# Assessing source contributions to air quality in southeast New Mexico

## Research Team

Meredith Franklin (Assoc. Professor, Univ. of Toronto) Exposure assessment, statistics, data science

Gunnar Schade (Associate Professor, Texas A&M University), Unconventional oil and gas development studies, distributed sampling

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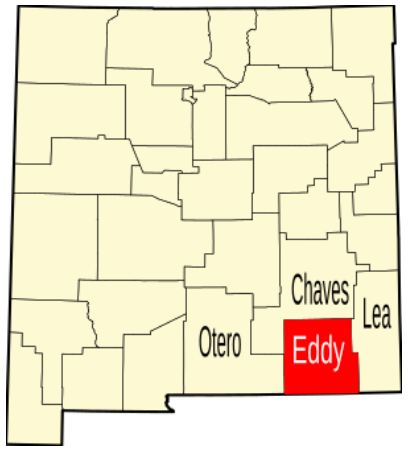
Jill Johnston (Associate Professor, University of Southern California) Environmental health and justice, community engagement

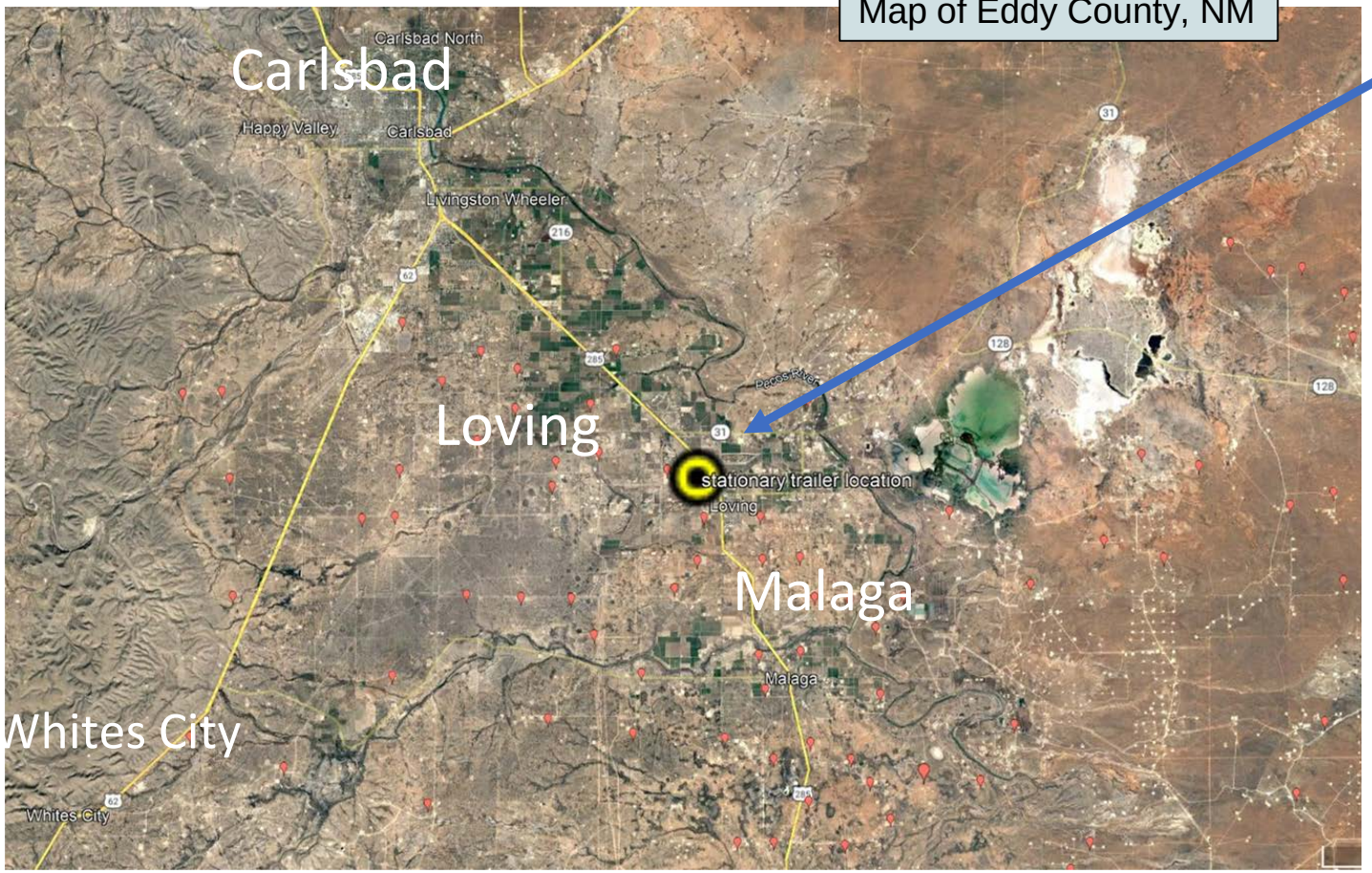
Lara Cushing (Assistant Professor, University of California LA), Environmental health and epidemiology, community engagement

# Overview of study site in Loving, NM




Stationary monitoring trailer location

Map of Eddy County, NM



# Overview of stationary monitoring

- One year duration, April 2023 – May 2024
- Highly sensitive, regulatory rated instruments and protocols
- Fully automated, 24/7 operation, less than 2% downtime
- Most extensive (# of monitored pollutants, # of measurements) air monitoring in New Mexico

- Data reported in real time to the public within minutes after measurement (https://bouldair.com/loving.htm)

# Study Findings

NEW MEXICO POLITICAL REPORT ☰ MENU SEARCH GOT A TIP? SUBSCRIBE DONATE

NEWS ENVIRONMENT ABORTION LOCAL QUICK READS

August 26, 2024

## In this tiny New Mexico town, the air quality is worse than in downtown L.A.

By Jerry Redfern, Capital & Main A group of air quality scientists with decades of experience have found some of the worst air pollution they've encountered in years in the tiny town of Loving, New Mexico, where the ozone level is often worse than it is in downtown Los Angeles. Despite the elevated readings, the Environmental [...]

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By Capital & Main

- **Ozone pollution – Highest levels ever recorded in NM**
- **Causes of high ozone – Mostly oil and natural gas emissions**

# Why are we so concerned about ozone?

Ozone ($O_3$) is a strong oxidant. It has been regulated through the Clean Air Act since 1970.

<u>Elevated levels of surface ozone can cause:</u>

- Shortness of breath
- Chest pain when inhaling deeply
- Wheezing and coughing
- Increased susceptibility to respiratory infections
- Inflammation of the lungs and airways
- Increased risk of asthma attacks

….. (American Lung Association)

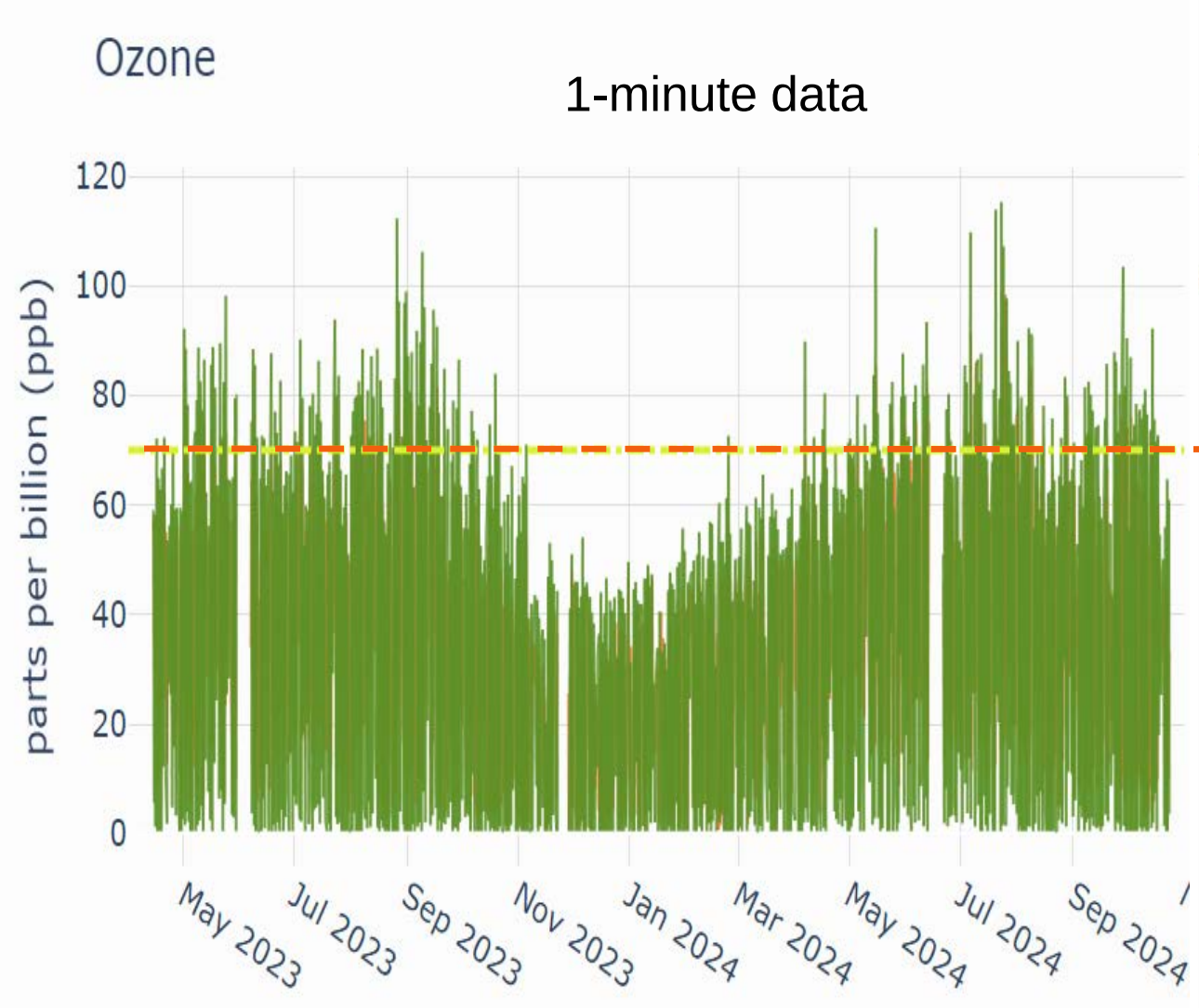
→ Increased risk of death;
~ 5000-6000 premature deaths in US per year

**Also – Ozone in Greenhouse Gas:**

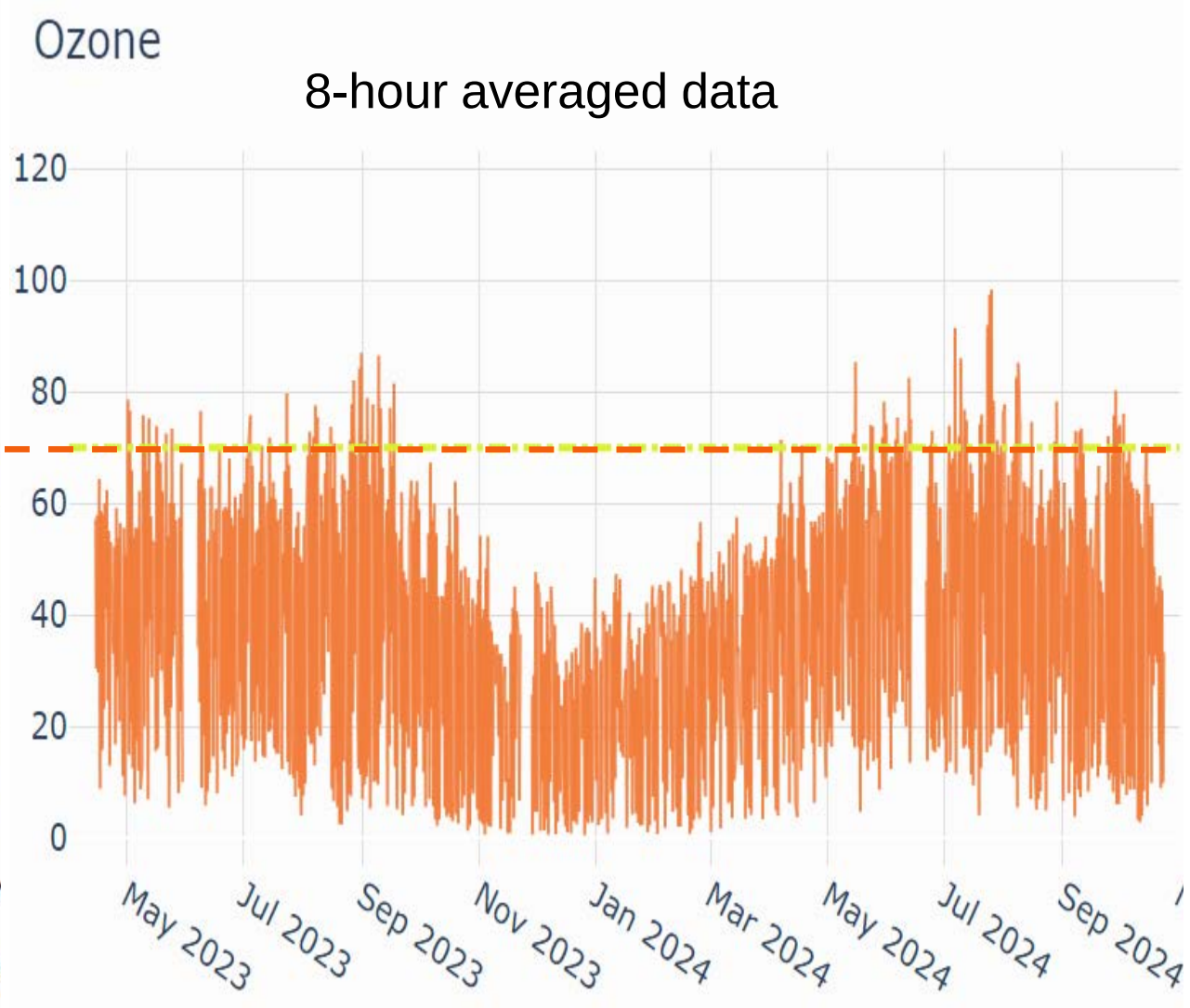
1. $CO_2$ (55%)
2. Methane (30%)
3. <u>Ozone (8%)</u>

# 2023 – 2024 Ozone results for Loving, NM

1-minute data



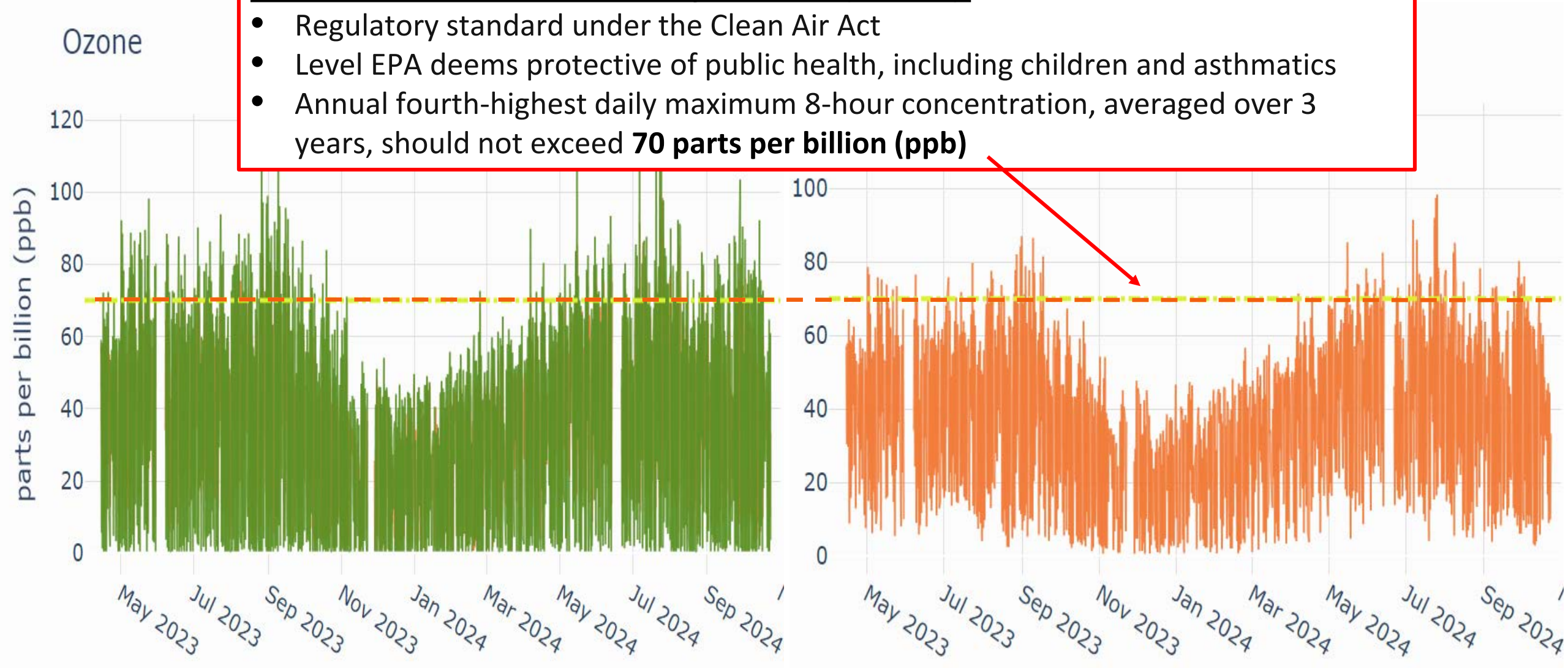

8-hour averaged data



# 2023 – 2024 Ozone results for Loving, NM

**EPA National Ambient Air Quality Standard (NAAQS):**

- Regulatory standard under the Clean Air Act
- Level EPA deems protective of public health, including children and asthmatics
- Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years, should not exceed **70 parts per billion (ppb)**



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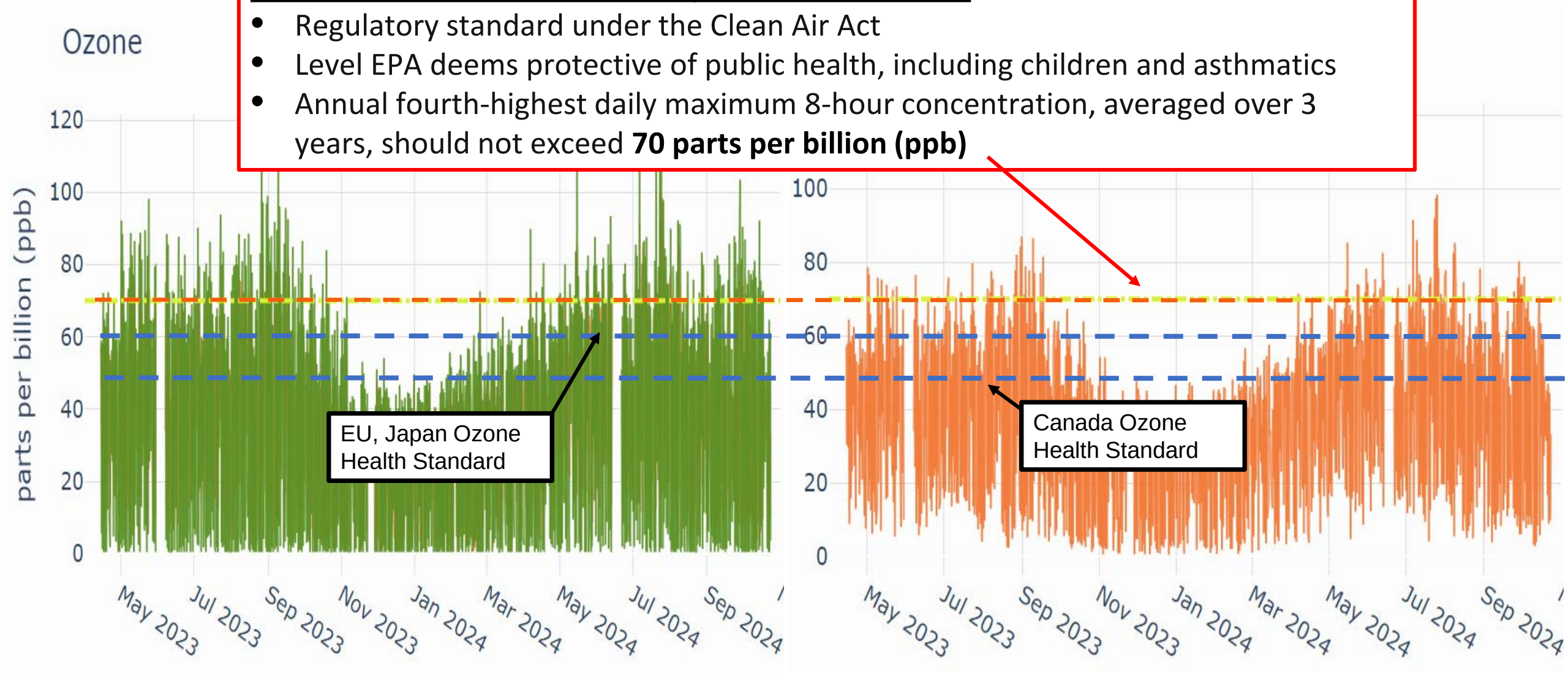


# 2023 and 2024 occurrences of 8-hour ozone > 70 ppb at Loving, NM

| 2023 (full year) | | | |
|---|---|---|---|
| O3_8hr (ppb) | day-month | year | # days > 75/70 ppb NAAQS |
| 87.1 | 31-Aug | 2023 | |
| 86.7 | 9-Sep | 2023 | |
| 84.3 | 30-Aug | 2023 | |
| 82.1 | 27-Aug | 2023 | |
| 81.6 | 17-Sep | 2023 | |
| 79.7 | 23-Jul | 2023 | |
| 78.9 | 3-Sep | 2023 | |
| 78.6 | 1-May | 2023 | |
| 77.9 | 26-Aug | 2023 | |
| 77.8 | 6-Sep | 2023 | |
| 77.7 | 7-Aug | 2023 | |
| 77.7 | 6-Jun | 2023 | |
| 77.3 | 15-Sep | 2023 | |
| 77.2 | 10-Sep | 2023 | |
| 76.6 | 2-May | 2023 | |
| 76.6 | 8-Jun | 2023 | |
| 76.0 | 4-Jul | 2023 | 17 |
| 75.8 | 9-May | 2023 | |
| 75.7 | 12-May | 2023 | |
| 75.7 | 15-Aug | 2023 | |
| 75.6 | 8-Aug | 2023 | |
| 74.0 | 16-May | 2023 | |
| 73.5 | 24-May | 2023 | |
| 72.9 | 4-Aug | 2023 | |
| 72.6 | 21-May | 2023 | |
| 72.0 | 6-Aug | 2023 | |
| 71.8 | 14-Jul | 2023 | |
| 71.7 | 10-Jul | 2023 | |
| 71.3 | 25-Aug | 2023 | |
| 71.2 | 2-Sep | 2023 | |
| 71.0 | 3-Jul | 2023 | |
| 70.9 | 17-Aug | 2023 | |
| 70.4 | 10-May | 2023 | |
| 70.3 | 18-Jun | 2023 | |

**31**

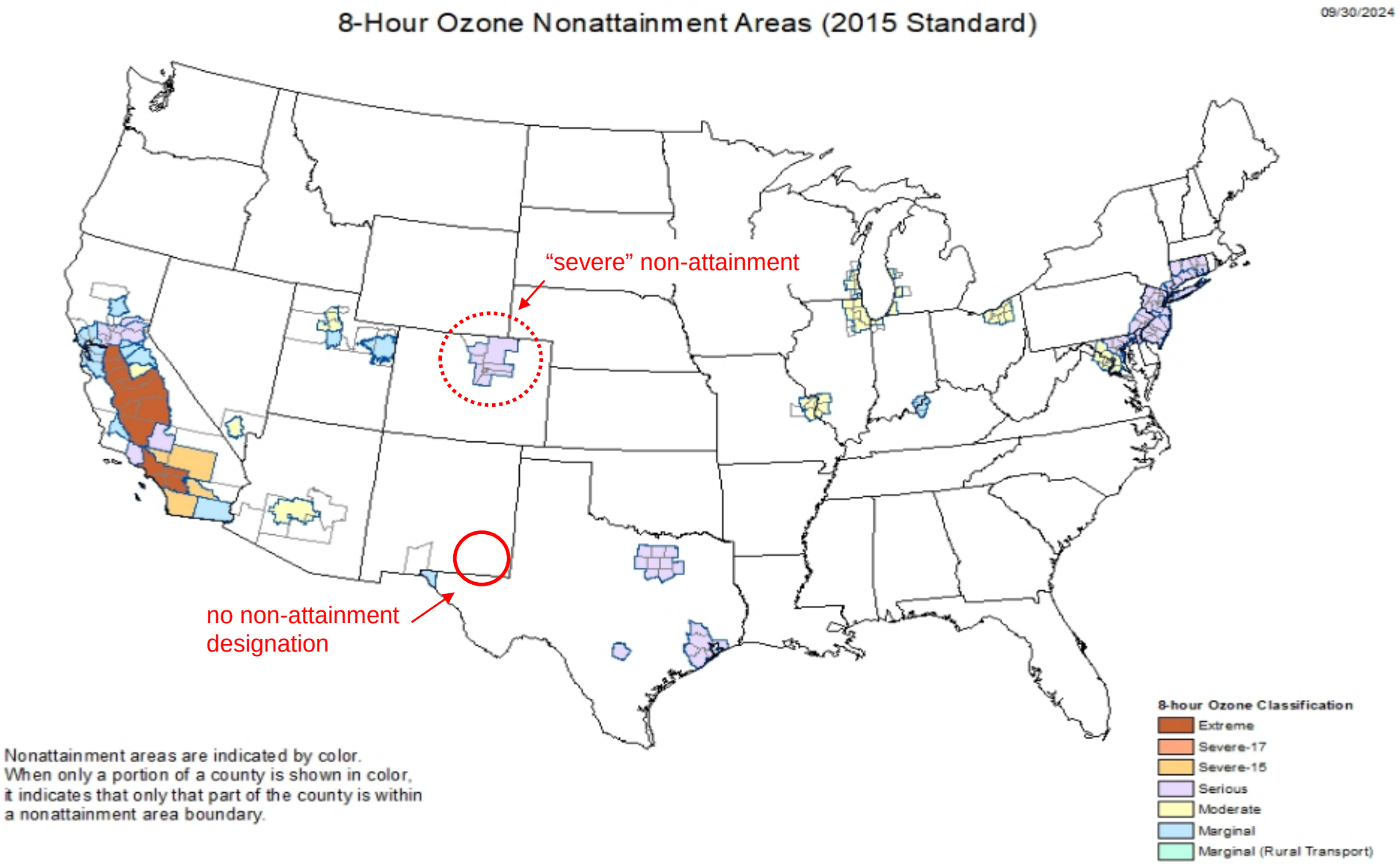
| 2024 (until Oct 25th) | | | |
|---|---|---|---|
| O3_8hr (ppb) | day-month | year | # days > 75/70 ppb NAAQS |
| 99.8 | 25-Jul | 2024 | |
| 97.7 | 24-Jul | 2024 | |
| 92.4 | 23-Jul | 2024 | |
| 91.5 | 6-Jul | 2024 | |
| 86.8 | 26-Jul | 2024 | |
| 86.3 | 9-Jul | 2024 | |
| 85.4 | 8-Aug | 2024 | |
| 85.4 | 15-May | 2024 | |
| 82.7 | 7-Aug | 2024 | |
| 82.5 | 12-Jun | 2024 | |
| 80.4 | 28-Sep | 2024 | |
| 79.6 | 30-Sep | 2024 | |
| 78.3 | 28-Aug | 2024 | |
| 78.3 | 30-May | 2024 | |
| 78.1 | 1-Aug | 2024 | |
| 77.7 | 10-Jul | 2024 | |
| 77.5 | 11-Jul | 2024 | |
| 77.2 | 20-Jul | 2024 | |
| 76.3 | 27-Jul | 2024 | |
| 76.1 | 2-Oct | 2024 | |
| 76.0 | 31-Jul | 2024 | 21 |
| 75.8 | 27-Sep | 2024 | |
| 75.6 | 6-Jun | 2024 | |
| 75.2 | 12-Jul | 2024 | |
| 75.1 | 23-May | 2024 | |
| 75.1 | 13-Jun | 2024 | |
| 74.7 | 3-Jul | 2024 | |
| 74.7 | 9-Aug | 2024 | |
| 74.6 | 15-Aug | 2024 | |
| 74.6 | 31-May | 2024 | |
| 74.3 | 19-Jul | 2024 | |
| 74.2 | 24-May | 2024 | |
| 73.6 | 29-Sep | 2024 | |
| 73.5 | 10-Sep | 2024 | |
| 73.2 | 7-Sep | 2024 | |
| 73.0 | 24-Jun | 2024 | |
| 73.0 | 10-Jun | 2024 | |
| 73.0 | 9-Sep | 2024 | |
| 72.6 | 14-May | 2024 | |
| 72.1 | 24-Sep | 2024 | |
| 72.0 | 8-Jul | 2024 | |
| 71.9 | 29-May | 2024 | |
| 71.6 | 5-Jun | 2024 | |
| 71.4 | 6-Apr | 2024 | |
| 71.3 | 28-Jul | 2024 | |
| 71.0 | 27-Aug | 2024 | |
| 70.7 | 7-Apr | 2024 | |
| 70.7 | 14-Oct | 2024 | |
| 70.6 | 6-Aug | 2024 | |
| 70.5 | 17-Apr | 2024 | |
| 70.4 | 23-Jun | 2024 | |
| 70.4 | 30-Jul | 2024 | |
| 70.2 | 3-Jun | 2024 | |
| 70.1 | 5-May | 2024 | |

**46**

**Loving 2023-2024 mean 4th:**
**86.8 ppb**

Number of ozone NAAQS exceedance days

# US ozone non-attainment areas



# Loving 2023-2024 4th highest mean ozone compared to EPA ozone non-attainment area design values

Table 1a. Design Values in Areas Previously Designated Nonattainment for the 2015 8-Hour Ozone NAAQS

AQS Data Retrieval: 5/7/2024 | Last Updated: 6/4/2024

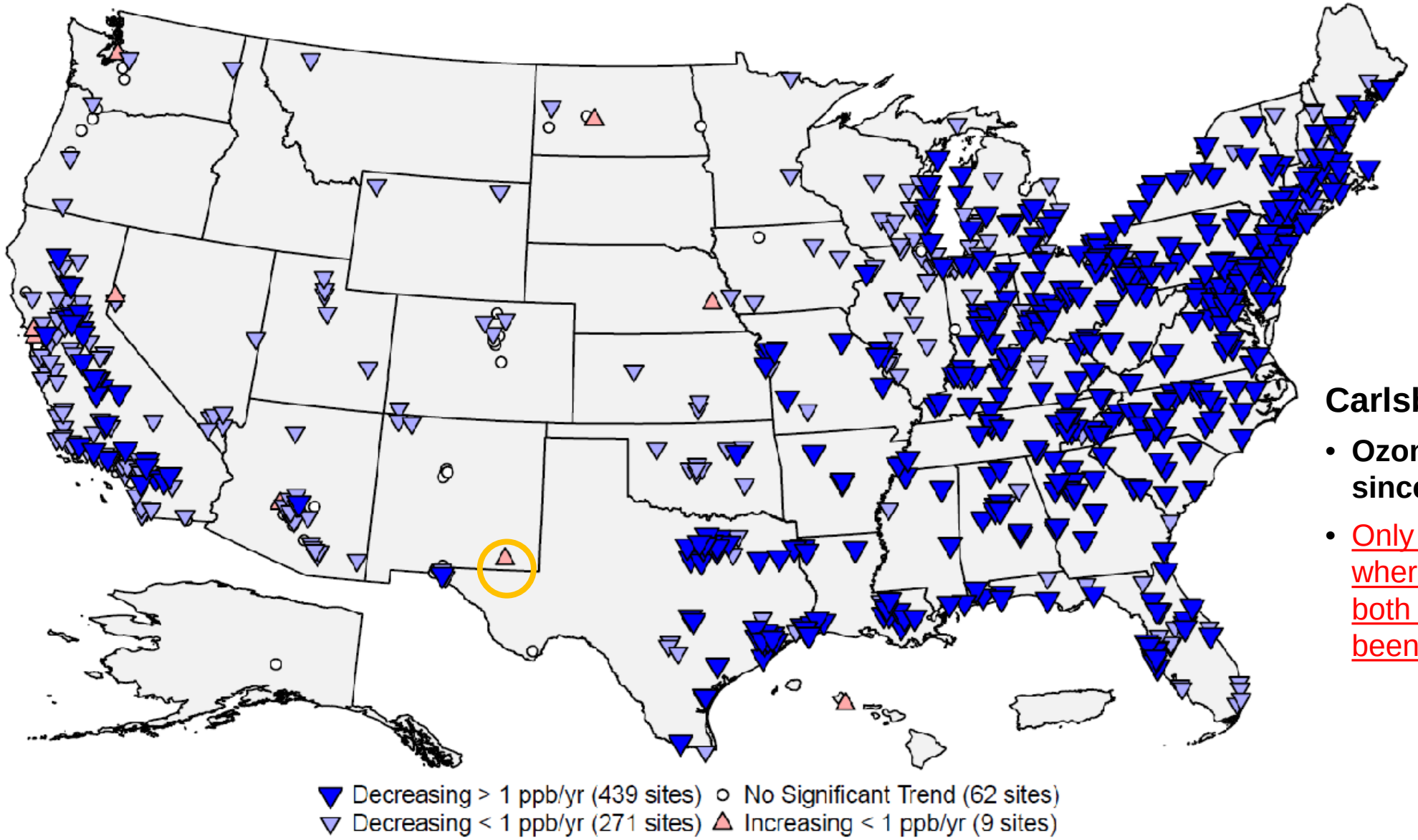
| Designated Area | EPA Region(s) | Designation Status [1] | Classification [1] | 2021-2023 Design Value (ppm) [2,3] | Met NAAQS? |
|---|---|---|---|---|---|
| Los Angeles-South Coast Air Basin, CA | 9 | Nonattainment | Extreme | 0.106 | No |
| Morongo Band of Mission Indians, CA | 9 | Nonattainment | Serious | 0.094 | No |
| Los Angeles-San Bernardino Counties (West Mojave Desert), CA | 9 | Nonattainment | Severe 15 | 0.090 | No |
| San Joaquin Valley, CA | 9 | Nonattainment | Extreme | 0.090 | No |
| **Loving, NM** | **6** | **n/a** | **n/a** | **0.087** | **n/a** |
| Riverside County (Coachella Valley), CA | 9 | Nonattainment | Severe 15 | 0.085 | No |
| Houston-Galveston-Brazoria, TX | 6 | Nonattainment | Moderate | 0.083 | No |
| New York-Northern New Jersey-Long Island, NY-NJ-CT | 1,2 | Nonattainment | Moderate | 0.082 | No |
| Dallas-Fort Worth, TX | 6 | Nonattainment | Moderate | 0.081 | No |
| Denver Metro/North Front Range, CO | 8 | Nonattainment | Moderate | 0.081 | No |
| Phoenix-Mesa, AZ | 9 | Nonattainment | Moderate | 0.080 | No |
| El Paso-Las Cruces, TX-NM | 6 | Nonattainment | Marginal | 0.079 | No |
| San Diego County, CA | 9 | Nonattainment | Severe 15 | 0.079 | No |
| Nevada County (Western part), CA | 9 | Nonattainment | Serious | 0.078 | No |
| Chicago, IL-IN-WI | 5 | Nonattainment | Moderate | 0.077 | No |
| Imperial County, CA | 9 | Nonattainment | Marginal | 0.077 | No |
| Muskegon County, MI | 5 | Nonattainment | Moderate | 0.077 | No |
| Northern Wasatch Front, UT | 8 | Nonattainment | Moderate | 0.077 | No |
| Sheboygan County, WI | 5 | Nonattainment | Moderate | 0.077 | No |
| Uinta Basin, UT | 8 | Nonattainment | Marginal | 0.077 | No |
| Sacramento Metro, CA | 9 | Nonattainment | Serious | 0.076 | No [5] |
| San Antonio, TX | 6 | Nonattainment | Moderate | 0.076 | No |
| Allegan County, MI | 5 | Nonattainment | Moderate | 0.075 | No |
| Kern County (Eastern Kern), CA | 9 | Nonattainment | Serious | 0.075 | No |
| Ventura County, CA | 9 | Nonattainment | Serious | 0.075 | No |
| Las Vegas, NV | 9 | Nonattainment | Moderate | 0.074 | No |
| Milwaukee, WI | 5 | Nonattainment | Moderate | 0.074 | No |
| St. Louis, MO-IL | 5,7 | Nonattainment | Moderate | 0.074 | No |
| Baltimore, MD | 3 | Nonattainment | Moderate | 0.073 | No |
| Berrien County, MI | 5 | Nonattainment | Moderate | 0.073 | No |
| Cleveland, OH | 5 | Nonattainment | Moderate | 0.073 | No |
| Greater Connecticut, CT | 1 | Nonattainment | Moderate | 0.073 | No |
| Manitowoc County, WI | 5 | Maintenance | Marginal | 0.073 | No |
| Mariposa County, CA | 9 | Nonattainment | Moderate | 0.073 | No |
| Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE | 2,3 | Nonattainment | Moderate | 0.073 | No |
| Door County, WI | 5 | Maintenance | Marginal | 0.072 | No |
| Louisville, KY-IN | 4,5 | Nonattainment | Moderate | 0.072 | No |
| Southern Wasatch Front, UT | 8 | Nonattainment | Marginal | 0.072 | No |
| Tuscan Buttes, CA | 9 | Nonattainment | Marginal | 0.072 | No |
| Detroit, MI | 5 | Maintenance | Moderate | 0.071 | No |
| San Luis Obispo (Eastern part), CA | 9 | Nonattainment | Marginal | 0.071 | No |
| Sutter Buttes, CA | 9 | Nonattainment | Marginal | 0.071 | No |
| Washington, DC-MD-VA | 3 | Nonattainment | Moderate | 0.071 | No |
| Atlanta, GA | 4 | Maintenance | Marginal | 0.070 | Yes |
| Cincinnati, OH-KY | 4,5 | Maintenance | Moderate | 0.070 | Yes |
| San Francisco Bay Area, CA | 9 | Nonattainment | Marginal | 0.070 | Yes [5] |
| Yuma, AZ | 9 | Nonattainment | Marginal | 0.070 | Yes |
| Butte County, CA | 9 | Nonattainment | Marginal | 0.067 | Yes |
| Columbus, OH | 5 | Maintenance | Marginal | 0.067 | Yes |
| Calaveras County, CA | 9 | Nonattainment | Marginal | 0.066 | Yes |
| Amador County, CA | 9 | Nonattainment | Marginal | 0.065 | Yes |
| Tuolumne County, CA | 9 | Nonattainment | Marginal | | Incomplete |

**51 ozone non-attainment areas**

**With its 2023-2024 value of 86.9 Loving would be 5th worst ozone polluted area in the US.**

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

# Ozone design value trends across the United States (EPA 2023)




**Carlsbad-Artesia:**

- **Ozone above NAAQS since 2018**
- Only location in the US where ozone has been both increasing and been above the NAAQS.

source: www.epa.gov/air-quality-analysis/ozone-naaqs-review-analyses-and-data-sets

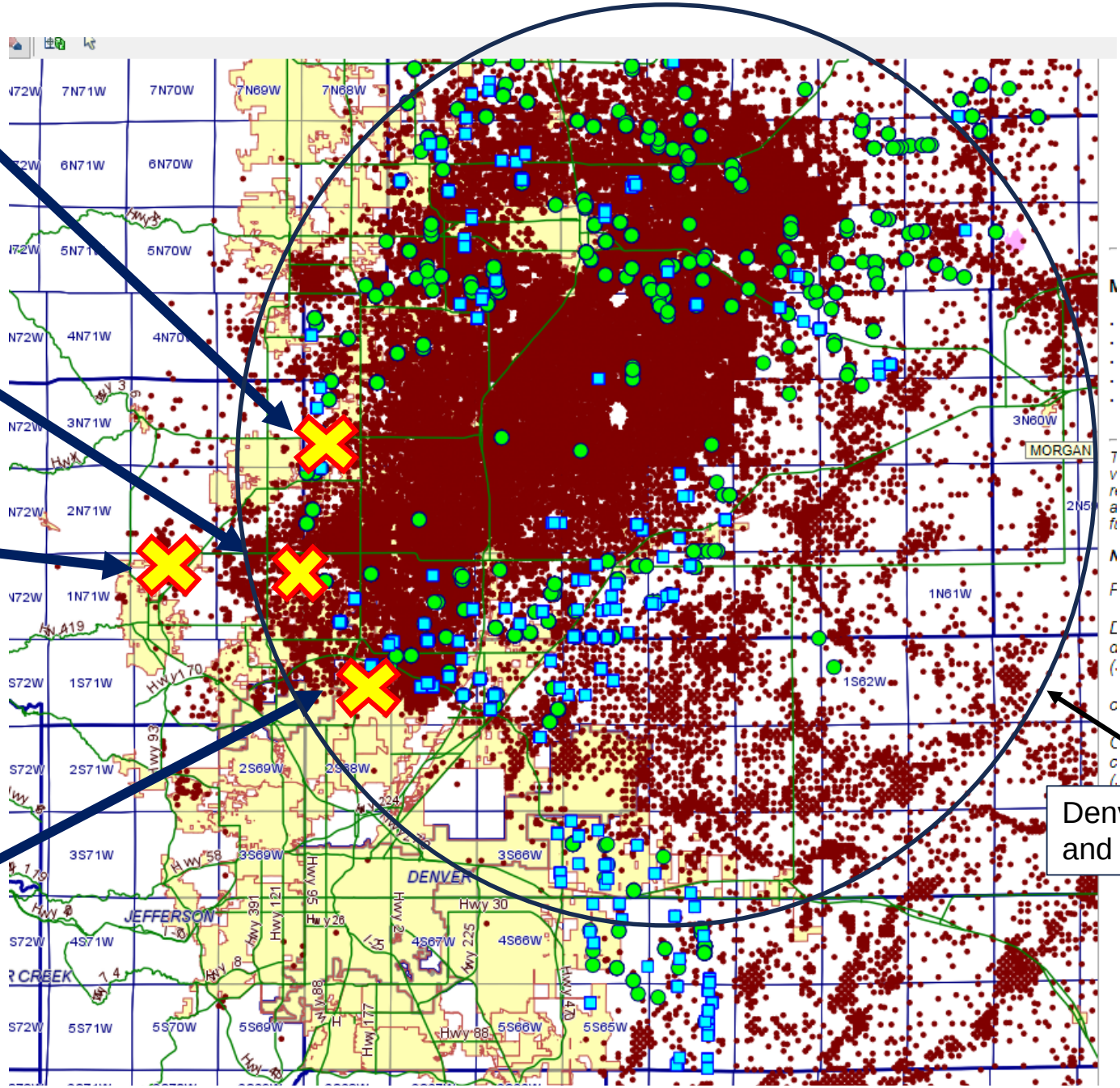
# Comparison data from Colorado Front Range monitoring stations

**Longmont Union Reservoir (LUR)**

**Erie Community Center (ECC)**

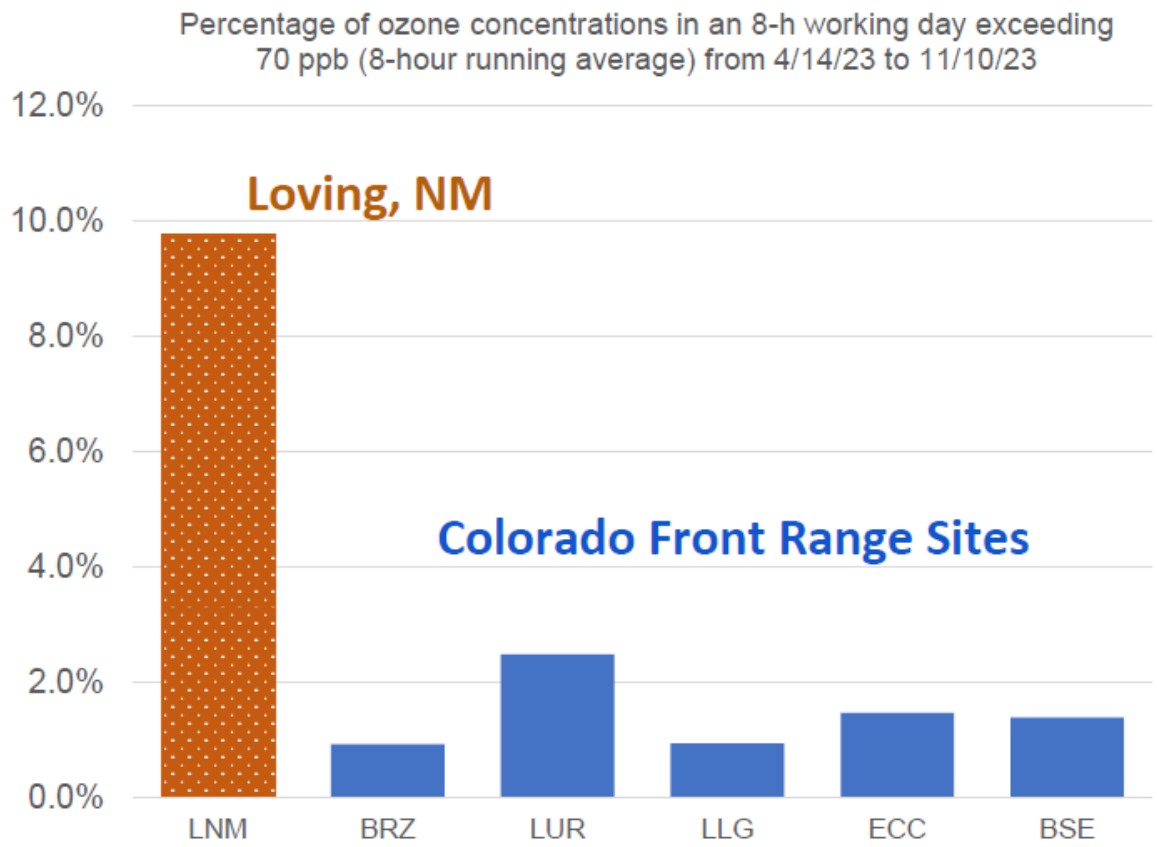
**Boulder Reservoir (BRZ)**

**Broomfield Soaring Eagle (BSE)**




Denver Julesburg Oil and Gas Basin

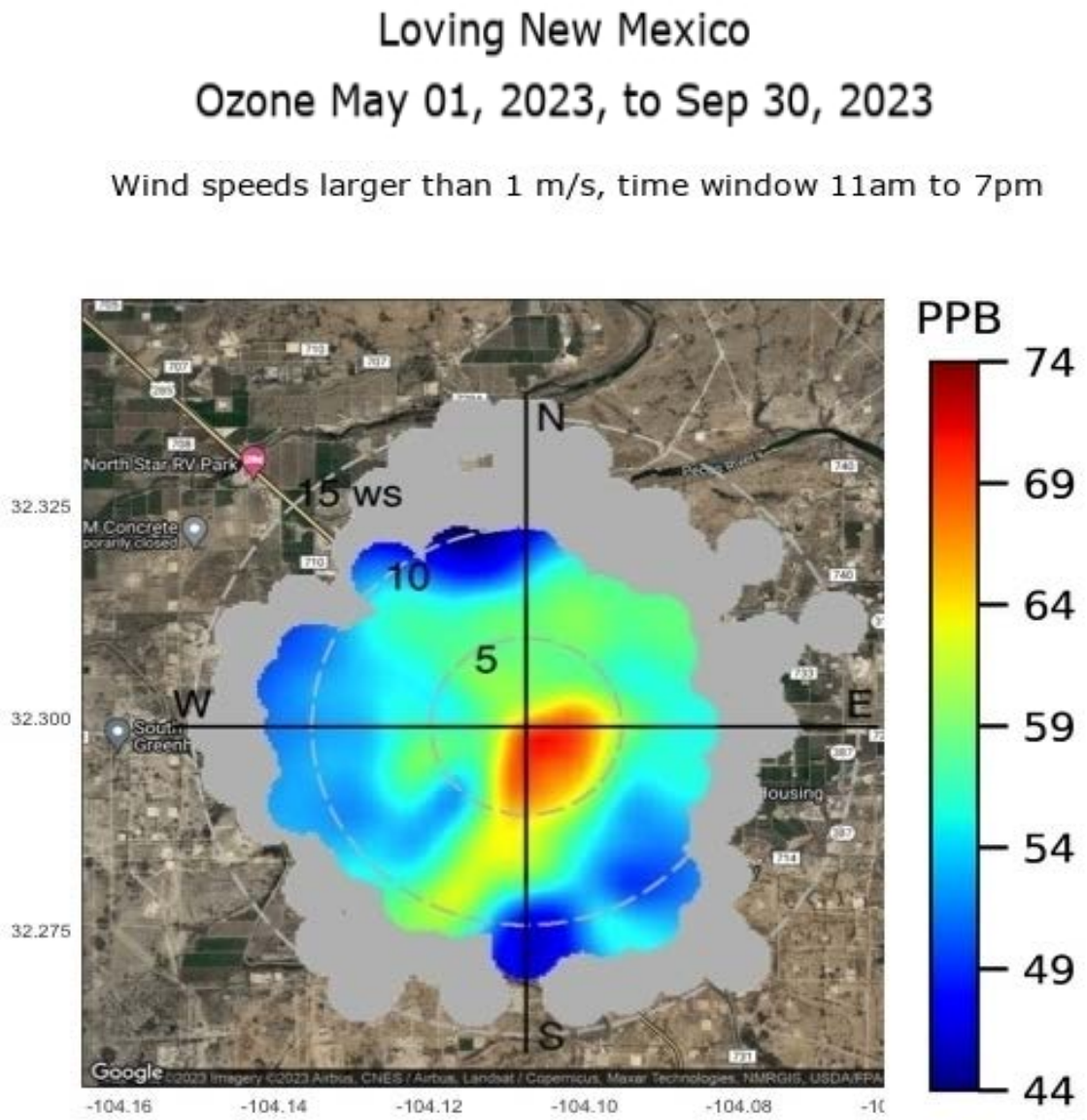
# Comparison of 2023 Loving ozone with Colorado Front Range




In summer 2023, when compared to five Colorado Front Range sites that are in an ozone *non-attainment* area, we found:

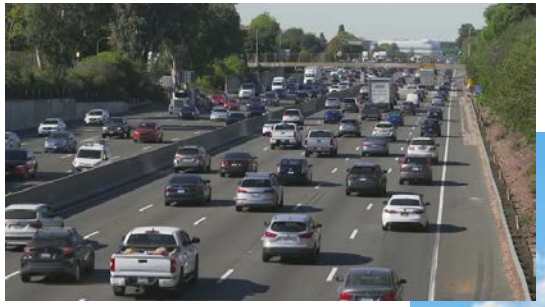
→ **Number of minutes with ozone >70 ppb was 5-7 times higher in Loving, NM, than at CO sites.**

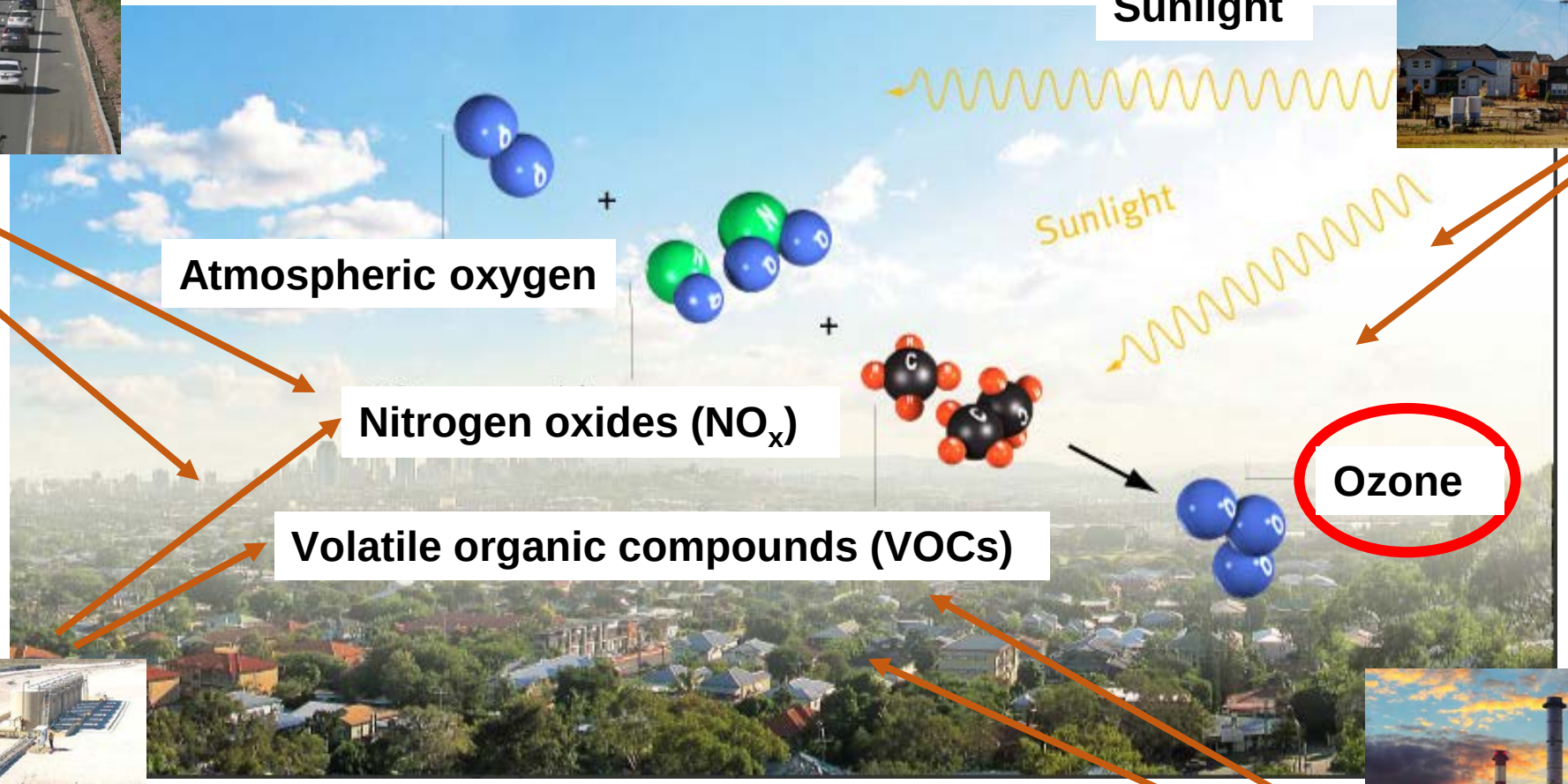
# Where is the high ozone coming from?




- Weak southeast winds associated with highest daytime ozone.
- On average, air transported from the Permian Basin had 10–15 ppb higher ozone than air from most other directions.

# What is causing ozone pollution?






https://www.qld.gov.au/environment/management/monitoring/air/air-pollution/pollutants/ozone

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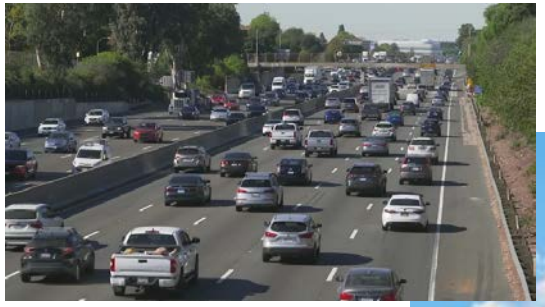


Sunlight

Atmospheric oxygen

Nitrogen oxides ($NO_x$)

Volatile organic compounds (VOCs)

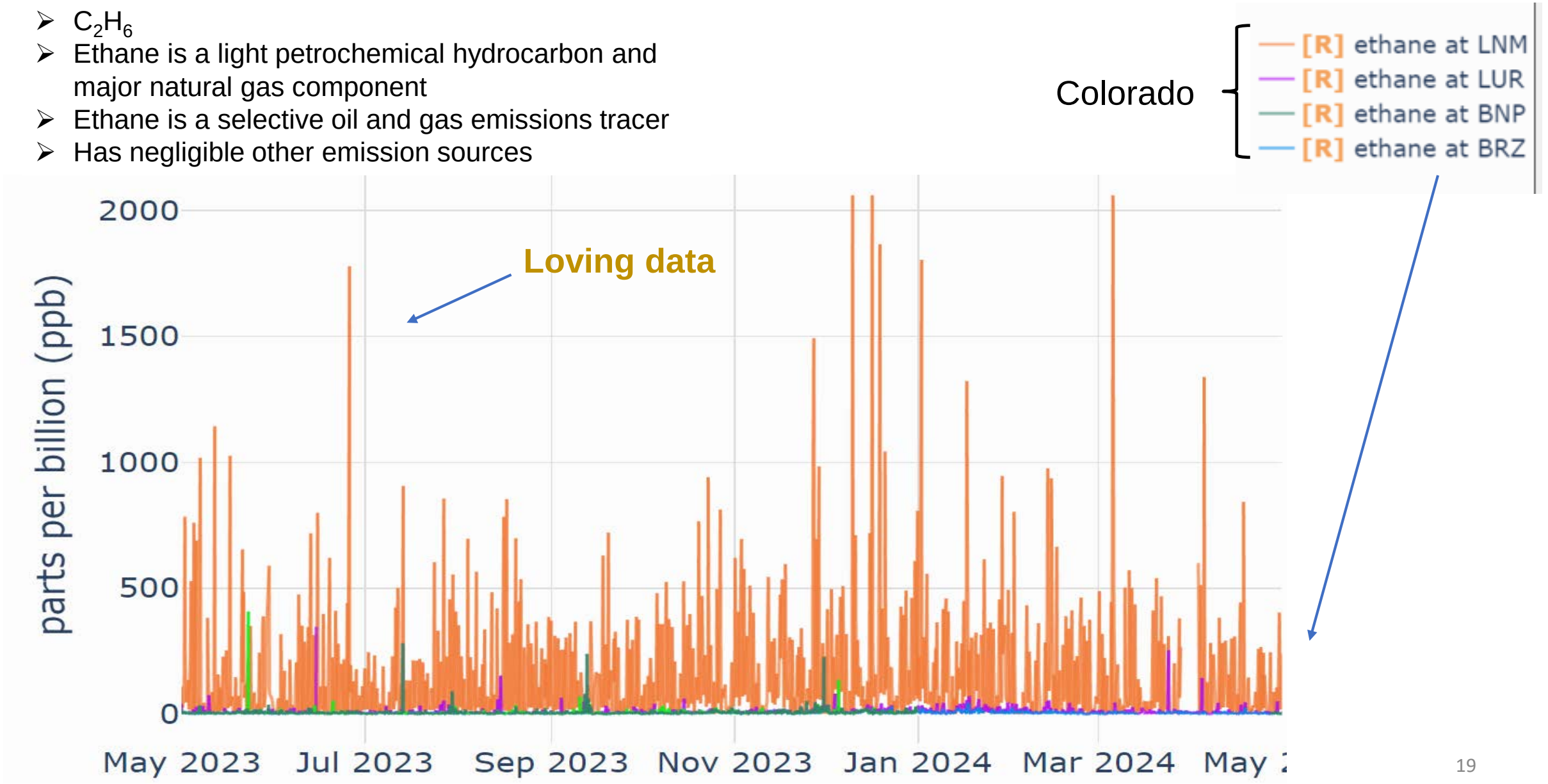
Sunlight

Ozone

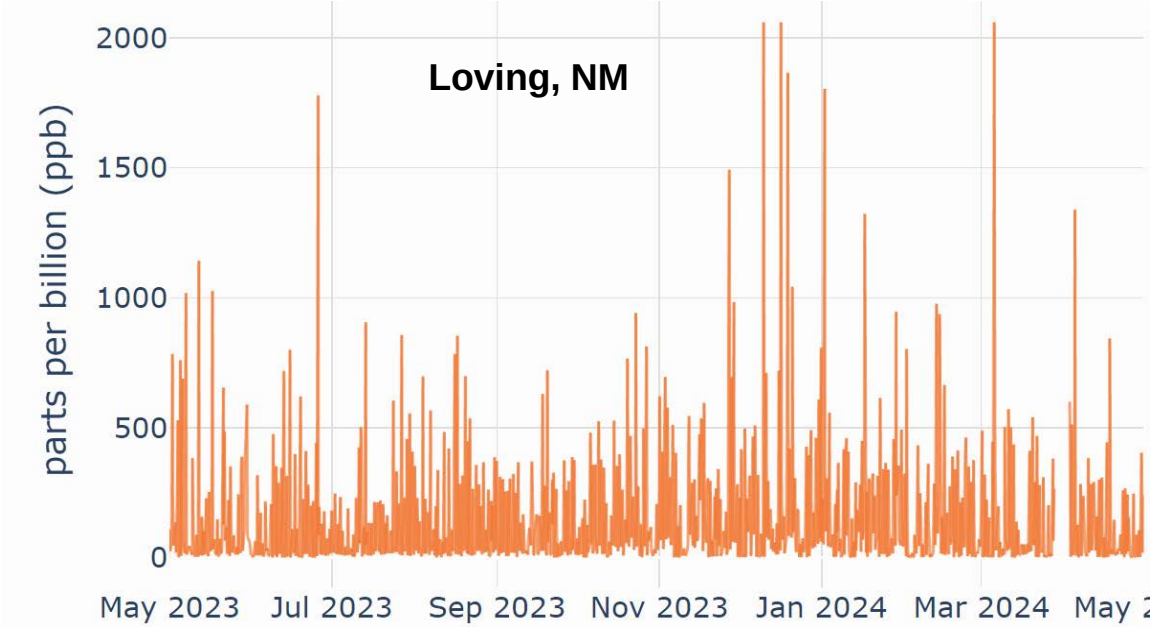
https://www.qld.gov.au/environment/management/monitoring/air/air-pollution/pollutants/ozone

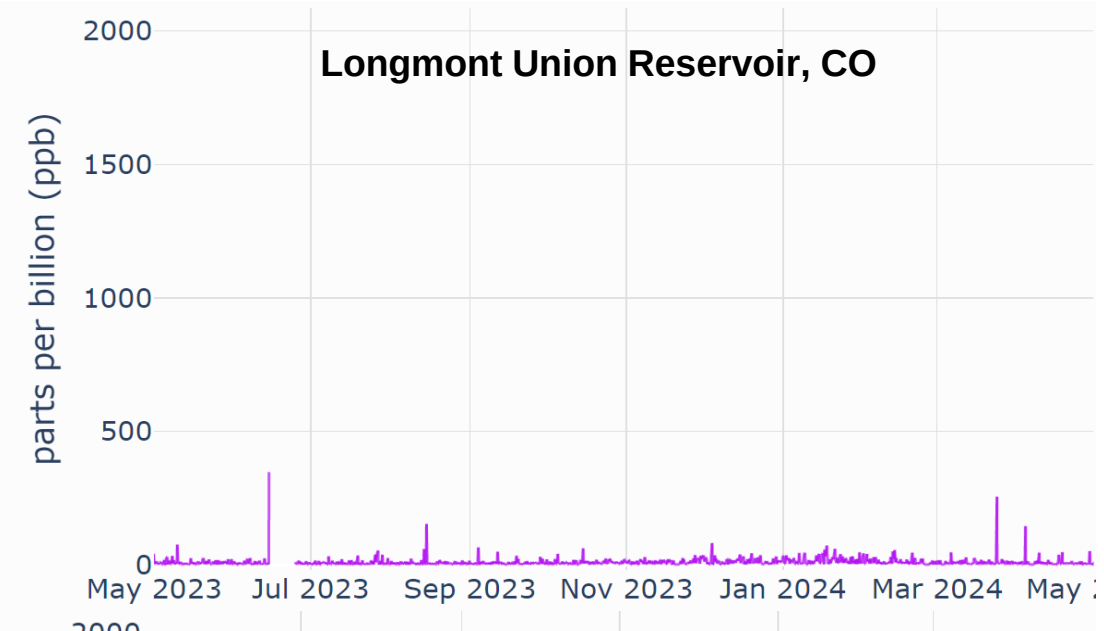
# Ethane at Loving, NM, compared to Colorado sites

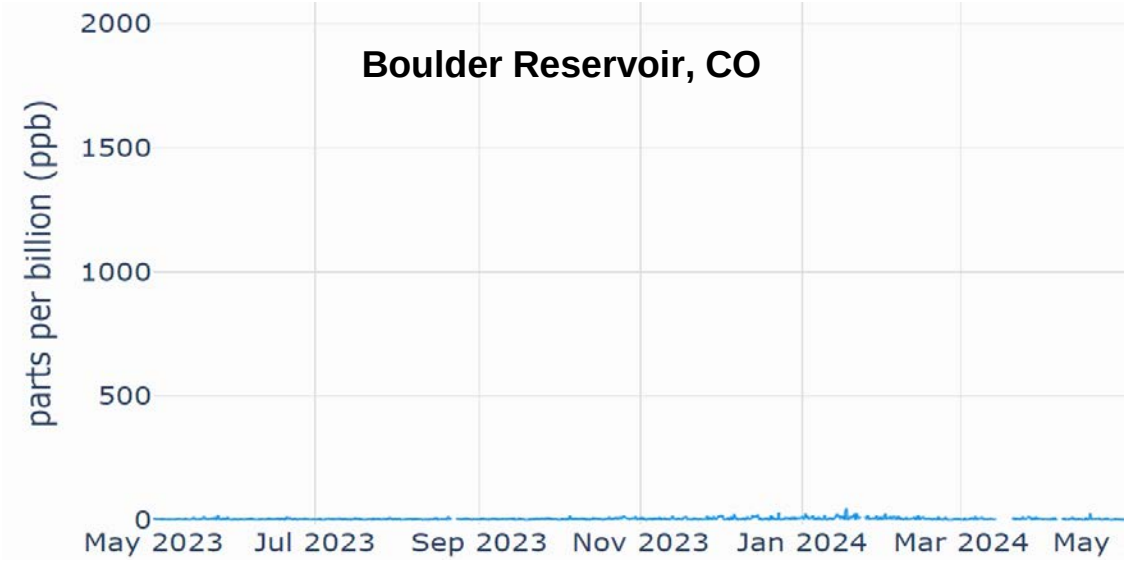
- $C_2H_6$
- Ethane is a light petrochemical hydrocarbon and major natural gas component
- Ethane is a selective oil and gas emissions tracer
- Has negligible other emission sources

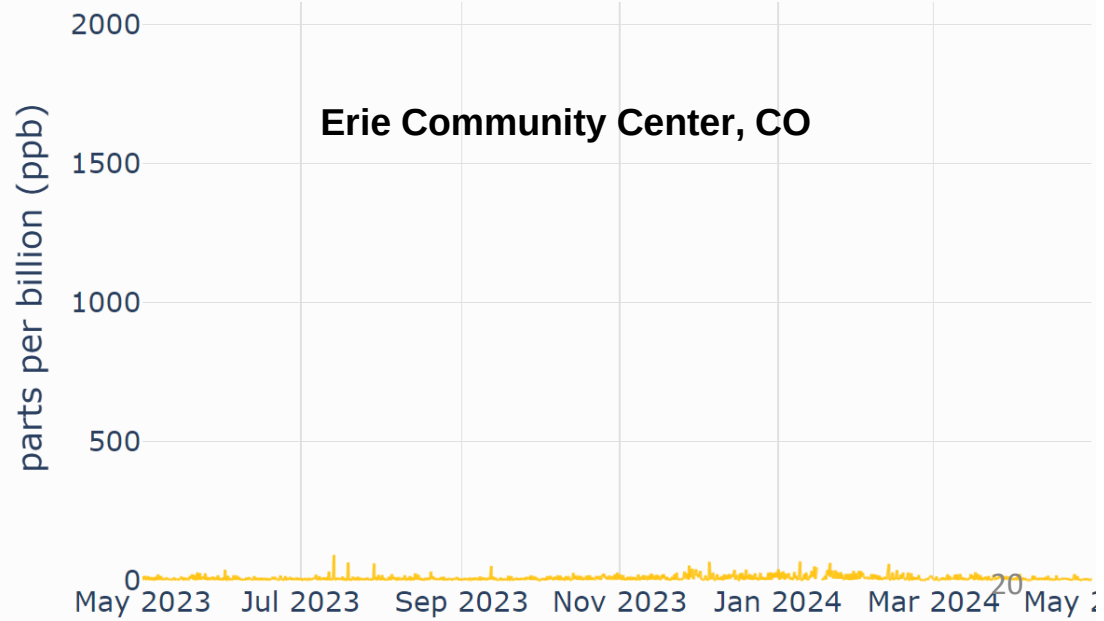


# Ethane at Loving, NM, compared to Colorado sites

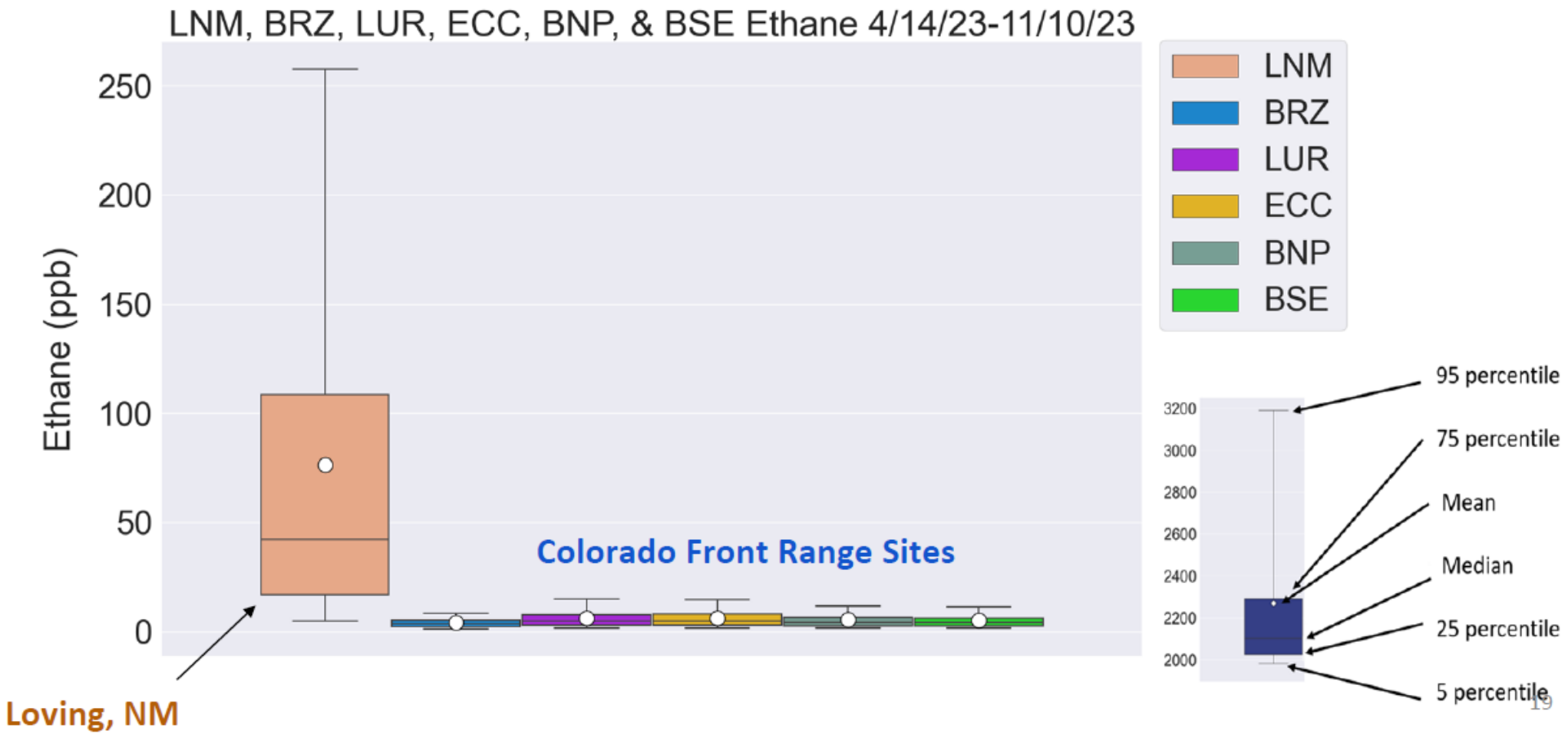


# Ethane at Loving, NM, compared to Colorado sites



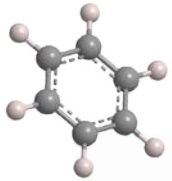
# Benzene at Loving, NM, compared to Colorado sites

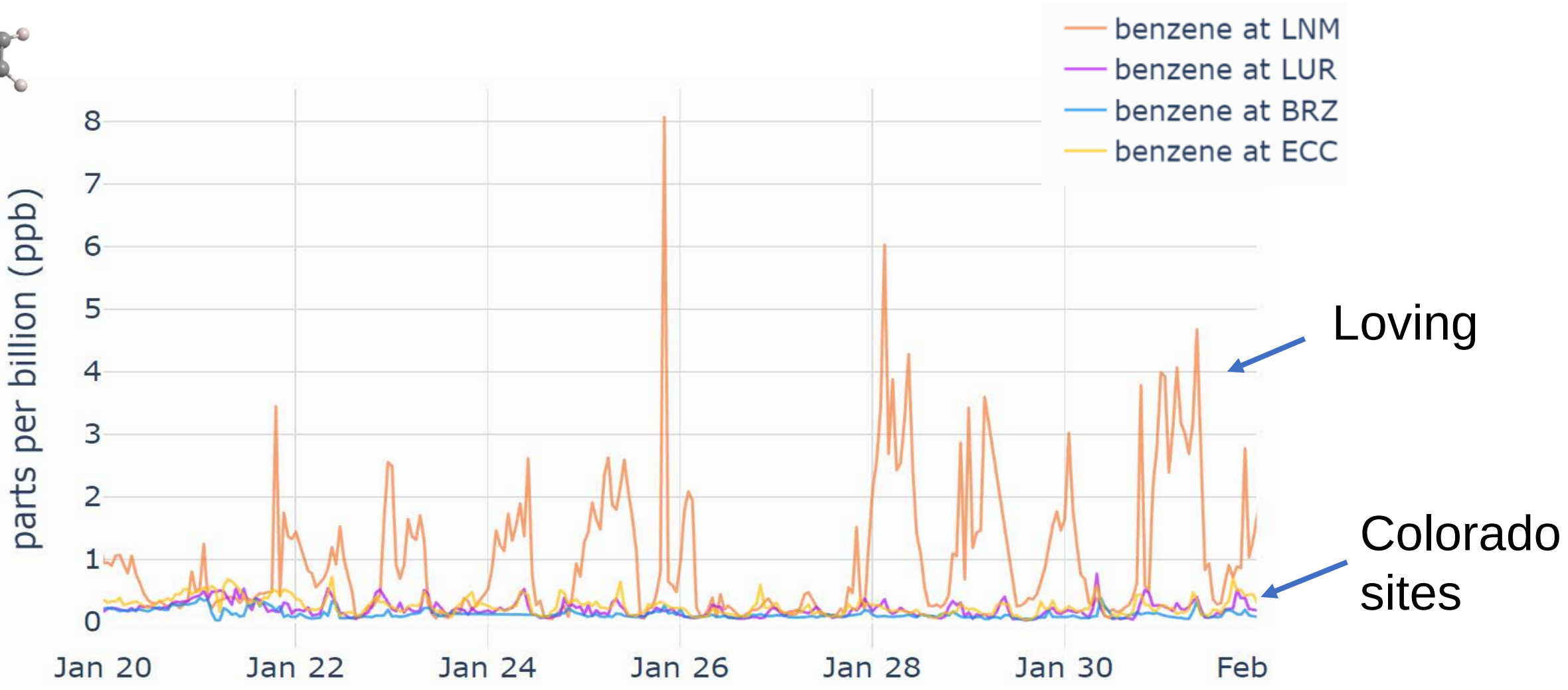
***Web Search: "Health Risks" "Exposure" "Benzene" "No safe levels"***

"There is no safe level of exposure to benzene, as it can cause health problems even at low levels. Benzene is a chemical that can cause acute leukemia and other hematological cancers. It can affect the blood-forming system at low levels of exposure, and there is no evidence of a threshold."

"Key sources including the CDC (Centers for Disease Control and Prevention), the EPA (Environmental Protection Agency), and the International Agency for Research on Cancer (IARC), classify benzene as a known human carcinogen and state that there is no safe level of exposure due to its potential to cause health issues even at low levels."

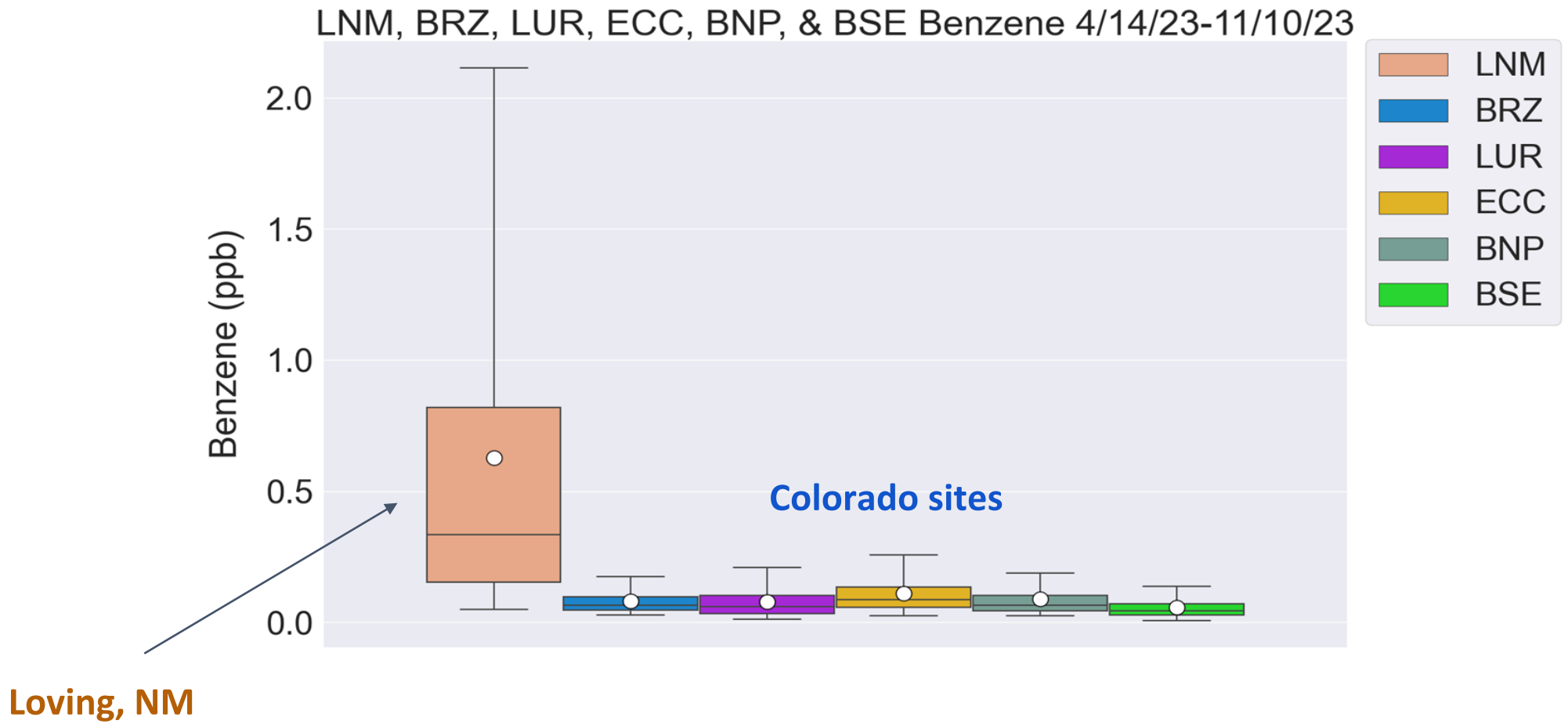
# Benzene at Loving, NM, compared to Colorado sites





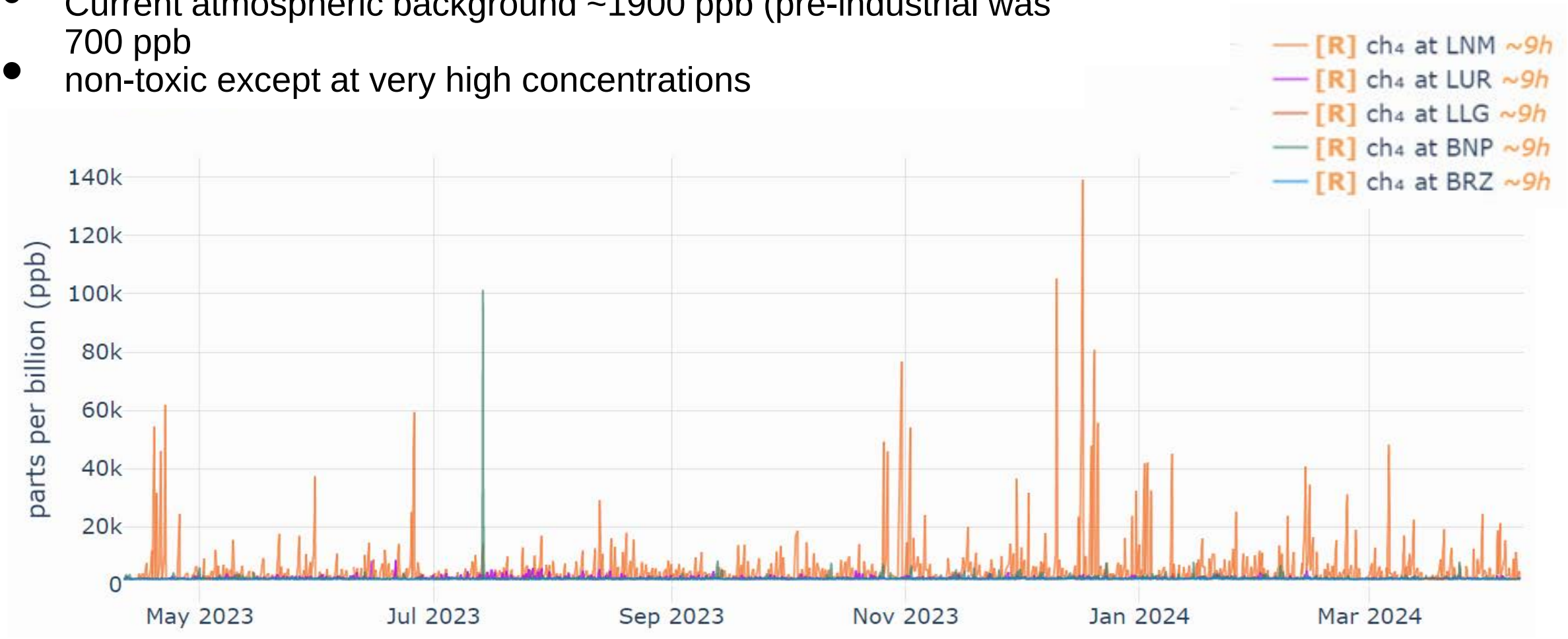
# Benzene at Loving, NM, compared to Colorado sites

- Benzene average concentration was 9–11 times higher in Loving than at Colorado comparison sites.

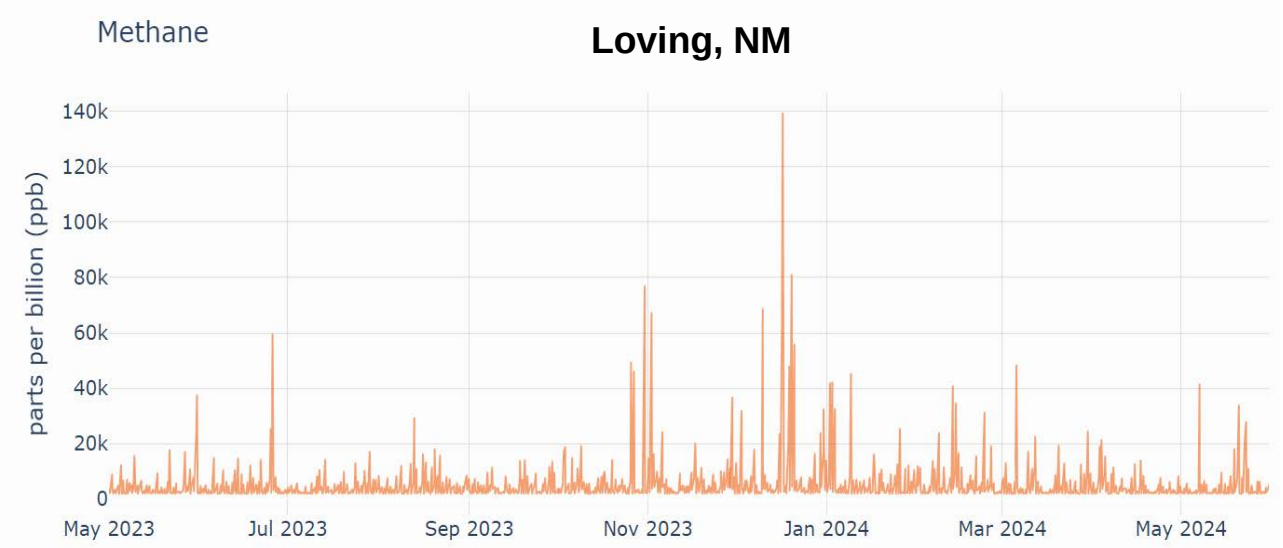


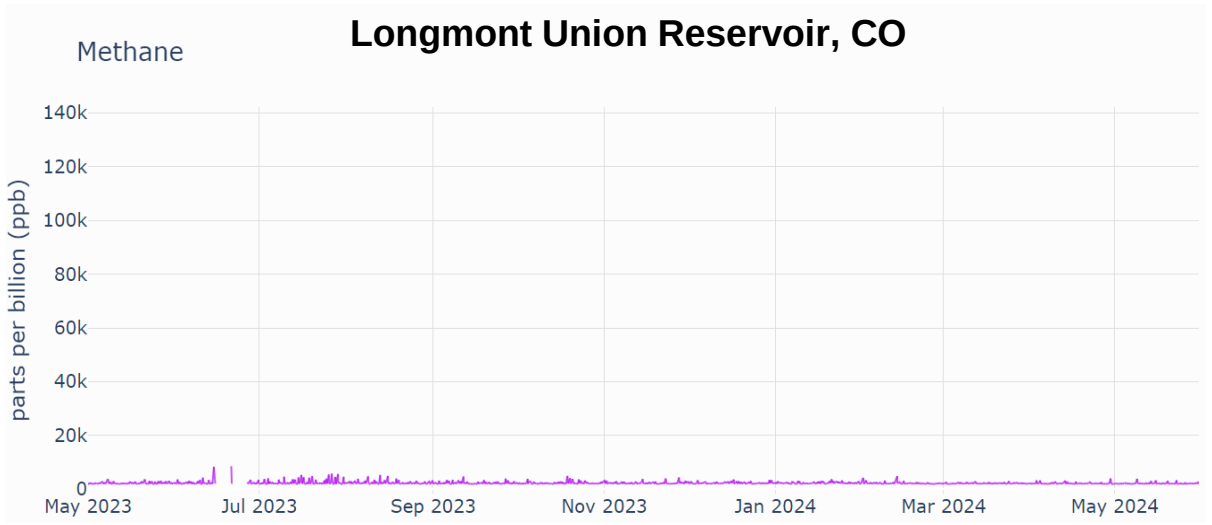
# Methane at Loving, NM, compared to Colorado sites

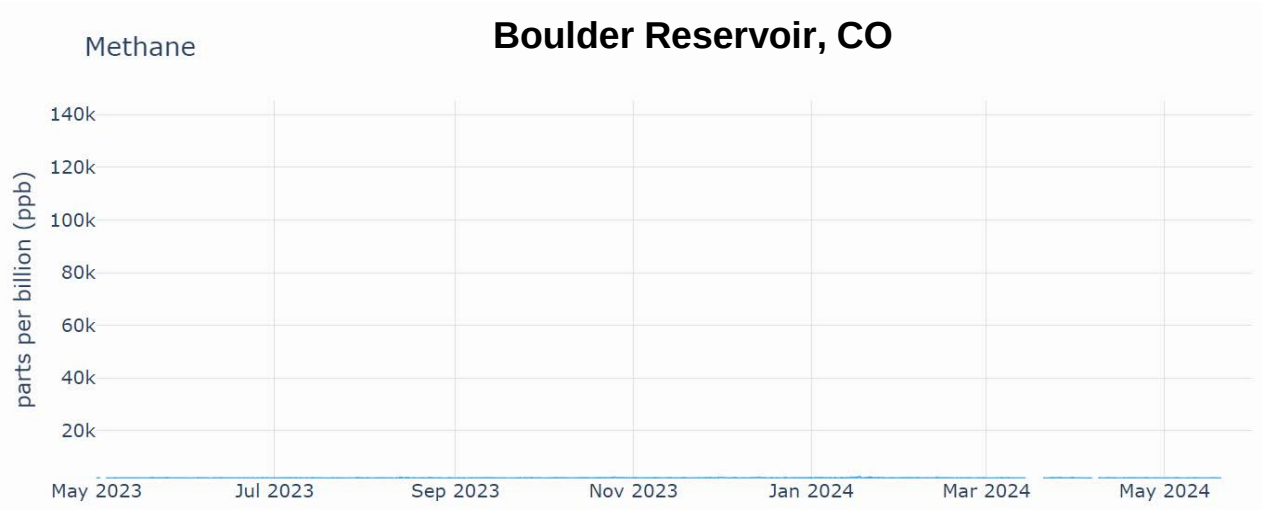
- potent Greenhouse Gas causing ~ 30% of Global Warming
- major constituent of natural gas
- Current atmospheric background ~1900 ppb (pre-industrial was 700 ppb
- non-toxic except at very high concentrations

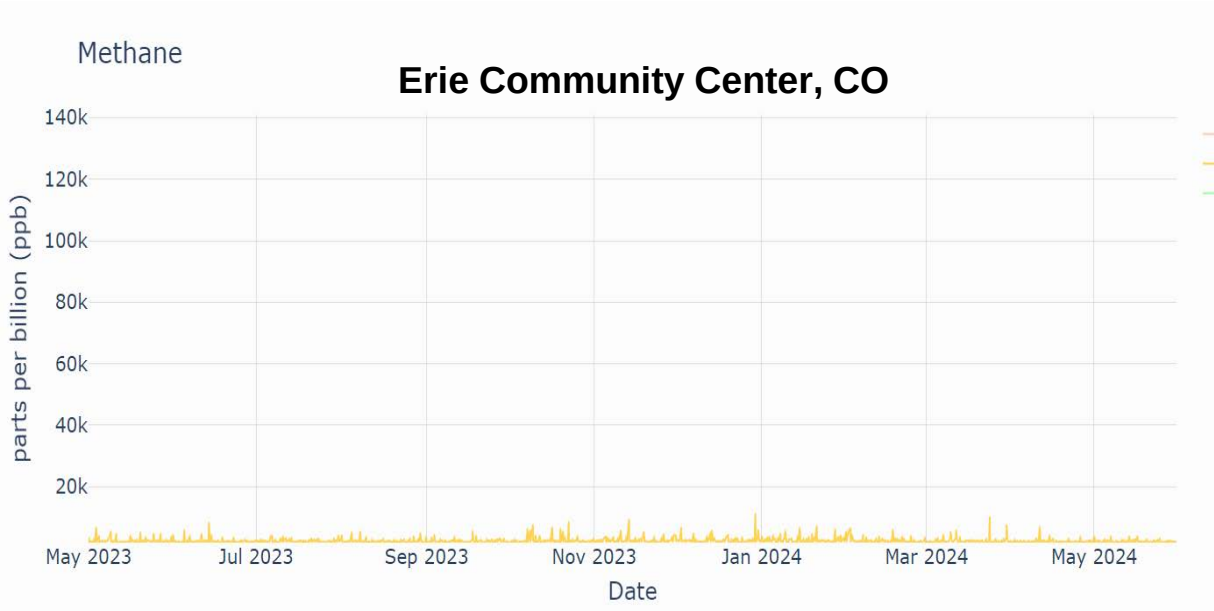


# Methane at Loving, NM, compared to Colorado sites

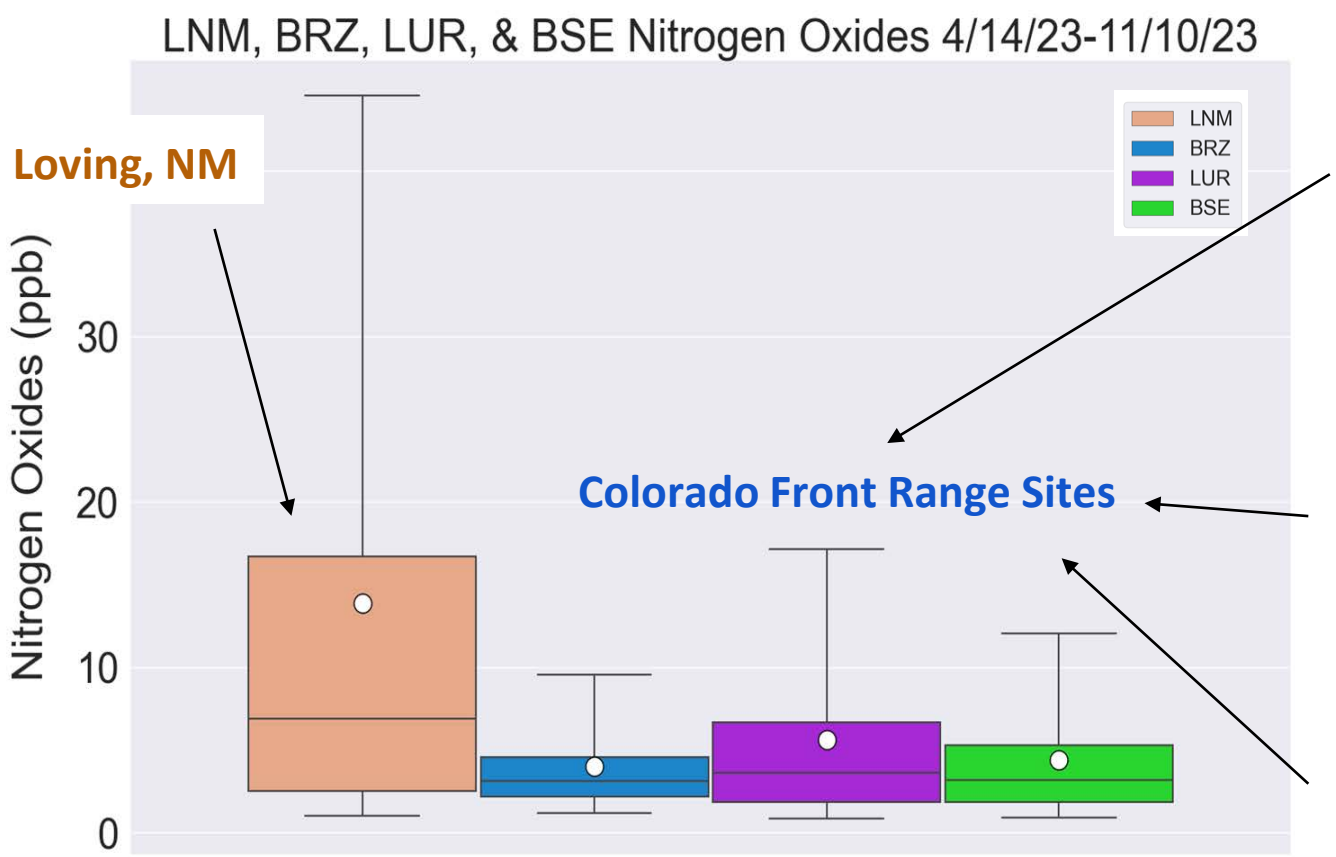


# Nitrogen oxides (NOx) at Loving, NM, compared to Colorado sites




Eddy County population density 13 vs 4,674 people per square mile in Denver

# Summary

- Implemented air monitoring in Loving, NM, in April 2023 and operated for one year – ended in June 2024.
- Operated continuously with less than 2% downtime.
- To the best of our knowledge, most extensive air monitoring program in NM.
- Eddy County has been exceeding the NAAQS threshold but is not yet been designated as out of compliance under the Clean Air Act.
  - more ozone exceedances and higher ozone than comparison sites in CO and nationwide that have been designated as serious non-attainment status for the ozone NAAQS.
- Comparing our data with other prior monitoring results suggests that ozone pollution levels are increasing, defying trends seen in most of the USA.
- Our data, and several prior peer-reviewed studies, suggest the regional ozone problem is largely due to very significant emissions of NOx and VOC emissions from oil & gas operations.

Acknowledgements

HEI energy

ConocoPhillips for letting us carry out this research on their property in Loving, NM

Disclaimer

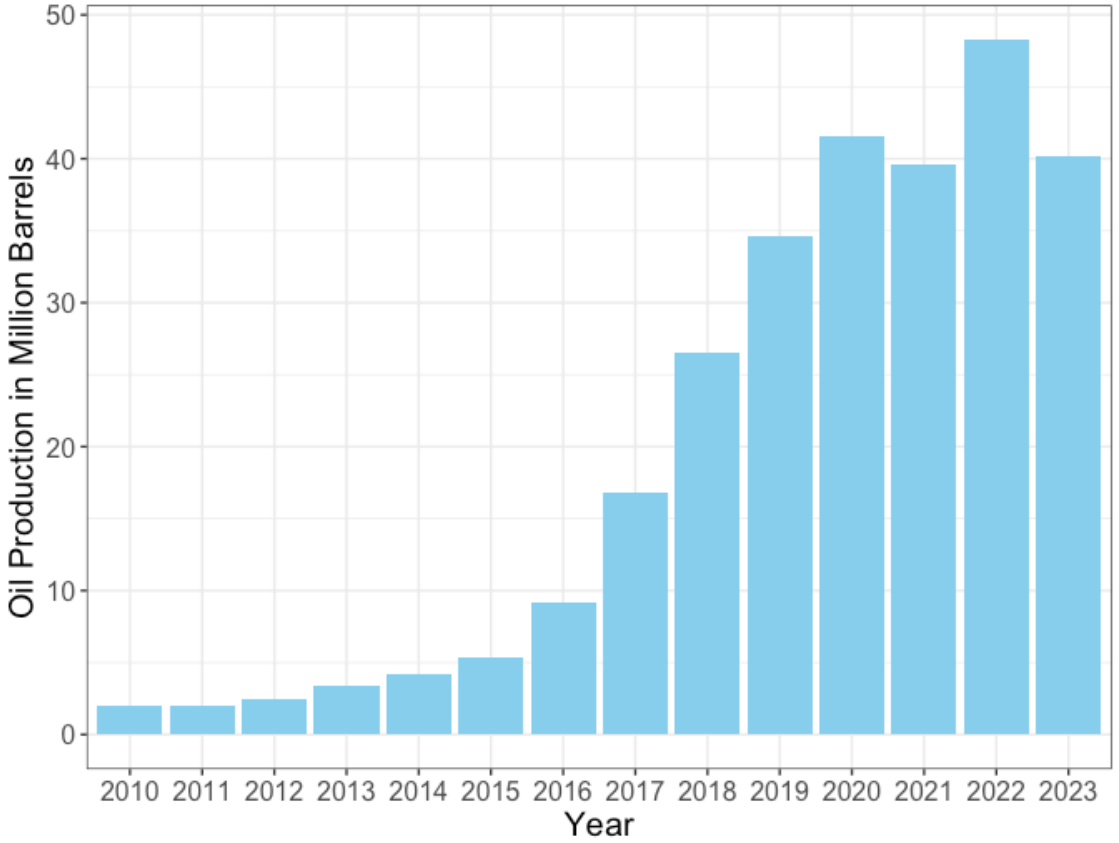
None of the research results presented herein have yet undergone HEI's rigorous peer review process.

# Q&A Slides

# General

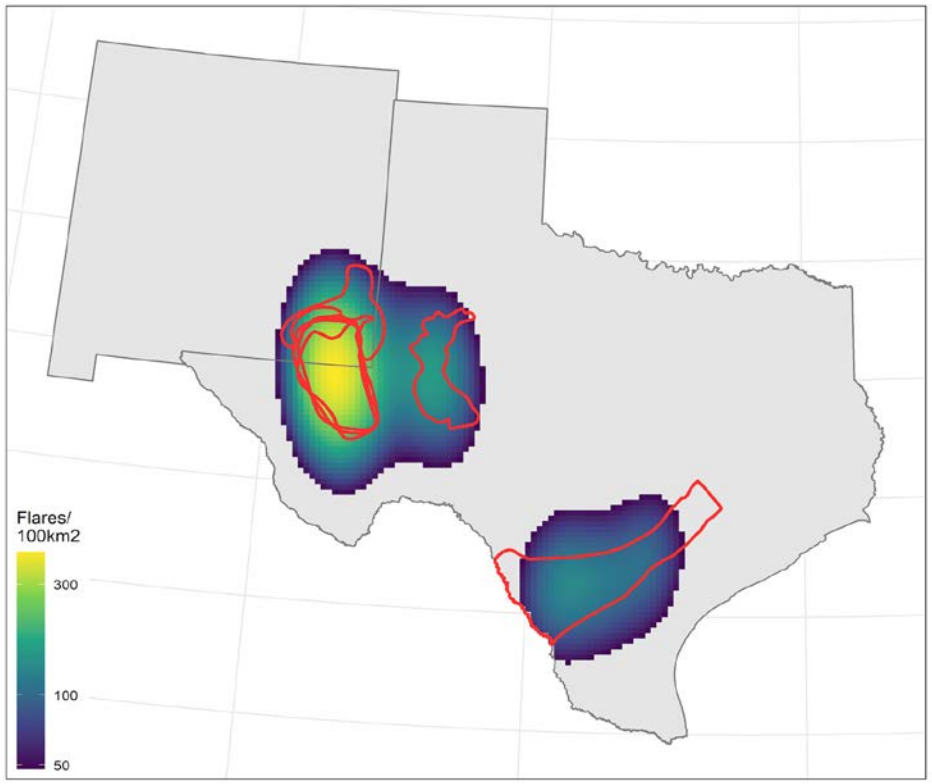
# Study Motivation

Annual oil production has increased over 5 times since 2016 at wells located within 15 miles of Carlsbad, NM.



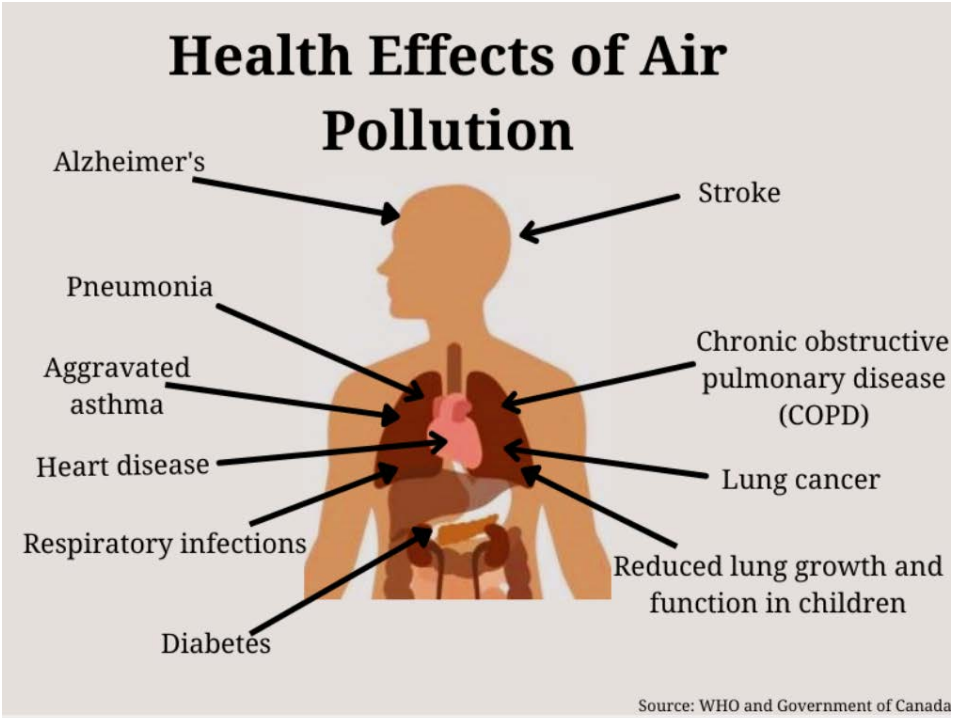

Data from EnverusTM (pulled 12/6/2023)

Density of gas flaring in the Permian Basin and the Eagle Ford Shale reflects oil exploration.



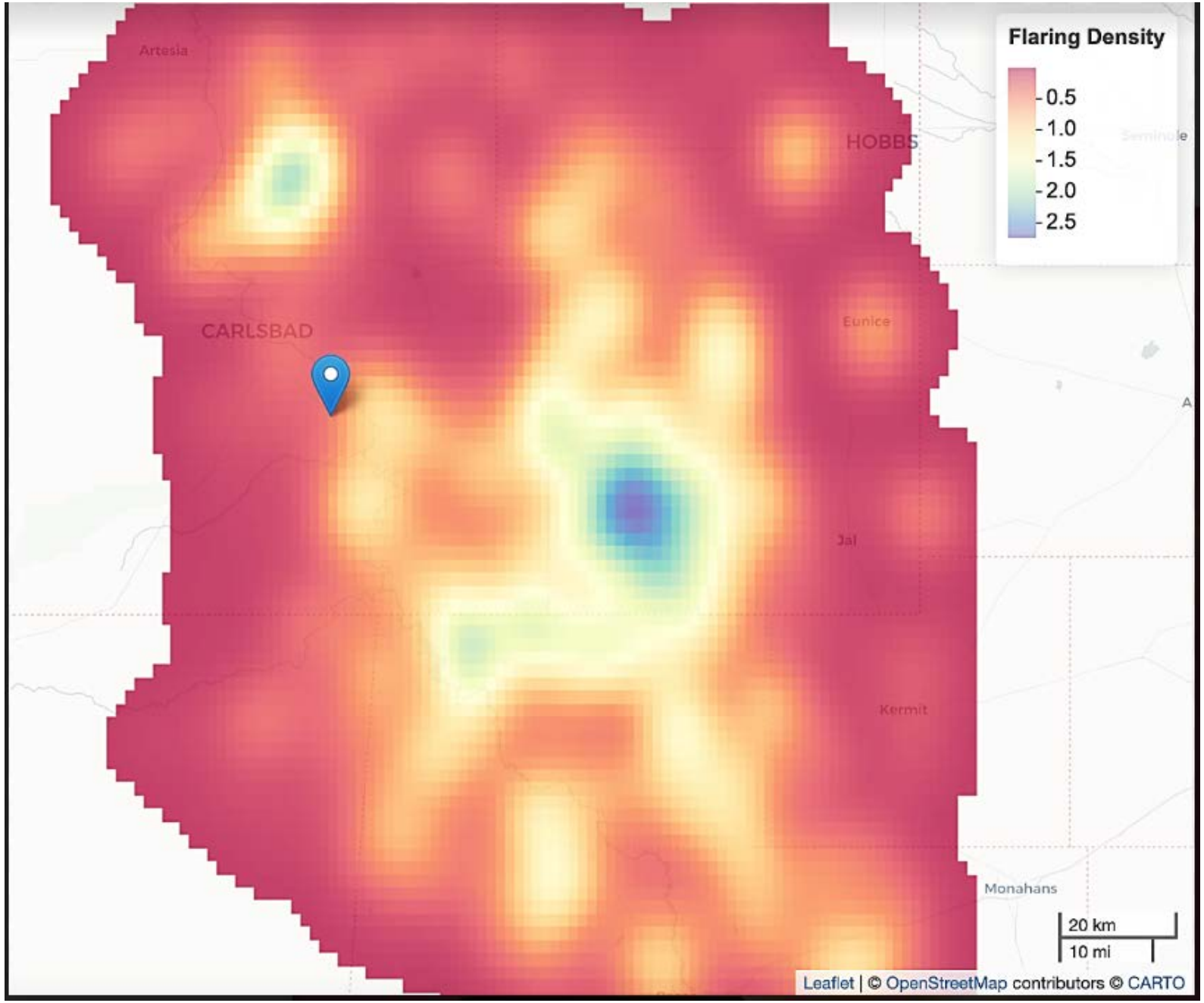

Cushing *et al* (2021) *Environ. Res. Lett.* **16** 034032

# Air pollutants studied




*The health effects of air pollution on the body. Media by Chantal Schromeda.*

- Ozone
- Carbon Monoxide
- Sulfur Dioxide
- Hydrogen Sulfide
- Nitric Oxide, Nitrogen Dioxide
- Methane
- Volatile Organic Compounds (VOCs, ethane, propane, benzene, hexane, toluene, … )
- Airborne Gas and Particle Radioactivity (radon, thoron….)




Flaring density (#/km^2) around our site

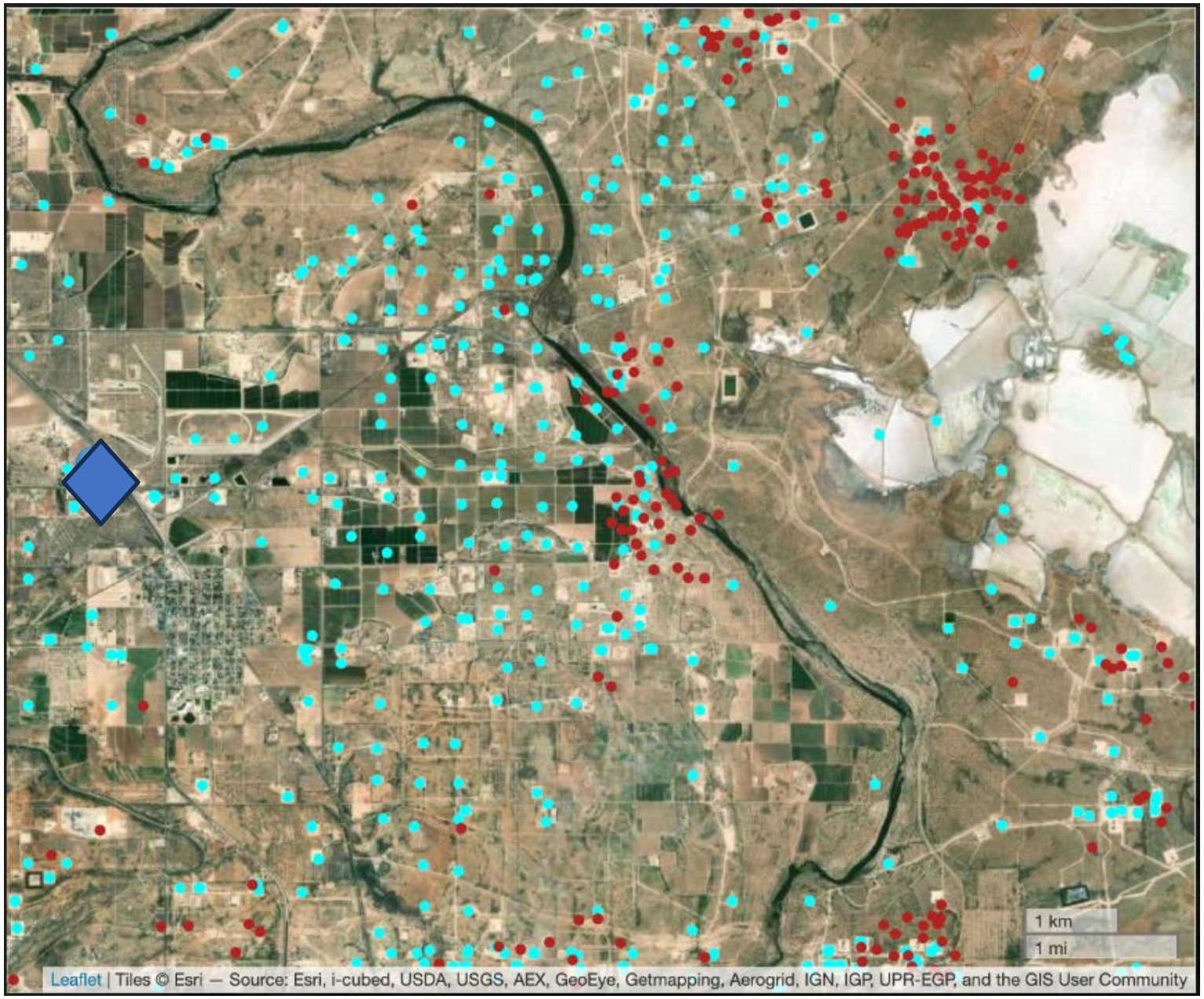
# Study Objectives

Our study is designed to better understand emissions and population exposure to air pollutants and noise coming from Unconventional Oil and Gas Development (UOGD)

1) Use fixed-placed, active air quality monitoring to characterize the emissions and impacts from UOGD (stationary trailer)

2) Use distributed, passive sampling to understand the potentially uneven distribution of selected toxic air pollutants (volunteer-driven)

3) Focus on UOGD related flaring by combining our measured data with satellite observations




Blue marker is our site, cyan dots are wells, red dots are flares between 5/1/23 and 4/31/24.

# What we are measuring in Loving, NM

## Air Pollutants and Greenhouse Gases

- ***Ozone ($O_3$)***
- Volatile organic compounds (VOCs), 24 species, incl. *ethane*, propane, … acetylene, BTEX, ….
- Nitrogen Oxides ($NO_x$)
- Sulfur Dioxide ($SO_2$)
- Hydrogen Sulfide ($H_2S$)
- Carbon Monoxide (CO)
- *Methane ($CH_4$)*
- Carbon Dioxide ($CO_2$)

## Radioactivity

- *Radon (Gas)*
- *Radon decay products (Particles)*

## Noise

- Decibel levels at different frequencies

**Ozone forms from:**

- **VOCs as the fuel**
- **$NO_x$ as the catalyst**
- **Sunlight as the driver**

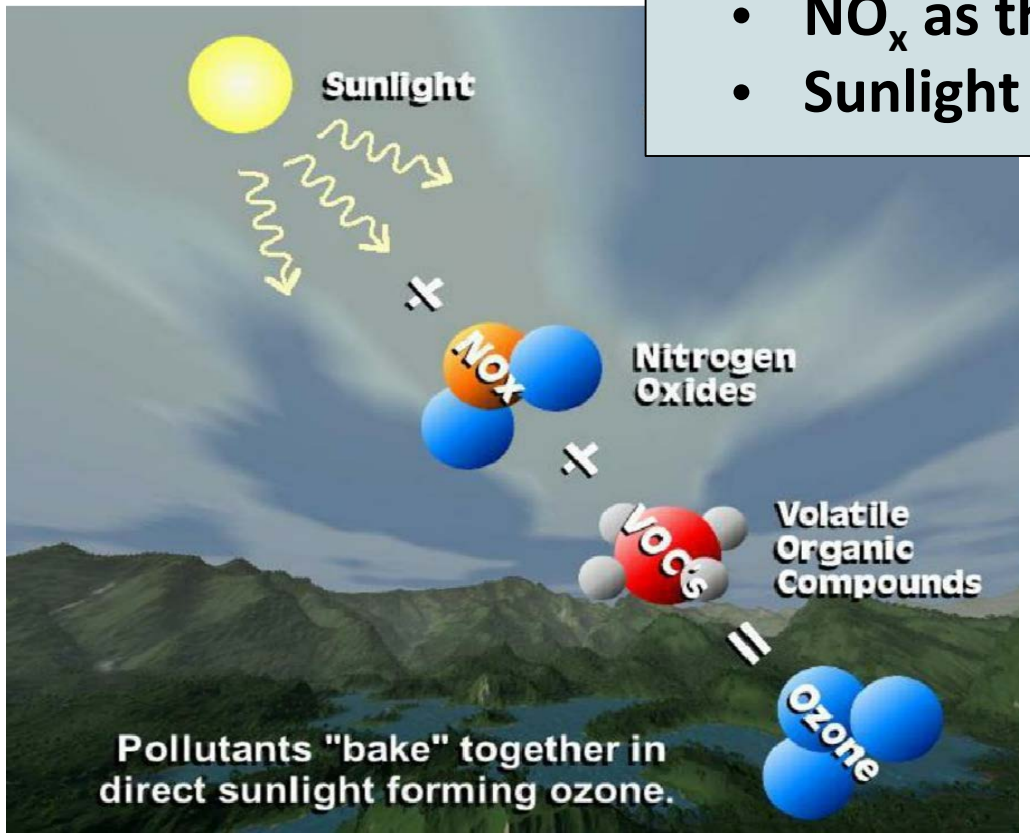



image credit: NASA/NSF

# Real-Time (Continuous) Measurements

Wind Speed
Wind Direction
Rain
Relative Humidity
Temperature

Carbon Monoxide
Carbon Dioxide
Sulfur Dioxide  Hydrogen Sulfide
Nitrogen Oxides  Ozone
Methane

Volatile Organic Compounds (ethane, propane, … acetylene, benzene, toluene, ….)

Airborne gas and particle radioactivity

# Measures to reduce exposure to air pollutants

**Children**, **workers,** and those with **pre-existing conditions** are most at risk

## Individual-level

Wear a face covering outdoors.

Limit outdoor physical activity on bad air days.

Keep house windows closed.

Use home air purifiers to improve indoor air quality.

Avoid and safely store products that contain VOCs (paint, glues)

## Community-level

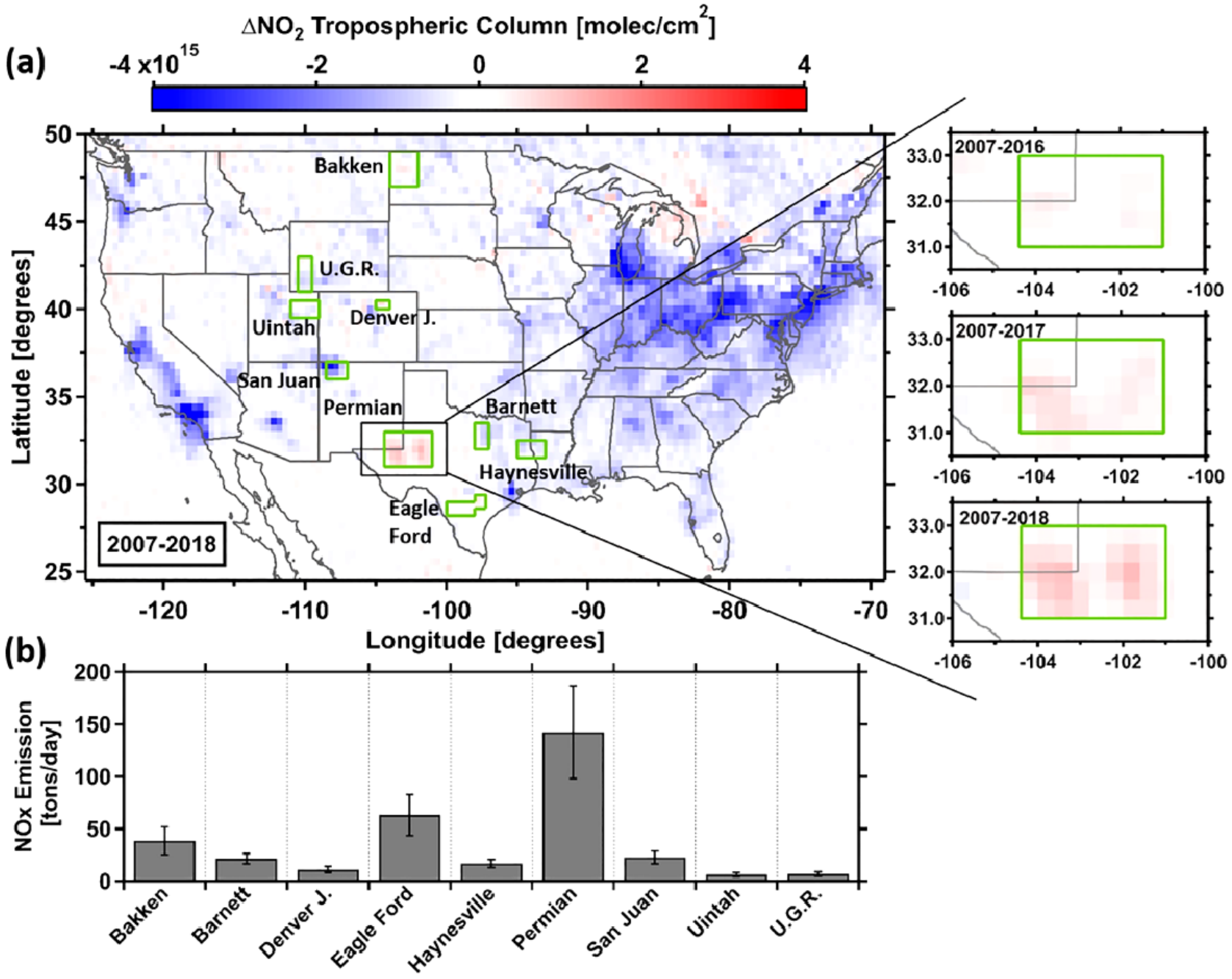
Increase buffers (setbacks) between homes & industry.

Reduce outdoor recess on bad air days.

Increase green space & vegetation.

Support investing in HVAC in schools & community centers.

# Nitrogen Oxides

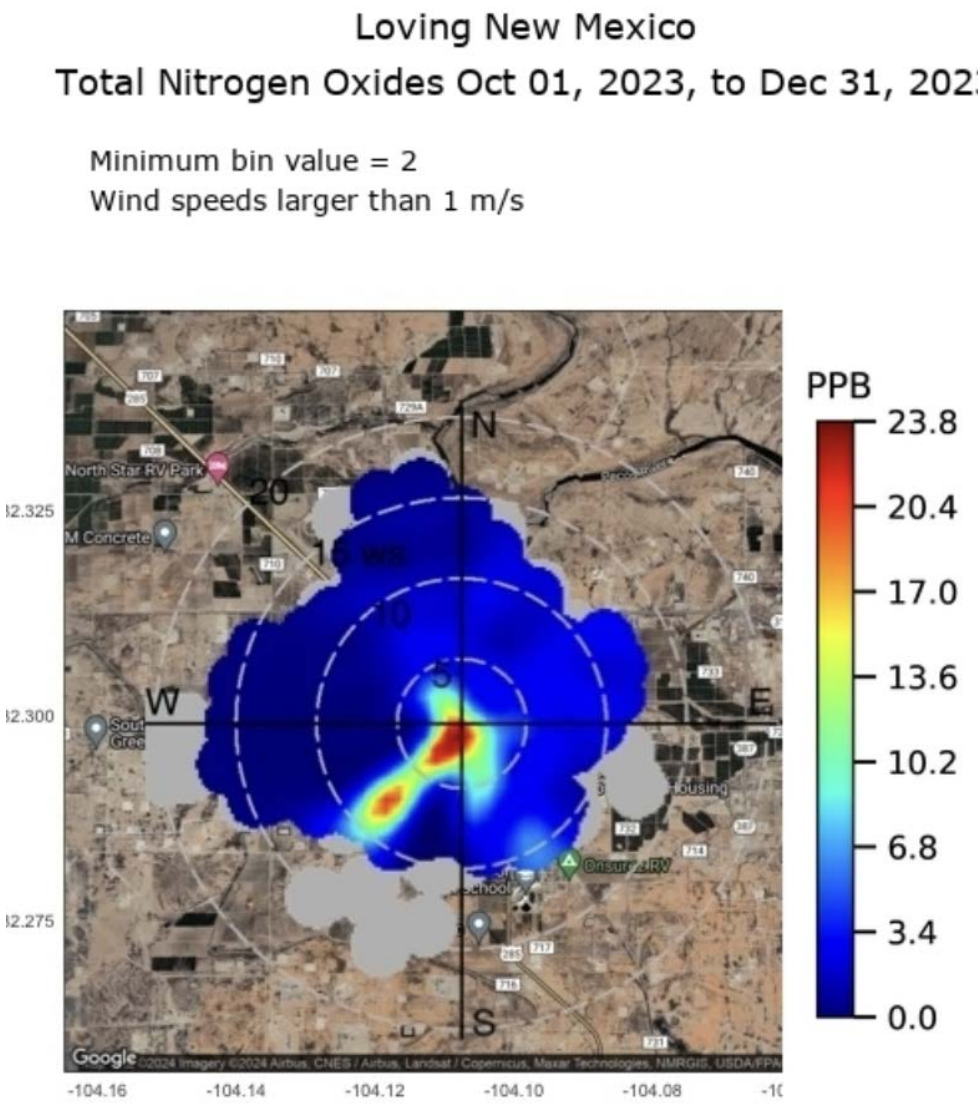



**Upward NOx trend in the Permian as determined from satellite measurements**

Dix et al., GRL 2019: *Nitrogen Oxide Emissions from U.S. Oil and Gas Production: Recent Trends and Source Attribution*

Figure 2, 2007-2018 trend

# Nitrogen oxides at Loving (LNM) probably has strong signal from nearby flaring




- Nitrogen oxides (NOx) are the catalyst for ozone formation
- Emitted from combustion processes
- 2–3 times higher mean than at Colorado comparison sites despite Colorado having a 10 times higher population (and traffic)
- However, wind analyses suggest that emissions are dominated by strong point source(s), possibly gas flaring

# Passive Sampling Network and Benzene

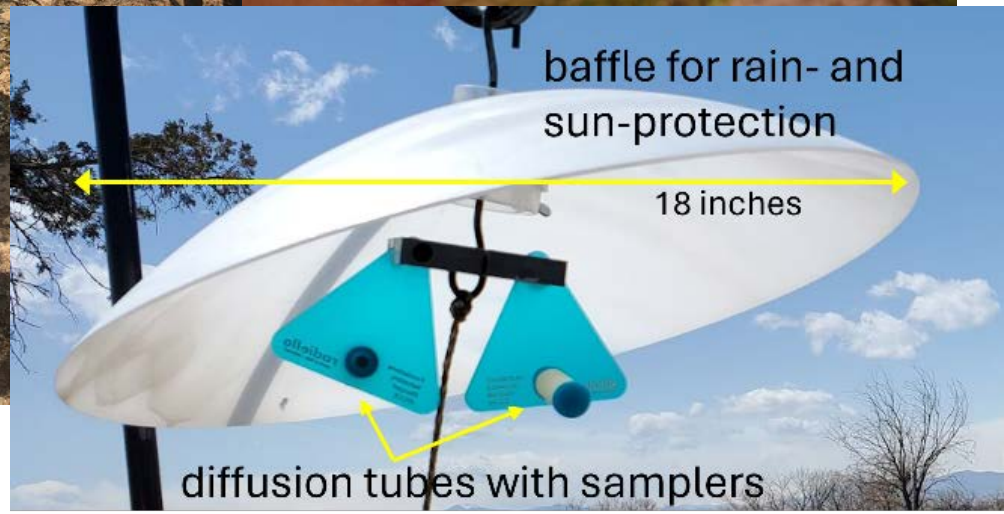
# Volatile organic compounds

Passive sampling for VOCs like benzene and toluene, in areas where people live and work.

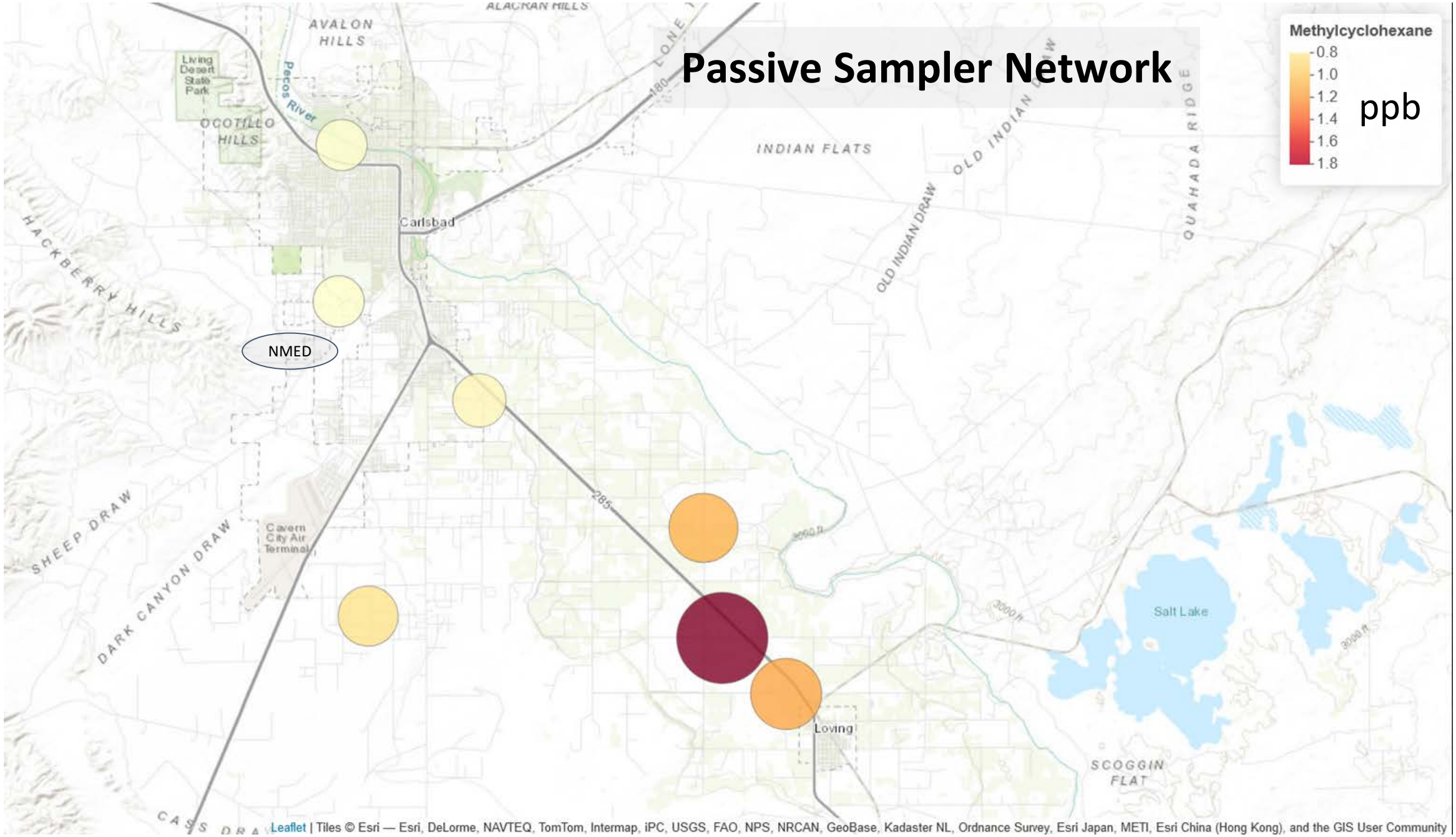
Ambient air average exposure during 5-10 days at a time

- two replicate samples
- white baffle as sampler protection from intense sunlight and rain
- samplers were shipped weekly to and from College Station, TX

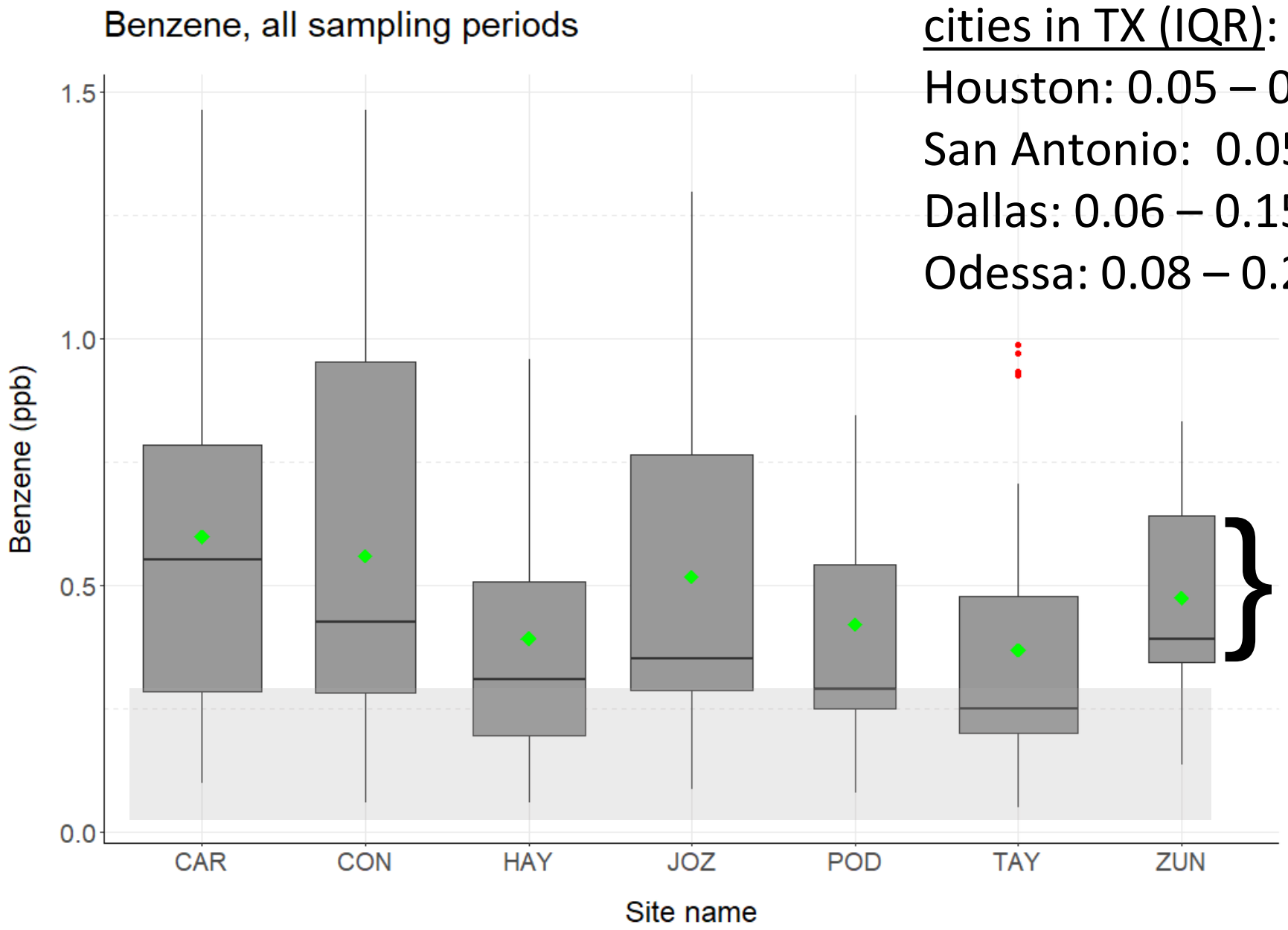




# Passive Sampler Network



# Exposure comparisons, I




<u>cities in TX (IQR)</u>:

Houston: 0.05 – 0.2 ppb

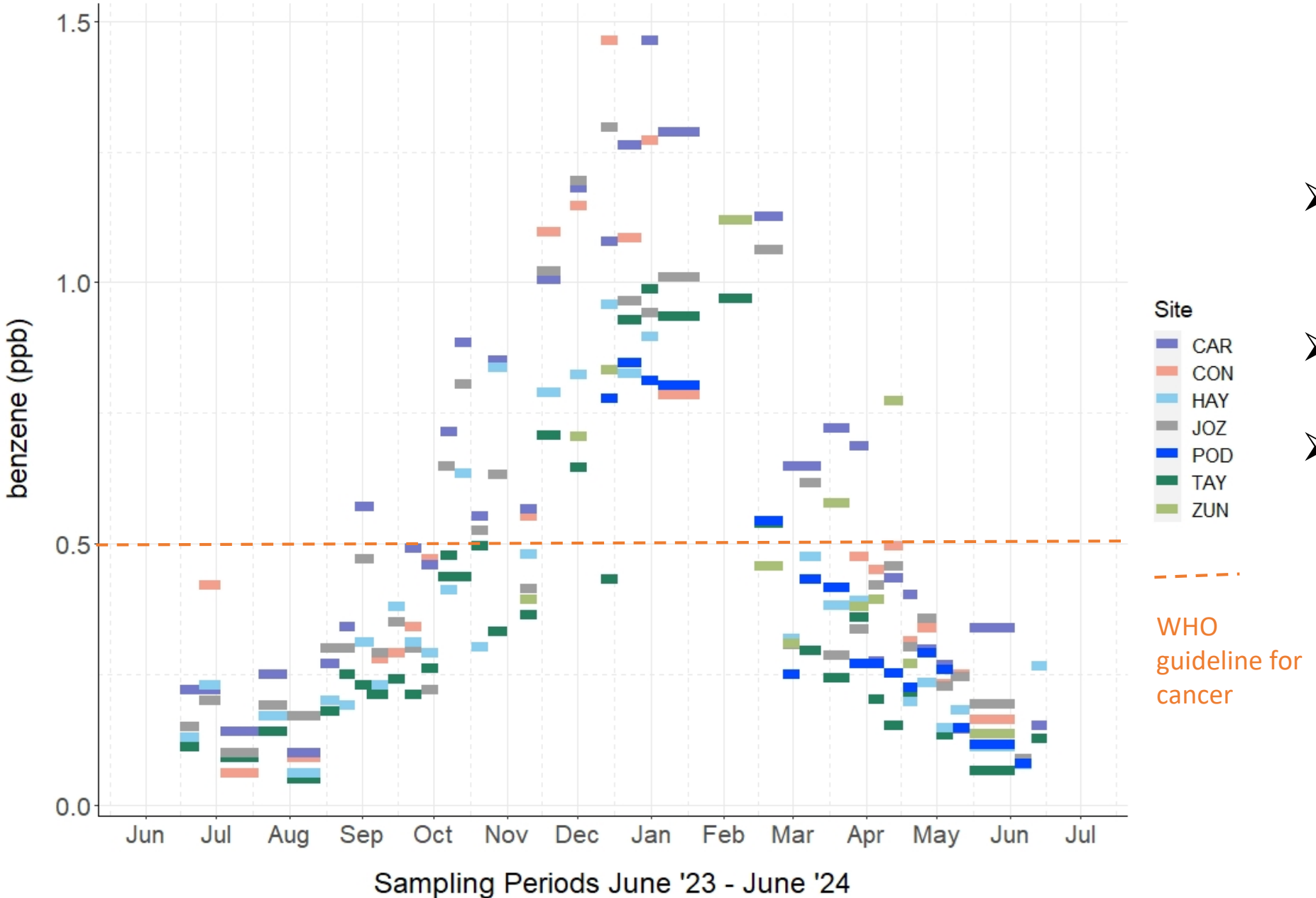
San Antonio: 0.05 – 0.1 ppb

Dallas: 0.06 – 0.15 ppb

Odessa: 0.08 – 0.29 ppb

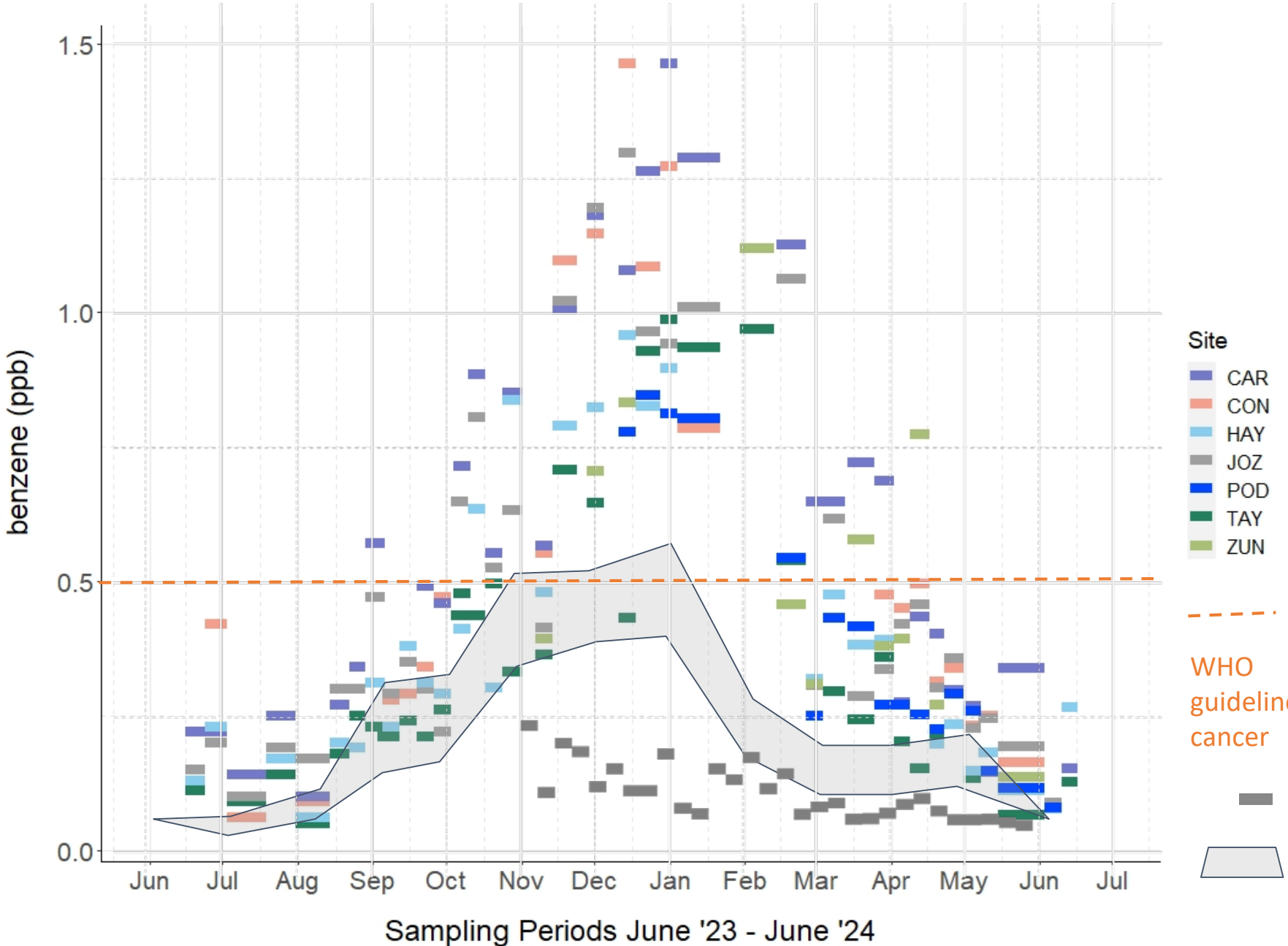
interquartile range (IQR)

# Passive sampling network: benzene concentrations



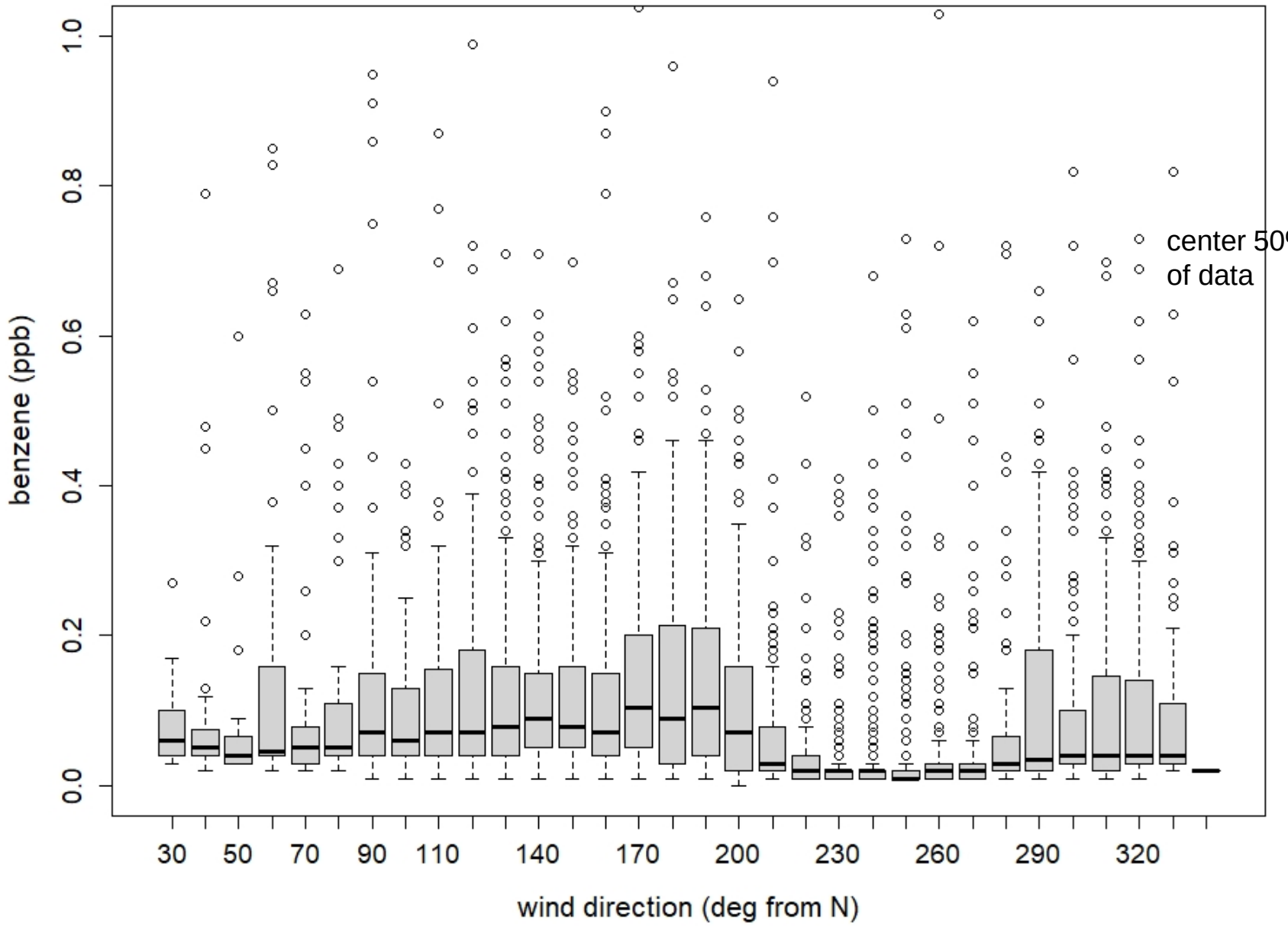

- Seasonal cycle (higher concentrations in fall and winter)
- Strong gradients between sites
- Some exceeding cancer risk guidelines for long-term exposure

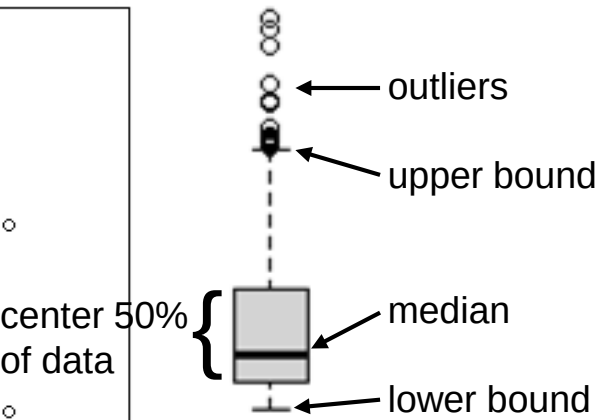
# Passive sampling network: benzene concentrations




- Seasonal cycle (higher concentrations in fall and winter)
- Strong gradients between sites
- Higher levels than in Houston
- Higher than NMED reference site

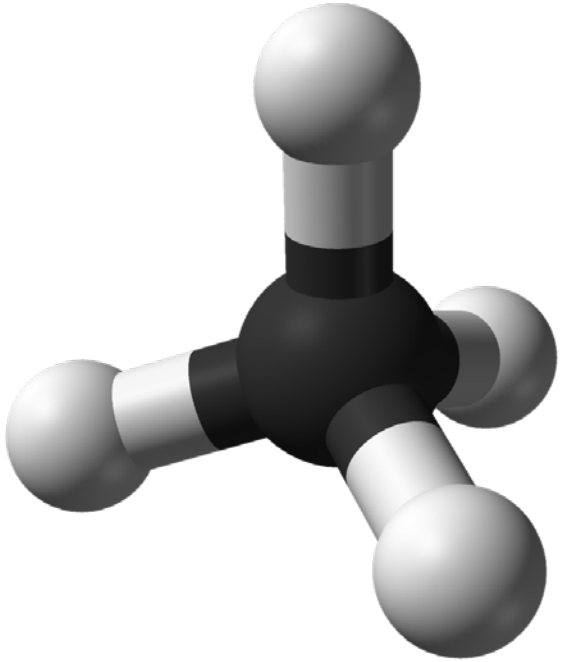
# Benzene data (Nov ‘23 - Jun ‘24) from the NMED Carlsbad site



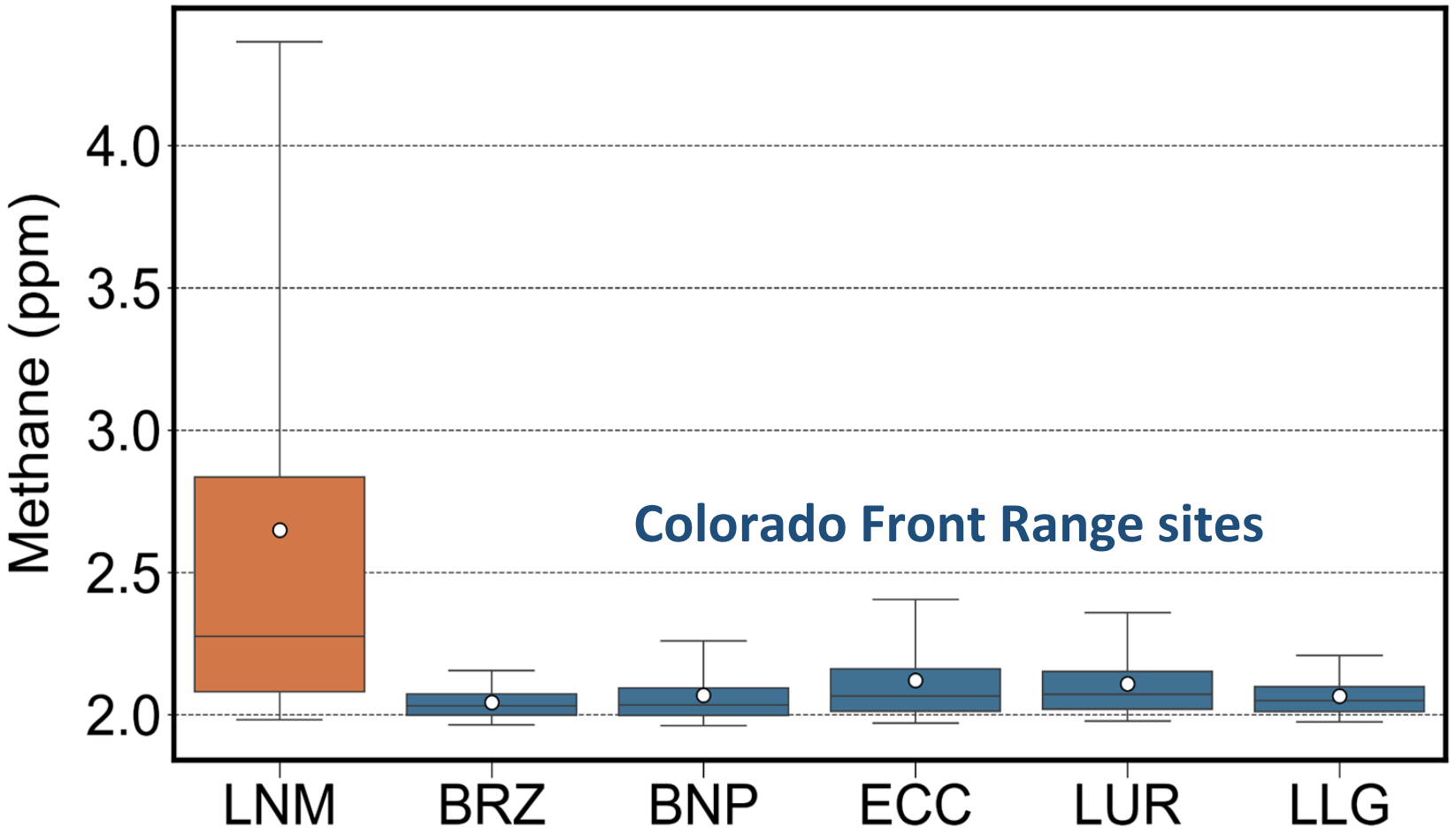
# Methane

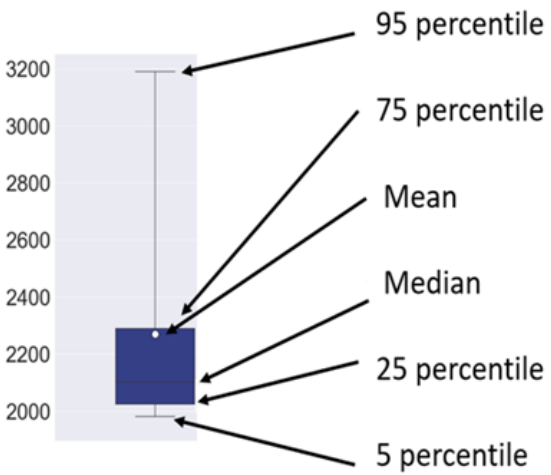
# 4. Methane

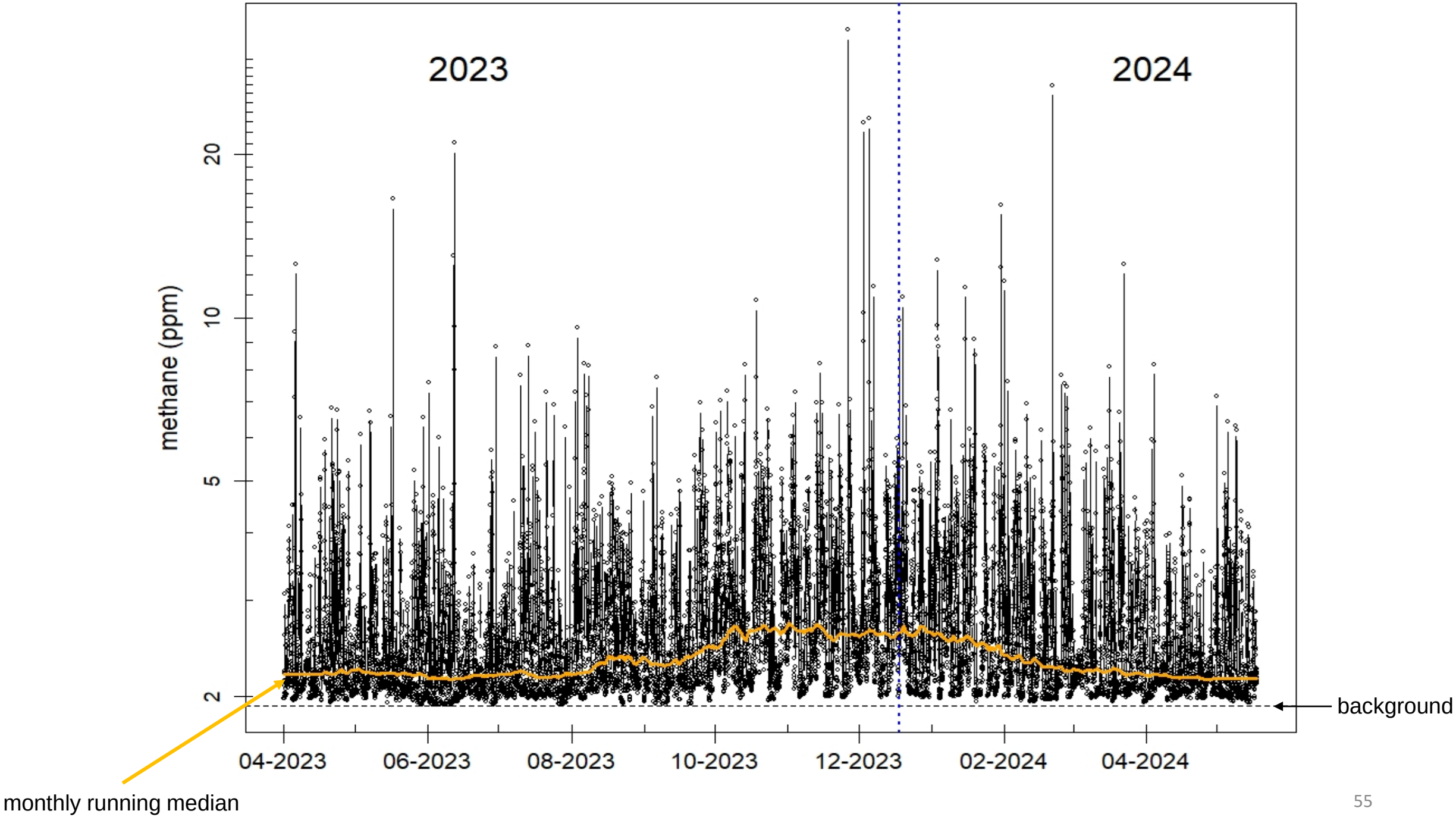


- potent Greenhouse Gas (GHG)
- major component of *natural gas*
- common atmospheric constituent
  - “background” of 1.9 ppm (pre-industrial: 0.7 ppm)
- non-toxic except at very high concentrations

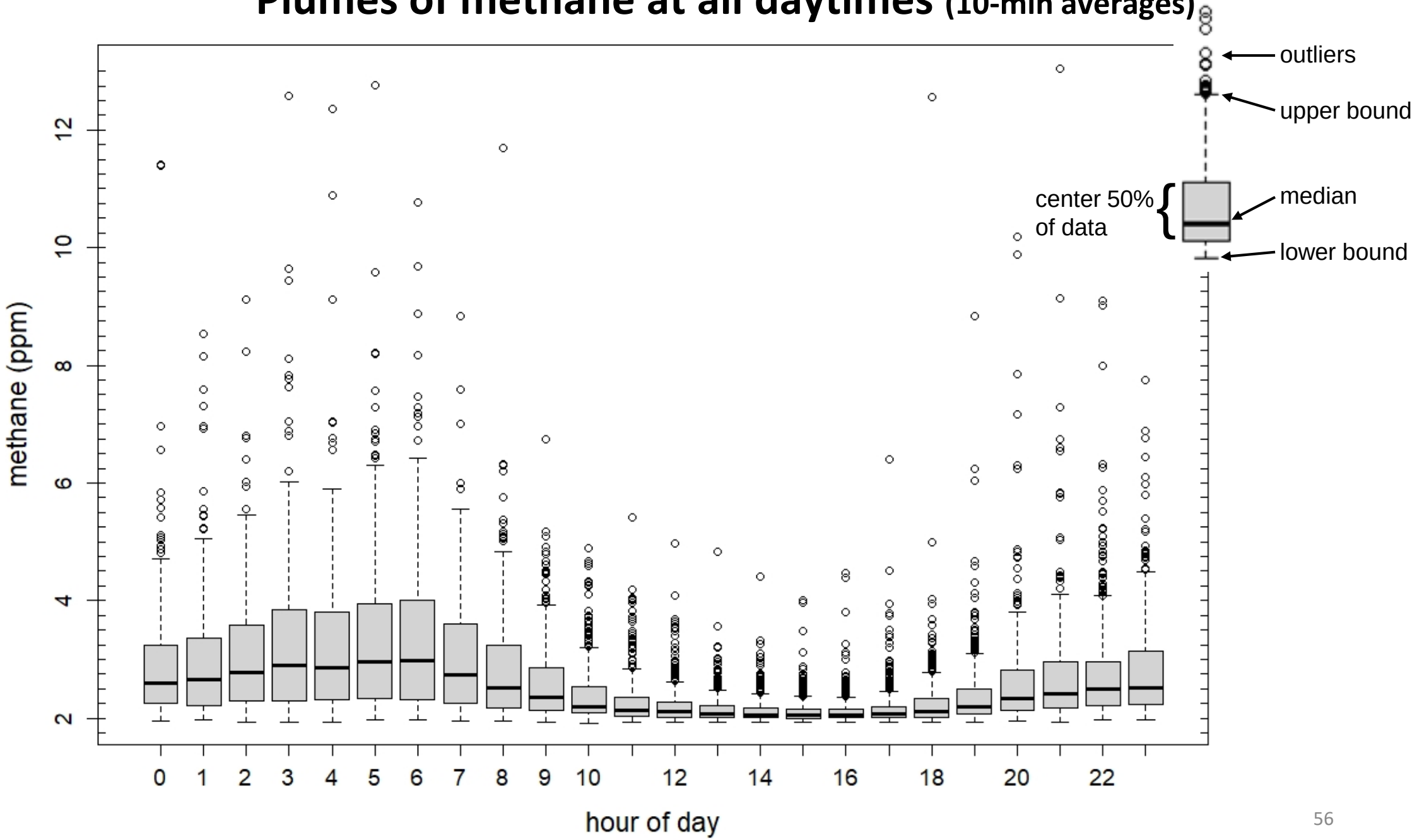
# Methane at Loving, NM, compared to Colorado sites



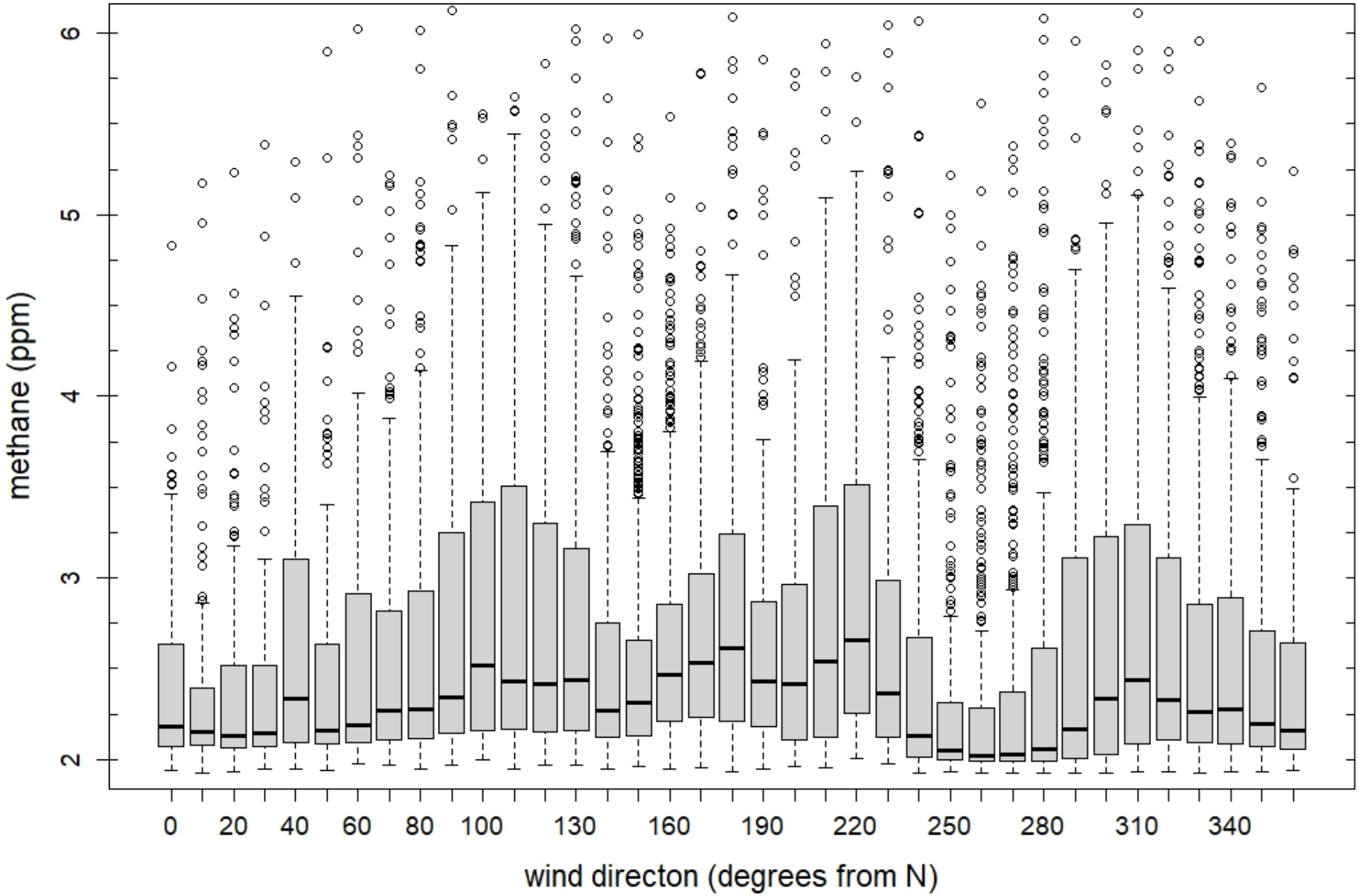



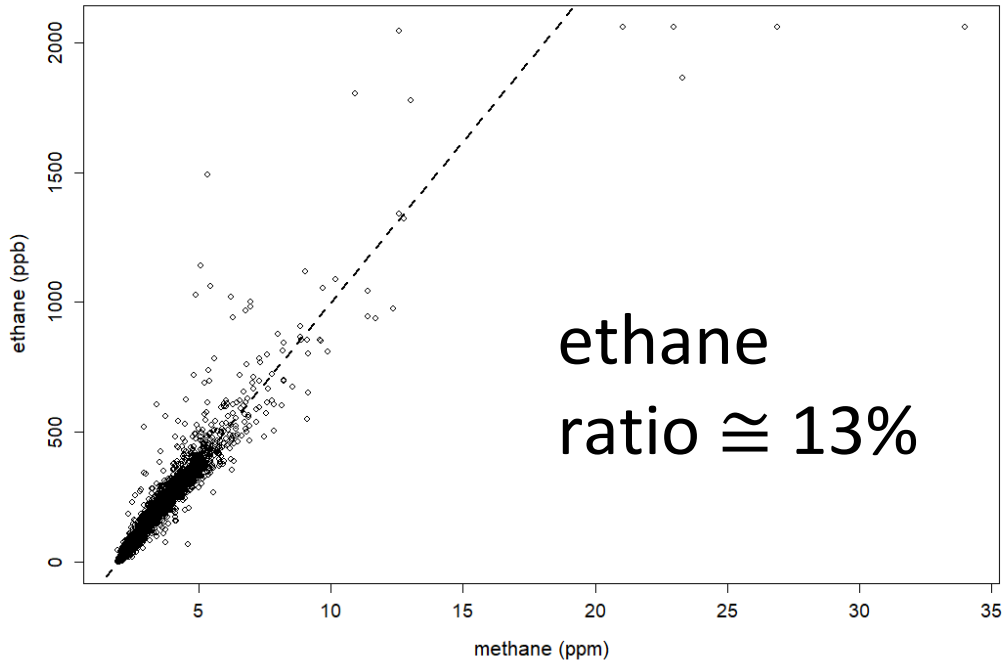

2023
2024
methane (ppm)
2
5
10
20
04-2023
06-2023
08-2023
10-2023
12-2023
02-2024
04-2024
background
monthly running median

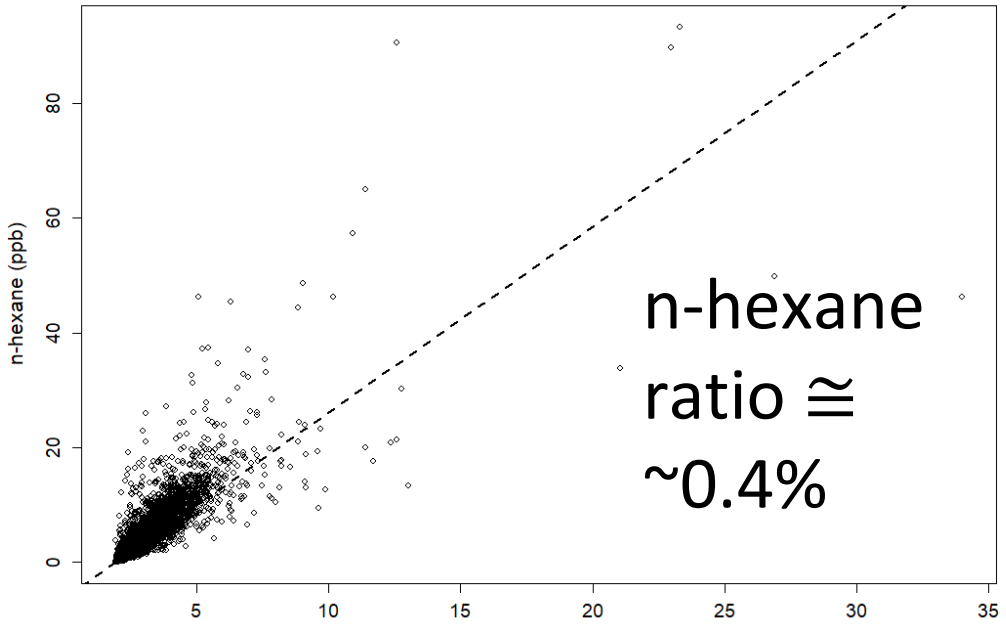
# Plumes of methane at all daytimes (10-min averages)

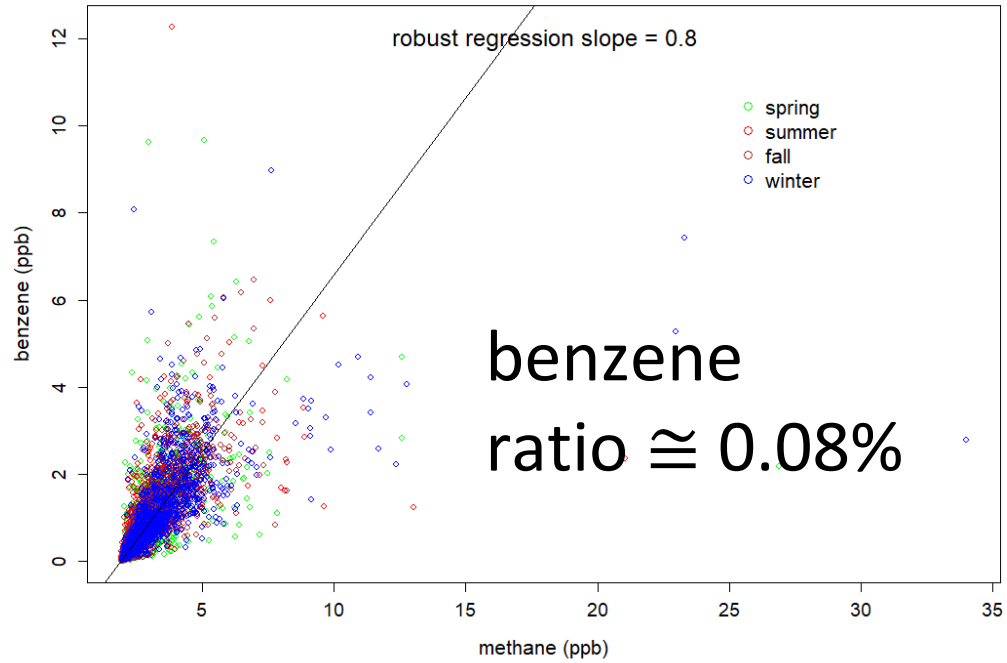


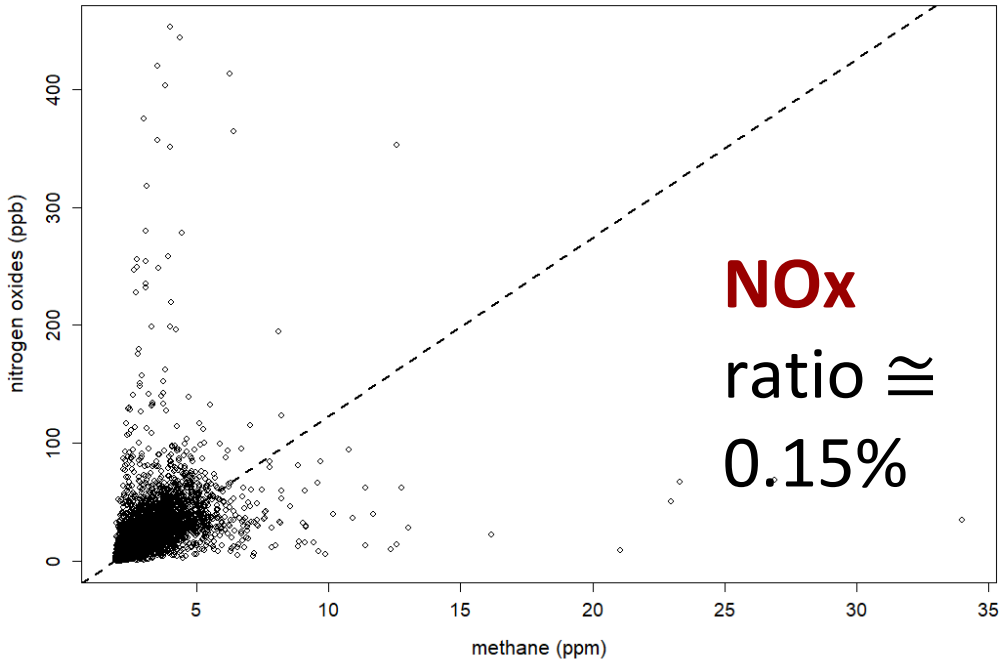
# Plumes from all directions (10-min averages)




ethane (ppb)
methane (ppm)
ethane
ratio ≅ 13%


n-hexane (ppb)
n-hexane
ratio ≅
~0.4%


robust regression slope = 0.8
spring
summer
fall
winter
benzene (ppb)
methane (ppb)
benzene
ratio ≅ 0.08%


nitrogen oxides (ppb)
methane (ppm)
NOx
ratio ≅
0.15%

# Ozone

# Health Effects of Ozone

## Elevated ozone can cause:

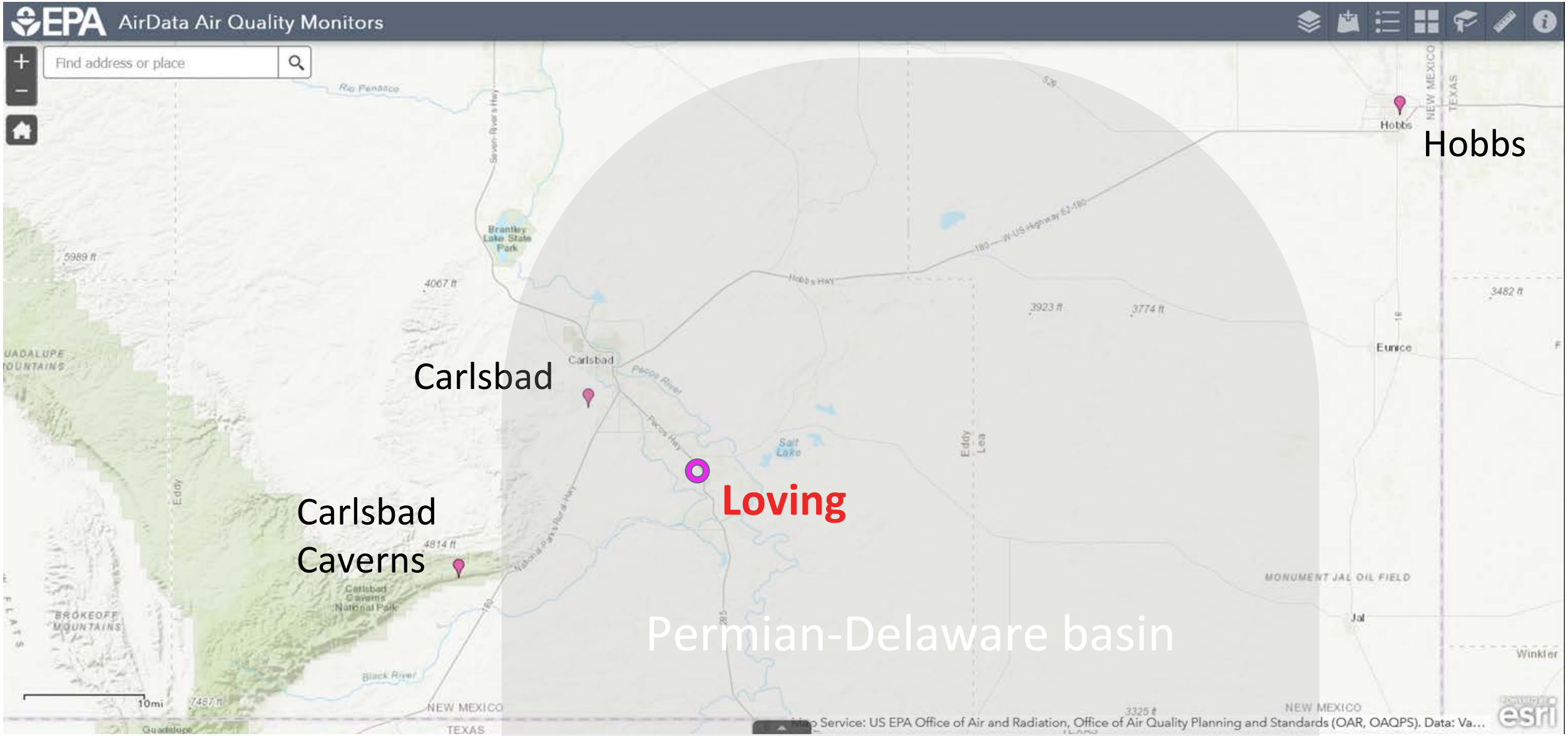
- Asthma attacks, aggravated asthma
- Coughing, wheezing, difficulty breathing
- Reduced lung function
- Reduced resistance to infections
- Emphysema and bronchitis

## EPA National Ambient Air Quality Standard (NAAQS):

- Regulatory standard under the Clean Air Act
- Level EPA deems protective of public health, including children and asthmatics
- Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years, should not exceed **70 parts per billion (ppb)**

Source: American Lung Association, US EPA
Photo: Nenad Stojkovic

# Regional ozone monitoring stations



# 2023 occurrences of 8-hour ozone > 70 ppb at Loving, NM and Carlsbad NMED

**Loving, NM, 8-hour Ozone Occurrences**

| 2023 (full year) | | | |
|---|---|---|---|
| O3_8hr (ppb) | day-month | year | # days > 75/70 ppb NAAQS |
| 87.1 | 31-Aug | 2023 | |
| 86.7 | 9-Sep | 2023 | |
| 84.3 | 30-Aug | 2023 | |
| 82.1 | 27-Aug | 2023 | |
| 81.6 | 17-Sep | 2023 | |
| 79.7 | 23-Jul | 2023 | |
| 78.9 | 3-Sep | 2023 | |
| 78.6 | 1-May | 2023 | |
| 77.9 | 26-Aug | 2023 | |
| 77.8 | 6-Sep | 2023 | |
| 77.7 | 7-Aug | 2023 | |
| 77.7 | 6-Jun | 2023 | |
| 77.3 | 15-Sep | 2023 | |
| 77.2 | 10-Sep | 2023 | |
| 76.6 | 2-May | 2023 | |
| 76.6 | 8-Jun | 2023 | |
| 76.0 | 4-Jul | 2023 | 17 |
| 75.8 | 9-May | 2023 | |
| 75.7 | 12-May | 2023 | |
| 75.7 | 15-Aug | 2023 | |
| 75.6 | 8-Aug | 2023 | |
| 74.0 | 16-May | 2023 | |
| 73.5 | 24-May | 2023 | |
| 72.9 | 4-Aug | 2023 | |
| 72.6 | 21-May | 2023 | |
| 72.0 | 6-Aug | 2023 | |
| 71.8 | 14-Jul | 2023 | |
| 71.7 | 10-Jul | 2023 | |
| 71.3 | 25-Aug | 2023 | |
| 71.2 | 2-Sep | 2023 | |
| 71.0 | 3-Jul | 2023 | 31 |
| 70.9 | 17-Aug | 2023 | |
| 70.4 | 10-May | 2023 | |
| 70.3 | 18-Jun | 2023 | |

**Carlsbad, NMED, 8-hour Ozone Occurrences**

| 2023 (full year) | | | |
|---|---|---|---|
| O3_8hr (ppb) | day-month | year | # days > 75/70 ppb NAAQS |
| 18-Sep | 81.8 | 2023 | |
| 17-Sep | 80.4 | 2023 | |
| 10-Sep | 79.9 | 2023 | |
| 1-Sep | 79.0 | 2023 | |
| 31-Aug | 78.0 | 2023 | |
| 9-Sep | 77.4 | 2023 | |
| 7-Jul | 76.6 | 2023 | 7 |
| 6-Jun | 75.9 | 2023 | |
| 24-Jul | 75.6 | 2023 | |
| 28-Aug | 75.4 | | |
| 13-May | 74.1 | | |
| 5-Aug | 73.8 | | |
| 25-May | 73.3 | | |
| 5-Jul | 73.1 | | |
| 23-Jul | 73.0 | | |
| 16-Aug | 72.9 | | |
| 24-May | 72.8 | | |
| 9-Jun | 72.8 | | |
| 4-Aug | 72.5 | | |
| 11-Sep | 72.4 | | |
| 8-Aug | 72.3 | 2023 | |
| 2-May | 72.0 | 2023 | |
| 12-Apr | 72.0 | 2023 | |
| 4-Jul | 71.9 | 2023 | |
| 27-Aug | 71.8 | 2023 | |
| 7-Sep | 71.7 | 2023 | |
| 12-May | 71.6 | 2023 | |
| 30-Aug | 71.0 | 2023 | 28 |
| 3-Jul | 70.9 | 2023 | |
| 8-Jun | 70.5 | 2023 | |
| 13-Apr | 70.4 | 2023 | |

| | Loving | Carlsbad NMED |
|---|---|---|
| 8-hour max | 87.1 ppb | 81.8 ppb |
| 4th -highest 8-hour | 82.1 ppb | 79.0 ppb |
| # days > 75 ppb | 17 | 7 |
| # days > 70 ppb | 31 | 28 |

# 2023 and 2024 occurrences of 8-hour ozone > 70 ppb at Loving, NM

| 2023 (full year) | | | |
|---|---|---|---|
| O3_8hr (ppb) | day-month | year | # days > 75/70 ppb NAAQS |
| 87.1 | 31-Aug | 2023 | |
| 86.7 | 9-Sep | 2023 | |
| 84.3 | 30-Aug | 2023 | |
| 82.1 | 27-Aug | 2023 | |
| 81.6 | 17-Sep | 2023 | |
| 79.7 | 23-Jul | 2023 | |
| 78.9 | 3-Sep | 2023 | |
| 78.6 | 1-May | 2023 | |
| 77.9 | 26-Aug | 2023 | |
| 77.8 | 6-Sep | 2023 | |
| 77.7 | 7-Aug | 2023 | |
| 77.7 | 6-Jun | 2023 | |
| 77.3 | 15-Sep | 2023 | |
| 77.2 | 10-Sep | 2023 | |
| 76.6 | 2-May | 2023 | |
| 76.6 | 8-Jun | 2023 | |
| 76.0 | 4-Jul | 2023 | 17 |
| 75.8 | 9-May | 2023 | |
| 75.7 | 12-May | 2023 | |
| 75.7 | 15-Aug | 2023 | |
| 75.6 | 8-Aug | 2023 | |
| 74.0 | 16-May | 2023 | |
| 73.5 | 24-May | 2023 | |
| 72.9 | 4-Aug | 2023 | |
| 72.6 | 21-May | 2023 | |
| 72.0 | 6-Aug | 2023 | |
| 71.8 | 14-Jul | 2023 | |
| 71.7 | 10-Jul | 2023 | |
| 71.3 | 25-Aug | 2023 | |
| 71.2 | 2-Sep | 2023 | |
| 71.0 | 3-Jul | 2023 | |
| 70.9 | 17-Aug | 2023 | |
| 70.4 | 10-May | 2023 | |
| 70.3 | 18-Jun | 2023 | |

**31**

| 2024 (until Oct 25th) | | | |
|---|---|---|---|
| O3_8hr (ppb) | day-month | year | # days > 75/70 ppb NAAQS |
| 99.8 | 25-Jul | 2024 | |
| 97.7 | 24-Jul | 2024 | |
| 92.4 | 23-Jul | 2024 | |
| 91.5 | 6-Jul | 2024 | |
| 86.8 | 26-Jul | 2024 | |
| 86.3 | 9-Jul | 2024 | |
| 85.4 | 8-Aug | 2024 | |
| 85.4 | 15-May | 2024 | |
| 82.7 | 7-Aug | 2024 | |
| 82.5 | 12-Jun | 2024 | |
| 80.4 | 28-Sep | 2024 | |
| 79.6 | 30-Sep | 2024 | |
| 78.3 | 28-Aug | 2024 | |
| 78.3 | 30-May | 2024 | |
| 78.1 | 1-Aug | 2024 | |
| 77.7 | 10-Jul | 2024 | |
| 77.5 | 11-Jul | 2024 | |
| 77.2 | 20-Jul | 2024 | |
| 76.3 | 27-Jul | 2024 | |
| 76.1 | 2-Oct | 2024 | |
| 76.0 | 31-Jul | 2024 | 21 |
| 75.8 | 27-Sep | 2024 | |
| 75.6 | 6-Jun | 2024 | |
| 75.2 | 12-Jul | 2024 | |
| 75.1 | 23-May | 2024 | |
| 75.1 | 13-Jun | 2024 | |
| 74.7 | 3-Jul | 2024 | |
| 74.7 | 9-Aug | 2024 | |
| 74.6 | 15-Aug | 2024 | |
| 74.6 | 31-May | 2024 | |
| 74.3 | 19-Jul | 2024 | |
| 74.2 | 24-May | 2024 | |
| 73.6 | 29-Sep | 2024 | |
| 73.5 | 10-Sep | 2024 | |
| 73.2 | 7-Sep | 2024 | |
| 73.0 | 24-Jun | 2024 | |
| 73.0 | 10-Jun | 2024 | |
| 73.0 | 9-Sep | 2024 | |
| 72.6 | 14-May | 2024 | |
| 72.1 | 24-Sep | 2024 | |
| 72.0 | 8-Jul | 2024 | |
| 71.9 | 29-May | 2024 | |
| 71.6 | 5-Jun | 2024 | |
| 71.4 | 6-Apr | 2024 | |
| 71.3 | 28-Jul | 2024 | |
| 71.0 | 27-Aug | 2024 | |
| 70.7 | 7-Apr | 2024 | |
| 70.7 | 14-Oct | 2024 | |
| 70.6 | 6-Aug | 2024 | |
| 70.5 | 17-Apr | 2024 | |
| 70.4 | 23-Jun | 2024 | |
| 70.4 | 30-Jul | 2024 | |
| 70.2 | 3-Jun | 2024 | |
| 70.1 | 5-May | 2024 | |

**46**

**Loving 2023-2024 mean 4th:**
**86.8 ppb**

Carlsbad 2020-2022 mean 4th:
78 ppb

Carlsbad Caverns 2020-2022 mean 4th:
78 ppb

Hobbs 2020-2022 mean 4th:
71 ppb

Number of ozone NAAQS exceedance days

# Carlsbad area Ozone is high …

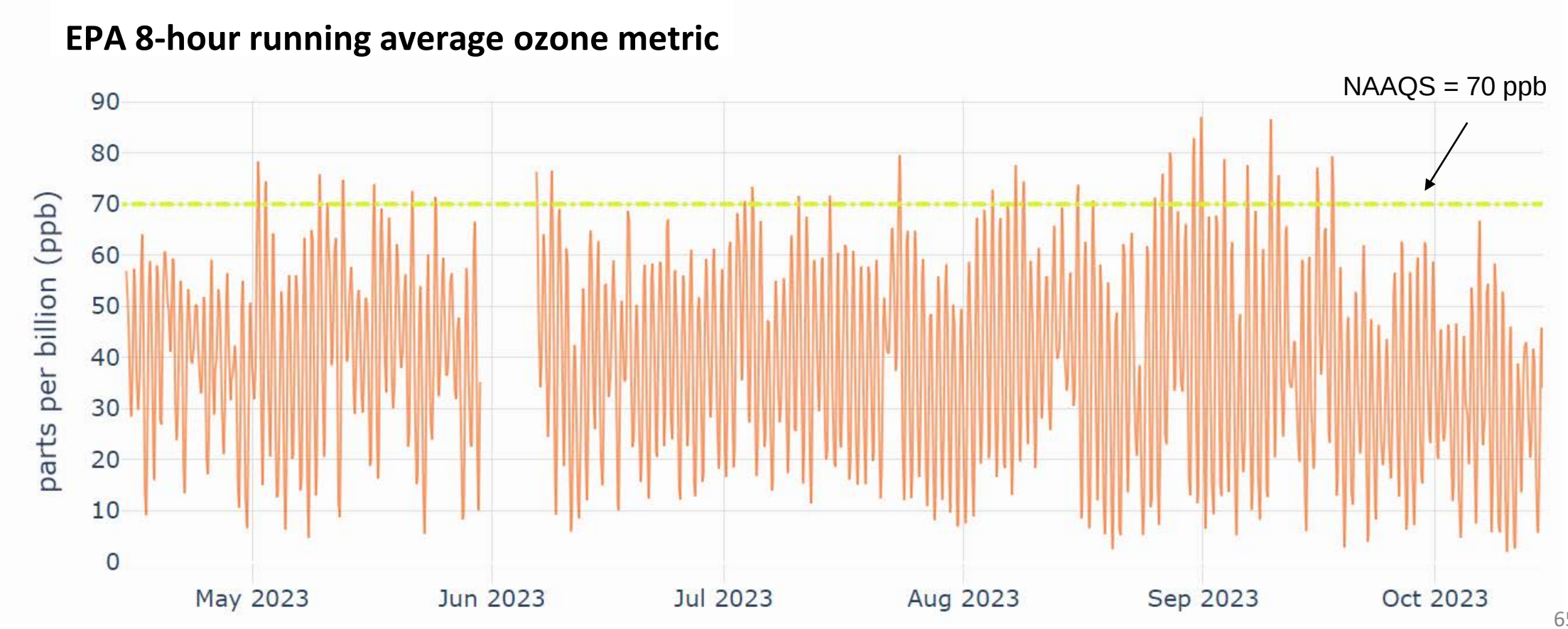
- … during daytime, especially noon to 6 pm, and for clear-skies
- … on spring and summer days, from April into October
  - … when it is dry, i.e. humidity is low
  - … when temperatures exceed 90 deg F.
  - … when winds are weak
  - … and air moves slowly from southerly to easterly directions

- Typically, since 2018, southeast NM has exceeded the 70-ppb threshold for ozone levels during about 20-30 days each year
  - the $4^{th}$-highest daily 8-h average enters the legal limit calculations

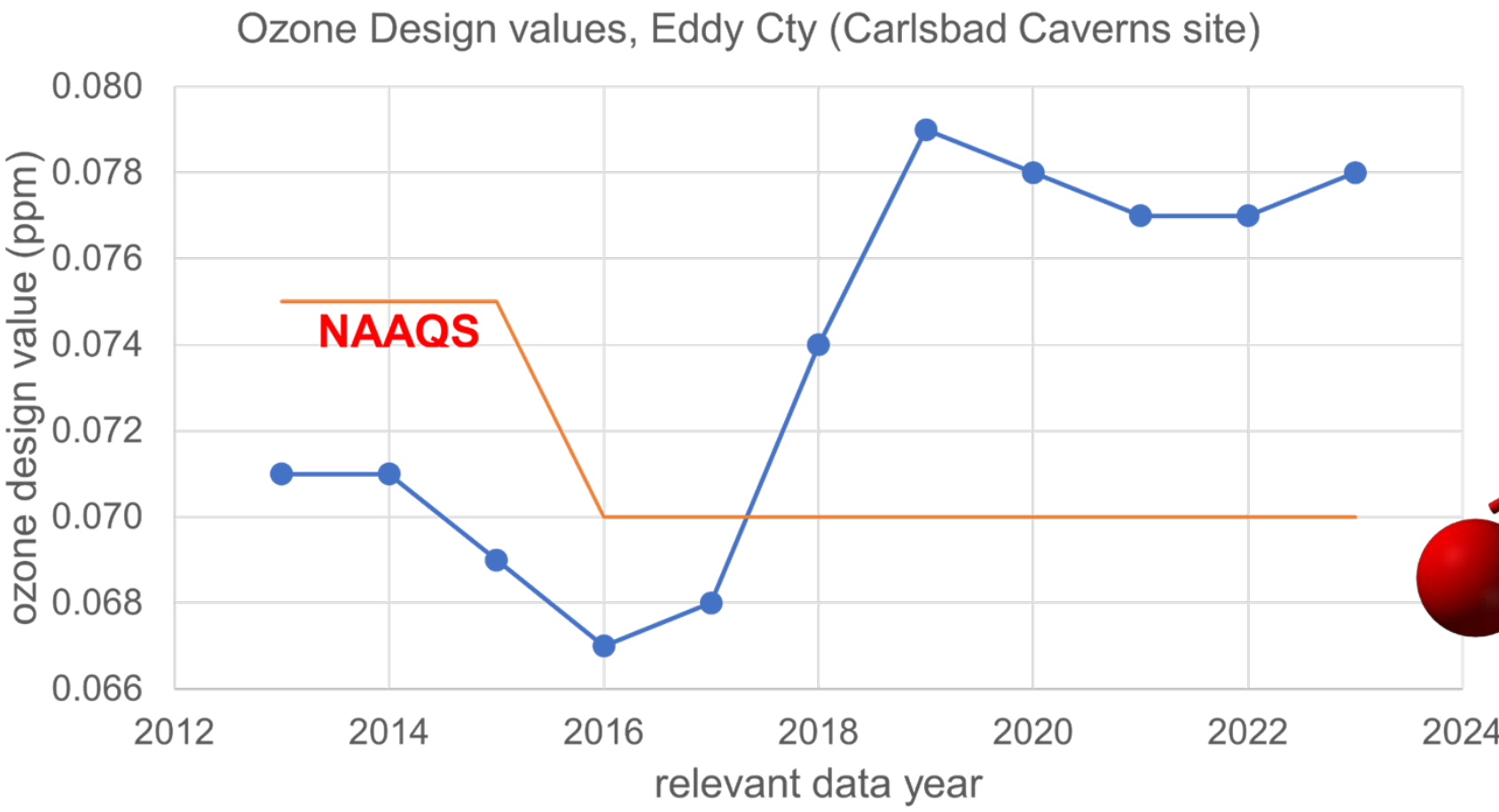
# Ozone at the Loving, NM site in 2023

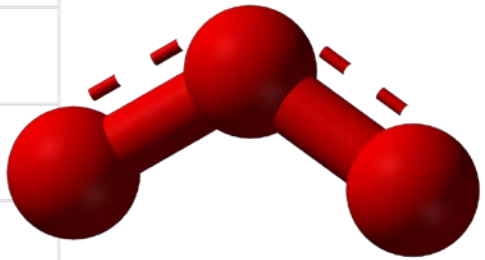
Ozone levels exceeded the current U.S. EPA NAAQS* of **70 ppb** on ***31 of 155*** days measured.
Similar exceedances have been observed for several years at Carlsbad Caverns.

* NAAQS = National Ambient Air Quality Standard



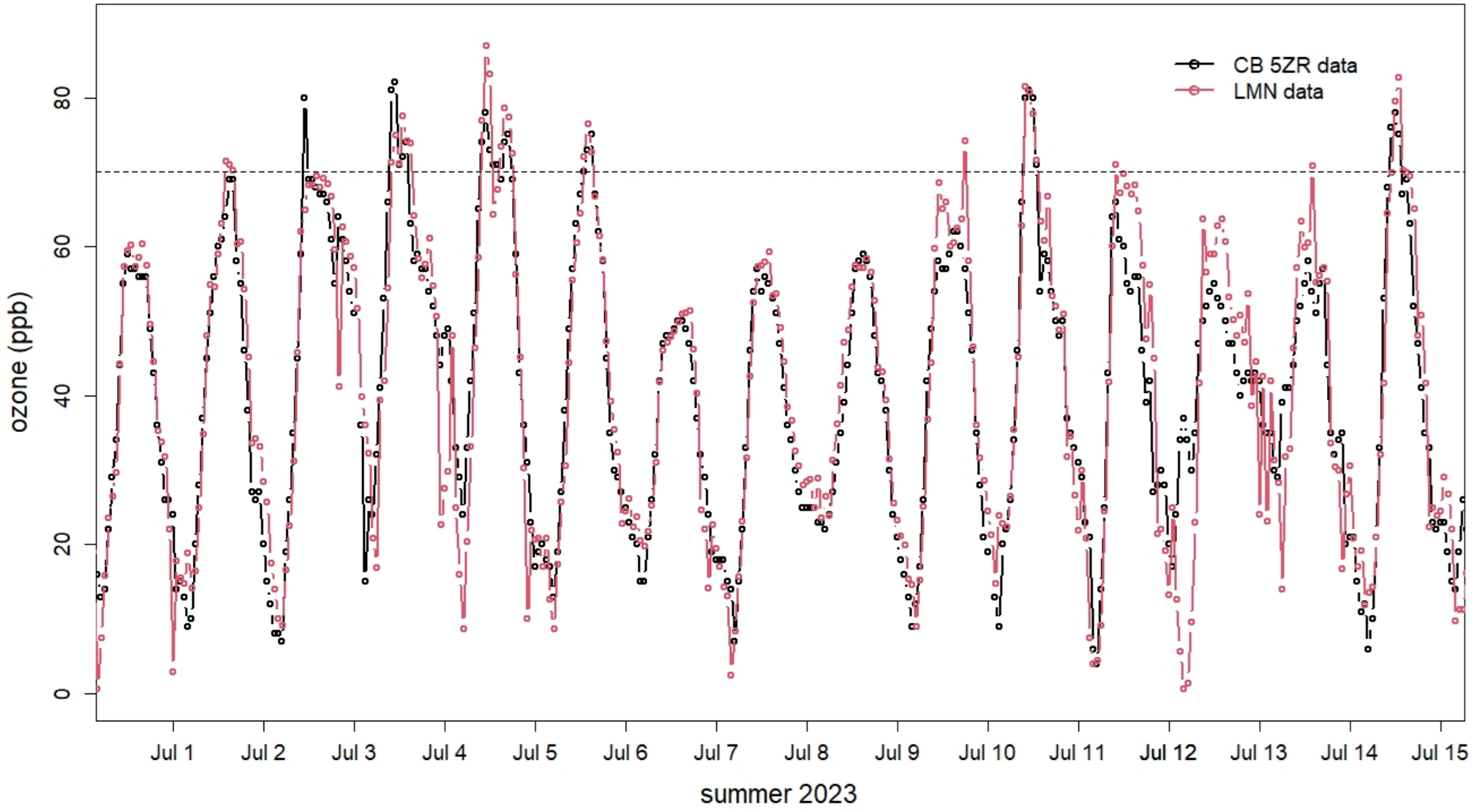
# 1. Ozone above the *National Ambient Air Quality Standard* (NAAQS)



https://www.env.nm.gov/air-quality/my-air-quality/#ozone

# Comparing the local NMED site data to data at our LMN site




NOTE: NMED's 5ZR monitoring location is 11 miles from our LMN site on the SW outskirts of Carlsbad

# Health Effects of Ozone

## Elevated ozone can cause:

- Asthma attacks, aggravated asthma
- Coughing, wheezing, difficulty breathing
- Reduced lung function
- Reduced resistance to infections
- Emphysema and bronchitis

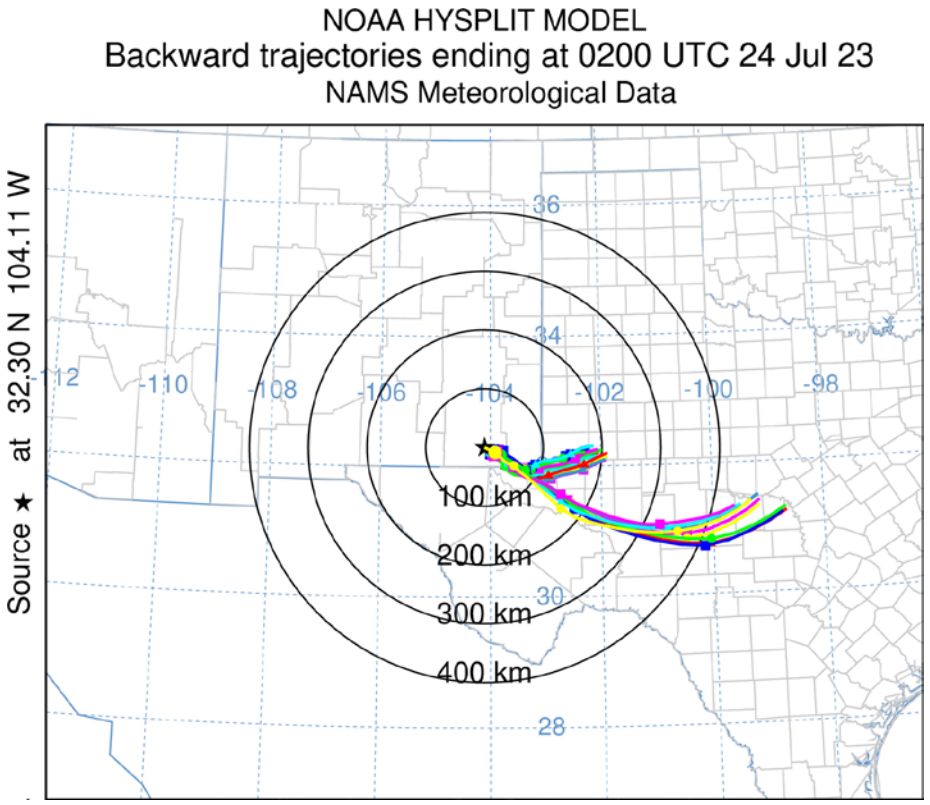
## EPA National Ambient Air Quality Standard (NAAQS):

- Regulatory standard under the Clean Air Act
- Level EPA deems protective of public health, including children and asthmatics
- Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years, should not exceed **70 parts per billion (ppb)**

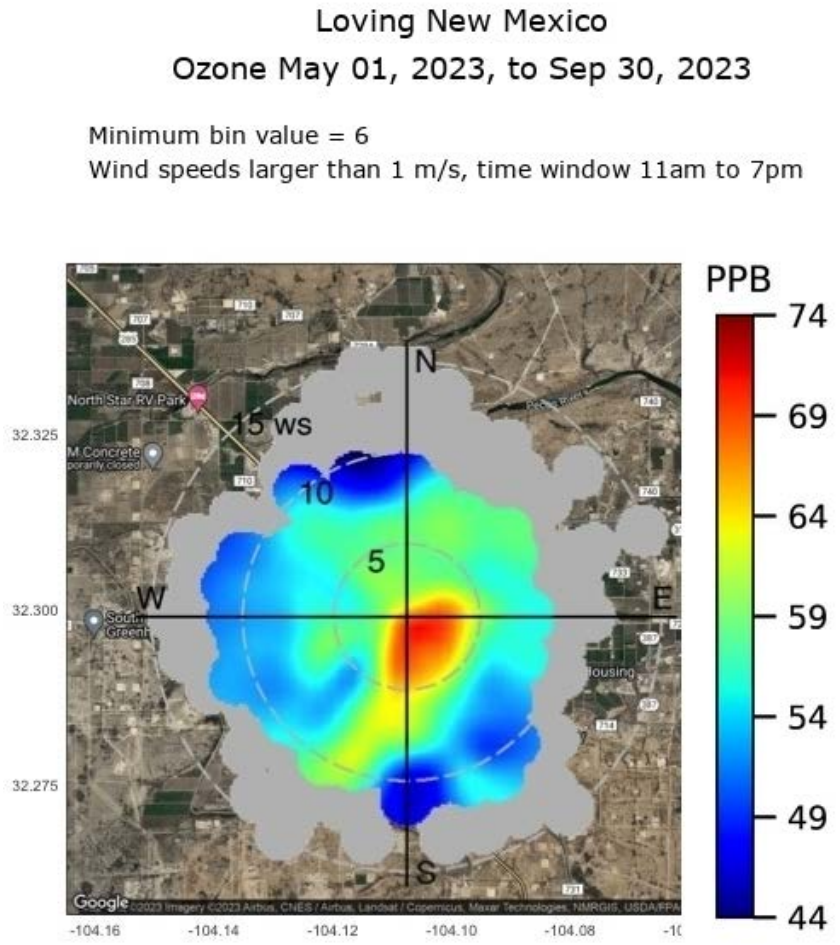
Source: American Lung Association, US EPA

Photo: Nenad Stojkovic

# Where is the high ozone coming from?




Example air mass origins for 23 July (7 pm local time), a high ozone day (80 ppb).




➔ **Weak southeast winds associated with highest daytime ozone.**

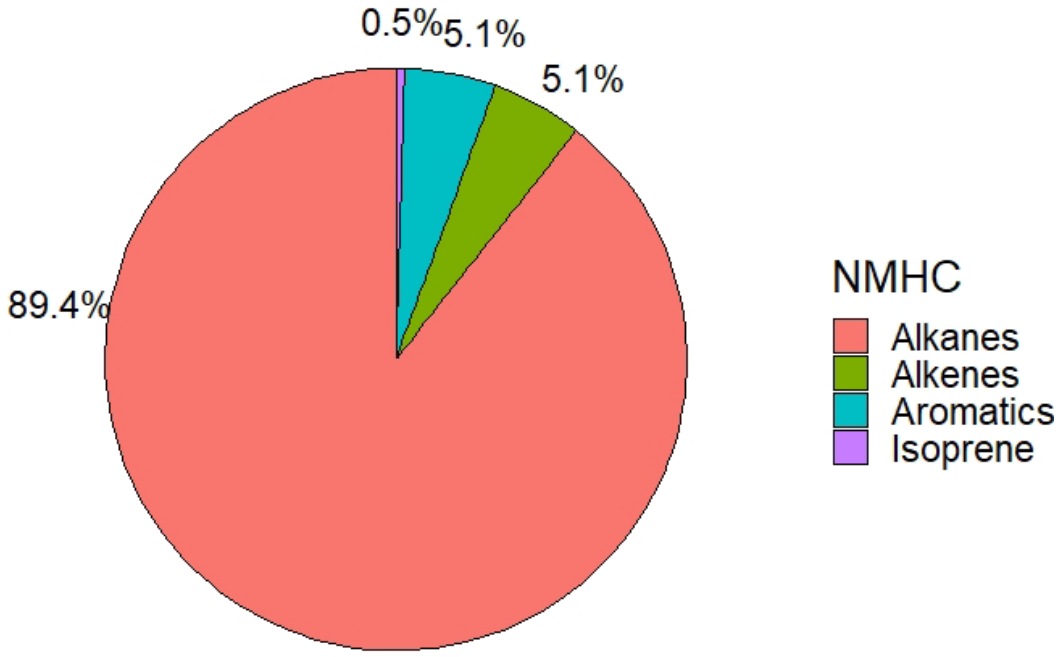
➔ **On average, air transported from the southeast sector had 10–15 ppb higher ozone than air from other directions.**

# Ozone ($O_3$) statistics at the LNM site

| 2023 May 1st - October 1st | | | | | 2024 May 1st - October 1st | | | |
|---|---|---|---|---|---|---|---|---|
| O3 Value (ppb) | # Hours, O3 1hr avg > val | # Hours, max O3 minute > val | # Days, max 8hr avg O3 > val | | O3 Value (ppb) | # Hours, O3 1hr avg > val | # Hours, max O3 minute > val | # Days, max 8hr avg O3 > val |
| 120 | 0 | 0 | 0 | | 120 | 0 | 0 | 0 |
| 115 | 0 | 0 | 0 | | 115 | 0 | 1 | 0 |
| 110 | 0 | 1 | 0 | | 110 | 0 | 4 | 0 |
| 105 | 0 | 4 | 0 | | 105 | 5 | 13 | 0 |
| 100 | 3 | 5 | 0 | | 100 | 13 | 25 | 0 |
| 95 | 4 | 17 | 0 | | 95 | 23 | 40 | 2 |
| 90 | 13 | 36 | 0 | | 90 | 38 | 68 | 4 |
| 85 | 35 | 103 | 2 | | 85 | 63 | 106 | 8 |
| 80 | 86 | 191 | 5 | | 80 | 106 | 199 | 11 |
| 75 | 190 | 324 | 21 | | 75 | 226 | 367 | 24 |
| 70 | 327 | 515 | 34 | | 70 | 391 | 570 | 48 |
| 65 | 488 | 736 | 60 | | 65 | 623 | 822 | 75 |
| 60 | 730 | 1000 | 89 | | 60 | 850 | 1084 | 100 |

# What compounds drive ozone formation?

**Measured hydrocarbon reactivity → ozone formation potential**




- May – October means, 11 – 19 hours

**→ The largest contributor to regional photochemical ozone formation is petroleum hydrocarbons.**

**→ Combined, hydrocarbons associated with oil and gas production contribute more than 90% to the measured ozone formation potential.**

cf. Pan et al., JAWMA 73(12), Nov. 2023

# VOCs

# Airborne Radioactivity

# 3. Airborne Radioactivity

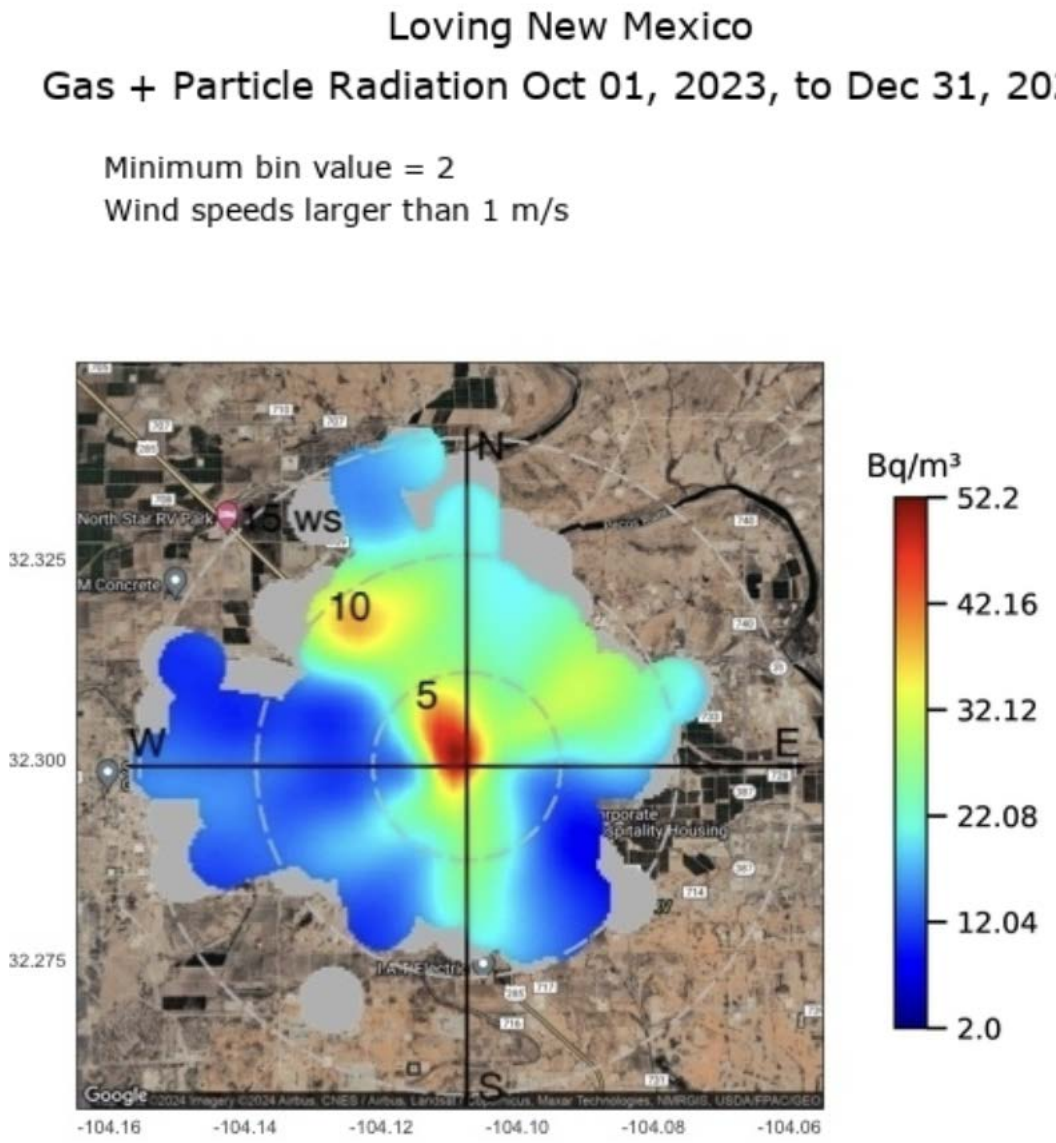
Radon in the atmosphere …

… is mostly due to emissions from the ground, creating a natural background level of radioactivity in air.

… may be elevated by mining, creating more pathways of Radon to escape into the lower atmosphere.

… is the second leading cause of lung cancer after smoking

# New insights from airborne radioactivity measurements




**Radioactive <u>Radon is a gas</u> and <u>Radon decay products are on particles</u>**

Radon emanation is enhanced as it is brought to the surface via drilling and gas production

- Elevated levels (yellow to red colors) are detected from various directions, especially under moderate northerly, especially NNW wind directions.
  - Under these conditions, levels are on average 2-3 times higher than background* levels (cyan and blue colors).
- Correlation with sulfur compounds may suggest a shared “sour gas” source.

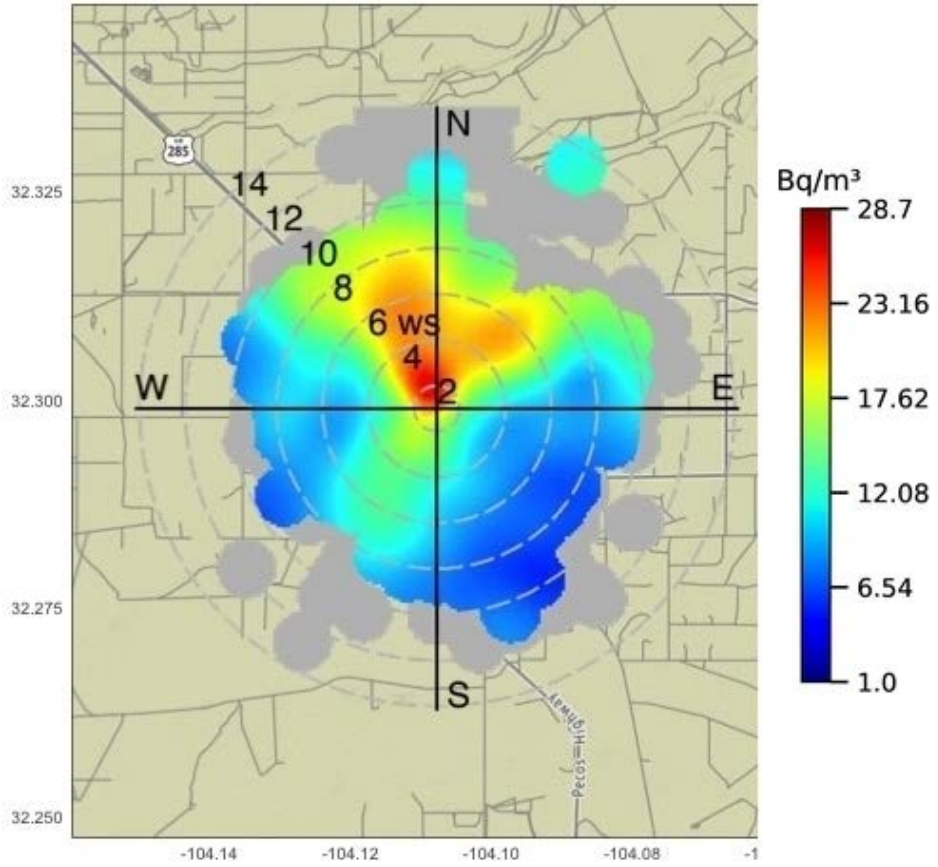
* cf. Gäggeler, *Radiochimica Acta* 70/71, 1995

# Airborne Radioactivity at Loving, NM (LNM)

Loving New Mexico

Gas Phase Radiation Jul 01, 2023, to Sep 12, 2023

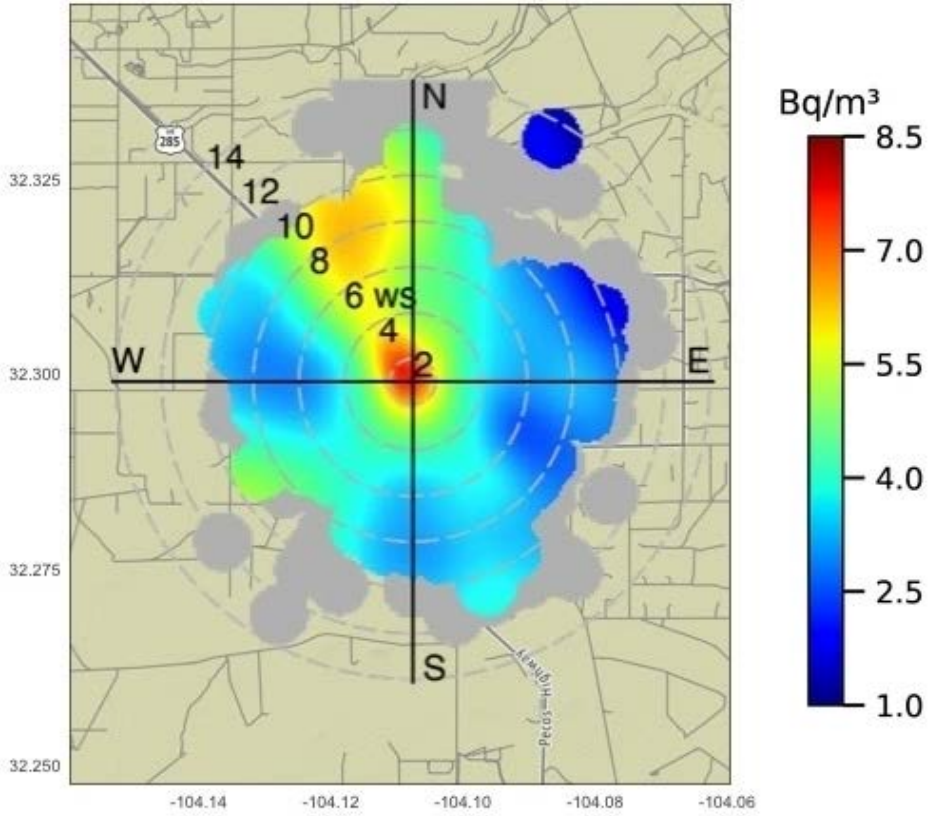
Minimum bin value = 2
Wind speeds larger than 1 m/s



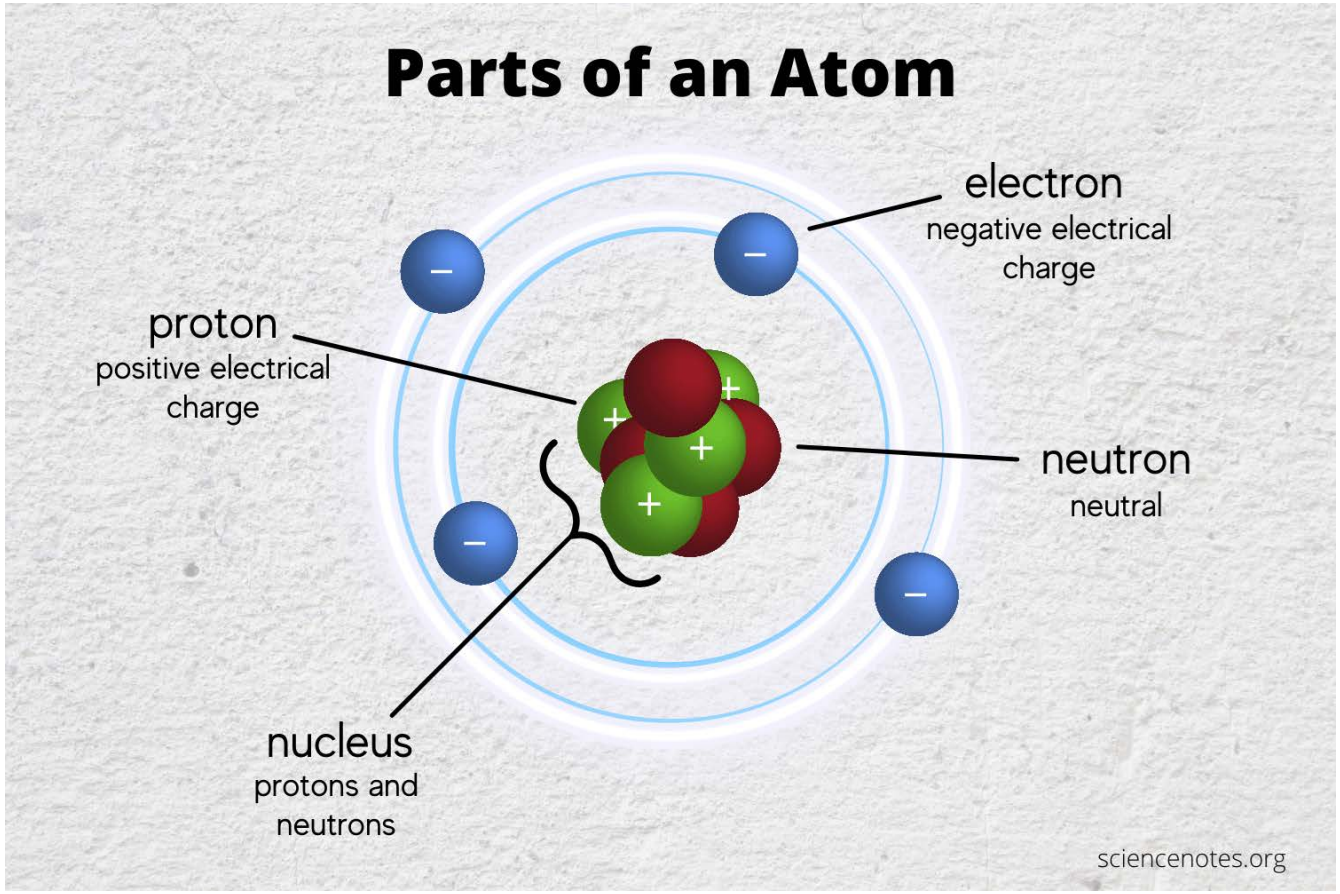

Loving New Mexico

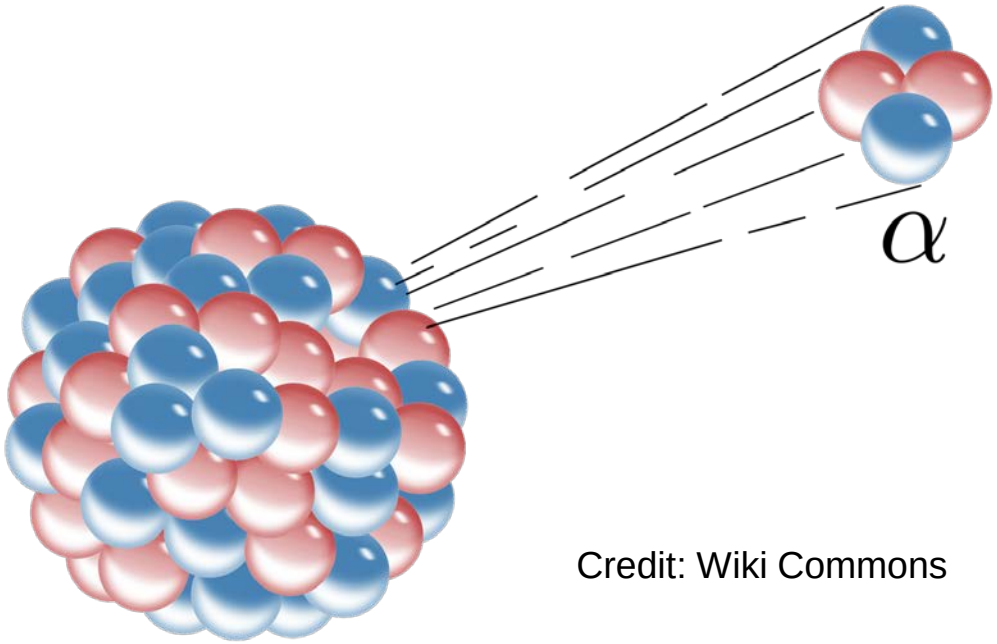
Particle Radiation Jul 01, 2023, to Sep 12, 2023

Minimum bin value = 2
Wind speeds larger than 1 m/s



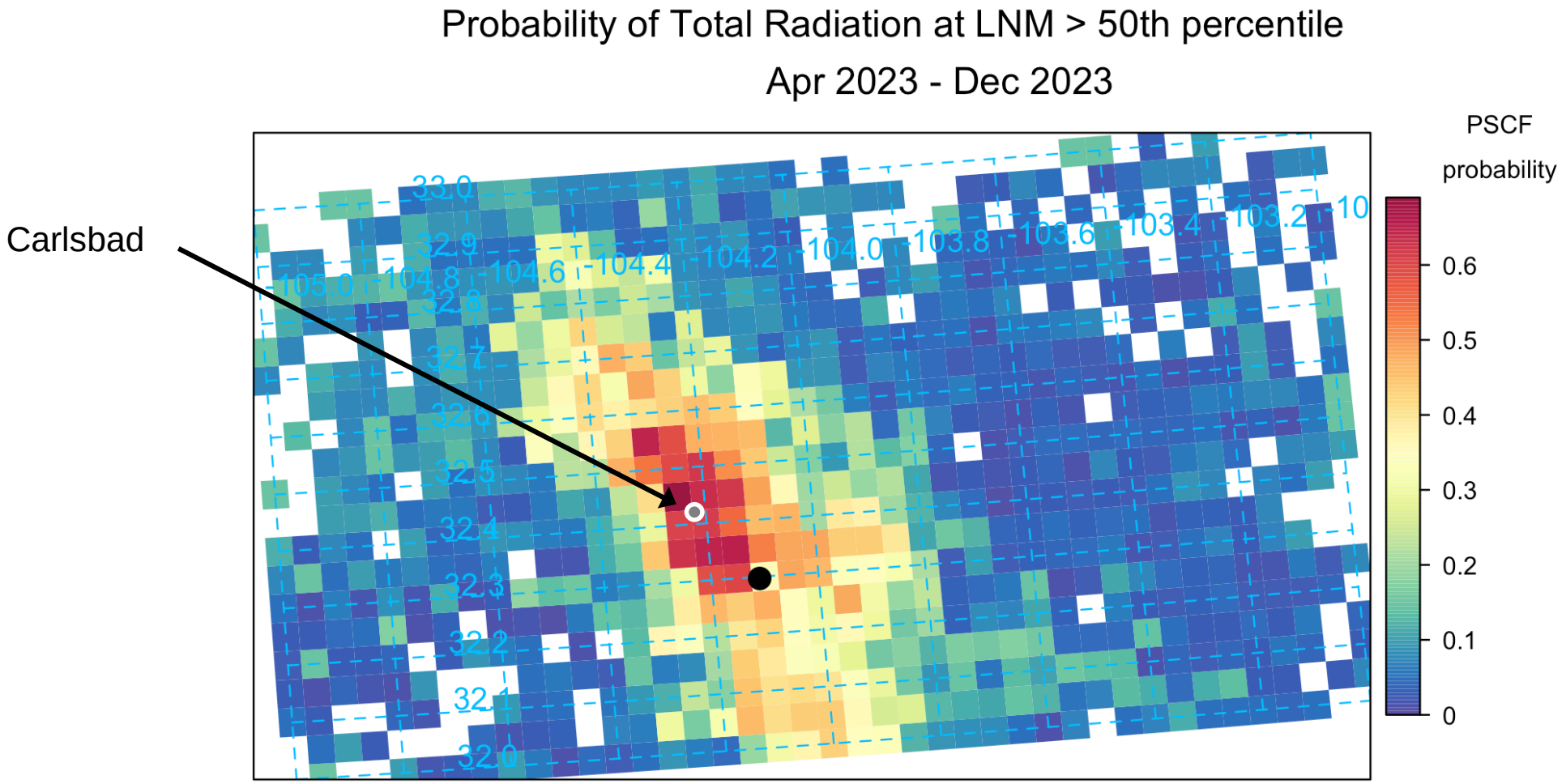
# What is Radioactivity?

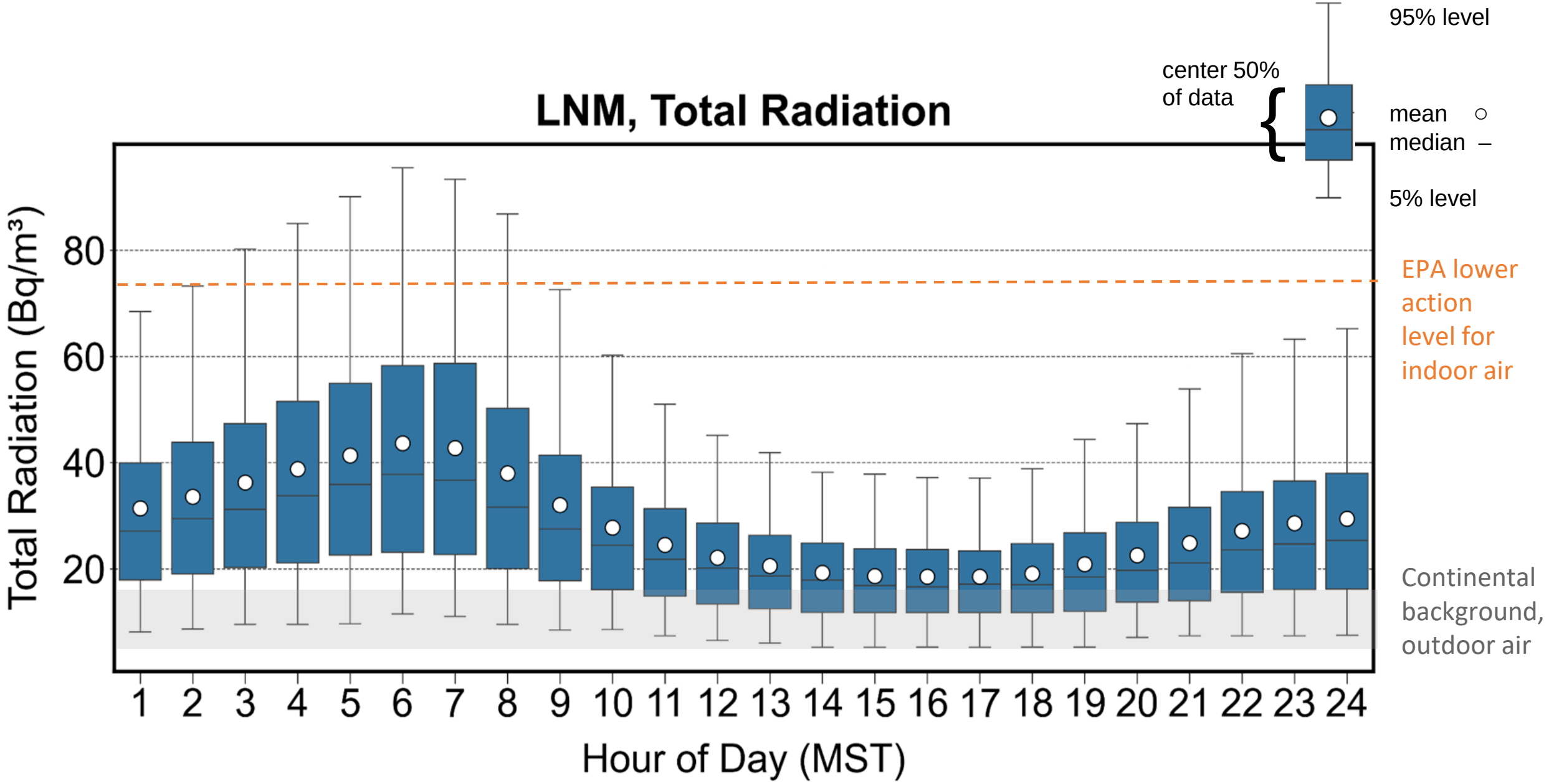



Credit: Wiki Commons

# Potential Source Contribution Function Results – Uses Correlation Analyses with HYSPLIT Trajectories




LNM, Total Radiation
Total Radiation (Bq/m³)
80
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (MST)
95% level
center 50% of data
mean ○
median –
5% level
EPA lower action level for indoor air
Continental background, outdoor air

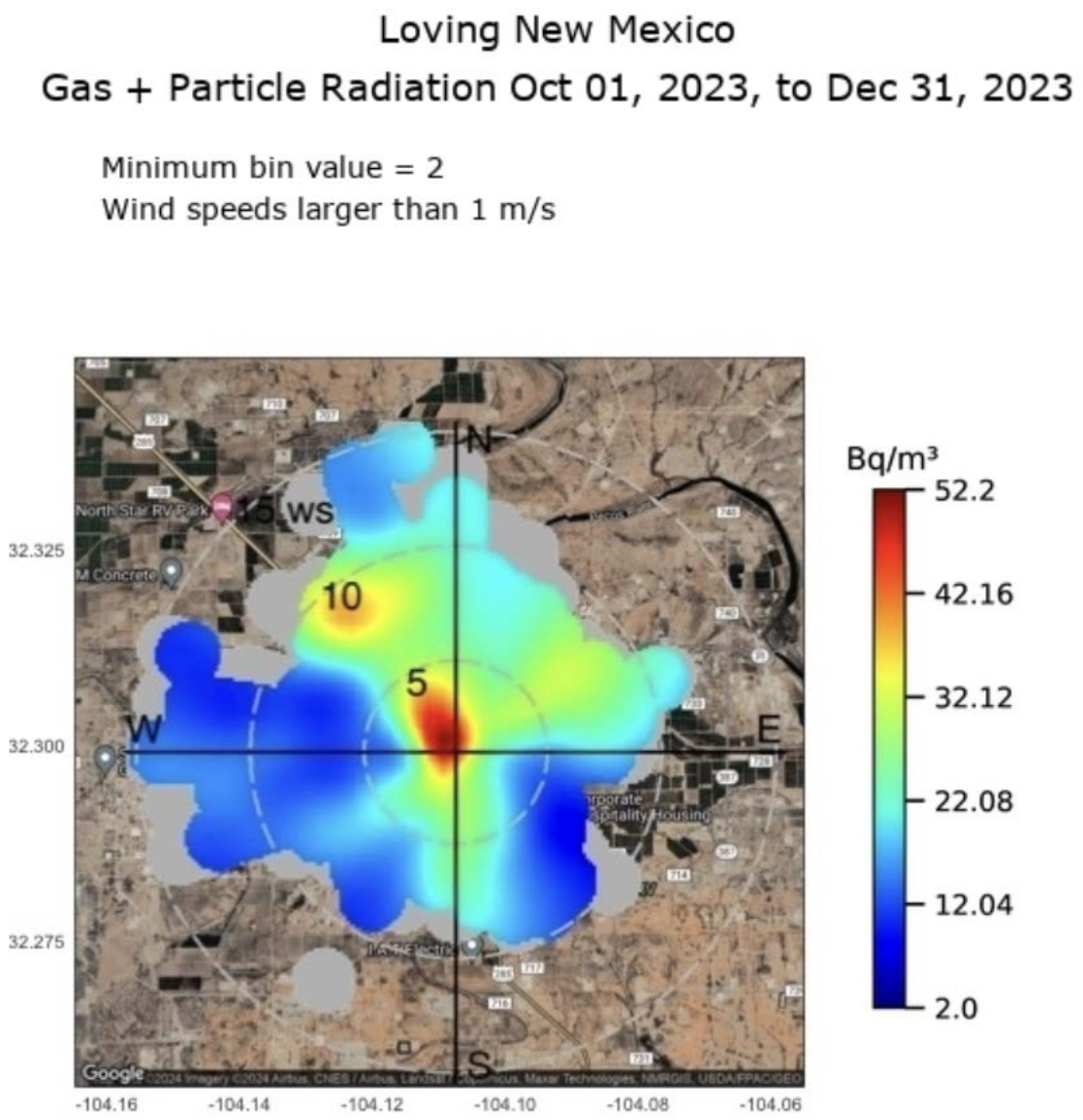
# The Periodic Table of Elemer

scientificgems.wordpress.com

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H Hydrogen | | | | | | | | | | | | | | | | | 2 He Helium |
| 3 Li Lithium | 4 Be Beryllium | | | | | | | | | | | 5 B Boron | 6 C Carbon | 7 N Nitrogen | 8 O Oxygen | 9 F Fluorine | 10 Ne Neon |
| 11 Na Sodium | 12 Mg Magnesium | | | | | | | | | | | 13 Al Aluminium | 14 Si Silicon | 15 P Phosphorus | 16 S Sulfur | 17 Cl Chlorine | 18 Ar Argon |
| 19 K Potassium | 20 Ca Calcium | 21 Sc Scandium | 22 Ti Titanium | 23 V Vanadium | 24 Cr Chromium | 25 Mn Manganese | 26 Fe Iron | 27 Co Cobalt | 28 Ni Nickel | 29 Cu Copper | 30 Zn Zinc | 31 Ga Gallium | 32 Ge Germanium | 33 As Arsenic | 34 Se Selenium | 35 Br Bromine | 36 Kr Krypton |
| 37 Rb Rubidium | 38 Sr Strontium | 39 Y Yttrium | 40 Zr Zirconium | 41 Nb Niobium | 42 Mo Molybdenum | 43 Tc Technetium | 44 Ru Ruthenium | 45 Rh Rhodium | 46 Pd Palladium | 47 Ag Silver | 48 Cd Cadmium | 49 In Indium | 50 Sn Tin | 51 Sb Antimony | 52 Te Tellurium | 53 I Iodine | 54 Xe Xenon |
| 55 Cs Cesium | 56 Ba Barium | 57–71 La–Lu Lanthanides | 72 Hf Hafnium | 73 Ta Tantalum | 74 W Tungsten | 75 Re Rhenium | 76 Os Osmium | 77 Ir Iridium | 78 Pt Platinum | 79 Au Gold | 80 Hg Mercury | 81 Tl Thallium | 82 Pb Lead | 83 Bi Bismuth | 84 Po Polonium | 85 At Astatine | 86 Rn Radon |
| 87 Fr Francium | 88 Ra Radium | 89–103 Ac–Lr Actinides | 104 Rf Rutherfordium | 105 Db Dubnium | 106 Sg Seaborgium | 107 Bh Bohrium | 108 Hs Hassium | 109 Mt Meitnerium | 110 Ds Darmstadtium | 111 Rg Roentgenium | 112 Cn Copernicium | 113 Nh Nihonium | 114 Fl Flerovium | 115 Mc Moscovium | 116 Lv Livermorium | 117 Ts Tennessine | 118 Og Oganesson |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 La Lanthanum | 58 Ce Cerium | 59 Pr Praseodymium | 60 Nd Neodymium | 61 Pm Promethium | 62 Sm Samarium | 63 Eu Europium | 64 Gd Gadolinium | 65 Tb Terbium | 66 Dy Dysprosium | 67 Ho Holmium | 68 Er Erbium | 69 Tm Thulium | 70 Yb Ytterbium | 71 Lu Lutetium |
| 89 Ac Actinium | 90 Th Thorium | 91 Pa Protactinium | 92 U Uranium | 93 Np Neptunium | 94 Pu Plutonium | 95 Am Americium | 96 Cm Curium | 97 Bk Berkelium | 98 Cf Californium | 99 Es Einsteinium | 100 Fm Fermium | 101 Md Mendelevium | 102 No Nobelium | 103 Lr Lawrencium |

# New insights from airborne radioactivity measurements




**Radioactive <u>Radon is a gas</u> and <u>Radon decay products are on particles</u>**

Radon emanation is enhanced as it is brought to the surface via drilling and gas production

- Higher concentrations (yellow to red colors) are detected from various directions, especially under moderate northerly, especially NNW wind directions.
  - Under these conditions, levels are on average 2-3 times higher than background* levels (cyan and blue colors).
- Correlation with sulfur compounds may suggest a shared “sour gas” source.

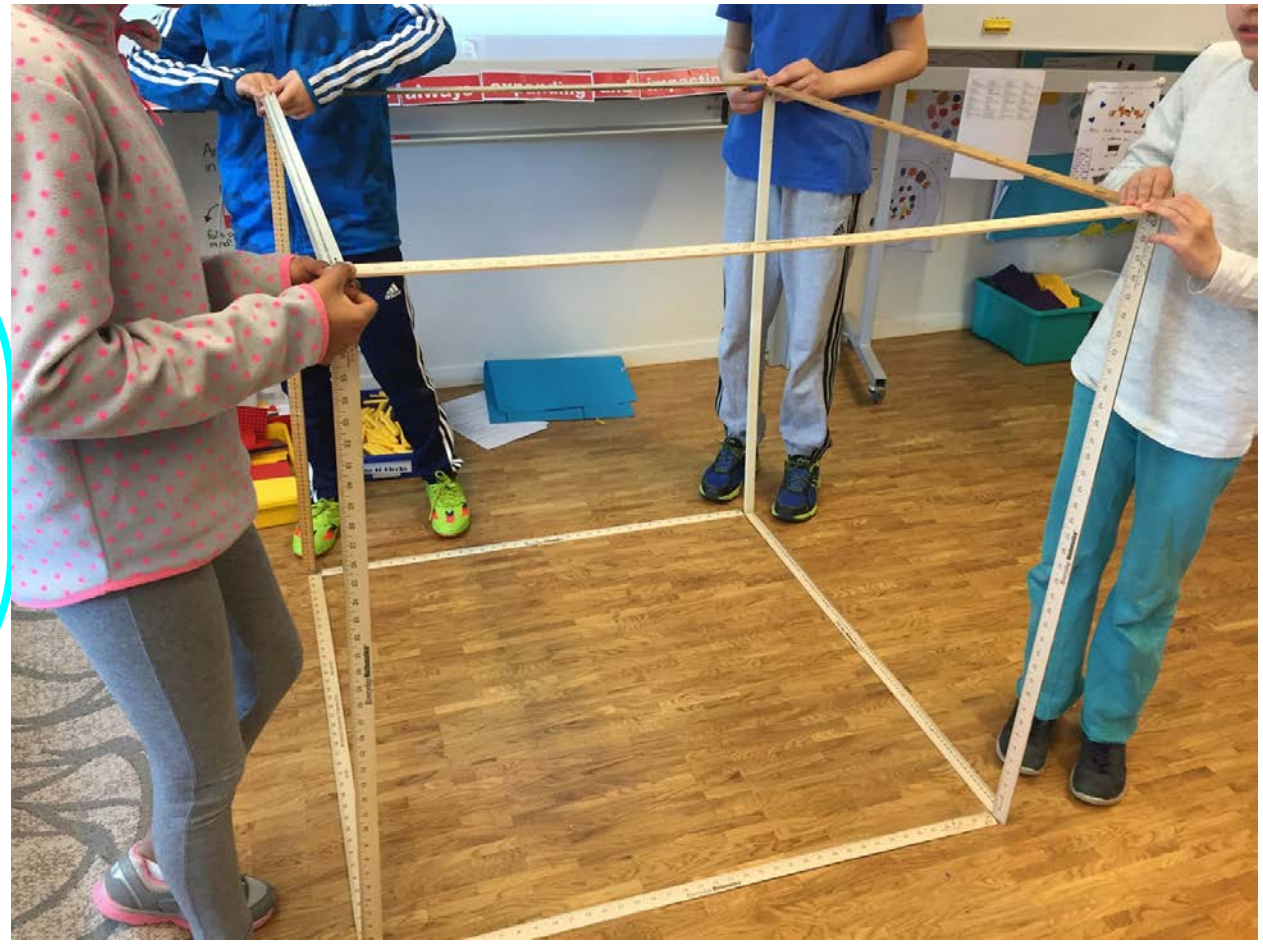
* cf. Gäggeler, *Radiochimica Acta* 70/71, 1995

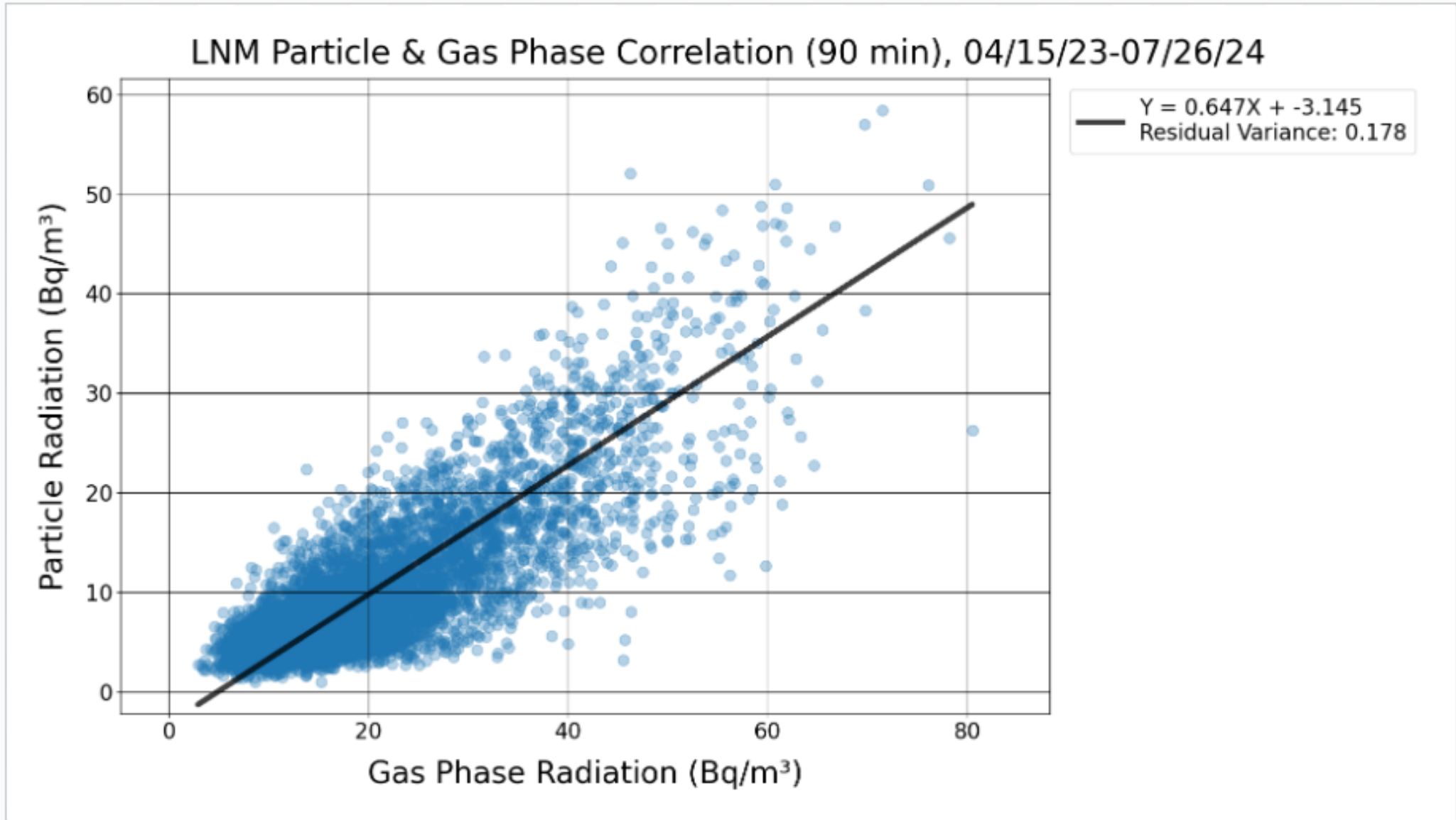
Blue to cyan colors represent normal, background radioactivity levels.

# Units for Ambient Radioactivity Monitoring

- **Becquerel per cubic meter: Bq/m³**
  - How many radioactive decays there are in a cubic meter every second

- Continental background, outdoor air: **5-15 Bq/m³**
- Action levels for indoor air:
  - **100 Bq/m³** (World Health Organization)
  - **75-150 Bq/m³** (U.S. Environmental Protection Agency)




LNM Particle & Gas Phase Correlation (90 min), 04/15/23-07/26/24
Y = 0.647X + -3.145
Residual Variance: 0.178
Particle Radiation (Bq/m³)
Gas Phase Radiation (Bq/m³)
0
10
20
30
40
50
60
0
20
40
60
80

# Bertin Technologies AlphaGUARD DF2000 + AlphaPM

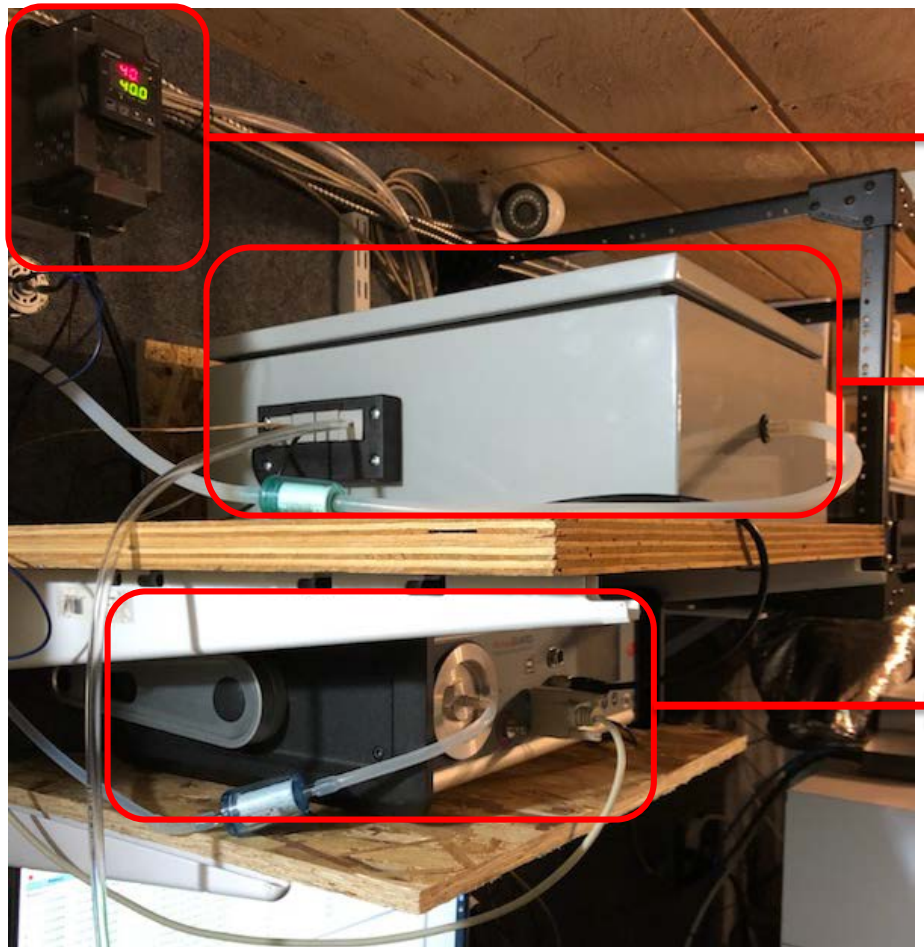
**AlphaGUARD DF2000** Radon gas alpha decay


Detector: Ionization chamber
Range: <0.05 pCi/l to 54,000 pCi/l (2 to 2,000,000 Bq/m3)
Flow rate 0.05 – 0.5, 1, 2 L/min; 620 mL chamber volume
1 min or 10 min measurement cycle
5-year calibration factor, traceable

**AlphaPM** Radon progeny on PM alpha decay


Detector: Semiconductor (PIPS)
Range: 0.5 to 1,000,000 Bq/m3 EEC (0.02 to 35,000 MeV/cm3)
Lower detection limit at 10 min and 2 L/min flow: 2 Bq/m3 EEC (0.07 MeV/cm3)
Flow rate 0.1, 0.5, 1.0, 1.5, 2.0 L/min
10 min measurement cycle, synchronized automatically with connected AlphaGUARD

# The radioactivity monitors (inside the trailer):

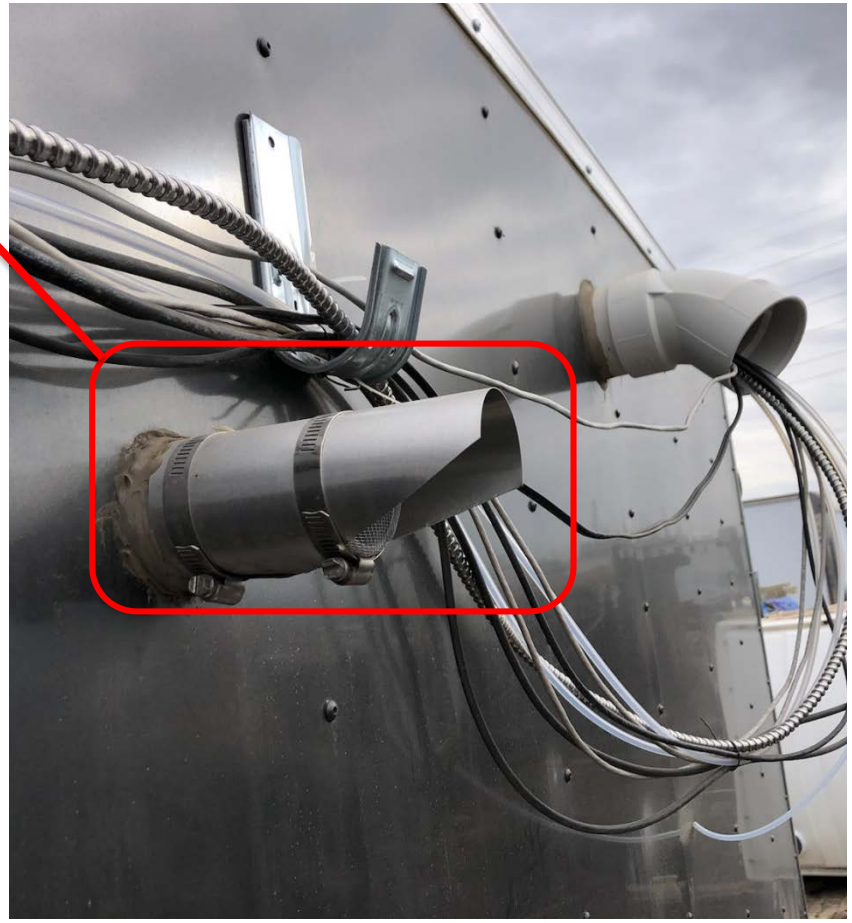


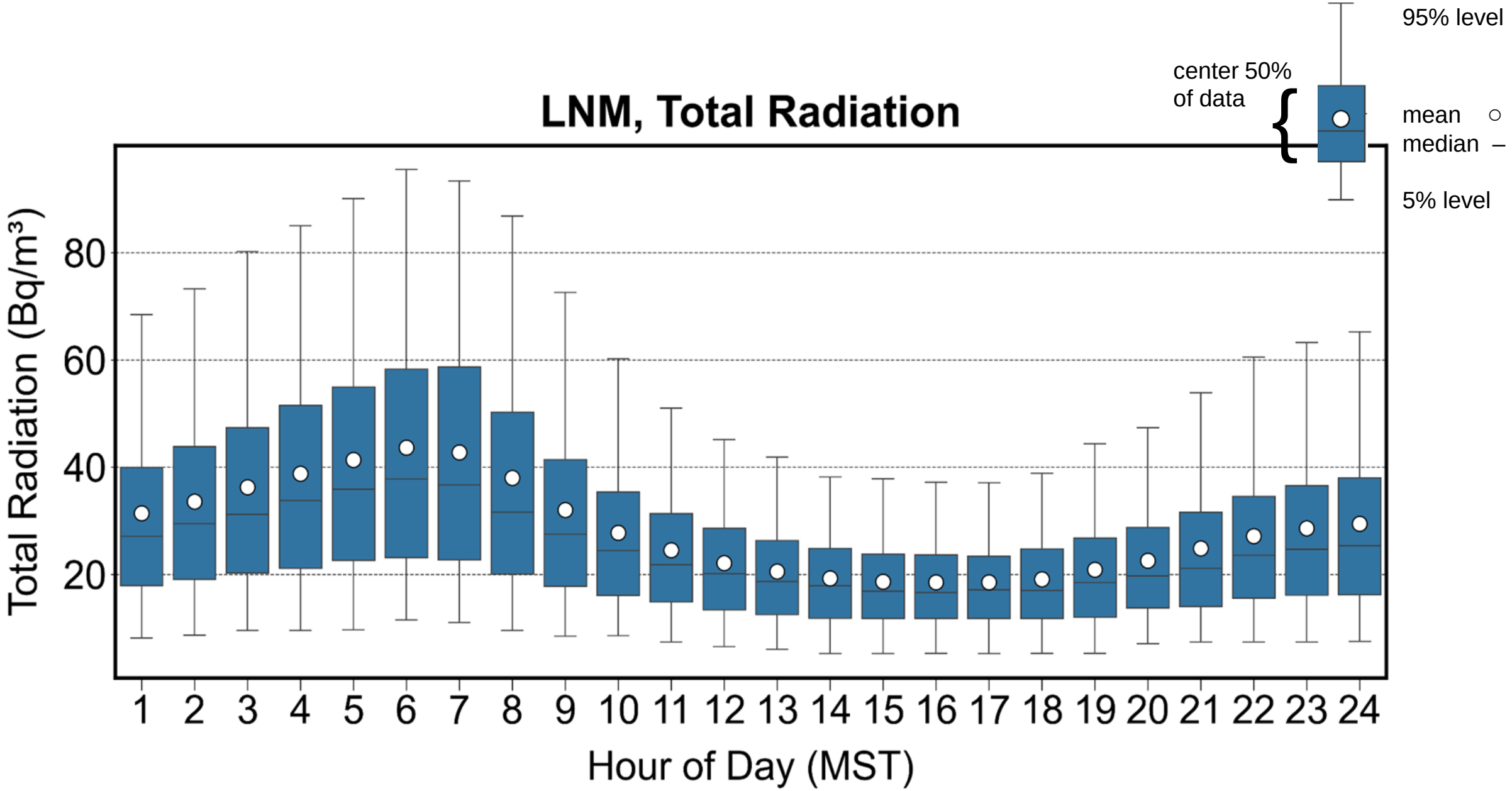
Particle radioactivity monitor inlet temperature controller

Particle radioactivity monitor enclosure

Gas phase radon monitor

Particle radioactivity monitor inlet




LNM, Total Radiation
Total Radiation (Bq/m³)
20
40
60
80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (MST)
95% level
center 50%
of data
mean ○
median –
5% level

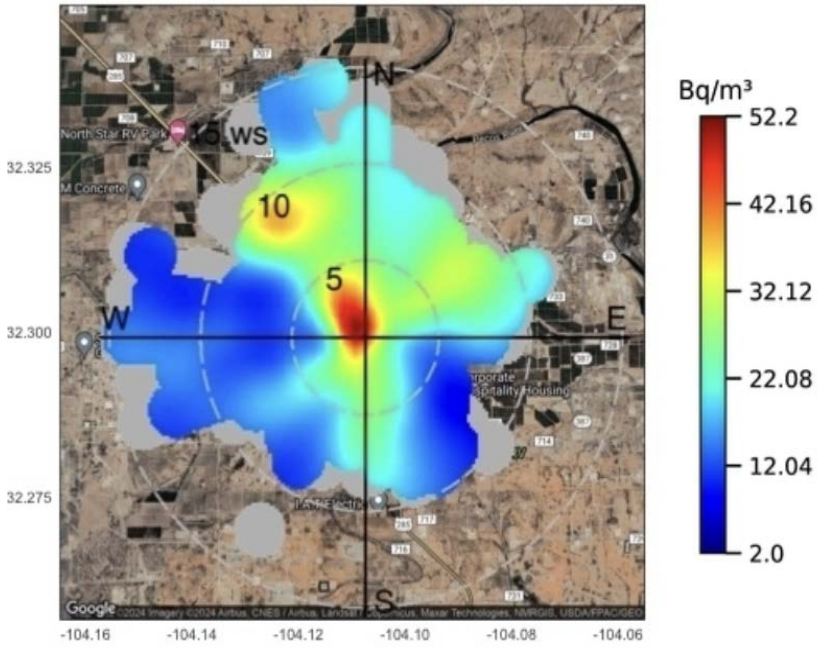
# Airborne gas and paraticle radioactivity at Loving, NM

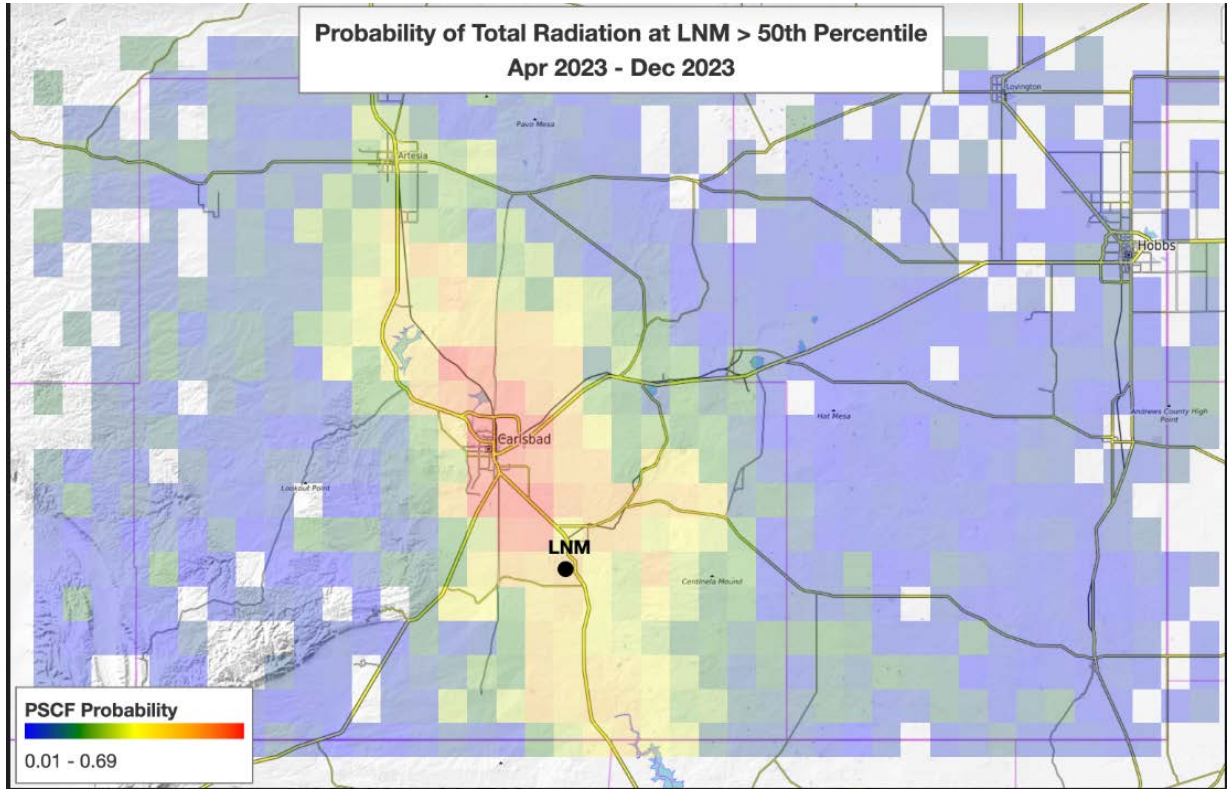
Loving New Mexico

Gas + Particle Radiation Oct 01, 2023, to Dec 31, 2023

Minimum bin value = 2

Wind speeds larger than 1 m/s



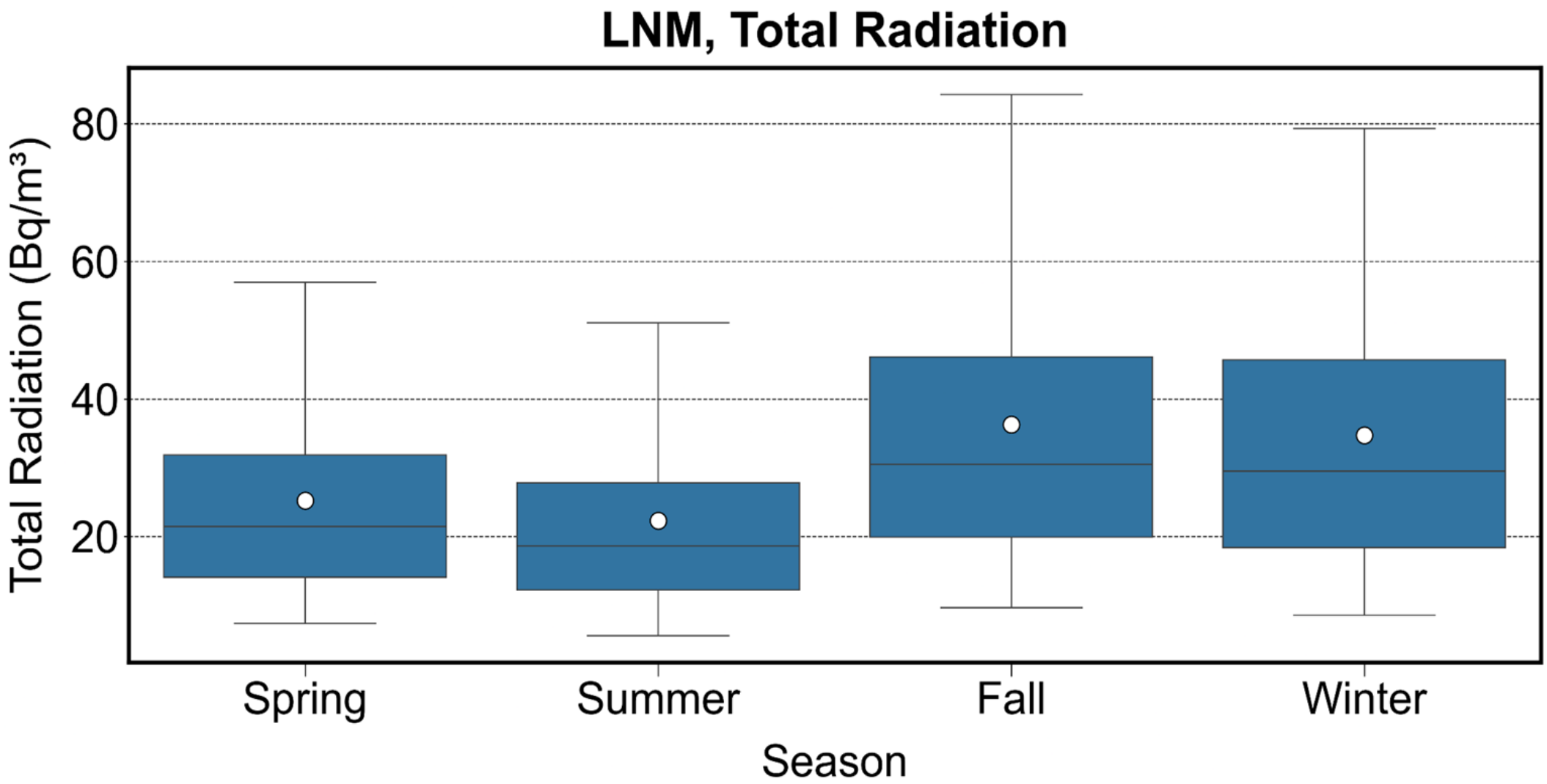



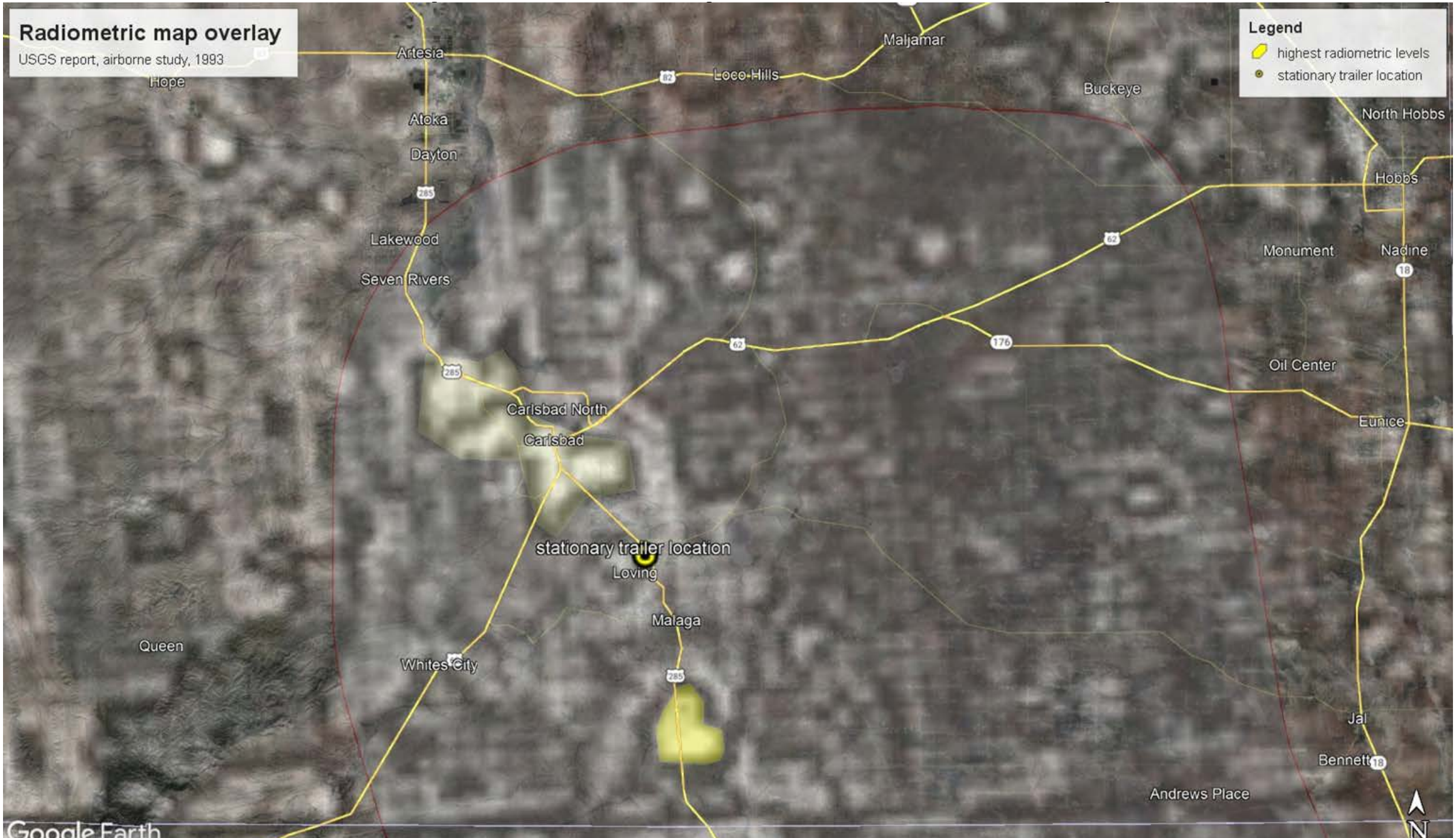
# Units for Ambient Radioactivity Monitoring

- Pico-Curie per Liter : pCi $L^{-1}$
- **Becquerel per cubic meter: Bq $m^{-3}$**

**1 pCi $L^{-1}$ is equivalent to 37 Bq $m^{-3}$**

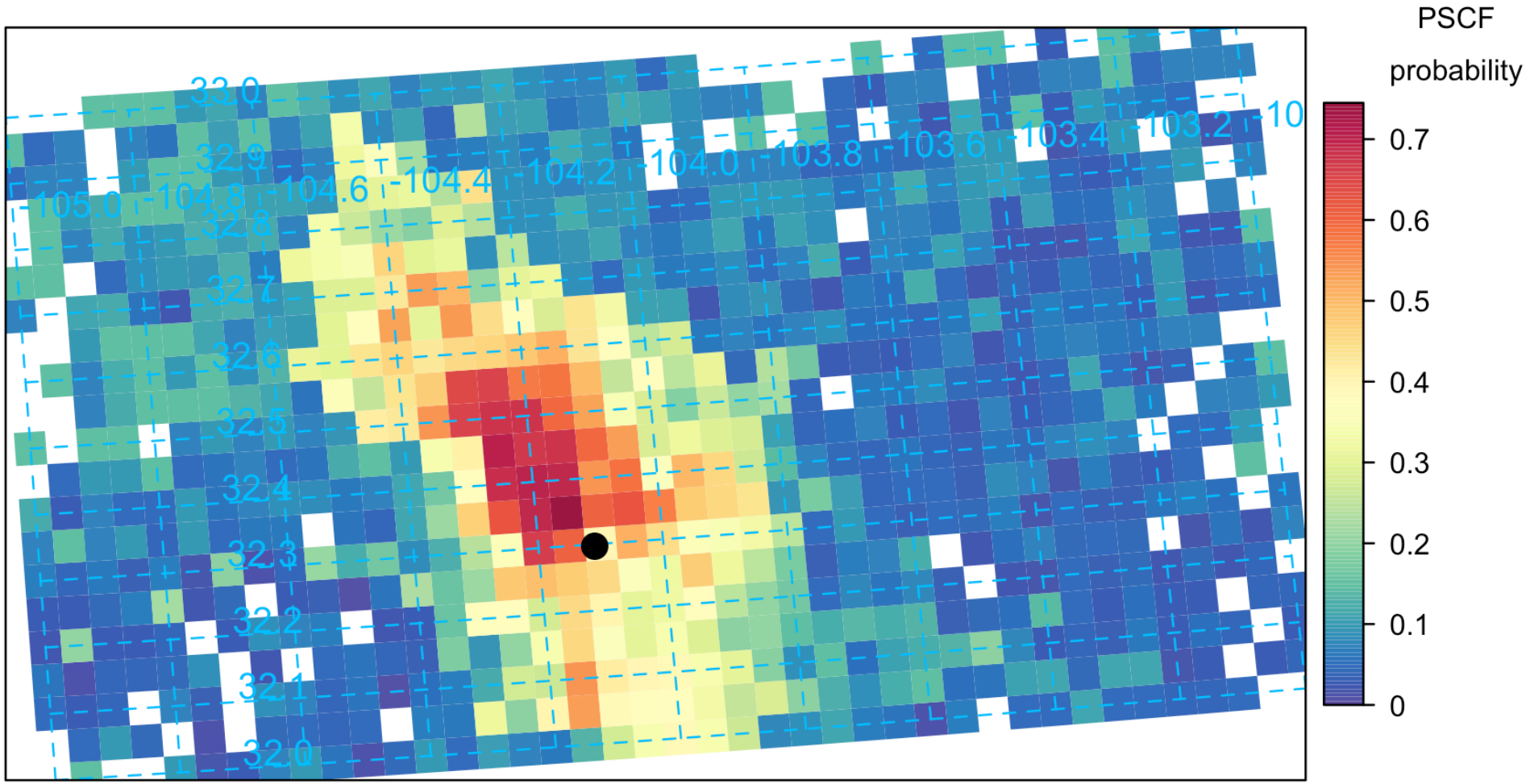
- Continental background, outdoor air: **5-15 Bq/$m^3$** (0.135-0.405 pCi/L)
- World Health Organization action level for indoor air: **100 Bq/$m^3$** (2.7 pCi/L)
- US EPA action level for indoor air: 4 pCi/L (~**150 Bq/$m^3$**)


LNM, Total Radiation
Total Radiation (Bq/m³)
80
60
40
20
Spring
Summer
Fall
Winter
Season


Radiometric map overlay
USGS report, airborne study, 1993
Legend
highest radiometric levels
stationary trailer location
Artesia
Hope
Maljamar
Loco Hills
Buckeye
North Hobbs
Atoka
Dayton
Hobbs
Lakewood
Seven Rivers
Monument
Nadine
Oil Center
Carlsbad North
Carlsbad
Eunice
stationary trailer location
Loving
Malaga
Queen
Whites City
Jal
Bennett
Andrews Place
Google Earth
N

# Probability of Gas Phase Radiation at LNM > 50th percentile

## Apr 2023 - Dec 2023



# Health effects of volatile organic compounds (VOCs)

## Central nervous system

- Dizziness, drowsiness, headaches, nausea, confusion
- Numb feet and hands
- Hearing and vision loss
- Nerve and brain damage

## Blood (benzene)

- Anemia
- Increased chance of infections
- Leukemia

## Reproduction & development

Source: EPA IRIS, EPA 2012, ATSDR

Images: Cedric Villain, Dhalia Nuraini, and Mahmure Alp for the Noun Project

## What levels of benzene in air are considered safe?

| | |
|---|---|
| **ATSDR** chronic minimal risk level (MRL) | **3 ppb** (non-cancer) |
| **EPA** reference concentration & inhalation unit risk | **9 ppb** (immune system)<br><br>**0.4 to 1.4 ppb**<br>(1 in 100,000 excess cancer risk) |
| **WHO** guidelines | **0.5 ppb**<br>(1 in 100,000 excess cancer risk) |

ATSDR = Agency for Toxic Substances and Disease Registry
EPA = Environmental Protection Agency
WHO = World Health Organization