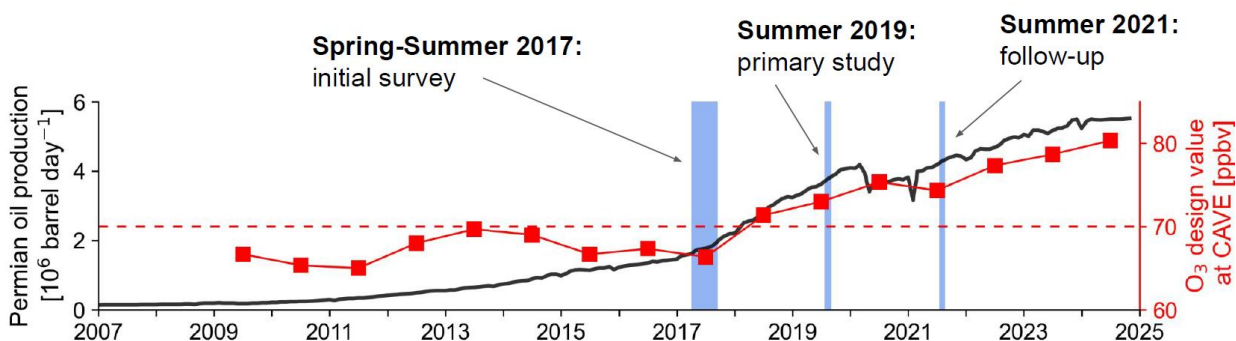


Figure 9-1. Three Air Quality Field Studies at Carlsbad Caverns and trends in Carlsbad Cavern ozone Design Value and oil production in the Permian Basin (Source: A. Marsavin, personal communication September 19, 2025).

Figure 9-2 provides a listing and comparison of the measurements that were collected during the 2019 and 2021 CarCavAQS. Since the CarCavAQS took place in 2017, 2019 and 2021 and the modeling year is 2022, we cannot match the model and measurements in time on a day-by-day basis. However, the special study data can be used to develop process-based evaluation of components of the modeling system by comparing distributions of ozone and precursor species over the 2022 model period and CarCavAQS field study periods.

Carlsbad Caverns Intensive Air Quality Study		
2019	Measurements	2021
7/24 → 9/3		7/17 → 8/19
• NO, NO₂, NO_y • CH₄, NH₃, CO₂ • PAN, PPN • Real-time GC: C₂-C₁₀ NMHCs, C₁-C₅ alkyl nitrates, C₁-C₂ halocarbons, OVOCs, etc. • PTR-MS: VOCs, OVOCs, S cmpds • PM_{2.5} mass and composition (Na⁺, NH₄⁺, K⁺, Mg²⁺, Ca²⁺, Cl⁻, NO₂⁻, NO₃⁻, SO₄²⁻, Acetate, Formate, Glycolate, Oxalate) • 24-hr NH₃, HNO₃, SO₂, & PM_{2.5} composition • Carbonyl cartridges (10 AM – 5 PM) • Aethalometer (black carbon) • NPS/ARS operated real-time O₃, SO₂, CO and meteorology • GUMO O₃ and Meteorology		• NO, NO₂, NO_y • CH₄, C₂H₂, CO₂ • Real-time GC: C₂-C₁₀ NMHCs, C₁-C₅ alkyl nitrates, C₁-C₂ halocarbons, OVOCs, etc. • EPA Remotely Operated Canister Sampler (ROCS) – 4 locations • Sensor PM_{2.5} & PM₁₀ (CAVE & GUMO) • NOAA GEM, THg & RM • UNR Passive Hg Samplers (GUMO) • SENSIT SPOD • Entanglement AROMA-VOC • NPS/ARS operated real-time O₃ & meteorology • GUMO O₃ and Meteorology

Figure 9-2. Comparison and measurements of the 2019 and 2021 CSU field studies (Source: B. Sive et al., AWMA Measurement Conference April 2025 Aurora, CO).

9.1.1 2017 Carlsbad Cavern VOC Pilot Sampling Study

VOC samples were collected at four National Parks in the southwestern U.S. from mid-April to mid-September 2017: Carlsbad Caverns (CAVE), NM; Great Basin (GRBA), NV; Grand Canyon (GRCA), AZ; and Joshua Tree (JOTR), CA. The VOC concentrations at CAVE were much higher than the other three parks due to an abundance of light alkanes that were approximately 94% of the VOCs at CAVE and an order magnitude higher than the other parks. The biogenic isoprene VOC species dominated the OH-reactivity at the National Parks except at CAVE where the concentration weighted OH-reactivity of biogenic VOC and light alkanes were about equal (Benedict et al., 2020). The higher light alkanes at the CAVE National Park was attributed to oil and gas activities in the Permian Basin.

9.1.2 2019 and 2021 CarCavAQS

The 2019 CarCavAQS is documented in several journal publications that are summarized in Appendix D. The 2021 CarCavAQS data are being analyzed and at this writing papers are under preparation, however we did discuss some of the 2021 CarCavAQS findings with some of the field study participants for use in this Conceptual Model (A. Marsavin, September 19, 2025, personal communication).

Marsavin and co-workers (2024) analyzed the 2019 CarCavAQS data and conducted one-dimensional photochemical box modeling of the measurements. They used the observations to classify the high ozone days as fresh O&G (high morning NO_x/NO_y ratios > 0.8 and high VOCs), aged O&G (lower morning NO_x/NO_y ratios with high secondary VOCs), and aged background. For the 11 fresh O&G days, ozone formation was VOC-sensitive in the morning transitioning to NO_x-sensitive by late morning and into the afternoon. The modeling found that reducing O&G VOC and NO_x both reduced ozone with NO_x emission reductions being more effective.

Da Pan et al., (2023) analyzed the 2019 CarCavAQS VOC measurements. They used the Positive Matrix Factorization (PMF) receptor model and classified the VOC species measured into seven factors. Three of the factors were comprised mainly of alkanes with some aromatics and were attributed to nearby oil and gas development and production activities and accounted for 62% of the VOC OH-reactivity. Two of the factors were rich in secondary VOCs that suggested aged oil and gas sources from further upwind sources, possibly oil and gas activity in the Eagle Ford and Barnett shale formations. The last two factors contained alkenes that were attributable to vehicles or other combustion sources.

The 2019 CarCavAQS ozone, VOC and reactive nitrogen observations were analyzed by Pollack et al., (2023) and they found elevated concentrations when winds were from the southeast, the direction of oil and gas operations in the Permian Basin. They found high observed VOC/NO_x ratios on high ozone days indicating more NO_x-sensitive ozone formation conditions. They noted that peroxypropionyl nitrate to peroxyacetyl nitrate (PPN/PAN) ratios were less than 0.15, which indicated photochemical processing by alkanes associated with oil and gas operations. The observations indicate ozone formation is more NO_x-sensitive than VOC-sensitive, but the high PPN/PAN ratios suggest controlling local oil and gas VOCs that are alkane rich would also be beneficial for reducing ozone.

Figure 9-3 compares the meteorological conditions during the 2019 and 2021 CarCavAQS intensive study periods. Although winds were primarily out of the southeast (i.e., from the Permian Basin) during both studies, the temperature and precipitation conditions during the two study period were quite different. The 500 mb heights were higher during 2019 resulting in warmer temperatures and lower wind speeds than in 2021. The average temperatures during the 2019 period were 2-4 °C warmer than in 2021. There was also more monsoon activity during 2021 producing more precipitation than 2019.

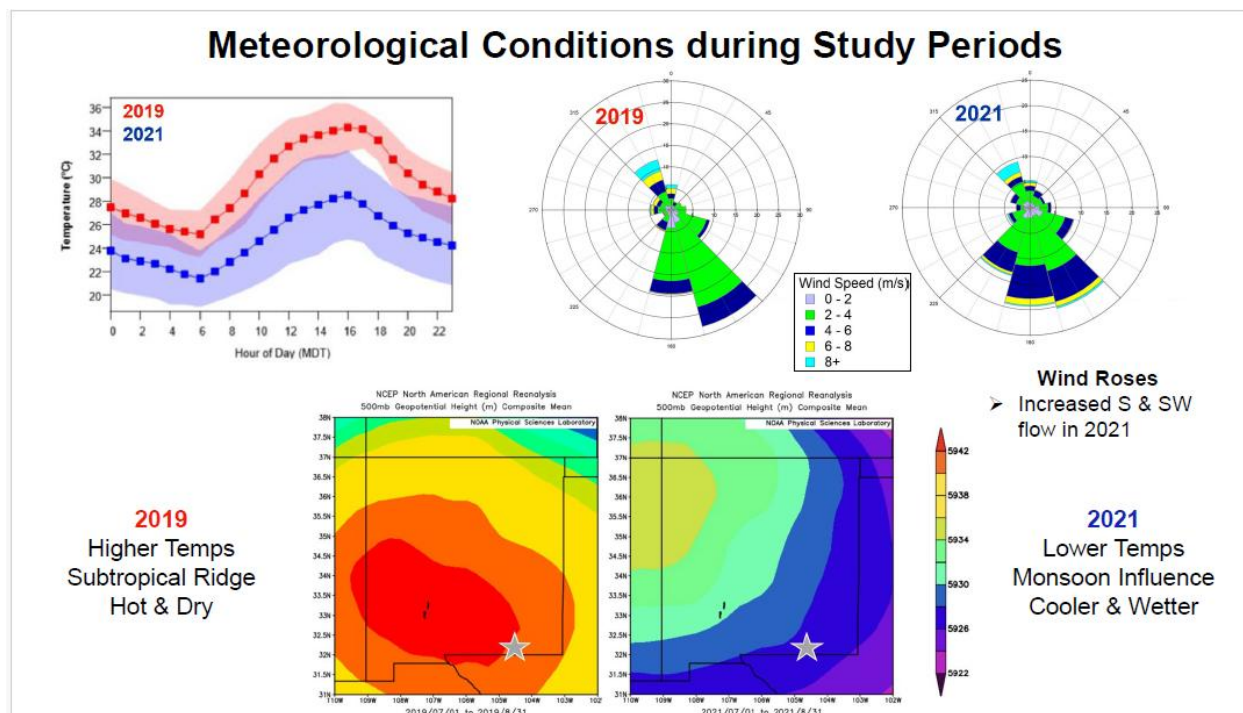


Figure 9-3. Comparison of the meteorological conditions between the 2019 and 2021 CarCavAQS. (Source: Sive et al., AWMA Measurement Conference April 2025 Aurora, CO).

2021 was a high wildfire year in the western U.S. For example, wildfires in California started particularly early in the year and burned approximately 2.5 million acres the second most on record to 4.4 million acres burned in 2022. Smoke from wildfires affected many of the sampling days during the 2021 CarCavAQS and were identified in the measurement data. In addition to smoke (PM), wildfires emit ozone precursors and the 2021 field study frequently observed higher ozone during wildfire day impacts, especially at night; nighttime ozone concentrations were ~6 ppb higher on smokey versus smoke free days.

9.2 Boulder Air Measurements

BoulderAir is based out of Boulder, Colorado and operates a number of monitoring programs in Colorado and elsewhere including the town of Loving New Mexico in the Permian Basin. The website describes their motivation and objectives for air monitoring in Loving, New Mexico as follows:³²

Domestic oil and gas production has increased in the United States to its highest level in over a decade. New extraction techniques, such as horizontal drilling and high-volume hydraulic fracturing, have enabled the exploitation of previously inaccessible or uneconomic shale rock resources, resulting in thousands of extraction sites across relatively small geographic areas. The oil and gas boom is happening near where people live and work, and it is increasing the potential for human exposure to air contaminants and noise. Our air quality research focuses on shale oil and gas exploration impacts in the Texas Western Gulf Basin (Eagle Ford), and the Permian Basin in Texas and New Mexico. We have previous and ongoing similar research in Texas shale areas and in the Denver Julesburg Basin of Colorado.

In measuring air quality near Loving, NM, our objectives are to: 1) characterize the impact of oil and gas production sources on ambient air pollution, radioactivity, and noise with continuous stationary monitoring, 2) learn how a subset of pollutants are distributed in the area using weekly integral measurements (passive sampling), and 3) link our monitoring data with satellite observations of gas flaring in the area.

Through these activities we will be able to identify the processes that result in air pollution and noise from the oil and gas industry while distinguishing them from other local sources, for example car traffic. We intend to quantify how large, how often, and for how long air pollutants from the industry are present. By combining these data with weather and land use information, we will inform about human exposures in the study area. Also, using satellites to identify gas flares in the area will help us to assess the role of flaring in these air pollutant exposures. Our study is designed to increase knowledge about air quality impacts before creating new with implications for the residents living and working in oil and gas production areas. Our results will provide local stakeholders and decision-makers with actionable evidence on air pollutants from the industry.

The BoulderAir measurements were taken at a location in Loving, New Mexico, (32.2974 N, 104.1095 W, 930 m asl). Loving is a small town (population ~1,500) approximately 20 km to the southeast of Carlsbad City and 45 km to the east-northeast of Carlsbad Caverns. The BoulderAir measurements were collected between April 2023 and March 2024 and included meteorological measurements (e.g., wind speed and direction, temperature, relative humidity and barometric pressure), ozone, and ozone precursor species as described in 4Figure 9-4. Ramboll contacted BoulderAir and they provided their raw data. The NO_x and VOC data may be used for a diagnostic evaluation in a similar manner to the CarCavAQS data (i.e., comparing distributions of precursor species) to the CAMx model concentration of those species.

³² <https://www.bouldair.com/loving.htm>

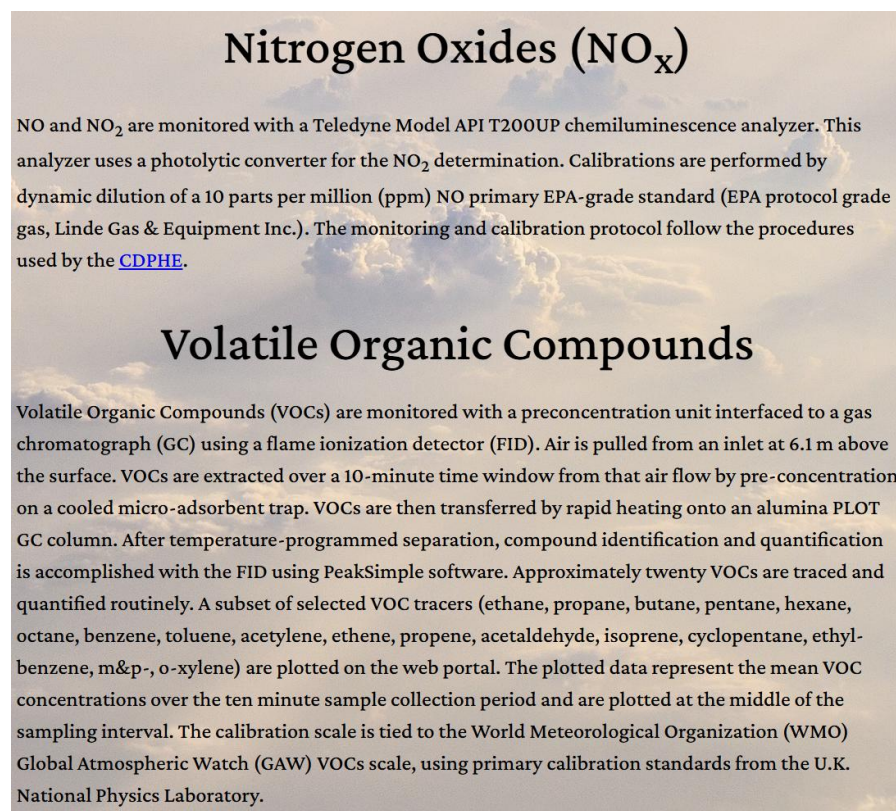


Figure 9-4. BoulderAir NO_x and VOC measurements details (Source: <https://www.bouldair.com/loving.htm>).

Figure 9-5 presents bivariate polar plots developed by BoulderAir that are similar to pollution roses that they describe as follows:

The bivariate polar plots you see above depict observed quantities of monitored chemicals as colors, plotted by wind direction and speed. Red colors indicate higher levels of the monitored chemical, whereas blue colors represent lower levels. The figure acts as a compass with the Loving air quality station (LNM) located at its center. Wind speeds are monitored in meters per second and increase as you move away from the center. This technique aggregates data into wind speed and direction bins and uses the chemical's median value in each bin to color the figure. As such, the scale values shown do not represent the absolute magnitude of the observed chemical. The minimum bin (min-bin) parameter specifies the minimum number of values in each bin needed to be shown in the figure. In some cases, min-bin values that are greater than one are selected to avoid outlier values biasing the results. Gray areas on the figure represent data that has been removed because there were too few data in the particular bin to meet the min-bin threshold. It is also important to note that data with wind speeds less than 1 meter per second are excluded from this analysis to ensure clear wind direction dependency results.

Figure 9-5 Figure 9-5 presents the BoulderAir 2023 quarter 2 and quarter 3 analyses for ozone and two ozone precursor species (NO_x and ethane). Additional plots are available on the BoulderAir website at <https://www.bouldair.com/loving.htm>.

As expected, ozone is generally higher when wind speeds are slower and from the southeast quadrant. During July through September there is also high ozone during periods with faster winds from the southeast. Ethane concentrations are also highest when winds are slow. The directional dependency of ethane is moderate with slightly higher concentrations when winds are from the east. For NO_x, the analysis for both quarters suggests a NO_x source to the southwest of the monitor, and quarter 3 has a period with the highest NO_x during moderately fast winds from the east. The reasons for the directional dependency of high NO_x are not known at this time but suggest emissions sources in those directions that could be investigated.

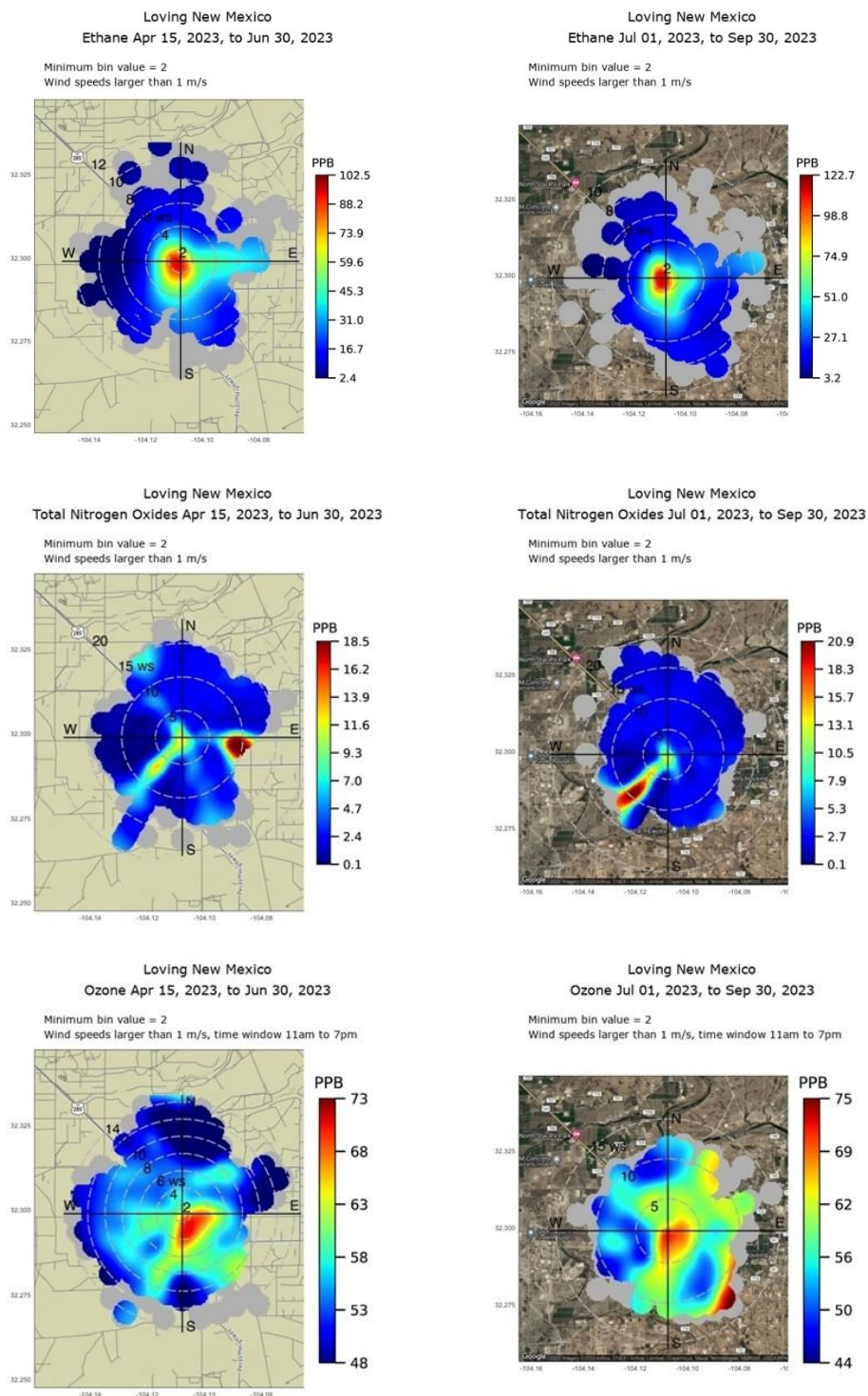


Figure 9-5. BoulderAir 2023 quarterly bivariate polar plots, showing Ethane (top), NO_x (middle) and Ozone (bottom) concentrations by windspeed and wind direction for the April 15 to June 30, 2023 (left) and July 1 to September 30, 2023 (right) periods. (Source: <https://www.bouldair.com/loving.htm>, permission to reproduce here obtained by personal communication from Detlev Helmig, October 31, 2025).

10.0 POTENTIAL DIAGNOSTIC MODEL PERFORMANCE EVALUATION TESTS

The Conceptual Model of ozone formation presented in this report has identified several attributes of ozone formation in New Mexico that lead to high concentrations that a modeling system should replicate. In this Chapter we provide a list of potential diagnostic tests that could be used to assist in evaluating and improving a photochemical grid model simulation of elevated ozone concentrations in New Mexico.

10.1 EPA Framework for Model Performance Evaluation

EPA's ozone modeling guidance for ozone, particulate matter and regional haze (EPA, 2018d) describes a model performance evaluation (MPE) framework that has four main components:

- Operational Evaluation: The Operational Evaluation compares the modeled concentration estimates against concurrent observations using statistical and graphical analysis aimed at determining how well the model simulates the base year observed concentrations (i.e., does the model get the right answer).
- Diagnostic Evaluation: The Diagnostic Evaluation evaluates various components of the modeling system. It can include a process-oriented evaluation and whether the model simulates the important processes for the air quality problem being studied (i.e., does the model get the right answer for the right reason).
- Dynamic Evaluation: The ability of the model's air quality predictions to correctly respond to changes in emissions and meteorology is part of the Dynamic Evaluation. This can include running the model for historical years to see whether the model's predictions match the changes in observations; comparison of model performance on weekdays versus weekend days can also help elucidate whether the model responds to changes in emissions correctly.
- Probabilistic Evaluation: The Probabilistic Evaluation assesses the level of confidence in the model predictions and estimates model uncertainty through techniques such as ensemble model simulations.

EPA's guidance recommends that "At a minimum, a model used for air quality planning should include a complete operational MPE using all available ambient monitoring data for the base case model simulations period" (EPA, 2018d, pg. 68). And goes on to say, "Where practical, the MPE should also include some level of diagnostic evaluation." EPA notes that there is no single definitive test for evaluating model performance, but instead there are a series of statistical and graphical MPE elements to examine model performance in as many ways as possible while building a "weight of evidence" that the model is performing sufficiently well for the air quality problem being studied.

10.2 NMED Phase I CAMx Operational Model Performance Evaluation

In Phase I of the NMED ozone source apportionment modeling study, we conducted an operational evaluation of the CAMx summer 2022v1 12 km modeling platform for ozone with a limited evaluation for NO_x (Ramboll, 2025c). The ozone Normalized Mean Bias (NMB) performance metric was compared against commonly used Performance Goal ($\leq \pm 5\%$) and Criterion ($\leq \pm 15\%$) from the peer-reviewed literature (Emery et al., 2017). Figure 10-1 displays the NMB performance statistic at sites across New Mexico for MDA8 and hourly ozone from the Phase I CAMx 2022v1 12 km base case simulation. The symbols are colored grey when they achieve the bias Performance Goal and bright yellow (overestimation) or bright green (underestimation) when they fall between the Performance Goal and Criterion. Within New Mexico, almost all sites achieve the Performance Criterion. The NMB for MDA8 ozone at many New Mexico sites also achieve the Performance Goal (grey symbols). The NMB at sites in the Permian Basin exhibit an underestimation bias with the NMB for the two Eddy County sites in the -10% to -15% range.

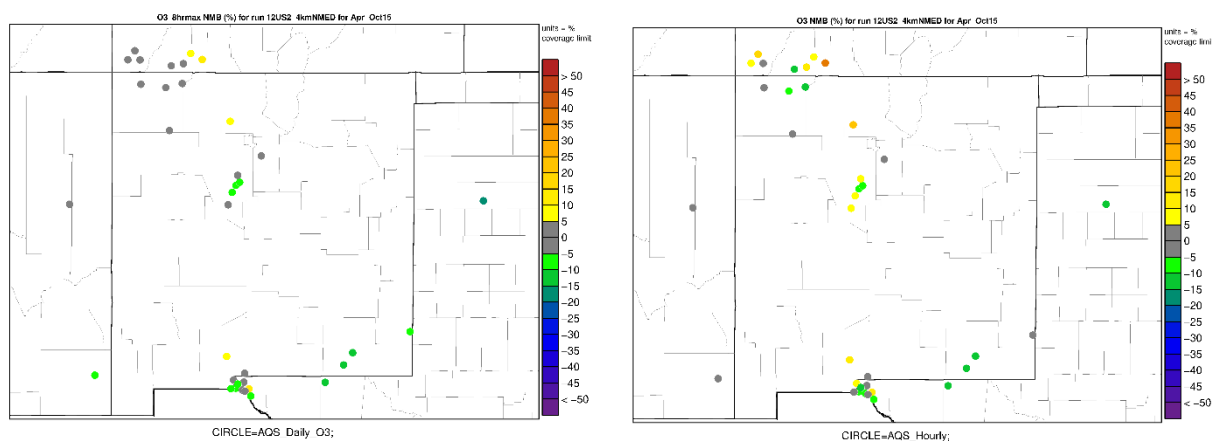


Figure 10-1. Spatial distribution of CAMx 2022v1 12 km MDA8 (left) and hourly (right) Normalized Mean Bias (NMB) ozone performance statistics at sites across New Mexico for summer 2022.

Figure 10-2 displays scatter plots and performance statistics of MDA8 ozone in the Permian Basin that illustrates the ozone underestimation at these sites. The NMB for the two Carlsbad sites is approximately -11% with Hobbs at -5%.

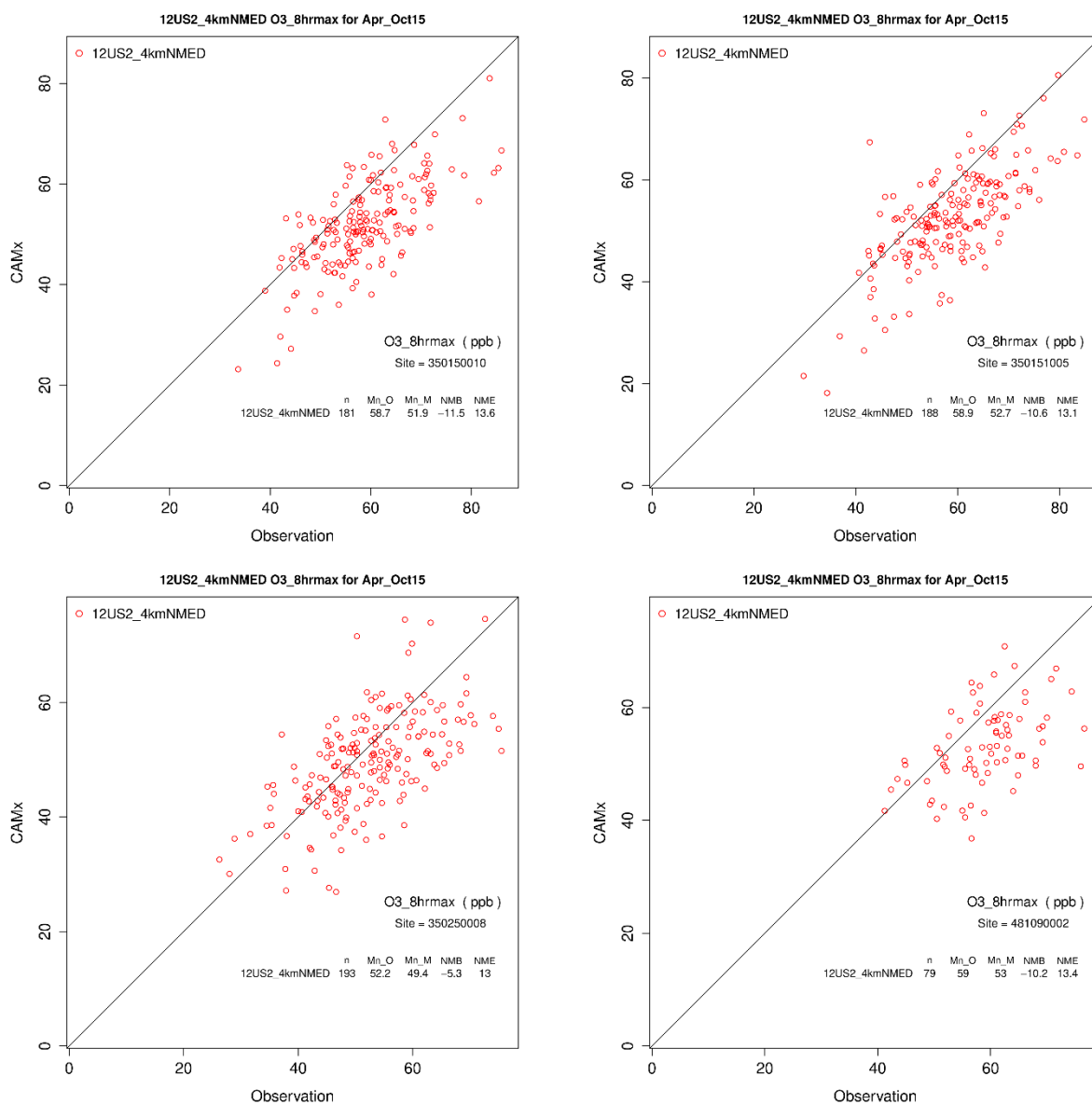


Figure 10-2. Scatter plots of predicted and observed MDA8 ozone concentrations at monitoring sites in the Permian Basin: Carlsbad Cavern (350150010), Carlsbad City (350151005), Hobbs (350250008) and Guadalupe Mountains NP (481090002).

The reasons for the underestimation of the MDA8 ozone at the Permian Basin sites are unclear. Figure 10-3 and Figure 10-4 display time series of predicted and observed hourly ozone and NO₂ concentrations during July 13-15, 2022, at Carlsbad City and Hobbs monitoring sites in the Permian Basin, respectively. In these figures, the CAMx “12US2_4kmNMED” 2022 base case simulation results (blue) are the CAMx 2022v1 12 km base case concentration estimates using the EPA 2022v1 platform as-is, whereas the CAMx “NMED_4kmflxnst” results (red) are from a CAMx 2022v1 12/4 km simulation that used 4 km WRF meteorological inputs but interpolated the 2022v1 12 km emissions to the 4 km New Mexico domain. On some days, the model is reproducing the observed morning rise in hourly ozone concentrations, but the modeled hourly ozone rise stalls out too early in the afternoon while the observed hourly ozone continues to rise. This is shown for Carlsbad City in Figure 10-3 where vertical lines (orange) have been added to the hourly ozone and NO₂ time series on July 14 and 15 at the hour that the modeled hourly ozone rise begins to slow down but the observed hourly ozone rise continues. At these times, the modeled hourly NO₂ concentrations begin to approach zero, whereas the observed NO₂ concentrations are higher so that NO₂ photolysis continues resulting in ozone formation. This issue is even more pronounced at the Hobbs monitoring site during July 13-15 where the modeled hourly ozone rise stalls out when the modeled hourly NO₂ concentrations drop to close to zero while the observed hourly ozone continues to rise with NO₂ concentration dropping to approximately 2 ppb. However, the observed hourly NO₂ concentrations may have interference from other reactive nitrogen species (e.g., HNO₃ and PAN) so we cannot determine with certainty that the observed true hourly NO₂ concentrations are not also approaching zero at these times.

There are several reasons that the modeled NO₂ concentrations being reduced to close to zero and inhibiting the continued rise in the modeled afternoon hourly ozone concentrations:

- Insufficient local emissions;
- Excessive vertical mixing diluting the local emissions;
- Failure to simulate a reservoir of ozone aloft that is entrained into the mixed layer as the mixing height rises; and/or
- Other processes not being properly simulated by the model.

Diagnostic tests that evaluate the emissions inventory, vertical mixing, and/or other aspects that lead to the ozone underestimation in the Permian Basin are warranted.

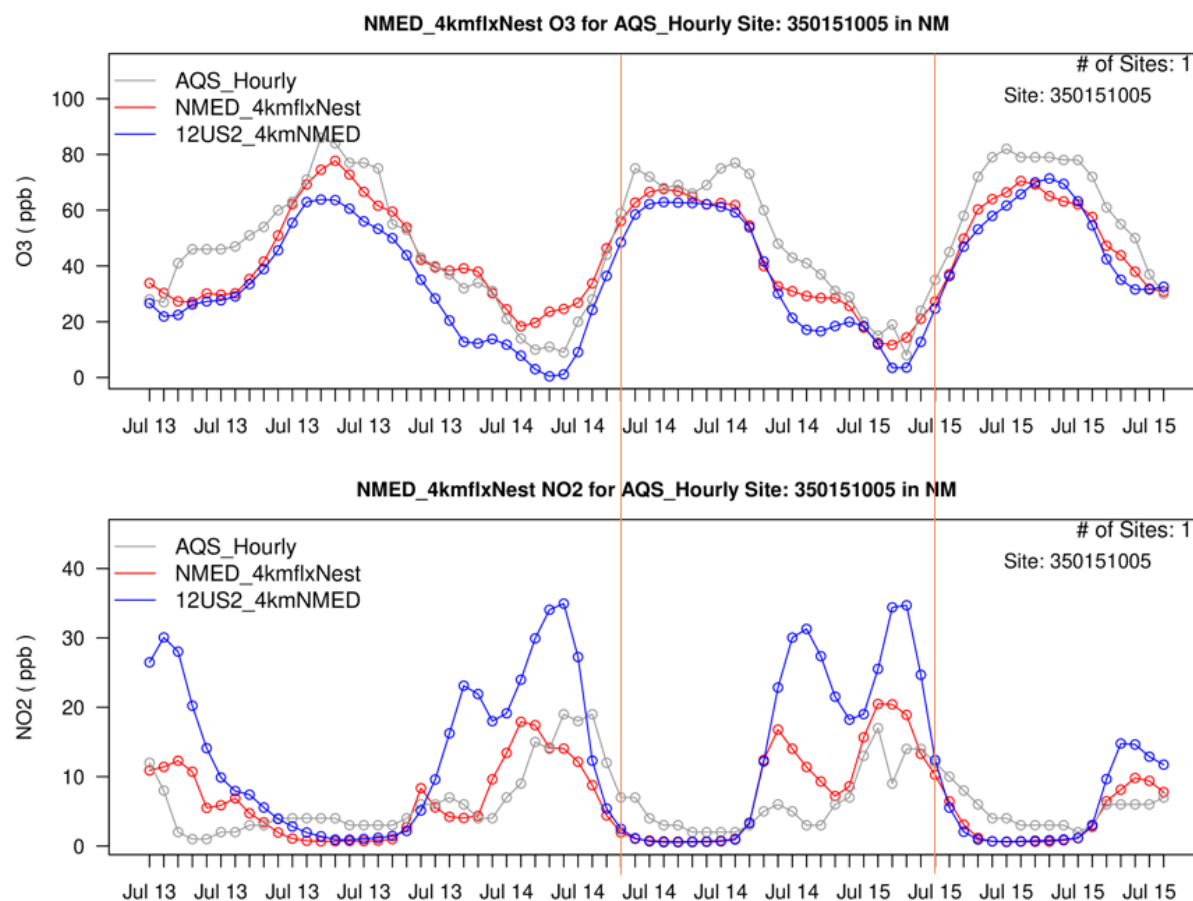


Figure 10-3. Time series of predicted and observed (gray) hourly ozone (top) and NO₂ (bottom) concentrations during July 13-15, 2022, at the Carlsbad City monitoring site for the CAMx 2022v1 12 km (blue) and CAMx 2022v1 12/4 km flexi-nest emissions base case simulations.

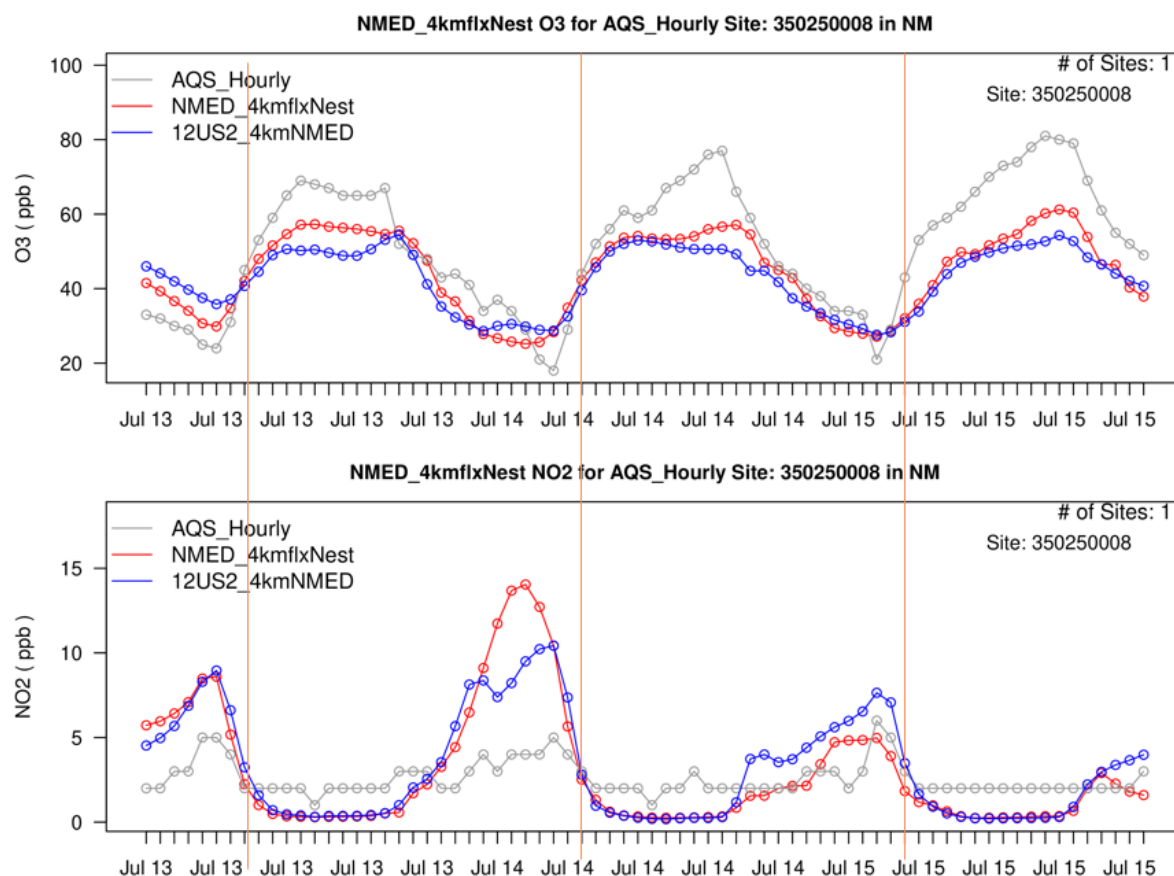


Figure 10-4. Time series of predicted and observed (gray) hourly ozone (top) and NO₂ (bottom) concentrations during July 13-15, 2022, at the Hobbs monitoring site for the CAMx 2022v1 12 km (blue) and CAMx 2022v1 12/4 km flexi-nest emissions base case simulations.

10.3 Phase I 2026 Ozone Source Apportionment Modeling

Phase I of the NMED ozone source apportionment study conducted CAMx 2026 12 km ozone source apportionment modeling for May through September 2022 that was described in Section 7.5. Although there were 8 ozone exceedance days in the Permian Basin during May 2022 (and April 30), the ozone source apportionment modeling found the May 2022 elevated ozone concentrations were due to transport from outside of the U.S., with most days having very small contributions from New Mexico emissions. For example, Figure 10-5 displays the source contributions to modeled 2026 MDA8 ozone concentrations at Carlsbad City monitoring site during the summer 2022 episode that shows large contributions of BCs (international emissions; light blue in Figure 10-5) during May and early June, as well as scattered days through the summer. Figure 10-6 displays the contributions of emissions from the New Mexico portion of the Permian Basin to the model MDA8 ozone concentrations at Carlsbad City and there are many days in May with near zero New Mexico contributions.

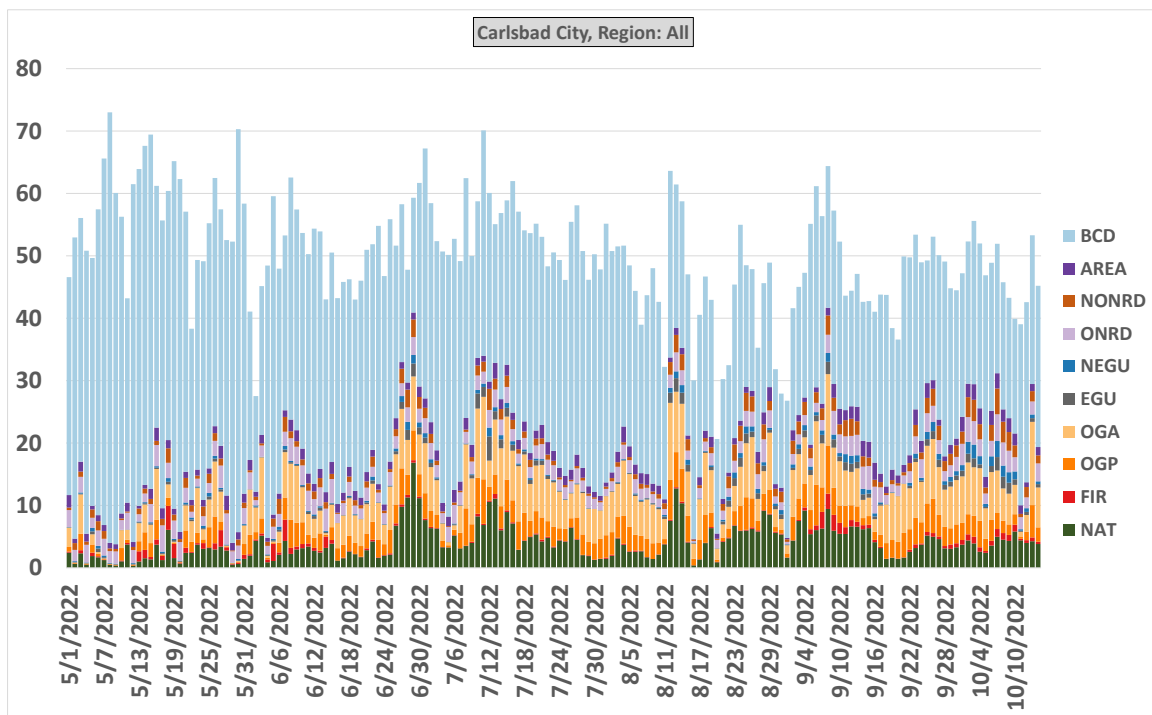


Figure 10-5. CAMx 2026v1 12 km APCA ozone source apportionment contributions to modeled 2026 MDA8 ozone concentrations at Carlsbad City monitoring site due to all sources (Source: NMED Phase I study, Ramboll, 2025c).

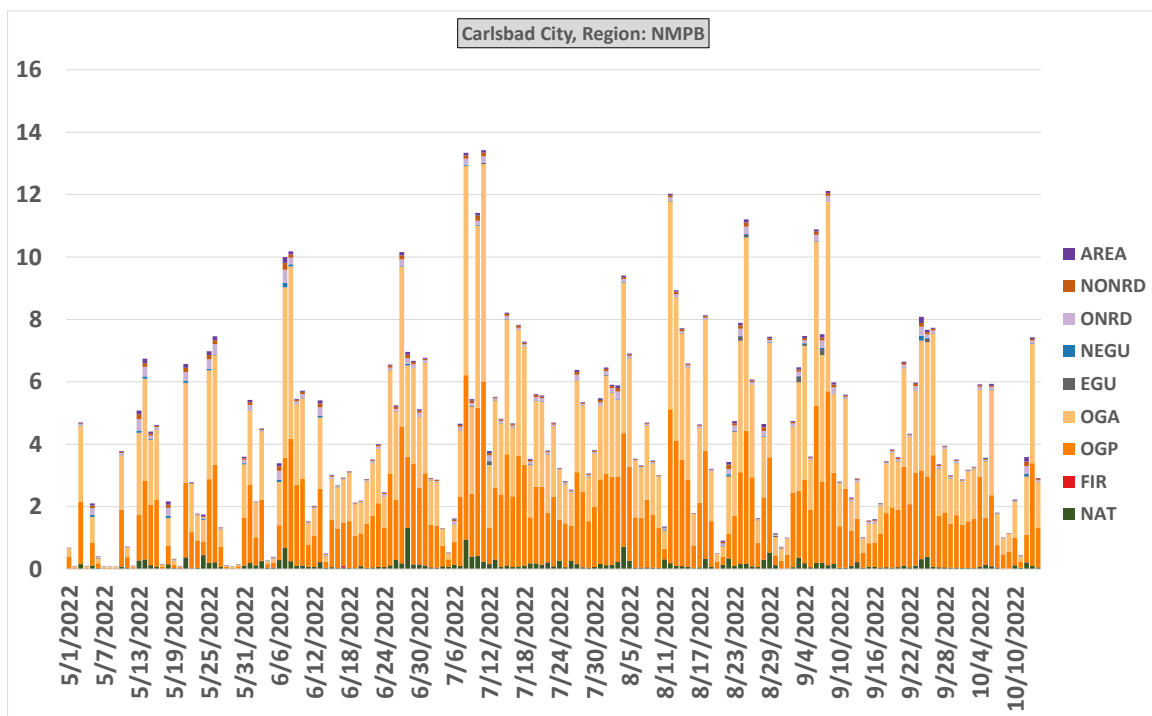


Figure 10-6. CAMx 2026v1 12 km ozone source apportionment contributions of emissions from the New Mexico portion of the Permian Basin to MDA8 ozone at Carlsbad City monitor (Source: NMED Phase I study, Ramboll, 2025c).

As discussed in Chapter 6, May had very large wildfires in New Mexico that produced smoke and ozone precursor emissions (see Figure 6-1, Figure 6-2 and Appendix E). Although May 2022 will be included in Phase II CAMx 2022v2 12/4 km modeling, the focus of the ozone analysis should emphasize the other summer months when there are more local anthropogenic emission contributions and less contributions from wildfires.

10.4 Potential Diagnostic Evaluation Tests of Model Performance for the Phase II CAMx 2022 12/4 km Modeling Platform

In this section we identify several different diagnostic evaluation tests that the new CAMx 2022v2 12/4 km New Mexico modeling platform can be subjected to that are designed to evaluate and improve model performance:

1. Process-Based Diagnostic Tests: Evaluate the modeling system for individual processes that lead to elevated ozone concentrations that can be separately evaluated.
2. Diagnostic Sensitivity Tests of Alternative Model Inputs or Options: Alternative meteorological, emissions, and/or boundary conditions or other model inputs/options could be examined to see their effects on model performance.

Some process-based evaluations require research grade field measurements that are rarely available. Colorado State University (CSU), National Park Service (NPS) and others have performed recent (2019 and 2021) air quality field sampling campaigns at the Carlsbad Caverns National Park (CarCavAQS). In addition, Boulder Atmosphere Innovation Research (BoulderAir) LLC took measurements in Loving, New Mexico (near the Permian Basin) in 2023/2024.³³ Data from the CarCavAQS and BoulderAir can be used to define diagnostic evaluation tests that include reactive nitrogen and VOC species concentrations to assess how well those important ozone precursor species are captured by the model.

10.4.1 Meteorological Diagnostic Tests

The analysis of meteorology identified several relationships between elevated ozone and meteorology that could be evaluated in the CAMx/WRF 2022 12/4 km modeling system (Chapters 2 and 6). As the WRF 2022 modeling was nudged to the ECMWF ERA5 reanalysis fields, comparing the WRF output against important variables such as the 500 mb heights is not that useful as WRF will match well given they are assimilated by WRF during its simulation using Four-Dimensional Data Assimilation (FDDA). The WRF evaluation obtained fairly good model performance for surface winds, temperature, and humidity and reasonable performance for precipitation, although reproducing summer monsoon convective precipitation in the southwest is always a challenge as it is stochastic in nature. Conducting WRF 2022 12/4 km sensitivity tests are unlikely to produce improved model performance as the WRF configuration is nearly the same as used in the Denver and Clark County WRF 2022 modeling that explored different WRF configurations and none produced better model performance. The mixed meteorological and air quality observations analysis (e.g., Figure 2-14) may provide some useful diagnostic tests that are discussed in the next sections.

³³ <https://bouldair.com/>

10.4.2 Potential Process-Based Diagnostic Evaluation Tests

The following is a partial list of process-based diagnostic tests that would allow a better understanding of the performance of the CAMx/WRF/SMOKE/Emissions/BC 2022v2 12/4 km air quality modeling system. The tests could help identify additional sensitivity tests potentially leading to a better performing modeling system for simulating ozone in New Mexico:

Ability to Reproduce Observed Frequency of Elevated Ozone Occurrences: Examine the frequency of occurrence of modeled 2022 exceedances of the 2015 ozone NAAQS (i.e., 71.0 ppb or higher) and other high ozone thresholds (e.g., 68 and 65 ppb) and compare them with the observed frequency of ozone exceedances at Carlsbad City, Carlsbad Caverns and Hobbs (Figure 2-6) as well as compare the frequency ozone exceedances occur by month (Figure 2-7) and by day-of-week (Figure 2-8), including weekdays and weekend days.

Relationship of MDA8 Ozone and Temperature: The WRF estimate surface daily maximum temperature and CAMx MDA8 ozone estimates from the CAMx/WRF 2022 12/4 km modeling system at the two Carlsbad and Hobbs sites can be compared with the observed values in scatter plots (Figure 2-13) and their distributions using box and whisker plots (Figure 2-14 and Figure 2-15).

Tests Using Satellite Data: Section 3.2 presented trends in observed satellite NO₂ columns from the OMI (2005-2024) and TROPOMI (2018-2024) over the Permian Basin, San Juan Basin, Bernalillo County (Albuquerque) and Doña Ana County regions (Figure 3-6 through Figure 3-8). The CAMx 2022v2 12/4 km results can be compared against these satellite data for 2022. The spatial distribution of the CAMx 2022 NO₂, HCHO and HCHO/NO₂ ratios (FNR) can be compared against the TROPOMI satellite 2022 measurements from Figure 3-9 and Figure 3-10.

- Some limitations and challenges with satellite comparisons are the need to obtain 3-dimensional output in the CAMx simulations that increases the computational requirements. In addition, the satellite data has to be filtered to consider only days with good quality data (per the associated data quality flags).

Process-Based Tests Using the 2019 and 2021 CarCavAQS Measurement Data:

Although the CarCavAQS field study measurement data are not concurrent with the CAMx modeling system summer 2022 period, they can still be used for testing the model, just not on a matched by time basis. Given the number of wildfires in New Mexico in 2022, the analysis of the diurnal ozone distribution on high ozone days when smoke occurs and smoke free days can be compared with the results from the 2019 and 2021 field study data (e.g., **Error! Reference source not found.**).

- The frequency distribution and longer-term averages of NO_x, NO_y and several key VOC species that are explicit in the CAMx chemistry mechanism may provide insight into the accuracy of some source categories in the inventory [e.g., ethane and propane (O&G), benzene (gasoline combustion), ethyne (combustion), isoprene (biogenic)].

The difference between the point measurements and the grid cell average model prediction makes it difficult to interpret the comparison of observed and modeled concentrations of primary emitted species, such as VOC and NO_x species. This is due to the differing effects of dilution in the model and in the observations. However, comparing predicted and observed ratios of species concentrations can be made and may provide valuable information as the differences in modeled and actual atmosphere dilution effects are canceled out when examining ratios of species. Some examples are as follows:

- I-Pentane/N-Pentane Ratios: The comparison of the modeled i-pentane/n-pentane ratios at the Carlsbad Caverns (CAVE) site with the 2019 and 2021 field study data (**Error! Reference source not found.**) can provide important information of the source of the VOCs (ratio < 1.0 implies oil and gas).
 - The Carbon Bond condensed chemical mechanism in CAMx does not explicitly model i-pentane and n-pentane species as they are speciated into the PAR (paraffin bond) species. To explicitly model the pentane species would require separate SMOKE emissions processing of all VOC categories to speciate into the pentane species and then model them using the CAMx RTRAC probing tool that treats their decay (reaction with OH radical). Thus, this would require some work but is feasible and could provide valuable insights.
- VOC/NO_x Ratios: Comparison of the frequency distribution of VOC/NO_x ratios at CAVE by time of day can provide information on NO_x- versus VOC-sensitivity of ozone formation as well as the accuracy of the emissions inventory.
 - Reconstructing VOC from the CB condensed chemical mechanism used in CAMx is imperfect and not consistent with the monitoring VOC so care must be taken in the interpretation of the VOC/NO_x ratio comparisons.
- HCHO/NO₂ Ratios: The comparison of modeled and observed formaldehyde to NO_x ratios at CAVE also provides information on NO_x- vs. VOC-sensitive and since HCHO is an explicit species in CB mechanism doesn't suffer the uncertainties due to reconstructing VOC.
- NO_x/NO_y Ratios: Provides a comparison of the amount of processing of the NO_x emissions in the model versus the real atmosphere.

10.4.3 Potential CAMx Modeling System Diagnostic Simulations

The CAMx modeling system diagnostic sensitivity simulations will depend on the results of the CAMx 2022v2 12/4 km model performance evaluation and process-based diagnostic tests. Given the underestimation of ozone concentrations in the Permian Basin in Phase I CAMx 2022v1 12 km modeling, tests related to generating more ozone from local sources are warranted, such as reduced vertical mixing or increases in oil and gas NO_x and/or VOC emissions.

11.0 CONCLUSIONS

The following presents some of the key findings and limitation from the Conceptual Model analyses.

11.1 Key Findings

11.1.1 Ozone Design Values and Attainment Status:

- New Mexico air monitors can be grouped into four geographic regions that have several common attributes and also unique conditions.
- Only the Sunland Park area in Doña Ana County was designated as a NAA based on observed 2014-2016 ozone DVs. A §179B demonstration was prepared for the Sunland Park NAA and approved by EPA that demonstrated without international anthropogenic emissions from Mexico the region would be in attainment, so the NAA was not reclassified as Moderate and remains a Marginal ozone NAA.
- Ozone NAA designations under the 2015 ozone NAAQS occurred just prior to increases in oil production in the Permian Basin.
- Maximum annual ozone DVs at Carlsbad City have consistently exceeded the 2015 ozone NAAQS since 2018.
- The Foothill monitor in the Albuquerque region has also exceeded the NAAQS for last five years.
- Recent ozone DV trends at monitors in the Doña Ana County and South San Juan Basin regions have been relatively flat

11.1.2 Permian Basin Ozone and Precursor Trends and Related Analyses:

- There are three New Mexico Permian Basin region ozone monitors: Carlsbad Caverns NPS site (historical inactive monitor and a currently active monitor), Carlsbad City that is close to Carlsbad Caverns and Hobbs-Jefferson further to the east.
- The Hobbs-Jefferson ozone DVs are approximately 5-10 ppb lower than the Carlsbad City and Carlsbad Caverns DVs for approximately the last 7 years.
- There are approximately two to four times more exceedances at the two Carlsbad monitors than at Hobbs-Jefferson.
- Exceedances at Hobbs-Jefferson have also become more frequent in the last 7 years.
- All three monitors had substantially fewer exceedances during the 2020 COVID shutdown year during which oil and gas production and drilling was reduced.
- Most exceedances occur from May through August at all monitors, July has the most exceedances at the two Carlsbad monitors.
- There are slightly more exceedances on midweek days compared to weekends. Thursdays had the most exceedances at Carlsbad City, it is unclear whether that is random or there is a reason.
- Daily maximum temperatures have increased about 1 degree Celsius over the last 10 years. Median and IQR distribution of O₃ increased about 5 ppb over the last 10 years and all three sites.

- NO₂ trends since 2007 at Hobbs decreased in the early period and were fairly flat in the recent period (i.e., 2017-2024), the NO₂ trend since 2007 at Carlsbad City was flat for the early period and rapidly increased since 2017.
- NO₂ at Carlsbad City was much lower than Hobbs in the early period and now they are comparable.
- Satellite NO₂ columns corroborate the increase NO₂ in recent years at Carlsbad City.
- Satellite NO₂ columns for the San Juan Basin monitors in the Northeast of the State had a large decrease over the full period, and includes a year-over-year decrease from 2013 to 2014 that may reflect the closure of Units 1-3 of the Four Corners Generating Station.
- The Albuquerque and Doña Ana regions have satellite NO₂ trends that are slightly decreasing over the early period and flat over the recent period.
- Satellite formaldehyde to NO₂ ratios (FNR) and weekend-effect analysis suggest that the Permian Basin region has a transitional to a more NO_x-sensitive ozone formation chemical regime that is corroborated by the analysis of the data from the 2019 CarCavAQS.

11.1.3 Emissions Trends and Analyses:

- EPA's emissions trends for New Mexico reports large O&G increases starting in 2017 that corresponds with increased oil production from Permian Basin.
- Future Carlsbad Field Office O&G emissions (per the BLM report) will remain significant for all scenarios through 2032.

11.1.4 Source Sectors that Contribute to High Ozone Based on Prior Modeling:

- Transport from outside of New Mexico is the biggest contributor to ozone in New Mexico.
- At Carlsbad Caverns, O&G is the largest anthropogenic sector contributing to ozone.
- O&G emissions in the New Mexico portion of the Permian Basin contribute 94% (8.5 ppb) of the 9.0 ppb total New Mexico anthropogenic emissions contribution to projected 2026 DVs.
- The projected 2026 ozone DVs without Mexico anthropogenic emissions in the 12 km CONUS domain are reduced by about 5-10 ppb and attain the NAAQS.

11.1.5 2022 Model Year

- 2022 had fairly typical meteorology, which suggests it is suitable as a modeling year.
- There were large wildfires in New Mexico in 2022 that occurred in April through mid-June and may impact ozone over that period.
- For most of the later summer 2022, there were many periods during which New Mexico was impacted by light smoke from distant fires, as is typical for most recent years.
- For Phase II, a diagnostic model performance is planned for the 2022 model year based on recent field study data in the Permian Basin region.

11.2 Key Uncertainties/Suggestions for Future Work

- Emission uncertainties
 - Oil production rates continue to increase in the Permian Basin while O&G emissions are relatively flat over the last approximately 5 years. Assess whether this is due to enacted controls or discrepancies in the inventories or other reasons?
- Investigate the Permian Basin monitors ozone and NO₂ concentrations in 2020 (COVID pandemic year) since the current analysis suggests a strong response to activity changes due to COVID restrictions.
- Extend the FNR analysis to multiple years to investigate potential shifts in chemical regimes.
- Process satellite NO₂, HCHO, FNR for the specific periods of field-studies to compare the field-study periods, assess potential anomalies from the longer-term and compare with the 2022 modeling period.
- Expand the satellite data analysis to include the new TEMPO satellite and include diurnal profiles of NO₂, HCHO, and FNR.

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APPENDIX A

Appendix A: NEW MEXICO MONITORS ADDITIONAL DETAILS

AQS Site ID	County Name	Local Site Name Short	Site Latitude	Site Longitude
350010023	Bernalillo	Del Norte HS	35.1343	-106.585
350010029	Bernalillo	South Valley	35.01708	-106.657
350011012	Bernalillo	Foothills	35.1852	-106.508
350012022	Bernalillo	San Jose	35.06357	-106.648
350037501	Catron	Gila Wilderness	33.22	-108.235
350130008	Doña Ana	La Union	31.93066	-106.631
350130020	Doña Ana	Chaparral	32.04121	-106.41
350130021	Doña Ana	Desert View	31.79622	-106.584
350130022	Doña Ana	Santa Teresa	31.78789	-106.683
350130023	Doña Ana	Solano	32.31759	-106.768
350150010	Eddy	Carlsbad Caverns	32.17816	-104.443
350151005	Eddy	Carlsbad City	32.38012	-104.263
350250008	Lea	Hobbs Jefferson	32.72666	-103.123
350431001	Sandoval	Bernalillo	35.29948	-106.549
350450009	San Juan	Bloomfield	36.74223	-107.978
350450018	San Juan	Navajo Lake	36.80974	-107.652
350450020	San Juan	Chaco Culture	36.035	-107.904
350451005	San Juan	Substation	36.79667	-108.473
350451233	San Juan	Dine College Gis Lab	36.8071	-108.695
350490021	Santa Fe	Santa Fe Airport	35.61975	-106.08
350610008	Valencia	Hobbs	34.8147	-106.74
350390026	Rio Arriba	Coyote Ranger District	36.18774	-106.698

AQS Site ID	Reporting Agency	Monitoring Network Affiliation(s)	Ozone	Nitrogen	Met	PM2.5	PM10
350010023	Albuquerque EHD-AQD	NCORE	yes	yes	yes	yes	yes
350010029	Albuquerque EHD-AQD		yes	yes	yes	yes	yes
350011012	Albuquerque EHD-AQD		yes	no	yes	yes	yes
350012022	Albuquerque EHD-AQD		yes	yes	no	yes	yes
350037501	US Forest Service		yes	no	no	no	no
350130008	NMED		yes	no	no	no	no
350130020	NMED		yes	no	no	no	yes
350130021	NMED		yes	yes	no	yes	yes
350130022	NMED		yes	yes	no	yes	no
350130023	NMED		yes	no	no	no	no
350150010	National Park Service	CASTNET	yes	no	yes	no	no
350151005	NMED		yes	yes	no	no	no
350250008	NMED		yes	yes	no	yes	no
350431001	NMED		yes	no	no	no	no
350450009	NMED		yes	yes	no	no	no
350450018	NMED		yes	yes	no	no	no
350450020	National Park Service	CASTNET	yes	yes	yes	no	no
350451005	NMED		yes	yes	no	no	yes
350451233	Navajo Nation, AZ, NM, UT		yes	yes	no	no	no
350490021	NMED		yes	no	yes	yes	no
350610008	NMED		yes	no	no	no	no
350390026	NMED		yes	no	no	no	no

APPENDIX B

APPENDIX B: MONITORS MDA8 (PPM) CONCENTRATIONS BY DAY FOR THE 2022 OZONE SEASON

Site Name	Carlsbad Caverns	Carlsbad (City)	Hobbs Jefferson	Coyote Ranger District	Bloomfie Id	Navajo Lake	Chaco Culture	Substati on	Dine College Gis Lab	Sante Fe Airport
AQS ID	350150010	350151005	350250008	350390026	350450009	350450018	350450020	350451005	350451233	350490021
4/1/2022	0.052	0.052	0.054		0.047	0.05	0.05	0.052	0.028	0.052
4/2/2022	0.056	0.06	0.055		0.048	0.05	0.047	0.05	0.028	0.052
4/3/2022	0.06	0.059	0.059		0.045	0.047	0.048	0.046	0.026	0.054
4/4/2022	0.05	0.05	0.053		0.05	0.052	0.051	0.051	0.031	0.053
4/5/2022	0.046	0.045	0.042		0.046	0.053	0.048	0.049	0.029	0.049
4/6/2022	0.057	0.054	0.049	0.049	0.052	0.057	0.054	0.054	0.038	0.062
4/7/2022	0.056	0.052	0.049	0.046	0.043	0.047	0.049	0.048	0.032	0.053
4/8/2022	0.058	0.057	0.05	0.04	0.044	0.049	0.045	0.045	0.025	0.051
4/9/2022	0.055	0.054	0.055	0.046	0.044	0.046	0.049	0.052	0.03	0.052
4/10/2022	0.05	0.049	0.047	0.043	0.048	0.051	0.048	0.053	0.034	0.05
4/11/2022	0.044	0.044	0.043	0.039	0.043		0.044	0.046	0.028	0.049
4/12/2022	0.044	0.042	0.039	0.037			0.047	0.053	0.033	0.051
4/13/2022		0.056	0.05	0.041			0.05	0.05	0.028	0.052
4/14/2022	0.057	0.059	0.06	0.044	0.031	0.052	0.052	0.052	0.028	0.055
4/15/2022	0.055	0.055	0.052	0.046	0.05	0.055	0.052	0.054	0.032	0.055
4/16/2022	0.064	0.055	0.049	0.044	0.043	0.047	0.048	0.047	0.029	0.053
4/17/2022	0.06	0.054	0.048	0.046	0.045	0.05	0.049	0.049	0.031	0.054
4/18/2022	0.068	0.066	0.052	0.044	0.045	0.051	0.054	0.054	0.034	0.053
4/19/2022	0.055	0.065	0.051	0.042	0.043	0.046	0.048	0.047	0.029	0.051
4/20/2022	0.043	0.044	0.037	0.044	0.047	0.054	0.052	0.053	0.034	0.052
4/21/2022	0.045	0.051	0.052	0.044	0.047	0.052	0.049	0.051	0.033	
4/22/2022	0.046	0.049	0.041	0.044	0.047	0.049	0.051	0.051	0.03	0.052

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4/23/2022	0.051	0.053	0.047	0.044	0.047	0.05	0.051	0.051	0.03	0.057
4/24/2022	0.056	0.058	0.051	0.046	0.051	0.054	0.051	0.051	0.031	0.056
4/25/2022	0.058	0.058	0.046	0.054	0.053	0.06	0.059	0.06	0.035	0.06
4/26/2022	0.058	0.064	0.057		0.055	0.061	0.061	0.06	0.038	0.06
4/27/2022	0.054	0.061	0.047		0.053	0.058	0.056	0.061	0.038	0.056
4/28/2022	0.06	0.063	0.053		0.054	0.061	0.06	0.059	0.038	0.064
4/29/2022	0.062	0.063	0.054		0.058	0.065	0.065	0.062	0.039	
4/30/2022	0.07	0.073	0.053		0.054	0.059	0.055	0.058	0.037	0.058
5/1/2022	0.052	0.053	0.042		0.057	0.061	0.061	0.062	0.043	
5/2/2022	0.057	0.06	0.053		0.051	0.057	0.063		0.033	0.065
5/3/2022	0.071	0.072	0.056		0.055	0.058	0.058	0.063	0.041	0.055
5/4/2022	0.053	0.054	0.046		0.05	0.054	0.054	0.057	0.034	0.057
5/5/2022	0.061	0.062	0.055	0.059	0.02	0.054	0.054	0.054	0.033	0.06
5/6/2022	0.06	0.063	0.05	0.053	0.05	0.057	0.055	0.059	0.038	0.053
5/7/2022	0.061	0.064	0.059	0.054	0.05	0.056	0.056	0.056	0.037	0.055
5/8/2022	0.062	0.065	0.058	0.052	0.043	0.048	0.049	0.05	0.031	0.049
5/9/2022	0.055	0.055	0.054	0.05	0.046	0.051	0.052	0.054	0.035	0.044
5/10/2022	0.055	0.058	0.046		0.044	0.046	0.048	0.05	0.032	0.054
5/11/2022	0.044	0.05	0.05	0.049	0.048	0.051	0.049		0.036	0.046
5/12/2022	0.056	0.056	0.046	0.072	0.057	0.064	0.074		0.036	0.063
5/13/2022	0.055	0.06	0.062		0.046	0.052	0.052	0.052	0.03	0.051
5/14/2022	0.064	0.071	0.063	0.05	0.046	0.052	0.049	0.051	0.031	0.05
5/15/2022	0.068	0.071	0.05	0.054	0.044	0.049	0.047	0.05	0.032	0.055
5/16/2022	0.071	0.079	0.055	0.057	0.051	0.058	0.056		0.037	0.055
5/17/2022	0.057	0.06	0.057	0.055	0.051	0.057	0.054	0.056	0.036	0.052
5/18/2022	0.058	0.065	0.058	0.054	0.047	0.053	0.05	0.052	0.032	0.053
5/19/2022	0.06	0.062	0.059	0.051	0.047	0.051	0.051	0.052	0.034	0.05
5/20/2022	0.058	0.06	0.052	0.055	0.049	0.054	0.054	0.051	0.031	0.052
5/21/2022	0.052	0.052	0.045	0.052	0.05	0.054	0.054	0.052	0.032	0.045
5/22/2022	0.057	0.056	0.049	0.047	0.048	0.046	0.047	0.056	0.036	0.041

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

5/23/2022	0.052	0.068	0.059	0.053	0.052	0.056	0.052	0.055	0.034	0.049
5/24/2022		0.061	0.052	0.057	0.055	0.061	0.059	0.061	0.038	0.055
5/25/2022		0.068		0.054	0.051	0.059	0.056	0.056	0.035	0.059
5/26/2022	0.071	0.073	0.07	0.049	0.046	0.057	0.047	0.048	0.03	0.049
5/27/2022	0.06	0.074	0.059	0.044	0.041	0.048	0.041	0.043	0.028	0.048
5/28/2022	0.051	0.053	0.051	0.048	0.039	0.045	0.046	0.045	0.029	0.048
5/29/2022	0.045	0.047	0.045	0.065	0.059	0.065	0.064	0.063	0.042	0.069
5/30/2022	0.072	0.072	0.072	0.058	0.049	0.056	0.058	0.052	0.032	0.06
5/31/2022	0.063	0.067	0.059	0.063	0.052	0.06	0.056	0.057	0.037	0.063
6/1/2022	0.051	0.05	0.031	0.053		0.071	0.064	0.06	0.039	0.044
6/2/2022	0.06	0.058	0.037	0.052		0.063	0.058	0.062	0.043	0.046
6/3/2022	0.064	0.064	0.057	0.052		0.059	0.055	0.058	0.039	0.05
6/4/2022	0.051	0.059	0.074	0.053		0.056	0.05	0.05	0.033	0.051
6/5/2022	0.059	0.062	0.056	0.048		0.048	0.045	0.044	0.03	0.047
6/6/2022	0.048			0.044	0.042	0.05	0.044	0.043	0.028	0.046
6/7/2022	0.066		0.063	0.046	0.045	0.052	0.047	0.049	0.032	0.049
6/8/2022	0.064	0.042	0.049	0.051	0.052	0.06	0.05	0.054	0.035	0.048
6/9/2022	0.072	0.071	0.052	0.05	0.047	0.054	0.049	0.054	0.034	0.051
6/10/2022	0.071	0.069	0.054	0.048	0.049	0.056	0.05	0.055	0.036	0.048
6/11/2022	0.058	0.061	0.055	0.05	0.049	0.056	0.049	0.051	0.034	0.049
6/12/2022	0.059	0.064	0.044	0.056	0.053	0.061	0.056	0.058	0.04	0.055
6/13/2022	0.059	0.045		0.052	0.048	0.054	0.052	0.053	0.037	0.05
6/14/2022	0.051			0.056	0.057	0.065		0.056	0.038	0.054
6/15/2022	0.068	0.069	0.05	0.055	0.051		0.057	0.058	0.04	0.056
6/16/2022	0.052	0.05	0.035	0.054	0.05	0.057	0.053	0.055	0.038	0.053
6/17/2022	0.048	0.048	0.035	0.05	0.051	0.057	0.053	0.052	0.035	0.046
6/18/2022	0.048	0.048	0.041	0.048	0.045	0.052	0.049	0.051	0.027	0.047
6/19/2022	0.046	0.045	0.035	0.045	0.038	0.043	0.045	0.047	0.032	0.046
6/20/2022	0.049	0.051	0.035	0.056	0.052	0.061	0.053	0.07	0.042	0.048
6/21/2022	0.048	0.047	0.046	0.051	0.05	0.056		0.058	0.038	0.041

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

6/22/2022	0.059	0.061	0.054	0.037	0.042			0.042	0.028	0.033
6/23/2022	0.061	0.063	0.039	0.05	0.047	0.051	0.053	0.051	0.032	0.051
6/24/2022	0.055		0.045	0.048	0.043	0.05	0.046	0.051	0.031	0.047
6/25/2022	0.064		0.051	0.046	0.051	0.055	0.049	0.061	0.043	0.043
6/26/2022	0.057		0.054	0.047	0.04	0.053		0.051	0.033	0.04
6/27/2022	0.07		0.054	0.04	0.048	0.05	0.05	0.056	0.038	0.049
6/28/2022	0.066		0.063	0.045	0.051	0.055	0.051	0.054	0.037	0.046
6/29/2022	0.081	0.077	0.075	0.052	0.052	0.058	0.055	0.056	0.038	0.055
6/30/2022	0.069	0.071	0.069	0.052	0.051	0.058	0.053	0.051	0.033	0.055
7/1/2022	0.078	0.076	0.069	0.043	0.05	0.058	0.056	0.05	0.033	0.053
7/2/2022	0.072	0.075	0.068	0.041	0.05	0.056	0.049	0.051	0.034	0.052
7/3/2022	0.068	0.069	0.058	0.05	0.046	0.05		0.049	0.035	0.058
7/4/2022	0.061	0.057	0.059	0.048	0.055	0.063	0.058	0.055	0.036	0.051
7/5/2022	0.056	0.054	0.065	0.049	0.049	0.056	0.05	0.047	0.031	0.058
7/6/2022	0.057	0.06	0.061	0.048	0.046	0.054	0.051	0.049	0.03	0.05
7/7/2022	0.066	0.068	0.058	0.053	0.052	0.06	0.05	0.055	0.035	0.049
7/8/2022	0.085	0.072	0.066	0.05	0.051	0.061	0.053	0.056	0.038	0.051
7/9/2022	0.071	0.071	0.062	0.052	0.052	0.058	0.053	0.057	0.039	0.056
7/10/2022	0.071	0.067	0.061	0.053	0.055	0.062	0.057	0.056	0.038	0.056
7/11/2022	0.083	0.079	0.065	0.05		0.057	0.055	0.05	0.034	0.054
7/12/2022	0.068	0.064	0.064	0.048	0.053	0.057	0.056	0.055	0.039	0.058
7/13/2022	0.071	0.074	0.066	0.051	0.052	0.061	0.061	0.056	0.038	0.056
7/14/2022	0.071	0.071	0.068	0.048	0.058	0.065	0.06	0.059	0.041	0.058
7/15/2022	0.076	0.078	0.075	0.055	0.058	0.066	0.059	0.059	0.039	0.058
7/16/2022	0.07	0.067	0.063	0.056	0.058	0.069	0.061	0.058	0.039	0.06
7/17/2022	0.063	0.066	0.057	0.055	0.057	0.063	0.058	0.06	0.043	0.059
7/18/2022	0.063	0.064	0.057	0.057	0.061	0.069	0.061	0.061	0.042	0.063
7/19/2022	0.062	0.062	0.061	0.062	0.056	0.065	0.06	0.055	0.037	0.058
7/20/2022	0.068	0.068	0.063	0.057	0.056	0.067	0.059	0.057		0.056
7/21/2022	0.064	0.069	0.058	0.055	0.059	0.067	0.066	0.059	0.042	0.06

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

7/22/2022	0.065	0.063	0.047	0.056	0.059	0.067	0.061	0.06	0.043	0.062
7/23/2022	0.057	0.055	0.044	0.059	0.054	0.063	0.057	0.055	0.038	0.064
7/24/2022	0.057	0.055	0.044	0.048	0.056	0.065	0.059	0.054	0.037	0.061
7/25/2022	0.054	0.061	0.04	0.048	0.06	0.067			0.039	0.055
7/26/2022	0.061	0.063	0.052	0.039		0.067	0.058	0.06	0.038	0.059
7/27/2022	0.063	0.07	0.048	0.053		0.063	0.06	0.061	0.039	0.056
7/28/2022	0.053	0.054	0.049		0.053	0.053		0.054	0.036	0.056
7/29/2022	0.053	0.055	0.046	0.036	0.054	0.054	0.051	0.051	0.028	0.051
7/30/2022	0.055	0.059	0.04	0.039	0.057		0.053	0.06	0.037	0.052
7/31/2022	0.056	0.061	0.045	0.051	0.055	0.057	0.058	0.056	0.036	0.053
8/1/2022	0.061	0.061	0.043	0.046	0.058	0.061	0.058	0.058	0.034	0.054
8/2/2022	0.065	0.067	0.048	0.055	0.052	0.057	0.053	0.053		0.055
8/3/2022	0.067	0.066	0.053	0.049	0.057		0.053	0.058	0.029	0.058
8/4/2022	0.063	0.065	0.051	0.051	0.069	0.071	0.065	0.067	0.035	0.069
8/5/2022	0.053	0.055	0.046	0.047	0.067	0.066	0.058	0.068	0.037	0.062
8/6/2022	0.055	0.053	0.046	0.044	0.058	0.059	0.054	0.06	0.034	0.061
8/7/2022	0.05	0.05	0.038	0.044	0.058	0.055	0.053	0.056	0.032	0.053
8/8/2022	0.048	0.048	0.045	0.041	0.059	0.056	0.05	0.056	0.032	
8/9/2022	0.05	0.051	0.048	0.045	0.055	0.054	0.05	0.056	0.033	0.047
8/10/2022	0.053	0.047	0.047	0.049	0.056	0.056	0.054	0.052	0.032	0.047
8/11/2022	0.053	0.05	0.058	0.052	0.055	0.056	0.049	0.054	0.034	0.055
8/12/2022	0.086	0.084	0.07	0.049	0.062	0.06	0.053	0.056	0.033	0.061
8/13/2022	0.084	0.083	0.067	0.051	0.06	0.061	0.056	0.054	0.03	0.064
8/14/2022	0.078	0.08	0.062	0.058	0.067	0.065	0.061	0.061	0.038	0.067
8/15/2022	0.055	0.057	0.053	0.057	0.06	0.057	0.055	0.054	0.031	0.068
8/16/2022		0.036	0.047	0.045	0.065	0.064	0.06	0.058	0.034	0.055
8/17/2022	0.056	0.055	0.044	0.036	0.051	0.049		0.05	0.035	0.044
8/18/2022	0.06	0.055	0.046	0.047	0.054	0.052	0.046	0.054	0.035	0.045
8/19/2022	0.062	0.063	0.054	0.043	0.053	0.051	0.052	0.053	0.032	0.056
8/20/2022	0.041	0.034	0.037	0.047	0.053	0.052	0.053	0.051	0.033	0.047

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

8/21/2022	0.042	0.045	0.045	0.043	0.058	0.058	0.051	0.049	0.031	0.052
8/22/2022		0.047		0.035	0.055	0.053	0.049	0.053	0.033	0.049
8/23/2022	0.059	0.057	0.06	0.04	0.058	0.054	0.052	0.053	0.034	0.053
8/24/2022	0.071	0.066	0.056	0.035	0.055	0.054	0.05	0.053	0.035	0.053
8/25/2022	0.061	0.06	0.048	0.044			0.051	0.049	0.031	0.06
8/26/2022		0.058	0.048	0.04	0.056	0.055	0.051	0.049	0.031	0.052
8/27/2022		0.056	0.055	0.047	0.056	0.057	0.054	0.052	0.03	0.052
8/28/2022	0.057	0.058	0.062	0.05	0.058	0.056	0.057	0.057	0.035	0.051
8/29/2022		0.064	0.051	0.046	0.06	0.061	0.058	0.053	0.032	0.054
8/30/2022	0.048	0.043	0.046	0.046	0.061	0.057	0.052	0.055	0.035	0.054
8/31/2022	0.044	0.041	0.042	0.045	0.061	0.061	0.053	0.051	0.034	0.055
9/1/2022	0.033	0.029	0.028	0.041	0.057	0.057	0.053	0.053	0.034	0.051
9/2/2022	0.05	0.053	0.043	0.045	0.06	0.053	0.053	0.056	0.037	0.051
9/3/2022	0.057	0.052	0.046	0.043	0.053	0.052	0.05	0.048	0.034	0.049
9/4/2022		0.058	0.048	0.043	0.058	0.06	0.052	0.05	0.032	0.052
9/5/2022		0.056	0.06	0.045	0.064	0.064	0.053	0.047	0.031	0.048
9/6/2022		0.062	0.057	0.044	0.059	0.056	0.051	0.05	0.034	0.054
9/7/2022			0.055	0.048	0.058	0.059	0.053	0.051	0.033	0.057
9/8/2022	0.083		0.068	0.048	0.061	0.06	0.052		0.034	0.061
9/9/2022		0.066	0.068	0.043	0.06	0.058	0.051	0.054	0.035	0.061
9/10/2022	0.065	0.067	0.062	0.044	0.057	0.057	0.05	0.051	0.033	0.054
9/11/2022	0.056	0.05	0.042	0.04	0.057	0.055	0.048	0.05	0.031	0.052
9/12/2022	0.047	0.054	0.059	0.042	0.052	0.055	0.048	0.045	0.026	0.046
9/13/2022	0.052	0.053	0.047	0.037	0.045	0.046		0.039	0.026	0.045
9/14/2022		0.043	0.045	0.037	0.025	0.039	0.041	0.036	0.021	0.045
9/15/2022		0.052	0.046	0.039	0.048	0.048	0.044	0.047	0.03	0.046
9/16/2022		0.04	0.045	0.038	0.044	0.044	0.039	0.043	0.028	0.047
9/17/2022	0.044	0.049	0.041	0.04	0.048	0.046	0.039	0.049	0.033	0.043
9/18/2022	0.041	0.044	0.034	0.033	0.042	0.04	0.036	0.038	0.025	0.043
9/19/2022	0.039	0.042	0.026	0.036	0.047	0.048	0.042	0.046	0.031	0.043

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

9/20/2022	0.043	0.043	0.028	0.03	0.04	0.04	0.036	0.033	0.024	0.037
9/21/2022	0.051	0.05	0.034	0.02	0.028	0.024	0.032	0.028	0.014	0.041
9/22/2022	0.052	0.054	0.052	0.027	0.033	0.033	0.034	0.03	0.019	0.044
9/23/2022	0.06	0.061	0.049	0.037	0.046	0.045	0.042	0.05	0.03	0.036
9/24/2022	0.049	0.054	0.047	0.049	0.054	0.057	0.055	0.054	0.033	0.053
9/25/2022	0.057	0.056	0.048	0.041	0.055	0.053	0.054	0.054	0.034	0.056
9/26/2022	0.063	0.065	0.055	0.04	0.055	0.055	0.05	0.055	0.036	0.053
9/27/2022	0.063	0.065	0.057	0.036	0.049	0.048	0.045	0.048	0.031	0.046
9/28/2022	0.062	0.065	0.055	0.035	0.047	0.046	0.045	0.046	0.031	0.05
9/29/2022	0.055	0.06	0.054	0.037	0.048	0.045	0.044	0.049	0.029	0.048
9/30/2022	0.059	0.057	0.048	0.036	0.049	0.047	0.047	0.048	0.029	0.045

Site Name	Del Norte HS	South Valley	Foothills	San Jose	Bernalillo	Hobbs	La Union	Chaparral	Desert View	Santa Teresa	Solano
AQS ID	350010023	350010029	350011012	350012022	350431001	350610008	350130008	350130020	350130021	350130022	350130023
4/1/2022	0.042	0.046	0.051		0.047	0.044	0.05	0.051	0.052		0.048
4/2/2022	0.044	0.051	0.054		0.051	0.048	0.049	0.051	0.049		0.049
4/3/2022	0.046	0.051	0.055		0.051	0.047	0.052	0.053	0.054		0.053
4/4/2022	0.045	0.051	0.055		0.051	0.049	0.05	0.05	0.052		0.05
4/5/2022	0.039	0.041	0.049		0.042	0.038	0.044	0.045	0.047		0.044
4/6/2022	0.048	0.054	0.056		0.054	0.053	0.045	0.045	0.051	0.05	0.043
4/7/2022	0.044	0.048	0.051		0.048	0.048	0.051	0.052	0.055	0.053	0.049
4/8/2022	0.043	0.05	0.052		0.049	0.047	0.055	0.053	0.054	0.051	0.05
4/9/2022	0.044	0.05	0.053		0.05	0.049	0.049	0.049	0.052	0.043	0.049
4/10/2022	0.043	0.049	0.051		0.047	0.048	0.044	0.044	0.047	0.041	0.046
4/11/2022	0.037	0.042	0.047		0.043	0.039	0.039	0.04	0.042	0.037	0.039
4/12/2022	0.039	0.047	0.05		0.047	0.046	0.045	0.049	0.043	0.048	0.049
4/13/2022	0.045	0.051	0.051		0.048	0.049	0.052	0.057	0.054	0.061	0.053
4/14/2022	0.045	0.051	0.053		0.05	0.049	0.053	0.055	0.054	0.054	0.051
4/15/2022	0.045	0.049	0.054		0.05	0.047	0.05	0.053	0.053	0.05	0.052
4/16/2022	0.043	0.049	0.052		0.048	0.046	0.049	0.05	0.052	0.047	0.048
4/17/2022	0.044	0.05	0.052		0.048	0.052	0.05	0.048	0.051	0.047	0.048
4/18/2022	0.046	0.052	0.057		0.048	0.051	0.058	0.059	0.059	0.049	0.06
4/19/2022	0.041	0.045	0.052		0.047	0.042	0.044	0.049	0.047		0.045
4/20/2022	0.046	0.05	0.054		0.051	0.048	0.037	0.04	0.041		0.04
4/21/2022	0.041	0.05	0.054		0.05	0.045	0.04	0.045	0.041	0.039	0.041
4/22/2022	0.043	0.049	0.052		0.049	0.047	0.041	0.044	0.044	0.043	0.043
4/23/2022	0.045	0.055	0.053		0.05	0.054	0.049	0.054	0.05	0.053	0.057
4/24/2022	0.048	0.052	0.057		0.052	0.049	0.057	0.057	0.059	0.058	0.058
4/25/2022	0.051	0.059	0.063		0.058	0.059	0.057	0.054	0.06	0.061	0.054

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

4/26/2022	0.05	0.056	0.061		0.058	0.054	0.05	0.046	0.049	0.051	0.047
4/27/2022	0.048	0.05	0.055		0.051	0.044	0.051	0.058	0.054		0.052
4/28/2022	0.05	0.053	0.06		0.057	0.048	0.051		0.054	0.052	0.052
4/29/2022	0.056	0.063	0.066		0.063	0.06	0.058	0.06	0.06	0.058	0.057
4/30/2022	0.055	0.061	0.063		0.059	0.058	0.063	0.06	0.066	0.067	0.06
5/1/2022	0.055	0.061	0.064		0.061	0.056	0.058	0.06	0.061	0.062	0.06
5/2/2022	0.055	0.067	0.062		0.056	0.067	0.054	0.053	0.056	0.052	0.055
5/3/2022	0.047	0.053	0.058		0.054	0.051	0.051	0.05	0.052	0.048	0.048
5/4/2022	0.045	0.053	0.055			0.054	0.053	0.053	0.055	0.054	
5/5/2022	0.048	0.054	0.059		0.057	0.053		0.058	0.059	0.06	0.06
5/6/2022	0.049	0.052	0.058		0.053	0.049	0.056	0.057	0.058	0.054	0.057
5/7/2022	0.049	0.054	0.061		0.054	0.049	0.057	0.057	0.06	0.06	0.06
5/8/2022	0.041		0.05		0.048	0.044	0.056	0.056	0.059	0.06	0.056
5/9/2022	0.038		0.046		0.043	0.039	0.045	0.044	0.047	0.046	0.046
5/10/2022			0.056		0.054	0.047	0.044	0.045	0.044	0.044	0.042
5/11/2022	0.044		0.047		0.043	0.038	0.04	0.041	0.042	0.042	0.041
5/12/2022	0.061		0.063		0.059	0.057	0.051	0.052	0.052	0.051	0.057
5/13/2022	0.057		0.057		0.053	0.055	0.055	0.056	0.058	0.057	0.056
5/14/2022	0.056		0.055		0.052	0.05	0.058	0.058	0.062	0.062	0.059
5/15/2022	0.061		0.062		0.051	0.049	0.066	0.068	0.073	0.065	0.06
5/16/2022	0.065		0.064		0.062	0.056	0.059	0.059	0.063	0.059	0.058
5/17/2022	0.058		0.06		0.055	0.047	0.049	0.048	0.051	0.05	0.049
5/18/2022	0.059		0.06		0.056	0.052	0.052	0.053	0.053	0.051	0.056
5/19/2022	0.055	0.054	0.057		0.053	0.05	0.05	0.049	0.053	0.052	0.053
5/20/2022	0.053	0.052	0.055		0.052	0.049	0.05	0.047	0.053	0.045	0.051
5/21/2022	0.049	0.048	0.05		0.049	0.045	0.05	0.048	0.051	0.051	0.05
5/22/2022	0.048	0.048	0.049		0.047	0.044	0.049	0.046	0.051	0.051	0.048
5/23/2022		0.051	0.055		0.051	0.045	0.054	0.054	0.056	0.052	0.051
5/24/2022	0.06	0.06	0.061		0.055	0.057	0.054	0.054	0.057	0.055	0.057
5/25/2022	0.06	0.057	0.062		0.059	0.051	0.059	0.057	0.063	0.059	0.06

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

5/26/2022	0.058	0.055	0.058		0.052	0.049	0.056	0.053		0.057	0.052
5/27/2022	0.053	0.051	0.054		0.048	0.047	0.055	0.057	0.058	0.048	0.053
5/28/2022	0.05	0.049	0.051		0.048	0.043	0.046	0.045	0.049	0.049	0.048
5/29/2022	0.07	0.068	0.071		0.069	0.064	0.041	0.039	0.038	0.04	0.056
5/30/2022	0.066	0.064	0.067		0.063	0.06	0.059	0.058	0.064	0.063	0.065
5/31/2022	0.065	0.063	0.066		0.064	0.059	0.057	0.053	0.062	0.06	0.057
6/1/2022	0.05	0.048	0.051		0.054	0.047	0.053	0.05	0.055	0.051	0.049
6/2/2022	0.049	0.046	0.051		0.051	0.042	0.056	0.049	0.057	0.057	0.052
6/3/2022	0.054	0.051	0.055		0.053	0.044	0.052	0.053	0.054	0.041	0.051
6/4/2022	0.056	0.053	0.057		0.052	0.045	0.042	0.044	0.045	0.044	0.041
6/5/2022	0.054	0.052	0.053		0.048	0.046	0.049	0.052	0.051	0.049	0.049
6/6/2022	0.053	0.048			0.049	0.043	0.04	0.042	0.044	0.038	0.043
6/7/2022	0.052	0.048	0.054		0.052	0.042	0.045	0.047	0.048	0.046	0.044
6/8/2022	0.051	0.049	0.053		0.052	0.045	0.053	0.055	0.055	0.054	0.052
6/9/2022	0.058	0.053	0.06		0.055	0.047	0.066	0.064	0.067	0.062	0.062
6/10/2022	0.058	0.053	0.057		0.052	0.045	0.055	0.061	0.058	0.054	0.055
6/11/2022	0.054	0.053	0.055		0.05	0.046	0.056	0.064	0.061	0.058	0.052
6/12/2022	0.059	0.057	0.06		0.055	0.048	0.052	0.055	0.056	0.055	0.051
6/13/2022	0.052	0.05	0.053		0.049	0.044	0.048	0.051	0.052	0.046	0.048
6/14/2022	0.056	0.052	0.043		0.052	0.048	0.045	0.048	0.049	0.046	0.048
6/15/2022	0.068	0.067	0.055		0.062	0.06	0.049	0.054	0.052	0.049	0.051
6/16/2022	0.054	0.058			0.059	0.049		0.051	0.061	0.059	0.054
6/17/2022	0.051	0.048	0.035		0.05	0.043	0.051	0.046	0.051	0.047	0.052
6/18/2022	0.057	0.054	0.035		0.051	0.046	0.059	0.055	0.064	0.055	0.055
6/19/2022	0.054	0.052	0.033		0.048	0.045	0.051	0.052	0.053	0.052	0.055
6/20/2022	0.057	0.055			0.054	0.046	0.054	0.054	0.06	0.061	0.051
6/21/2022	0.049	0.047			0.046	0.04	0.04	0.038	0.041	0.04	
6/22/2022	0.042	0.04	0.042		0.032	0.036	0.037	0.048	0.05	0.049	
6/23/2022	0.061	0.056	0.065			0.044		0.059	0.053	0.05	0.047
6/24/2022	0.056	0.051	0.059		0.049	0.042	0.06	0.063	0.063	0.059	0.054

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

6/25/2022	0.049	0.049	0.05		0.046	0.042	0.061	0.059	0.063	0.061	0.052
6/26/2022	0.047	0.044	0.046		0.045	0.04	0.055	0.057	0.057	0.057	0.044
6/27/2022	0.055	0.052	0.055		0.048		0.059	0.057	0.062	0.061	0.04
6/28/2022	0.067	0.059	0.064		0.051	0.048		0.057	0.062	0.064	0.047
6/29/2022	0.065	0.06	0.071		0.064	0.048	0.071	0.063	0.075	0.075	0.053
6/30/2022	0.064	0.059	0.065		0.058	0.047	0.068	0.075	0.083	0.065	0.053
7/1/2022	0.064	0.06	0.066		0.058	0.049	0.063	0.067	0.066	0.062	0.049
7/2/2022	0.064	0.06	0.065		0.057	0.05	0.063	0.067	0.068	0.065	0.05
7/3/2022	0.066	0.062	0.068		0.062	0.054	0.08	0.069	0.086	0.074	0.058
7/4/2022	0.064	0.059	0.066		0.057	0.052	0.064	0.078	0.064	0.061	0.05
7/5/2022	0.061	0.058	0.066		0.057	0.049	0.061	0.063	0.063	0.059	0.053
7/6/2022	0.056	0.053	0.059		0.052	0.043	0.05	0.056	0.053	0.05	0.044
7/7/2022	0.052	0.053	0.056		0.049	0.043	0.057	0.056	0.064	0.06	0.045
7/8/2022	0.058	0.056	0.063		0.06	0.046	0.062	0.061	0.063	0.066	0.048
7/9/2022	0.06	0.061	0.06		0.056	0.045	0.068	0.064	0.07	0.07	0.052
7/10/2022	0.065	0.063	0.072		0.063	0.048	0.072	0.063	0.071	0.073	0.052
7/11/2022	0.064	0.06	0.069		0.062	0.054	0.081	0.069	0.073	0.083	0.06
7/12/2022	0.072	0.065	0.074		0.063	0.057	0.065	0.063	0.068	0.07	0.054
7/13/2022	0.069	0.063	0.072		0.064	0.057	0.063	0.063	0.069	0.071	0.051
7/14/2022	0.067	0.062	0.07		0.066	0.054	0.064	0.057	0.062	0.062	0.05
7/15/2022	0.068	0.064	0.073		0.065	0.057	0.062	0.06	0.064	0.065	0.048
7/16/2022	0.069	0.071	0.071		0.064	0.055	0.059	0.061	0.067	0.071	0.051
7/17/2022	0.068	0.064	0.065		0.064	0.054	0.057	0.058	0.06	0.06	0.046
7/18/2022		0.065	0.07		0.065	0.056	0.058	0.052	0.065	0.067	0.044
7/19/2022	0.062	0.065	0.064		0.061	0.057	0.065	0.079	0.073		0.049
7/20/2022	0.059	0.059	0.066		0.057	0.052	0.056	0.058	0.065	0.059	0.044
7/21/2022	0.069	0.069	0.073		0.066	0.06	0.068	0.06	0.08	0.072	0.047
7/22/2022	0.066	0.063	0.073		0.069	0.055	0.067	0.07	0.072	0.066	0.048
7/23/2022	0.07	0.068	0.075		0.069	0.06	0.072	0.06	0.078	0.076	0.05
7/24/2022	0.066	0.066	0.071		0.068	0.059	0.061	0.057	0.067	0.066	0.044

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

7/25/2022		0.06	0.067		0.063	0.054	0.067	0.068	0.069	0.063	0.051
7/26/2022		0.06	0.068		0.062	0.056	0.068	0.07	0.068	0.063	0.055
7/27/2022		0.058	0.064		0.058	0.058	0.061	0.063	0.063	0.053	0.047
7/28/2022	0.058	0.052	0.057		0.052	0.049	0.059		0.061	0.057	0.046
7/29/2022	0.064	0.057	0.061		0.056	0.057	0.057	0.05	0.058	0.053	0.044
7/30/2022	0.058	0.054	0.059		0.053	0.052	0.057	0.05	0.058	0.052	0.047
7/31/2022	0.061	0.058	0.062		0.055	0.053	0.054	0.051	0.058	0.057	0.045
8/1/2022	0.056	0.055	0.06		0.05	0.054	0.063	0.058	0.071	0.064	0.044
8/2/2022	0.058	0.057	0.061			0.054	0.056	0.052	0.063	0.057	0.043
8/3/2022	0.059	0.061	0.067		0.054	0.056	0.057	0.056	0.061	0.059	0.044
8/4/2022	0.075	0.069	0.074		0.068	0.065	0.069	0.06	0.078	0.072	0.052
8/5/2022	0.066	0.062	0.071		0.063	0.061	0.068	0.053	0.066	0.068	0.051
8/6/2022	0.058	0.056	0.06		0.056	0.053	0.049	0.046	0.051	0.054	0.041
8/7/2022	0.055	0.052	0.058		0.053	0.051	0.045	0.039	0.048	0.048	0.034
8/8/2022	0.056	0.055	0.054		0.047	0.051	0.051	0.049	0.055	0.052	0.034
8/9/2022	0.054	0.054	0.053		0.046	0.047	0.05	0.041	0.052	0.052	0.039
8/10/2022	0.054	0.049	0.053		0.05	0.05	0.05	0.047	0.054	0.054	0.039
8/11/2022	0.051	0.049	0.055		0.052	0.048	0.047	0.045	0.05	0.05	0.037
8/12/2022	0.063	0.057	0.065		0.065	0.054	0.066	0.055	0.07	0.067	0.05
8/13/2022	0.065	0.063	0.067		0.063	0.062	0.078	0.076	0.08	0.076	0.068
8/14/2022	0.074		0.077		0.071	0.068	0.07	0.066	0.073	0.073	0.06
8/15/2022	0.069		0.073		0.068	0.063	0.064	0.059	0.068	0.067	0.049
8/16/2022	0.056	0.057	0.056		0.06	0.055	0.045	0.043	0.047	0.047	0.035
8/17/2022	0.044	0.042	0.045			0.041	0.037	0.037	0.04	0.039	0.033
8/18/2022	0.045	0.047	0.044		0.043	0.045	0.05	0.051	0.053	0.054	0.043
8/19/2022	0.054	0.05	0.055		0.049	0.046	0.052	0.049	0.053	0.055	0.046
8/20/2022	0.052	0.052	0.05		0.048	0.05	0.035	0.036	0.036	0.035	0.034
8/21/2022	0.06		0.058		0.053	0.061	0.038	0.039	0.039	0.037	0.038
8/22/2022	0.057		0.056		0.051	0.053		0.044	0.052	0.054	0.04
8/23/2022	0.066		0.067		0.054	0.059	0.041	0.041	0.045	0.046	0.039

Ramboll – Conceptual Model of Ozone in New Mexico with a Focus on the Permian Basin

8/24/2022	0.053	0.045	0.055		0.05	0.05	0.054	0.055	0.059	0.059	0.053
8/25/2022	0.07	0.061	0.072		0.062	0.062	0.063	0.058	0.067	0.068	0.06
8/26/2022	0.055	0.05	0.059		0.049	0.051	0.065	0.057	0.07	0.07	0.056
8/27/2022	0.054	0.052	0.056		0.051	0.052	0.05	0.06	0.053	0.051	0.048
8/28/2022	0.055	0.052	0.056		0.05	0.054	0.051	0.054	0.056	0.054	0.051
8/29/2022	0.056	0.053	0.057		0.051	0.056	0.052	0.049	0.058	0.057	0.049
8/30/2022	0.052	0.05	0.056		0.05	0.052	0.052	0.052	0.053		0.049
8/31/2022	0.059	0.052	0.057		0.055	0.052	0.045	0.045	0.047	0.048	0.042
9/1/2022	0.06	0.063	0.058		0.048	0.059	0.037	0.037	0.04	0.04	
9/2/2022	0.052	0.051	0.052		0.047	0.055	0.038	0.037	0.042	0.04	0.037
9/3/2022	0.052	0.047	0.053		0.048	0.05	0.051	0.051	0.052	0.052	0.047
9/4/2022	0.063	0.058	0.062		0.051	0.056	0.048	0.048	0.05	0.051	0.044
9/5/2022	0.06	0.054	0.062		0.053	0.053	0.06	0.053	0.061	0.06	0.055
9/6/2022	0.062		0.068		0.061	0.053	0.056	0.054	0.058	0.057	0.048
9/7/2022	0.061	0.061	0.061		0.053	0.06	0.051	0.054	0.057	0.057	0.049
9/8/2022	0.061	0.058	0.068		0.06	0.057	0.078	0.071	0.076	0.073	0.063
9/9/2022	0.06	0.055	0.063		0.058	0.052	0.058	0.06	0.06	0.05	0.053
9/10/2022	0.064	0.058	0.066		0.056	0.057	0.057	0.053	0.061	0.053	0.049
9/11/2022	0.056	0.053	0.059		0.053	0.049	0.05	0.046	0.053	0.055	0.04
9/12/2022	0.055	0.052	0.058		0.051	0.052	0.059	0.064	0.062	0.046	0.046
9/13/2022	0.05	0.046	0.053		0.047	0.043	0.047	0.052	0.045	0.041	0.041
9/14/2022	0.046	0.042	0.048		0.041	0.042	0.039	0.043	0.04	0.038	0.035
9/15/2022	0.048	0.045	0.05		0.045	0.046	0.046	0.049	0.048	0.036	0.038
9/16/2022	0.042	0.037	0.047		0.04	0.037	0.045	0.044	0.046	0.036	0.034
9/17/2022	0.042	0.039	0.044		0.04	0.037	0.04	0.049	0.041	0.039	0.037
9/18/2022	0.043	0.041	0.044		0.041	0.04	0.036	0.034	0.037	0.036	0.031
9/19/2022	0.049	0.042	0.053		0.046	0.042	0.041	0.033	0.044	0.04	0.031
9/20/2022	0.037	0.035	0.039		0.037		0.041	0.036	0.043	0.034	0.033
9/21/2022	0.042	0.039	0.045		0.04	0.039	0.049	0.044	0.048	0.037	0.041
9/22/2022	0.041	0.039	0.045		0.041	0.039	0.042	0.037	0.045	0.046	0.033

9/23/2022	0.037	0.038	0.039		0.034	0.04	0.047	0.048	0.048	0.037	0.042
9/24/2022	0.055	0.052	0.059		0.053	0.053	0.04	0.04	0.044	0.041	0.035
9/25/2022	0.057	0.054	0.058		0.053	0.054	0.046	0.045	0.049	0.045	0.044
9/26/2022	0.059	0.054	0.056		0.051	0.056	0.049	0.05	0.052	0.051	0.042
9/27/2022	0.055	0.05			0.053	0.051	0.05	0.046	0.05	0.05	0.041
9/28/2022	0.053	0.052	0.054		0.052	0.052	0.045	0.043	0.048	0.048	0.038
9/29/2022	0.045	0.043	0.048		0.044	0.044	0.049	0.045	0.05	0.05	0.039
9/30/2022	0.042	0.042	0.046		0.041	0.04	0.049	0.049	0.055	0.053	0.04

APPENDIX C

APPENDIX C: MAY AND SEPTEMBER CLIMATOLOGY AND 2020-2023 WEATHER ANOMALIES FOR 500 MB HEIGHTS, PRECIPITATION, AND TEMPERATURE

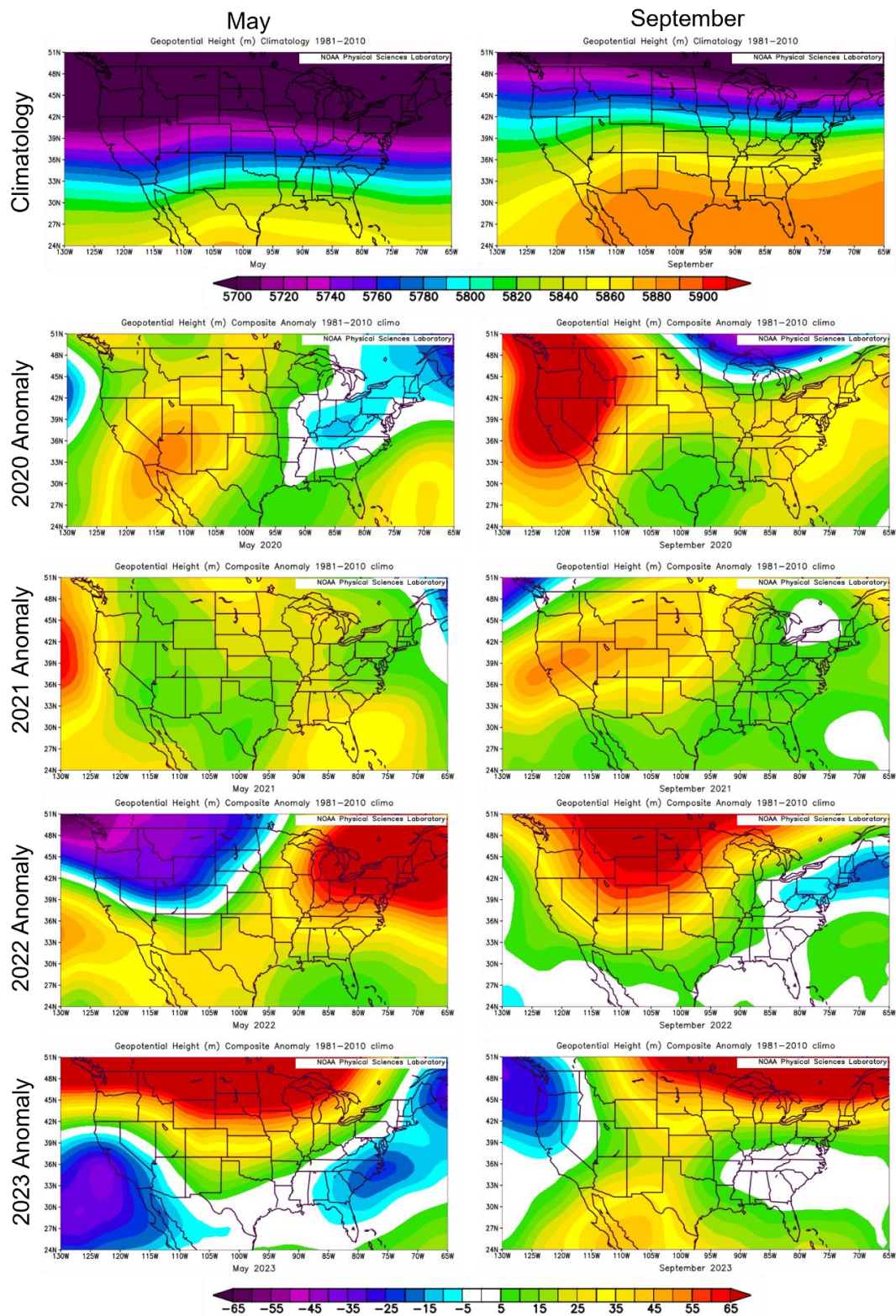


Figure C-1. 500 mb geopotential height climatology (1981-2010) and anomalies for 2020-2023 and May and September.

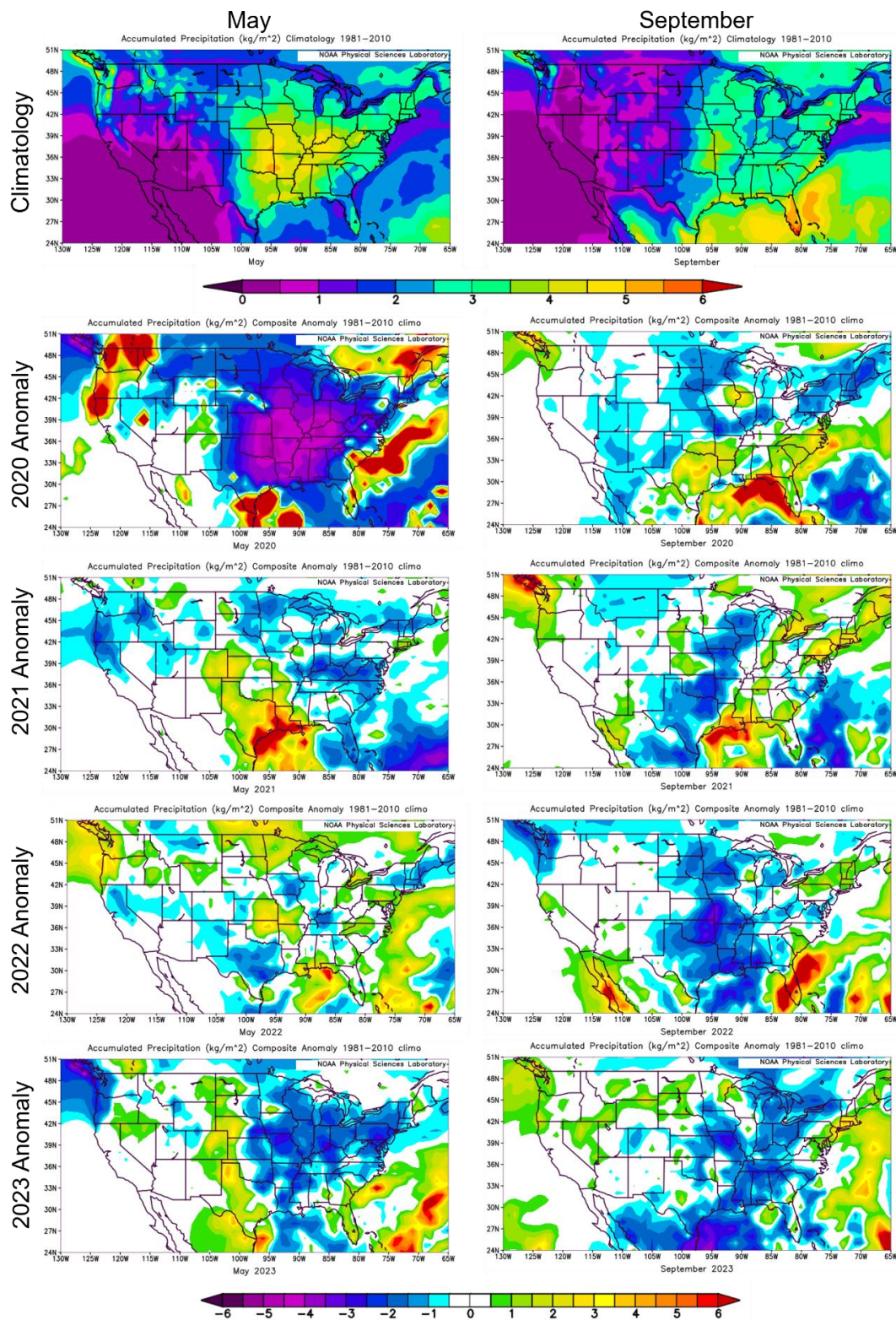


Figure C-2. Average monthly precipitation climatology (1981-2010) and anomalies for 2020-2023 and May and September.

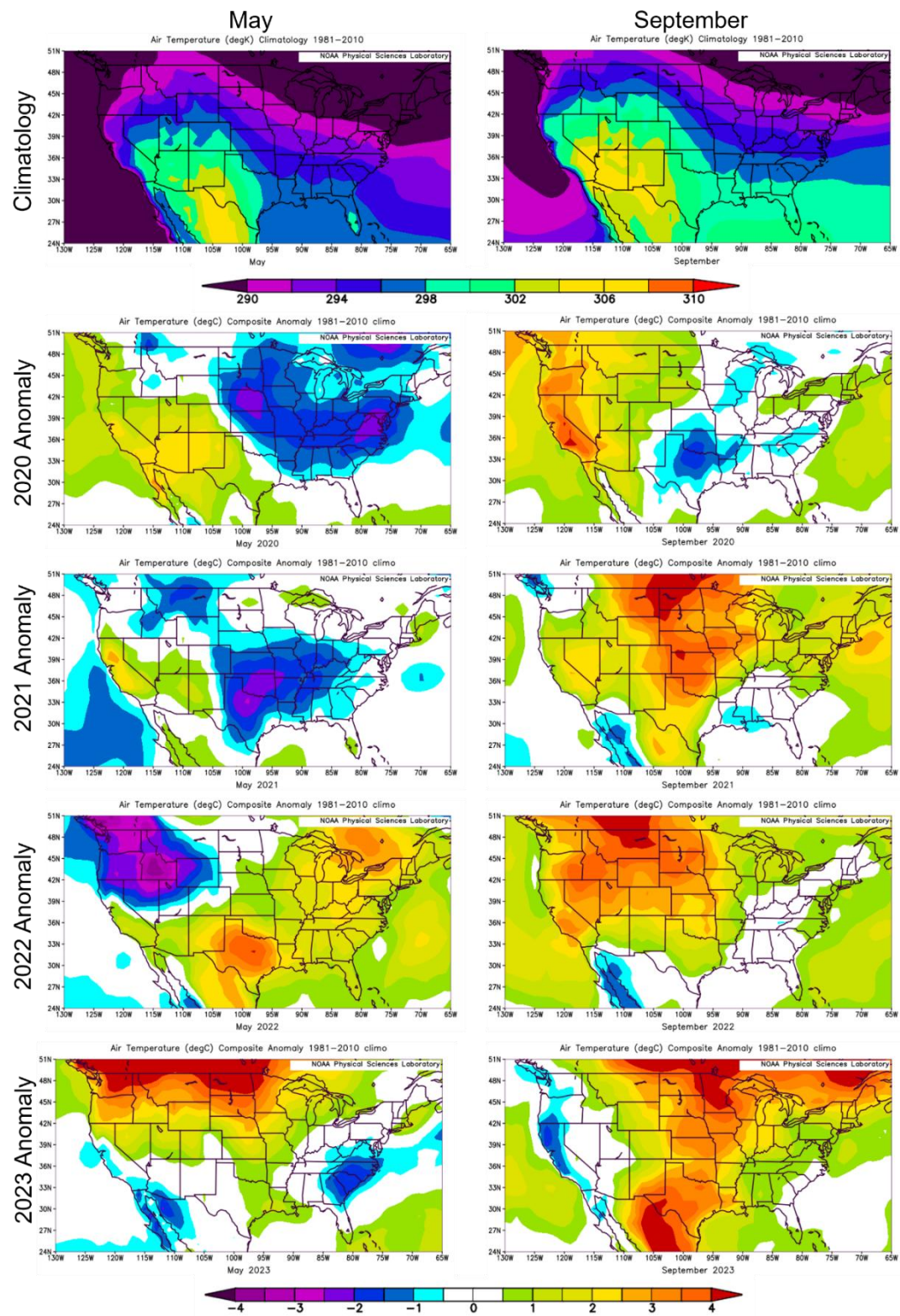


Figure C-3. Temperature climatology (1981-2010) and anomalies for 2020-2023 and May and September.

APPENDIX D

APPENDIX D: LISTING AND ABSTRACTS OF RESEARCH PAPERS THAT UTILIZE CARLSBAD CAVERNS FIELD MEASUREMENT DATA

2017 CarCavAQS Data	
#1	Benedict, K. B., Prenni, A. J., El-Sayed, M. M., Hecobian, A., Zhou, Y., Gebhart, K. A., et al. (2020). Volatile organic compounds and ozone at four national parks in the southwestern United States. <i>Atmospheric Environment</i>, 239, 117783. https://doi.org/10.1016/j.atmosenv.2020.117783
	"In this work we characterize volatile organic compounds (VOCs) at four national parks in the southwestern United States: Carlsbad Caverns (CAVE), Great Basin (GRBA), Grand Canyon (GRCA), and Joshua Tree (JOTR). Whole air samples were collected for VOC analysis for five months (mid-April through mid-September) in 2017. Samples were collected from 3 p.m. to 5 p.m. local time, corresponding approximately to the time of expected peak ozone concentrations, and were analyzed using gas chromatography for a variety of compounds including alkanes, alkenes, aromatics, biogenics, and alkyl nitrates. Among the four parks, the total measured VOC mixing ratio was greatest at CAVE, mostly due to an abundance of light alkanes (on average 94% of all VOCs measured) from oil and gas sources. VOC concentrations at the other three parks were similar to each other and approximately 7–10 times lower than at CAVE. While VOC sources varied across sites, VOC-OH reactivity was dominated by biogenic compounds at all sites except CAVE, which had similar contributions from biogenics and from light alkanes."..." CAVE is located near the Permian Basin, one of the most active oil and gas basins in the United States, and air in the park was clearly influenced by oil and gas emissions. Of the four parks, CAVE had the highest levels of light alkanes, by approximately an order of magnitude. These light alkanes play an important role in local ozone formation, based on calculations of VOC-OH reactivity and photochemical age,"..." Back-trajectories confirm that the source of elevated VOCs, as well as that of the highest levels of observed ozone, is southeast of the park, where the most extensive oil and gas development activities are located."
2019 CarCavAQS data	
#2	Marsavin, A., Pan, D., Pollack, I. B., Zhou, Y., Sullivan, A. P., Naimie, L. E., et al. (2024). Summertime ozone production at Carlsbad Caverns National Park, New Mexico: Influence of oil and natural gas development. <i>Journal of Geophysical Research: Atmospheres</i>, 129, e2024JD040877.
	Southeastern New Mexico's Carlsbad Caverns National Park (CAVE) has increasingly experienced summertime ozone (O₃) exceeding an 8-hr average of 70 parts per billion by volume (ppbv). The park is located in the western part of the Permian oil and natural gas (O&G) basin, where production rates have increased fivefold in the last decade. We investigate O₃–precursor relationships by constraining the FOAM box model to observations of nitrogen oxides (NO_x = NO + NO₂) and a suite of volatile organic compounds (VOCs) collected at CAVE during summer 2019. O&G-related VOCs dominated the calculated VOC reactivity with hydroxyl radicals (OH) on days when O₃ concentrations were primarily controlled by local photochemistry. Radical budget analysis showed that NO_x levels were high enough to impose VOC sensitivity on O₃ production in the morning hours, while subsequent NO_x loss through photochemical consumption led to NO_x-sensitive conditions in the afternoon. Maximum daily O₃ was responsive to

	both NO_x and O&G-related VOC reductions, with NO_x reductions proving most effective. The model underestimated observed O₃ during a 5-day high O₃ episode that was influenced by photochemically aged O&G emissions, as indicated by back-trajectory analysis, low <i>i</i>-/<i>n</i>-pentane ratios, enhanced secondary VOCs, and low ratios of NO_x to total reactive oxidized nitrogen (NO_y). Model-observation agreement was improved by constraining model NO_x with observed NO_y, which approximates NO_x at the time of emission, indicating that a large fraction of O₃ during this episode was formed nonlocally”
#3	Lillian E. Naimie, Amy P. Sullivan, K.B. Benedict, Anthony J. Prenni, B.C. Sive, Bret A. Schichtel, Emily V. Fischer, Ilana Pollack & Jeffrey Collett (2022) PM_{2.5} in Carlsbad Caverns National Park: Composition, sources, and visibility impacts, Journal of the Air & Waste Management Association, 72:11, 1201-1218, DOI: 10.1080/10962247.2022.2081634 Not Applicable since this paper is focused on PM and not ozone
#4	Da Pan, Ilana B. Pollack, Barkley C. Sive, Andrey Marsavin, Lillian E. Naimie, Katherine B. Benedict, Yong Zhou, Amy P. Sullivan, Anthony J. Prenni, Elana J. Cope, Julieta F. Juncosa Calahorrano, Emily V. Fischer, Bret A. Schichtel & Jeffrey L. Collett Jr. (2023) Source characterization of volatile organic compounds at Carlsbad Caverns National Park, Journal of the Air & Waste Management Association, 73:12, 914-929, DOI: 10.1080/10962247.2023.2266696 “Carlsbad Caverns National Park (CAVE), located in southeastern New Mexico, experiences elevated ground-level ozone (O₃) exceeding the National Ambient Air Quality Standard (NAAQS) of 70 ppbv. It is situated adjacent to the Permian Basin, one of the largest oil and gas (O&G) producing regions in the US. In 2019, the Carlsbad Caverns Air Quality Study (CarCavAQS) was conducted to examine impacts of different sources on ozone precursors, including nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Here, we use positive matrix factorization (PMF) analysis of speciated VOCs to characterize VOC sources at CAVE during the study. Seven factors were identified. Three factors composed largely of alkanes and aromatics with different lifetimes were attributed to O&G development and production activities. VOCs in these factors were typical of those emitted by O&G operations. Associated residence time analyses (RTA) indicated their contributions increased in the park during periods of transport from the Permian Basin. These O&G factors were the largest contributor to VOC reactivity with hydroxyl radicals (62%). Two PMF factors were rich in photochemically generated secondary VOCs; one factor contained species with shorter atmospheric lifetimes and one with species with longer lifetimes. RTA of the secondary factors suggested impacts of O&G emissions from regions farther upwind, such as Eagle Ford Shale and Barnett Shale formations. The last two factors were attributed to alkenes likely emitted from vehicles or other combustion sources in the Permian Basin and regional background VOCs, respectively. Implications: Carlsbad Caverns National Park experiences ground-level ozone exceeding the National Ambient Air Quality Standard. Volatile organic compounds are critical precursors to ozone formation. Measurements in the Park identify oil and gas production and development activities as the major contributors to volatile organic compounds. Emissions from the adjacent Permian Basin contributed to increases in primary species that enhanced local ozone formation. Observations of photochemically generated compounds indicate that ozone was also transported from shale formations and basins farther upwind.

	Therefore, emission reductions of volatile organic compounds from oil and gas activities are important for mitigating elevated O ₃ in the region.”
#5	Ilana B. Pollack, Da Pan, Andrey Marsavin, Elana J. Cope, Julieta Juncosa Calahorrano, L. Naimie, K. B. Benedict, Amy P. Sullivan, Y. Zhou, B. C. Sive, Anthony J. Prenni, Bret A. Schichtel, Jeffrey Collett & Emily V. Fischer (2023) Observations of ozone, acyl peroxy nitrates, and their precursors during summer 2019 at Carlsbad Caverns National Park, New Mexico, Journal of the Air & Waste Management Association, 73:12, 951-968, DOI: 10.1080/10962247.2023.2271436 “Carlsbad Caverns National Park (CAVE) is located in southeastern New Mexico and is adjacent to the Permian Basin, one of the most productive oil and natural gas (O&G) production regions in the United States. Since 2018, ozone (O₃) at CAVE has frequently exceeded the 70 ppbv 8-hour National Ambient Air Quality Standard. We examine the influence of regional emissions on O₃ formation using observations of O₃, nitrogen oxides (NO_x = NO + NO₂), a suite of volatile organic compounds (VOCs), peroxyacetyl nitrate (PAN), and peroxypropionyl nitrate (PPN). Elevated O₃ and its precursors are observed when the wind is from the southeast, the direction of the Permian Basin. We identify 13 days during the July 25 to September 5, 2019 study period when the maximum daily 8-hour average (MDA8) O₃ exceeded 65 ppbv; MDA8 O₃ exceeded 70 ppbv on 5 of these days. The results of a positive matrix factorization (PMF) analysis are used to identify and attribute source contributions of VOCs and NO_x. On days when the winds are from the southeast, there are larger contributions from factors associated with primary O&G emissions; and, on high O₃ days, there is more contribution from factors associated with secondary photochemical processing of O&G emissions. The observed ratio of VOCs to NO_x is consistently high throughout the study period, consistent with NO_x-limited O₃ production. Finally, all high O₃ days coincide with elevated acyl peroxy nitrate abundances with PPN to PAN ratios > 0.15 ppbv ppbv⁻¹ indicating that anthropogenic VOC precursors, and often alkanes specifically, dominate the photochemistry. <i>Implications:</i> The results above strongly indicate NO_x-sensitive photochemistry at Carlsbad Caverns National Park indicating that reductions in NO_x emissions should drive reductions in O₃. However, the NO_x-sensitivity is largely driven by emissions of NO_x into a VOC-rich environment, and a high PPN:PAN ratio and its relationship to O₃ indicate substantial influence from alkanes in the regional photochemistry. Thus, simultaneous reductions in emissions of NO_x and non-methane VOCs from the oil and gas sector should be considered for reducing O₃ at Carlsbad Caverns National Park. Reductions in non-methane VOCs will have the added benefit of reducing formation of other secondary pollutants and air toxics.”
2021 CarCavAQS data	
	In preparation

APPENDIX E

APPENDIX E: HMS SMOKE AND PM_{2.5} PLOTS FOR 2022 DAYS