Front Range Local Government Air Quality Studies

Boulder County, City of Longmont, Town of Erie, City & County of Broomfield

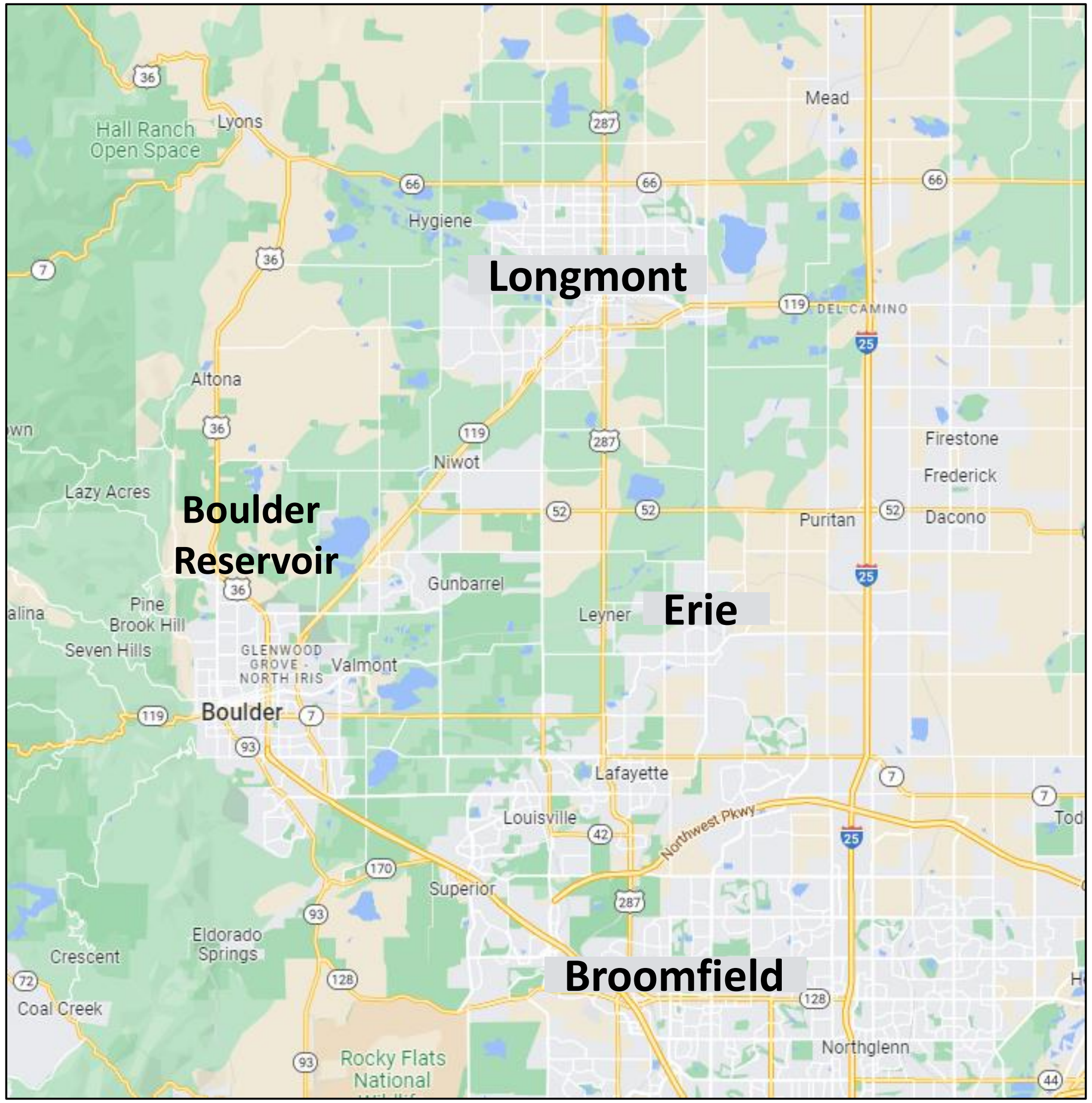
Legislative Committee on Ozone Air Quality

October 13, 2023

Presenters

- **Boulder County**
  - Cindy Copeland, Air & Climate Policy Advisor, Boulder County Commissioners' Office
- **Longmont**
  - Dr. Jane Turner, Oil & Gas & Air Quality Program Manager
- **Erie**
  - David Frank, Energy & Environmental Program Specialist
- **City and County of Broomfield**
  - Dr. Meagan Weisner, Senior Environmental Epidemiologist, Department of Public Health and Environment

Front Range Local Government Air Quality Study Locations



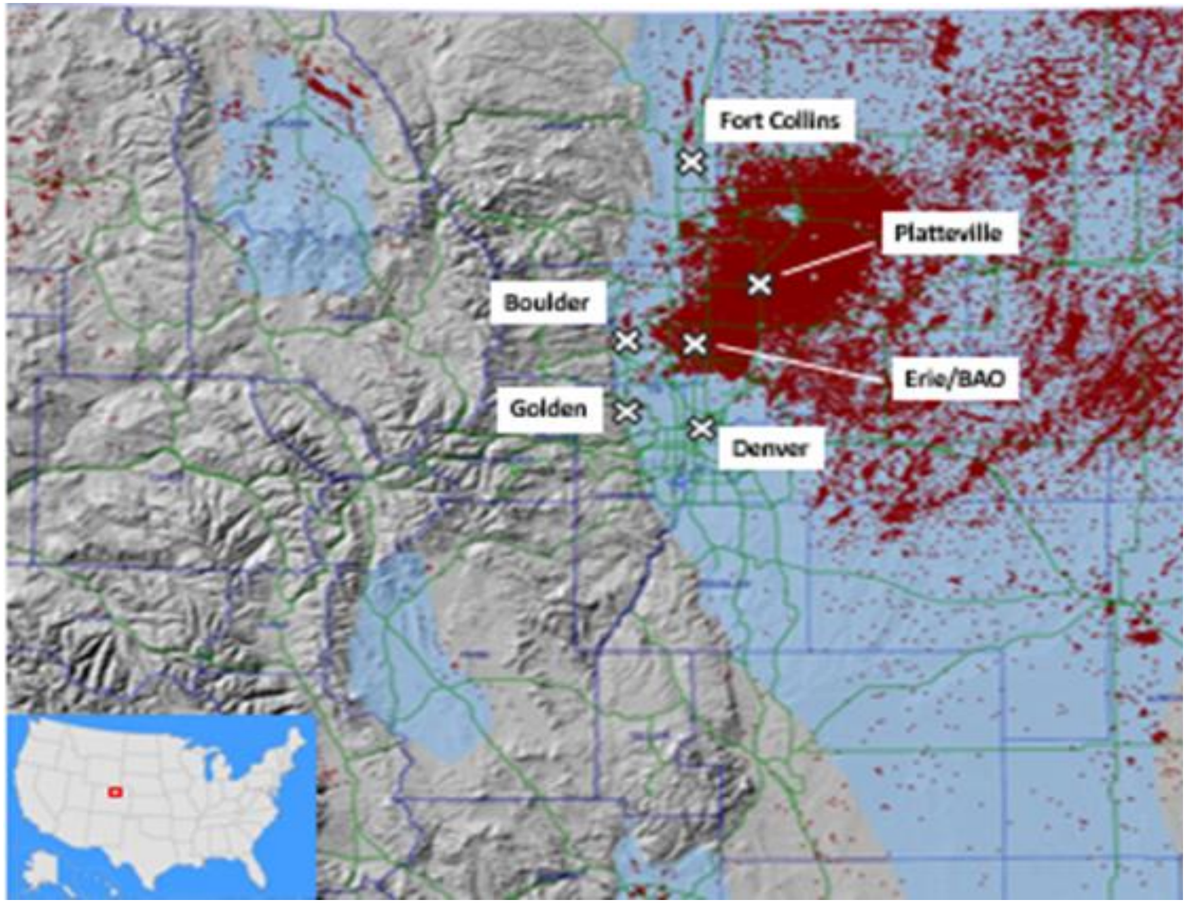
- **Boulder County**
  - 1 Boulder AIR Station
    - 2017 to present
- **City of Longmont**
  - 2 Boulder AIR Stations
    - Late 2019 to present
- **City & County of Broomfield**
  - 2 Boulder AIR Stations
    - 2020 to present
  - 5 Ajax Sensors
    - 2019 to present (number of sensors scaled up or down depending on oil and gas activity)
- **Town of Erie**
  - 1 Boulder AIR Station
  - 10 Ajax Sensors
    - Fall 2021 to present

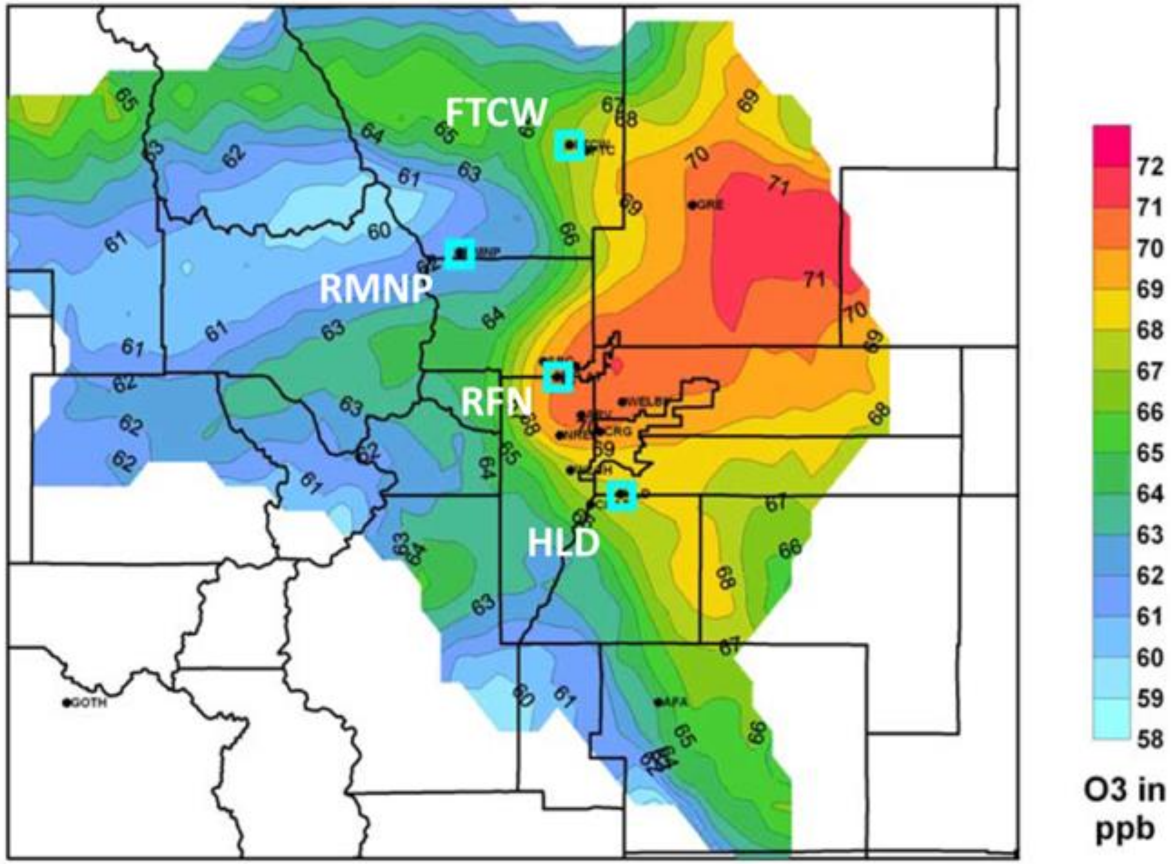
Why are local governments funding their own studies?

- Sampling near sources better reflects local emissions
- Desire to improve understanding of local air quality
  - Limited State monitors measure few pollutants
- Ozone, air toxics and other health concerns for residents
- Climate crisis
- Equity and Disproportionately Impacted Communities
- Leak detection – these emissions are not included in the inventory

Oil and gas infrastructure in Erie

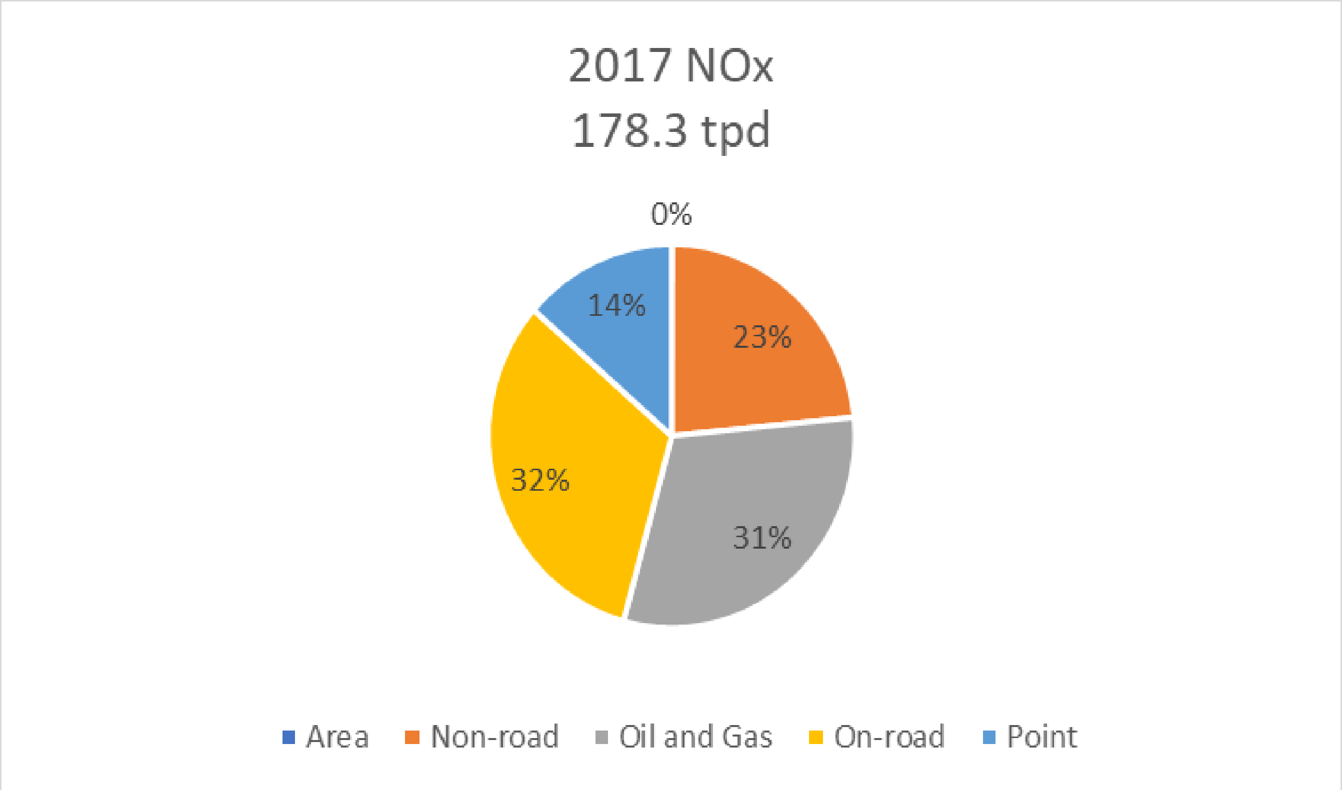
Colorado Front Range - Correlation of Oil and Gas Wells and Ozone Monitoring Data Analysis

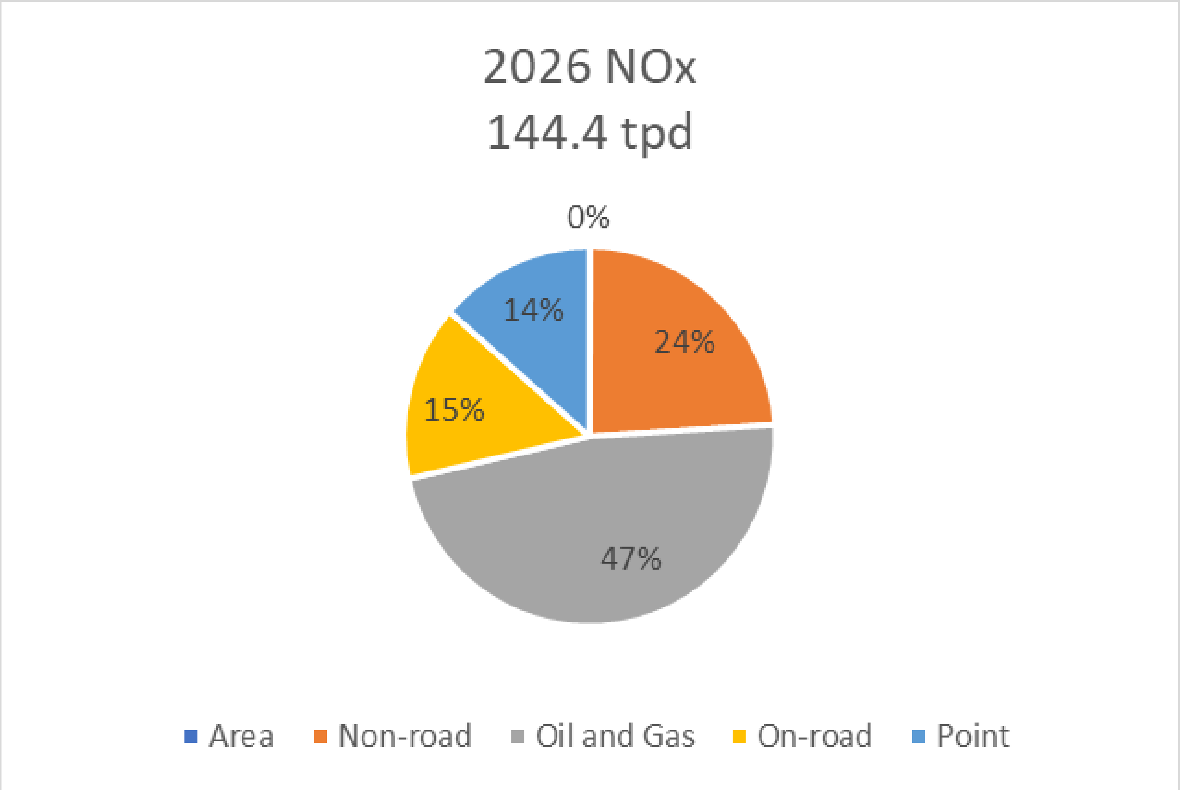




Slide Credit: Dr. Helmig, Boulder AIR

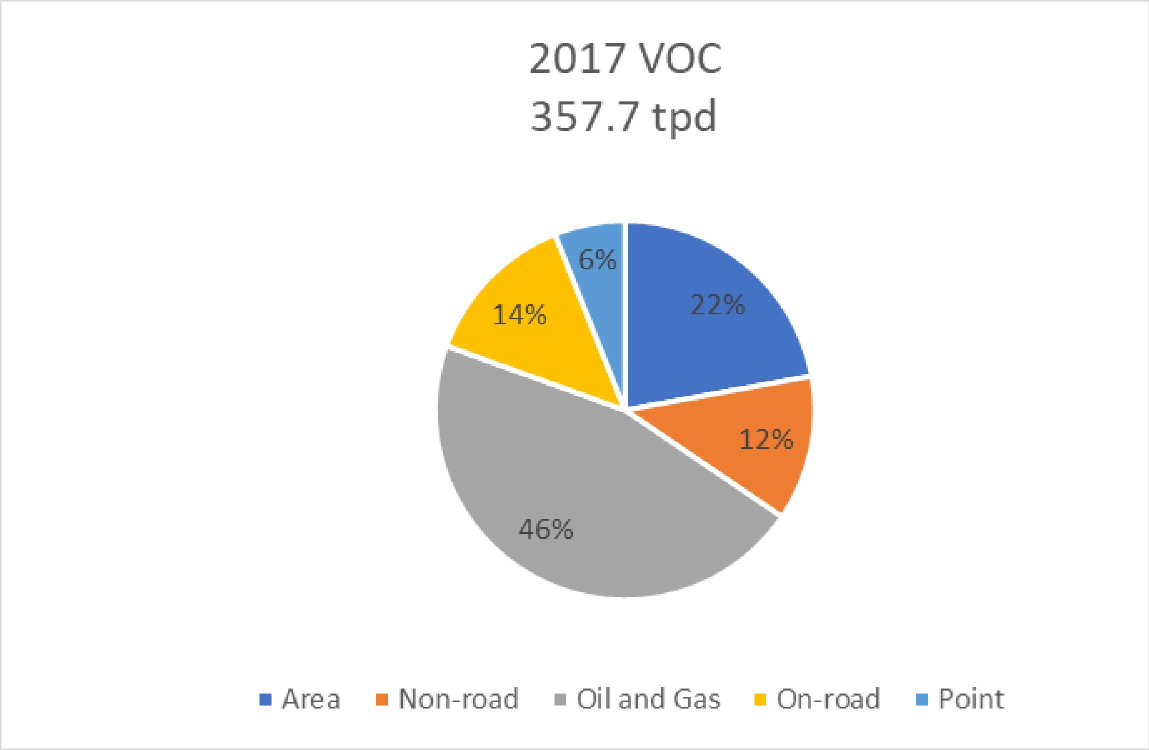
Inventoried 2017 NOX Emissions and Modeled 2026 for 2008 Boundary

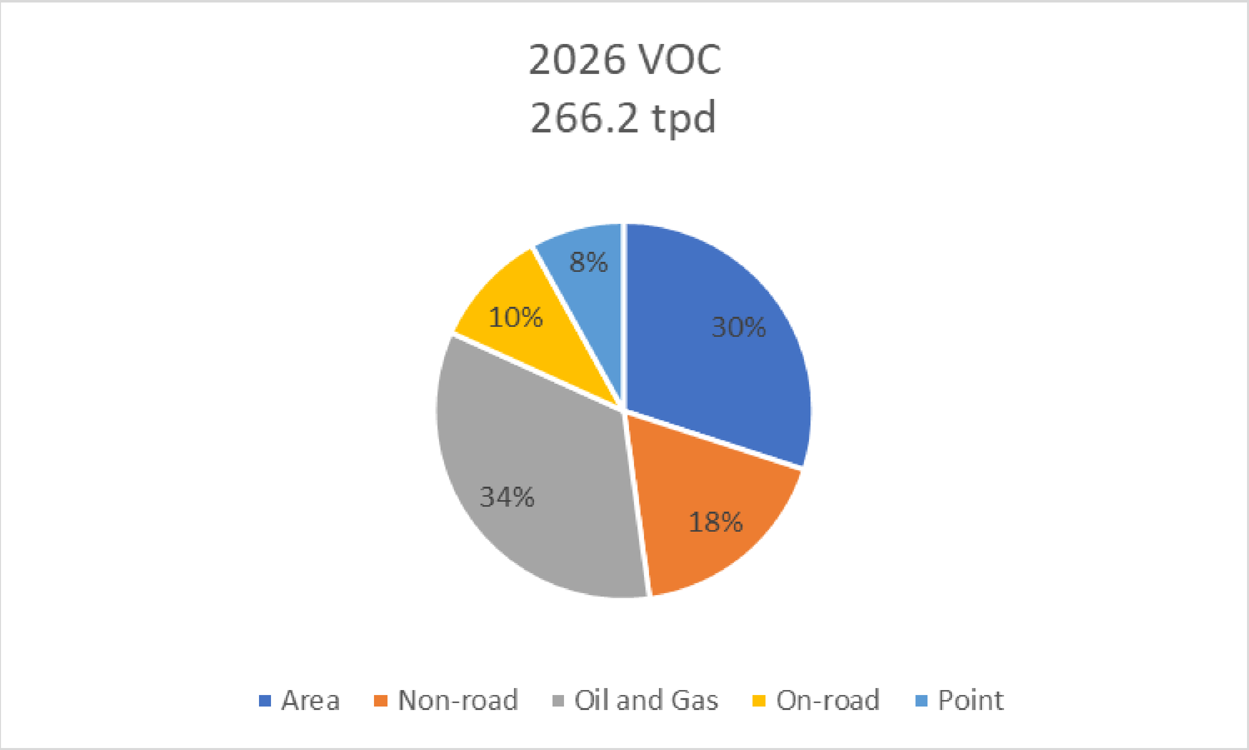




*2015 boundary emissions would be slightly higher

Inventoried 2017 VOC Emissions and Modeled 2026 for 2008 Boundary





*2015 boundary emissions would be slightly higher

Boulder County Air Studies

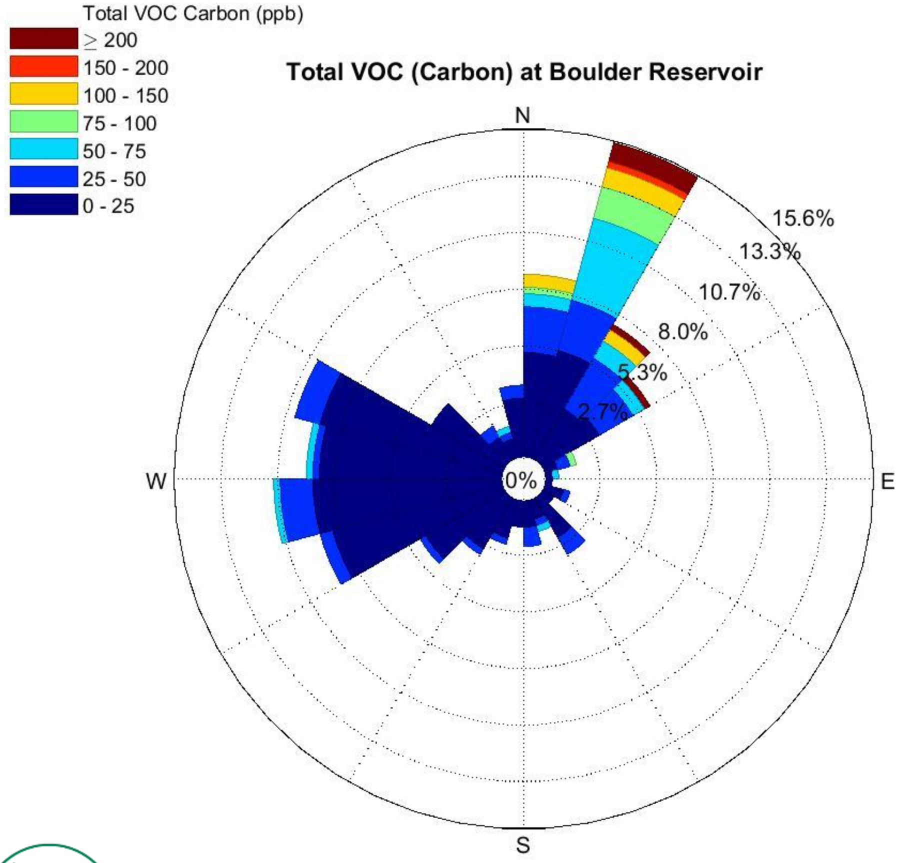
- Monitoring nitrogen oxides (NO_X), volatile organic compounds (VOCs), and methane began in 2017
- Quantify and understand impacts of oil and gas emissions on air quality
- Monitoring station located at Boulder Reservoir
  - Co-located with CDPHE's ozone monitor
- Modeling analyses of 13 non-methane VOCs (NMVOCs)
- Four peer-reviewed publications with data
- Boulder County oil & gas inspection program

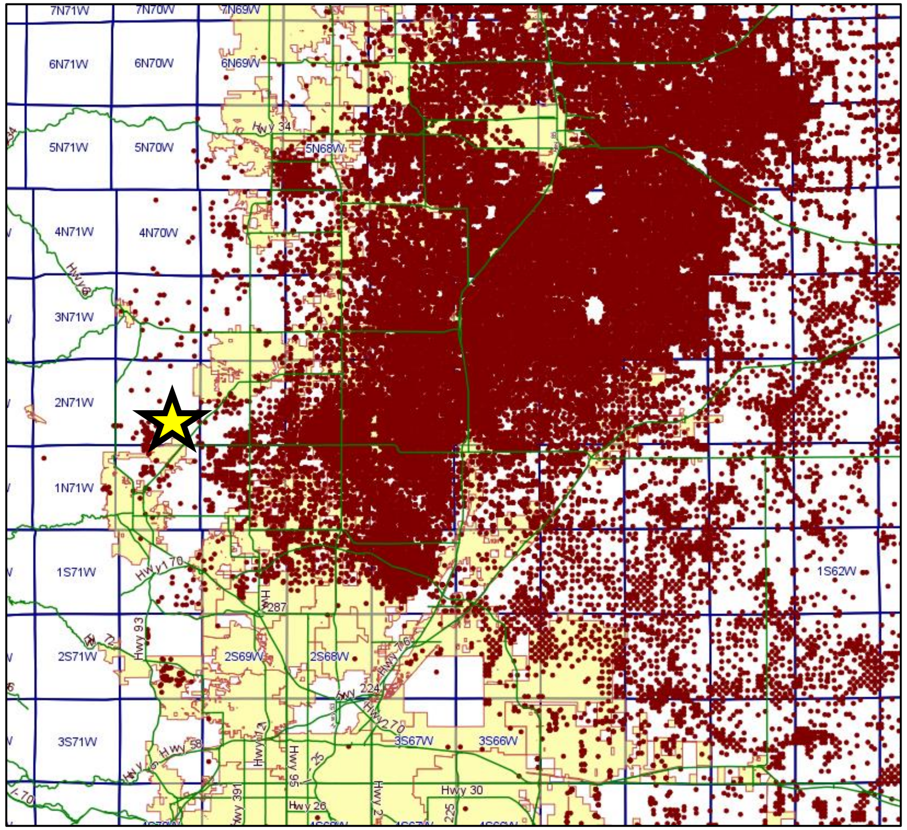
Study Findings Overview

- High correlation between concentrations and air transport
- Impacts from Northeast of site
- Link between ozone exceedances and emissions
- Ground level methane monitoring shows no decline in emissions, 2017-2021
- Oil & gas inspection program found that 64% of sites with leaks had them in multiple calendar years

Oil and gas infrastructure in Boulder County

Dependence of Concentrations on Wind Direction



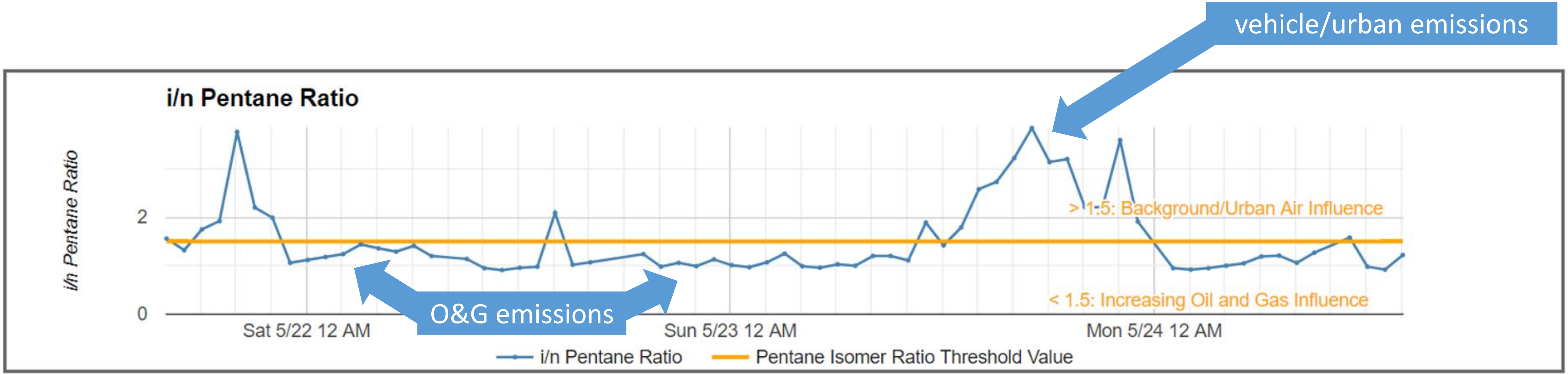


Boulder Reservoir Monitoring Station

Oil & gas well locations

Slide adapted from Boulder A.I.R.

i/n Pentane Ratio at Boulder Reservoir



In recent years, the average i/n pentane ratio at Boulder Reservoir has been 1.1, indicating that pentane emissions from oil and gas production are more prevalent than pentane emissions from vehicles and urban areas.

Colorado State University Modeling Analyses

- Partnered with CSU to analyze Boulder County air monitoring data (data record goes back to 2017)
  - Multiyear dataset of 13 nonmethane VOCs
  - Estimates oil and gas and other source contributions to NMVOCs
- 2 separate modeling analyses show that:
  - Elevated VOCs and non-methane VOCs are associated with oil and gas producing regions[1]
- The majority of high ozone days analyzed were not impacted by wildfire smoke[2]

1. Seasonality and Source Apportionment of Nonmethane Volatile Organic Compounds at Boulder Reservoir, Colorado, Between 2017 and 2019 – Pollack et al., 2021

2. Weekend-Weekday Implications and the Impact of Wildfire Smoke on Ozone and Its Precursors at Boulder Reservoir, Colorado Between 2017 and 2019 – Pollack et al., 2021

Methane Trends at Boulder Reservoir

- Soon to be published study of 2017-2021 data
- Difference between methane from West is consistently lower than levels from the Northeast (DJB)
- Levels have not decreased from 2017-2021
- No indications of reductions in local methane

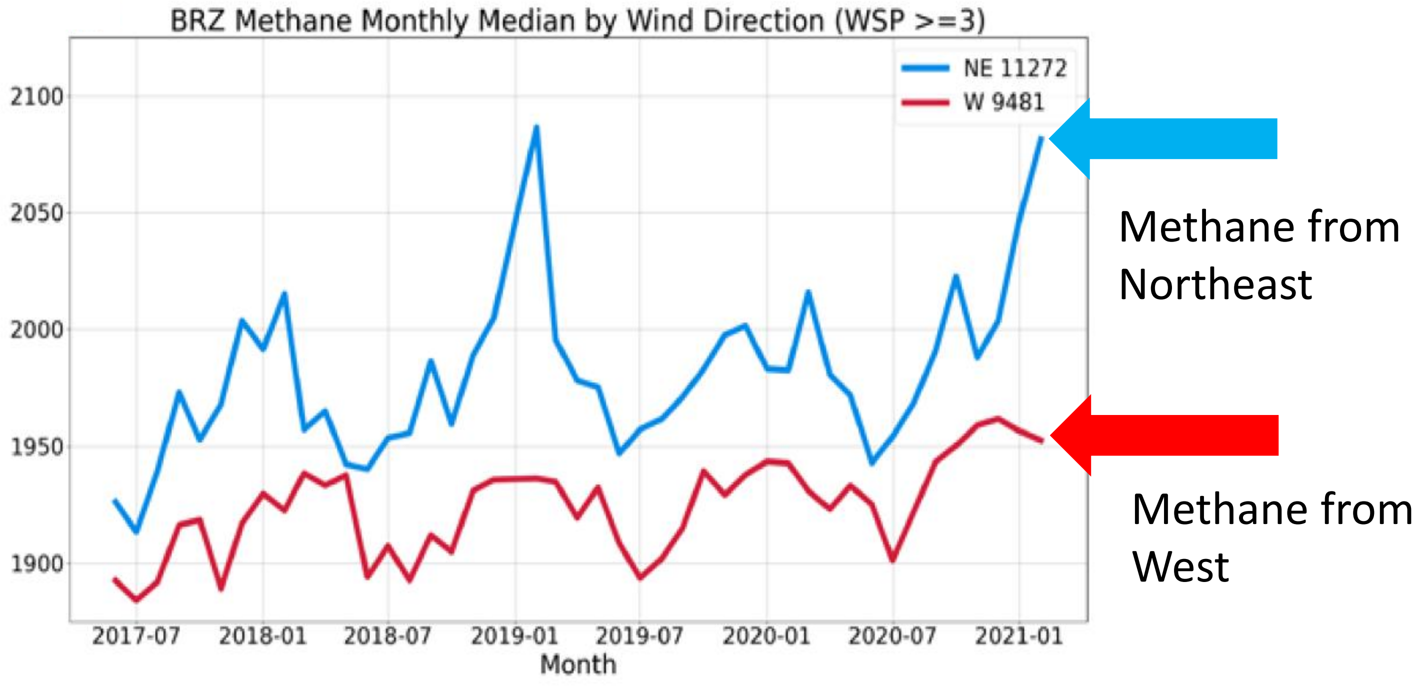


Figure adapted from Boulder A.I.R.
Graph shows methane when winds are greater than 3 m/s.

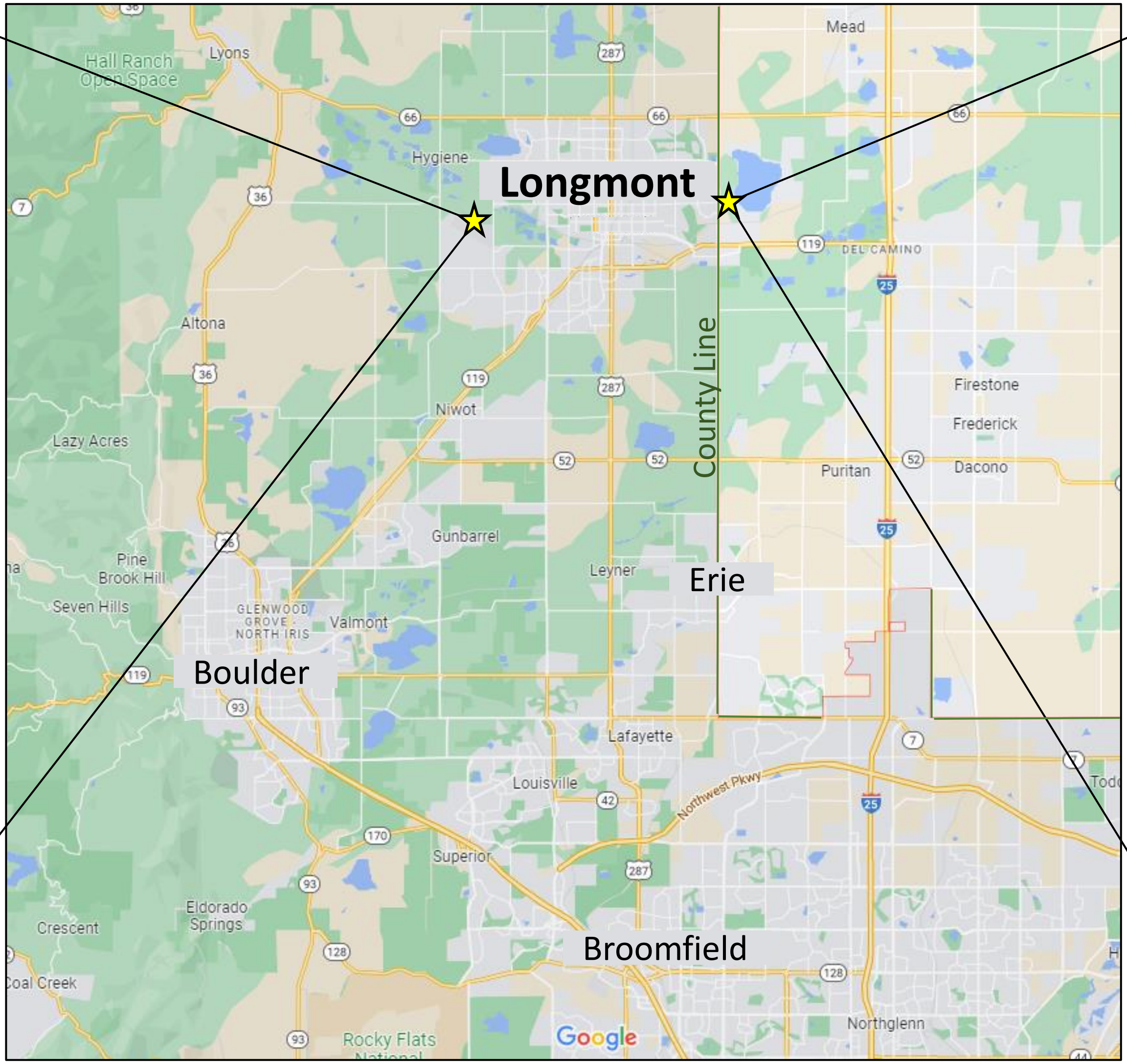
Boulder County

City of Longmont Air Quality Study

Jane Turner, PE, PhD
Oil & Gas and Air Quality Program Manager
Local Governmental Designee, COGCC

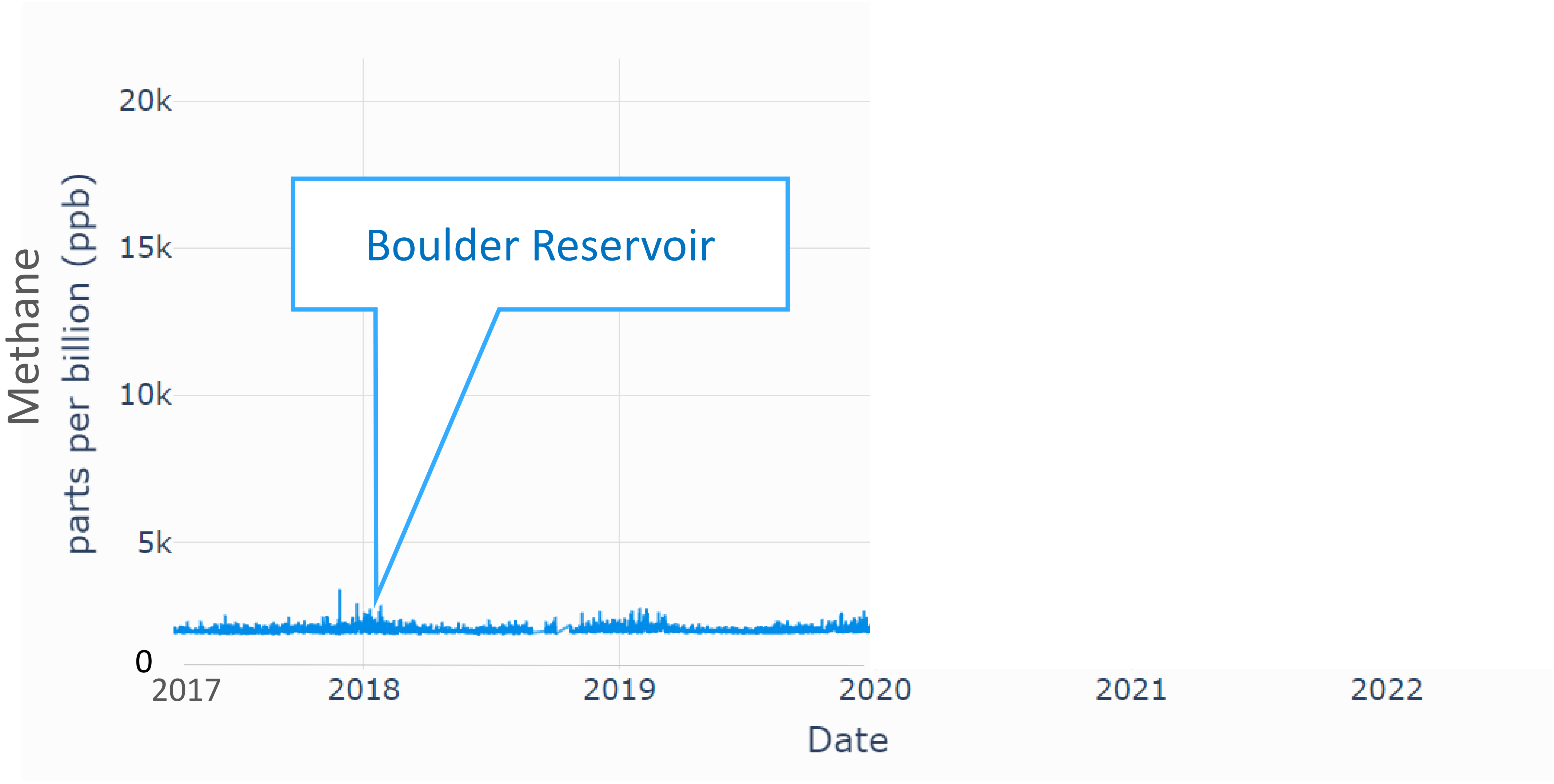
City of Longmont

Lykins Gulch Station

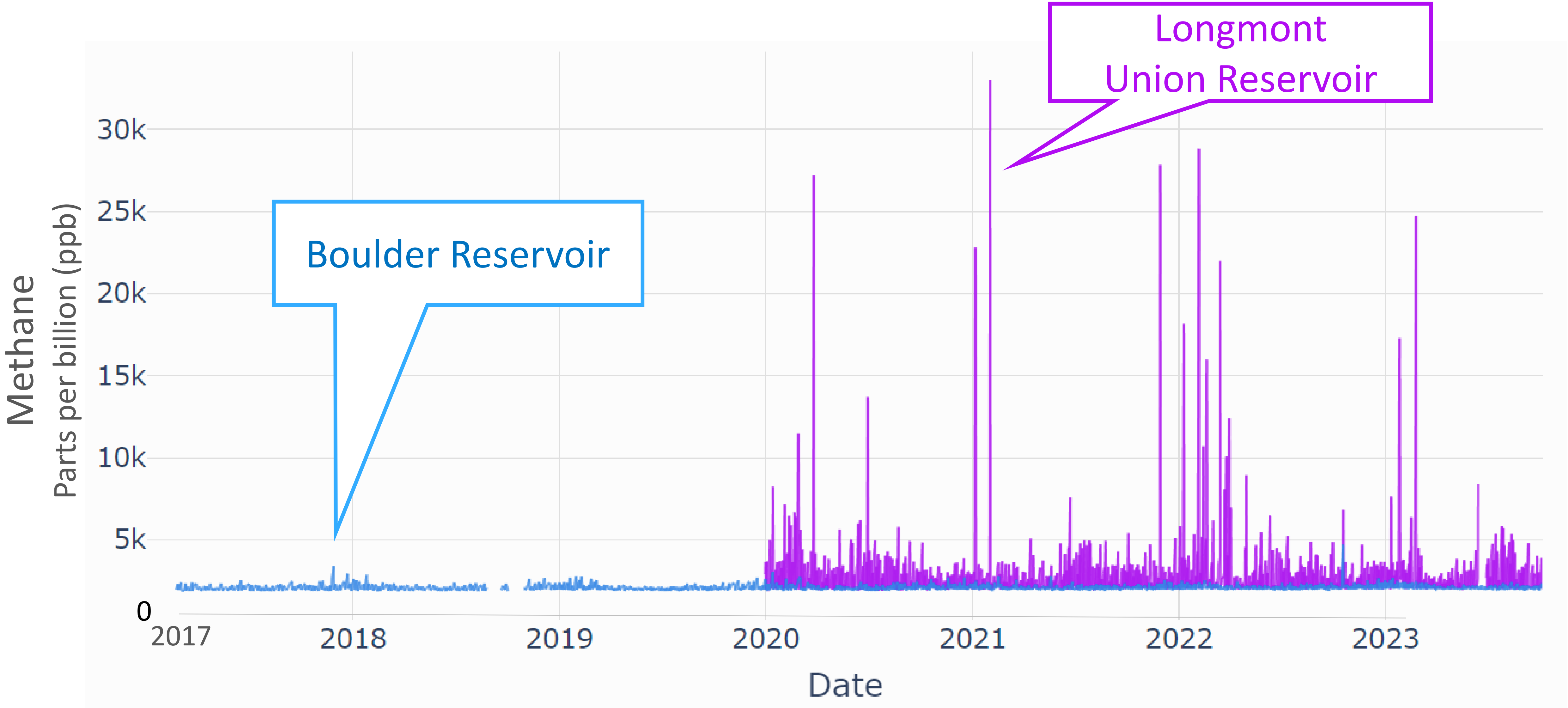


Union Reservoir Station

Methane:
Boulder Reservoir vs. Union Reservoir



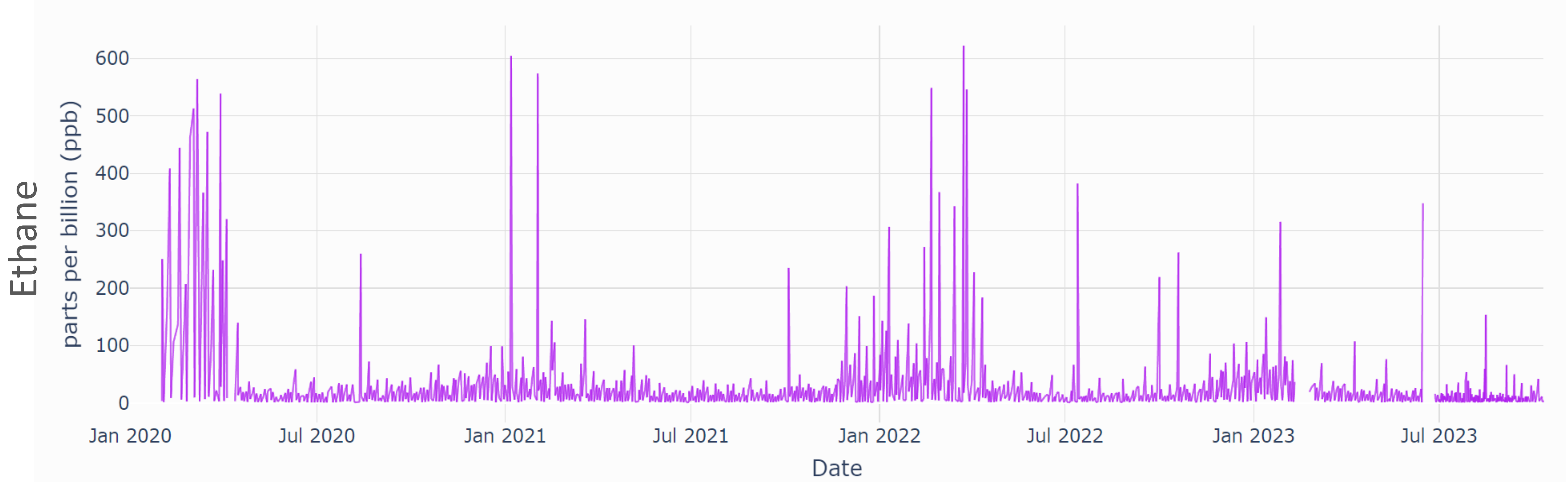
Methane:
Boulder Reservoir vs. Union Reservoir



Ethane plumes: Longmont Union Reservoir

Ethane is a selective tracer for oil and gas activity because there are few other sources.

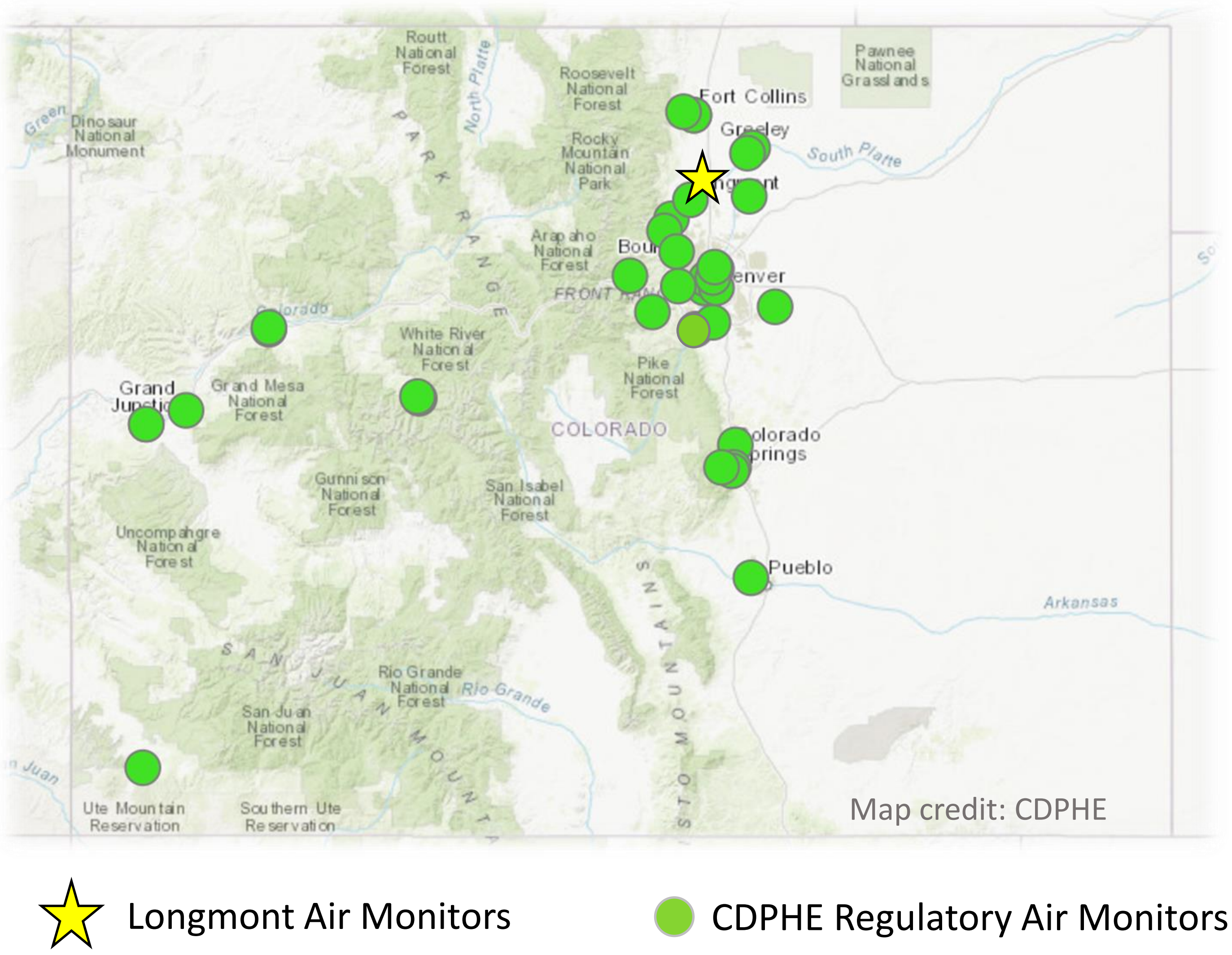
Over 400 major ethane plumes recorded measured since monitoring began.



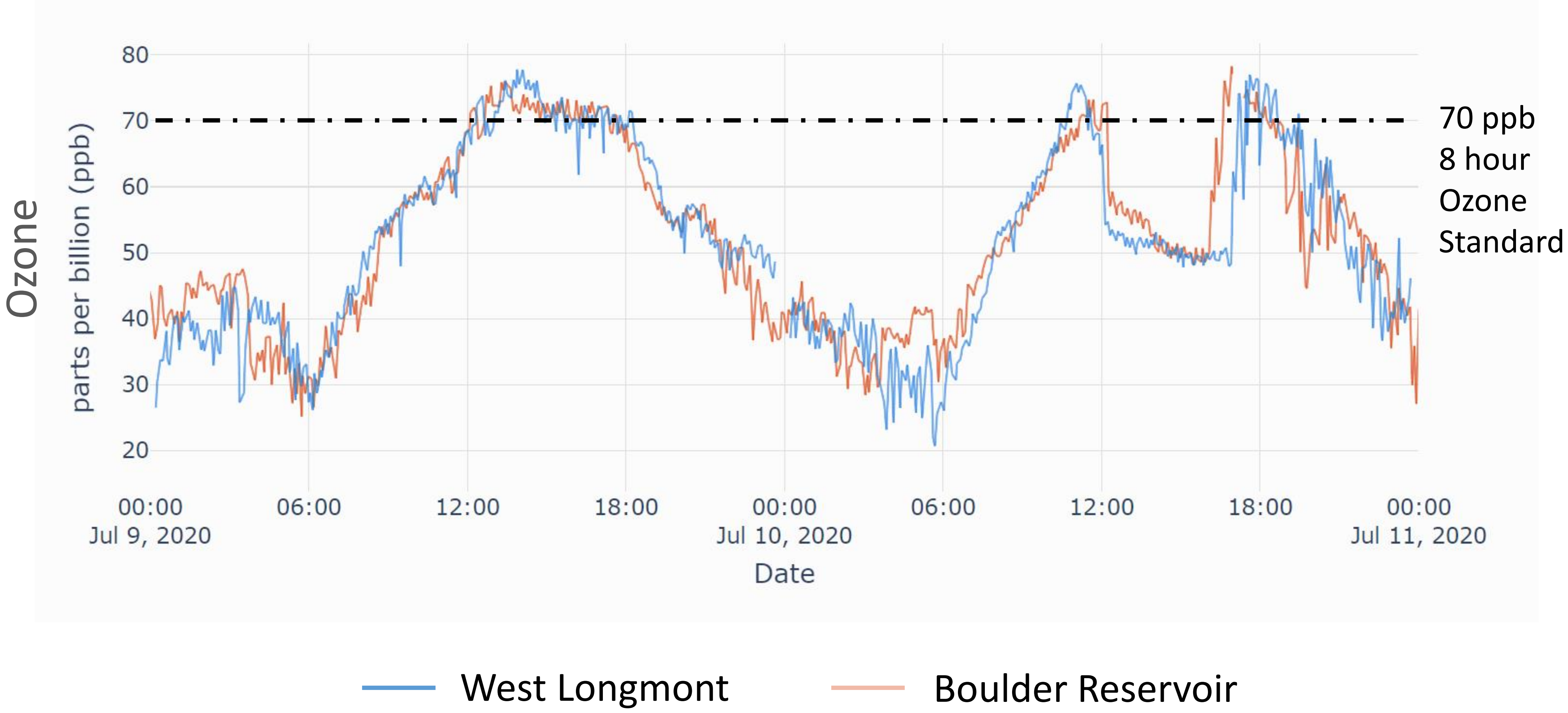
Ethane >25 times higher than background levels considered to be a plume

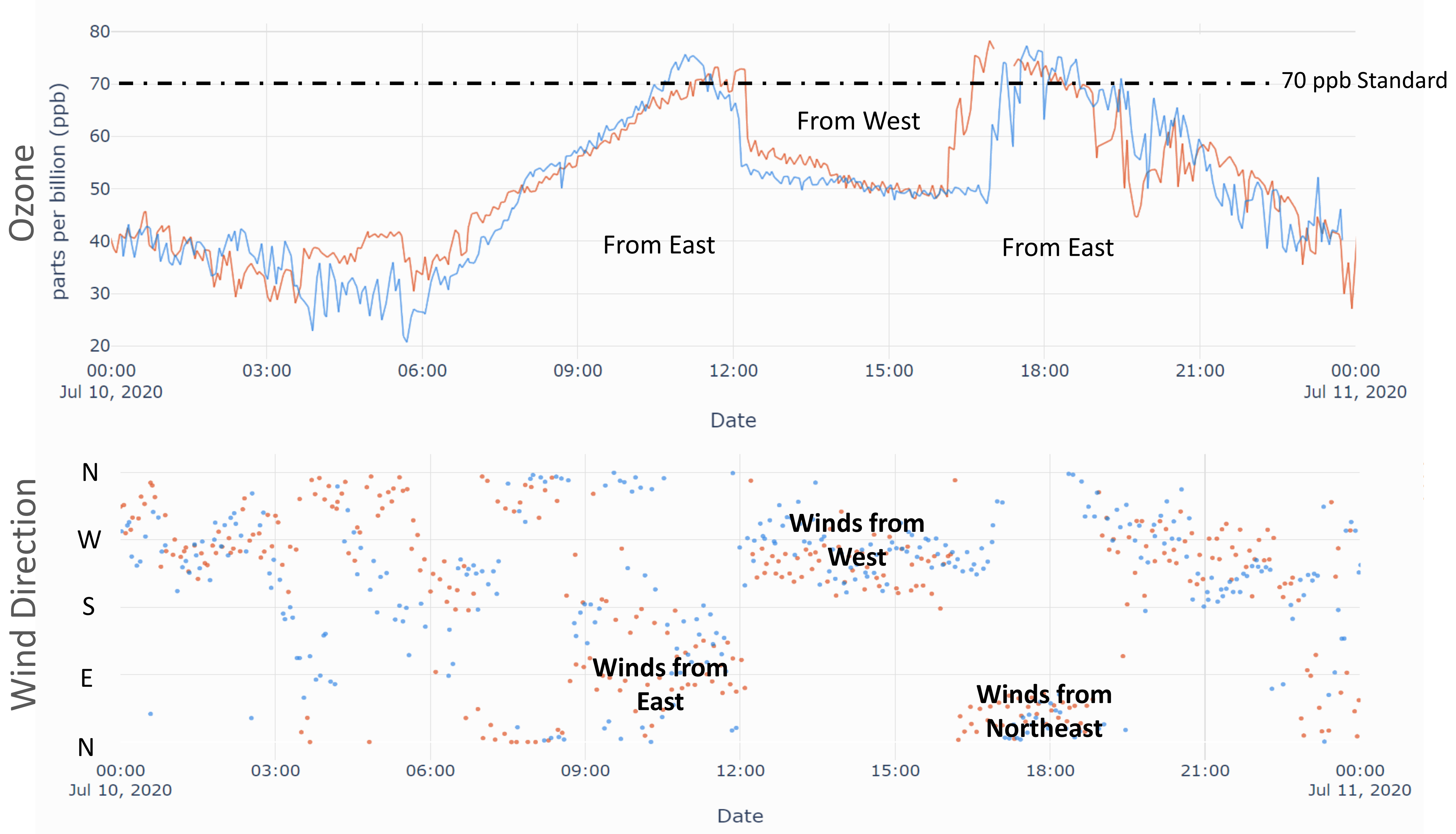
Ozone in Longmont

- Ozone is regional pollutant
- CDPHE has 32 regulatory monitors
  - Highest ozone locations
    - NREL (Boulder)
    - Rocky Flats
    - Chatfield S.P. (Littleton)
- Longmont's Ozone
  - ~ 7th highest in the State



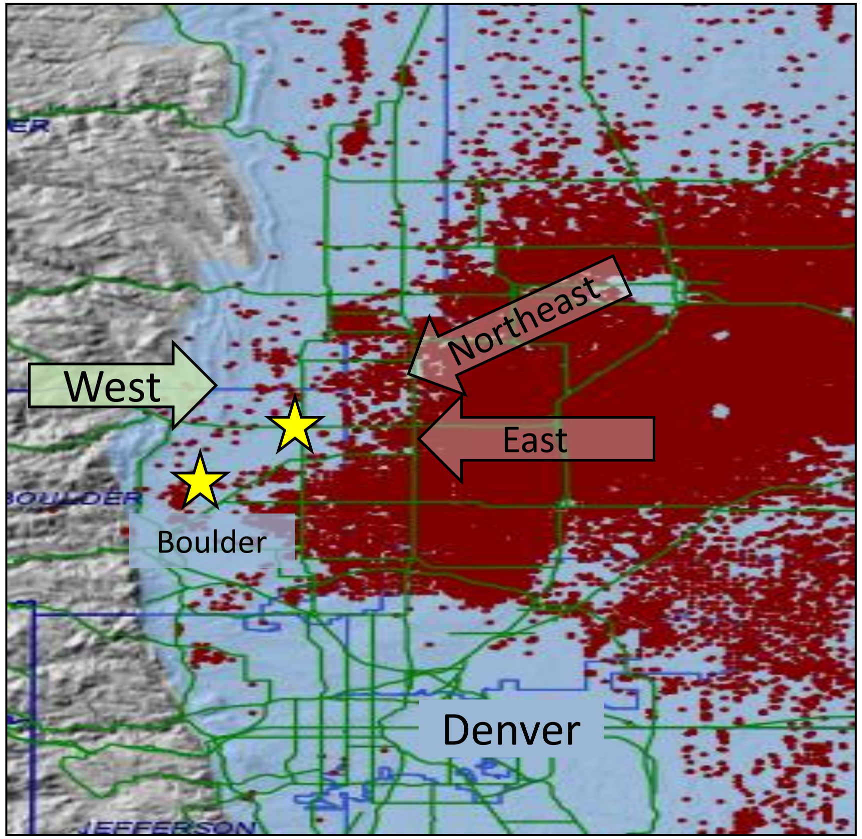
Ozone Patterns





Ozone
parts per billion (ppb)
80
70
60
50
40
30
20
70 ppb Standard
From West
From East
From East
00:00
Jul 10, 2020
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Jul 11, 2020
Date
Wind Direction
N
W
S
E
N
Winds from West
Winds from East
Winds from Northeast
00:00
Jul 10, 2020
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Jul 11, 2020
Date

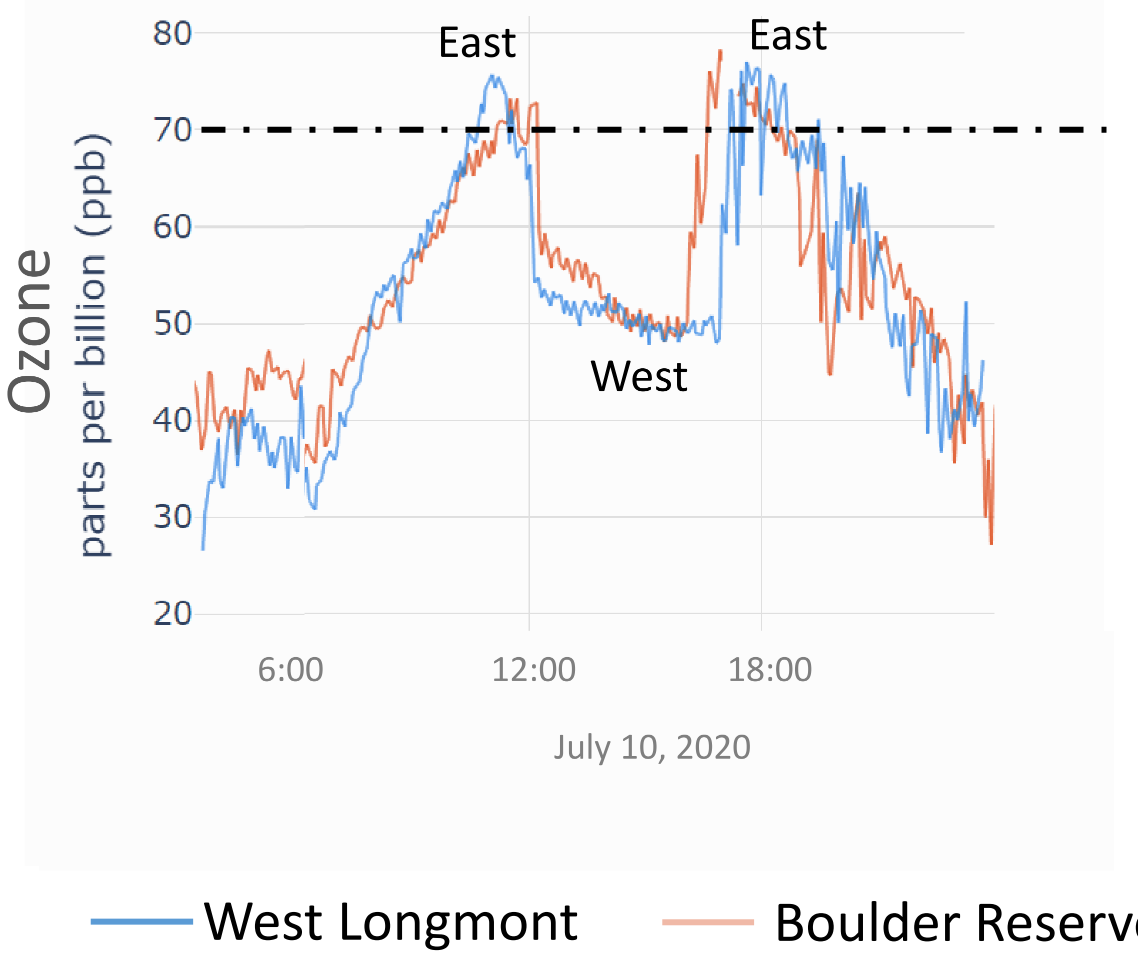
Ozone Patterns



Local Govt. Air Monitors

Oil & Gas Wells

Map credit: CECMC



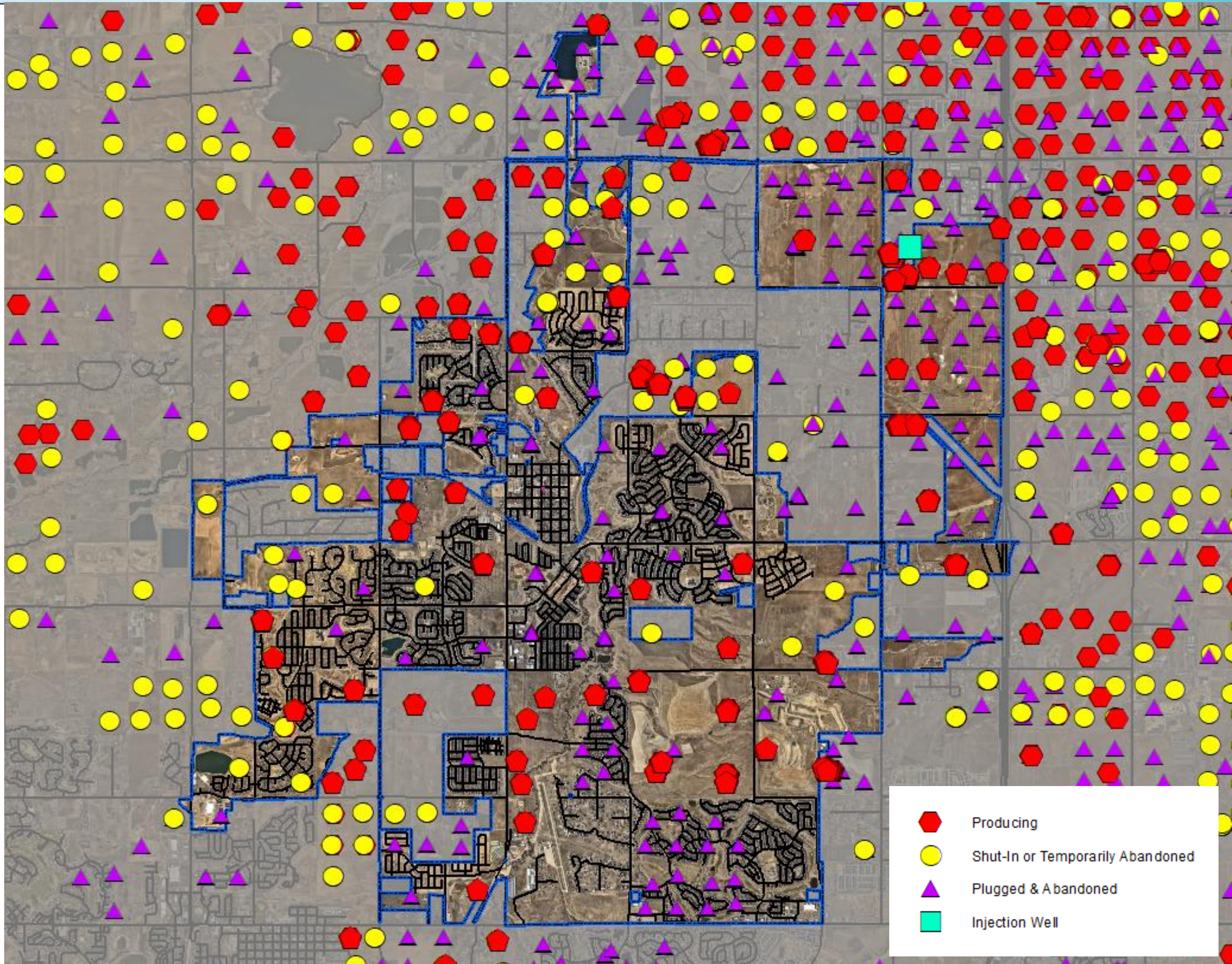
Town of Erie Air Quality Monitoring Program

David Frank
Energy and Environmental Program Specialist
Local Governmental Designee, CECMC

TOWN OF ERIE
1874

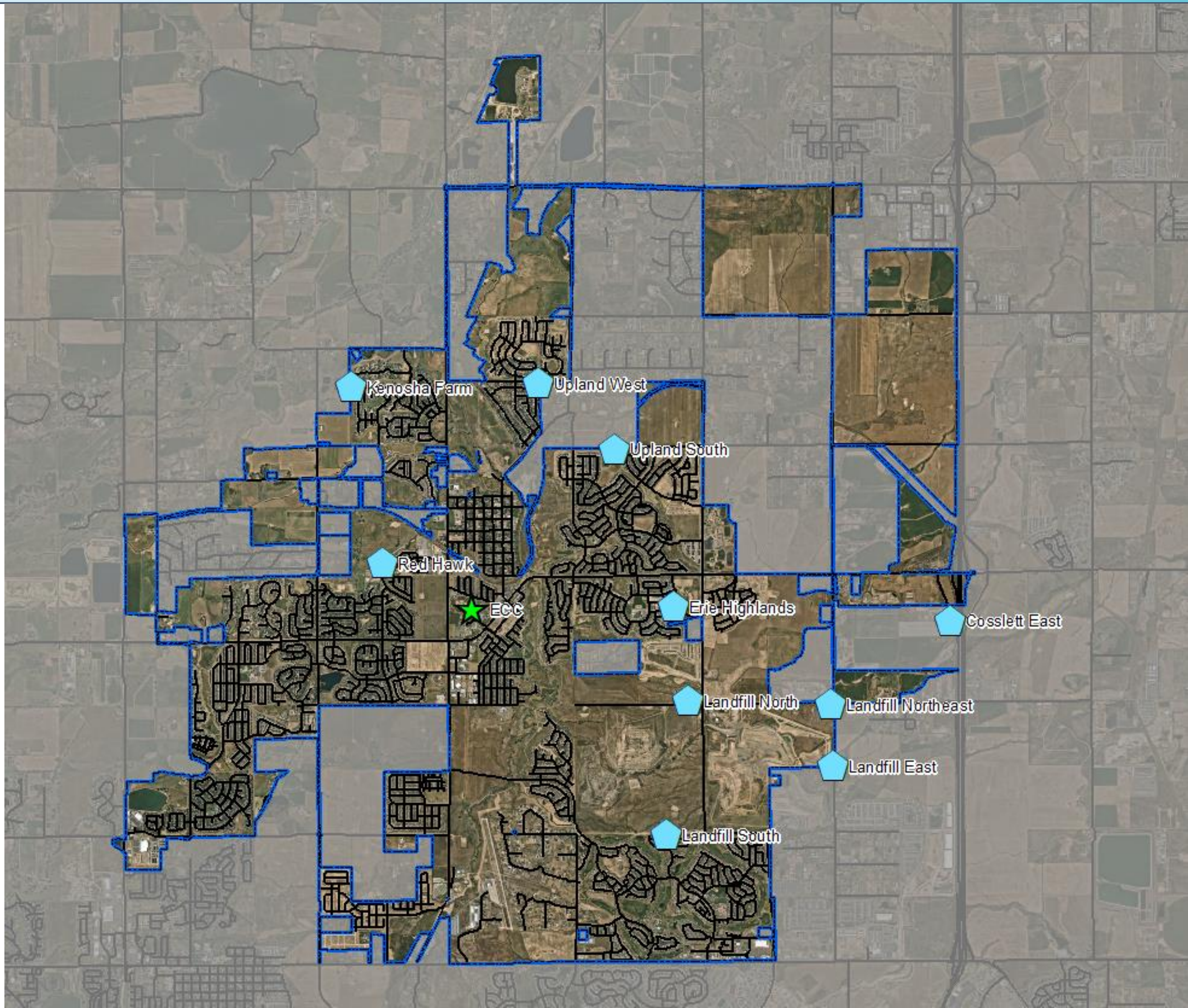
Oil and Gas Facilities near Erie

- 138 O&G wells within Erie limits (101 producing, 36 shut-in, 1 TA)
- 296 O&G wells within 2,000ft of Erie (223 producing, 60 shut-in, 13 TA)
- 209 Plugged and abandoned wells within Erie limits (13 pre-2013)
- 172 Plugged and abandoned wells within 2,000ft of Erie (29 pre-2013)
- 1 Deep Injection Well



Erie Air Quality Monitoring Program

- Contracts with Ajax Analytics/CSU and Boulder AIR approved May 11, 2021
- Site Selection and equipment deployment completed September, 2021
- 10 Ajax/CSU Monitoring Stations
- 1 BoulderAIR Monitoring Station



Erie Ajax/CSU Monitoring Stations

Ajax/CSU Stations located in Erie and Broomfield

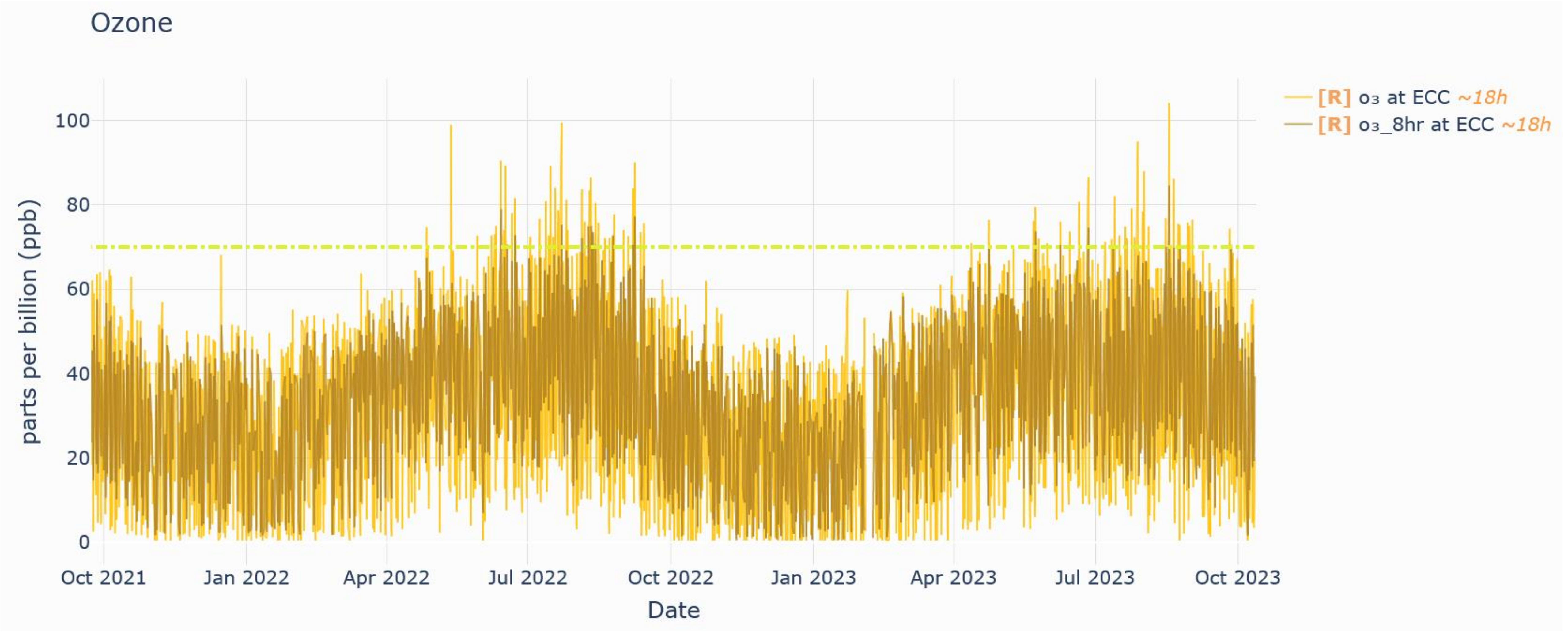
- Weekly whole air SUMA Canister Samples at four sites
- PID sensor triggered SUMA Canister sampling to capture plume events
- 49 VOCs analyzed at the CSU Atmospheric Sciences Lab

Erie BoulderAIR Monitoring Station

Boulder AIR Station located at the Erie Community Center

- Real-time monitoring of meteorological conditions as well as atmospheric constituents including methane (CH_4), volatile organic compounds (VOCs), ozone (O_3), and particulate matter (fine and coarse aerosol).
- >80,000 ozone measurements collected to date

Erie BoulderAIR Ozone Observations



Dependency of elevated Ozone on Wind Direction and Speed

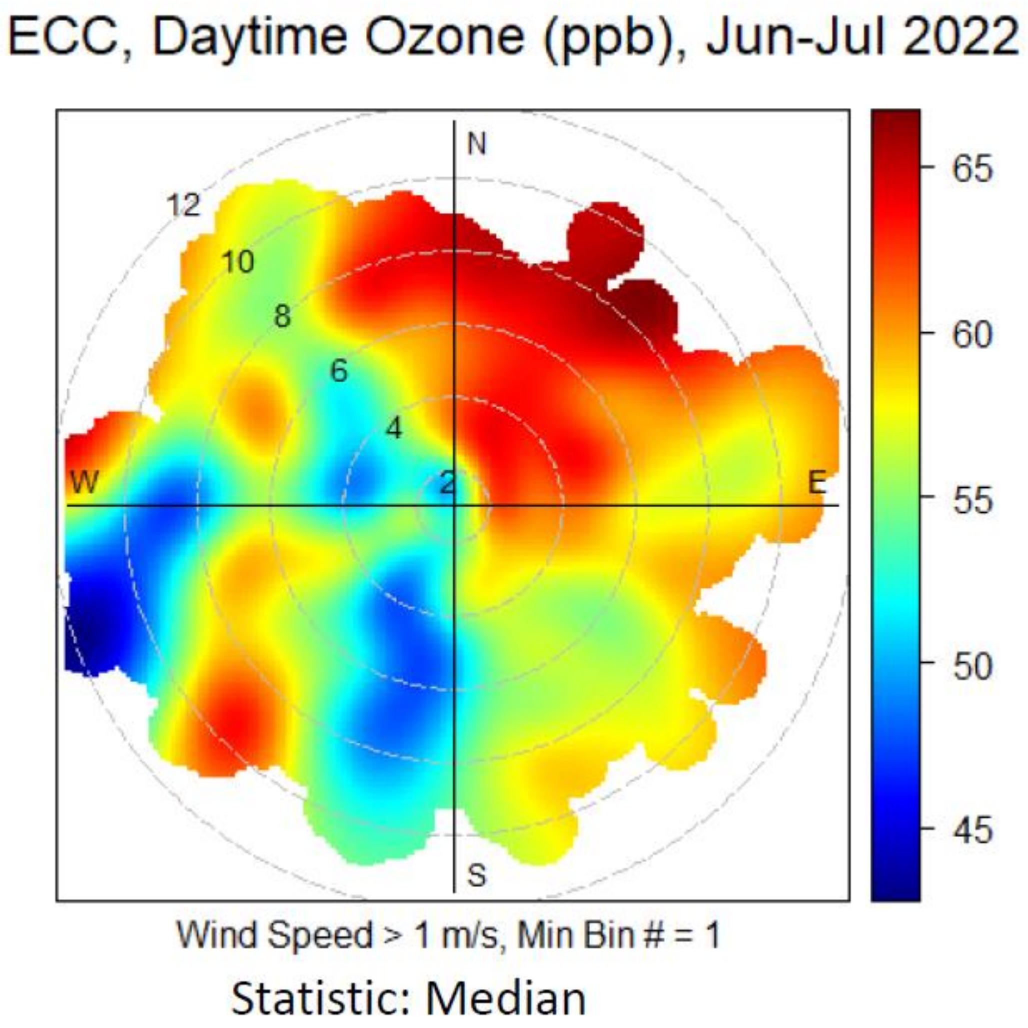
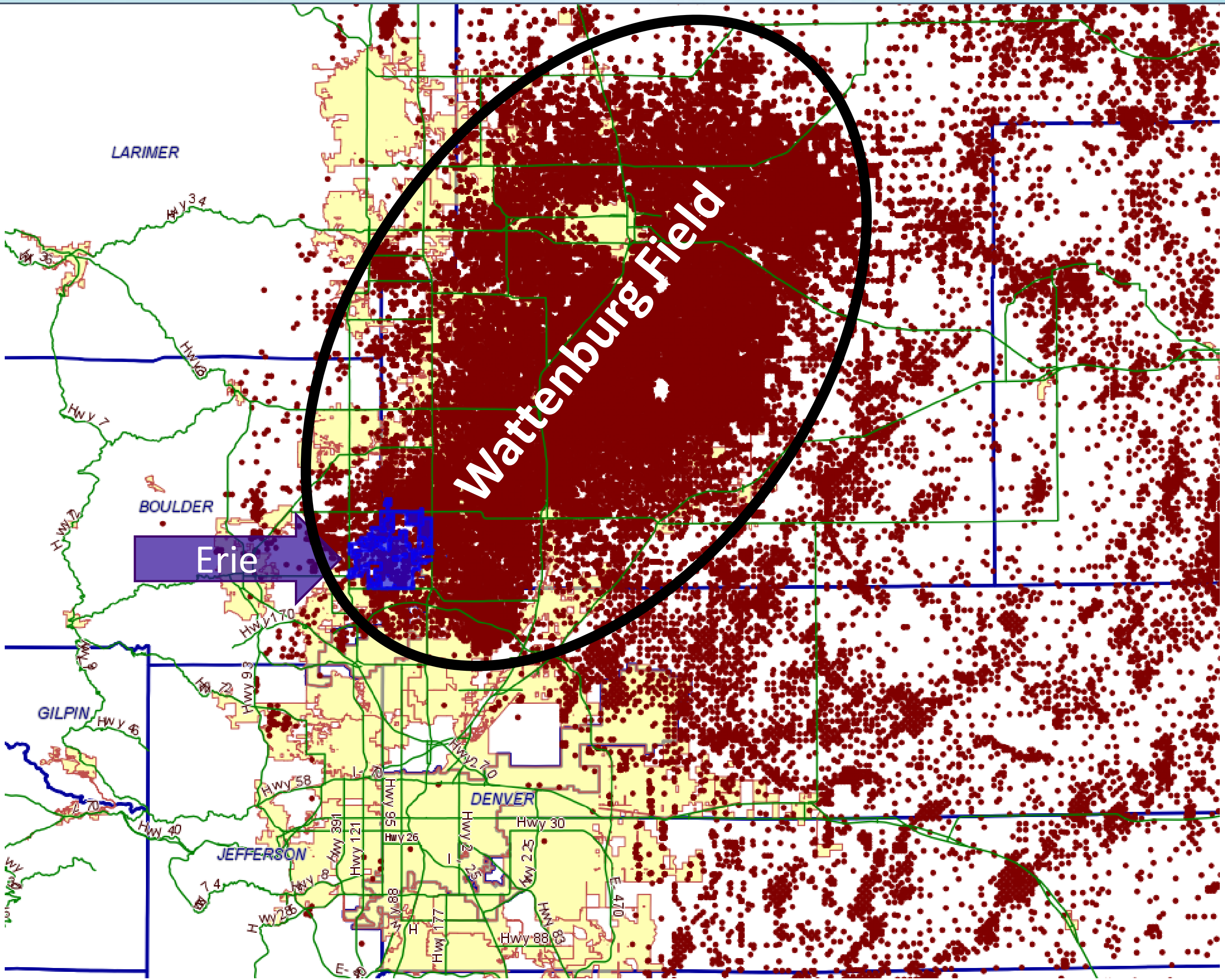


Image credit to BouderAIR, Dr. Detlev Helmig

Wattenburg Field of the DJ Basin



Oil & gas well locations

Image credit to CECMC

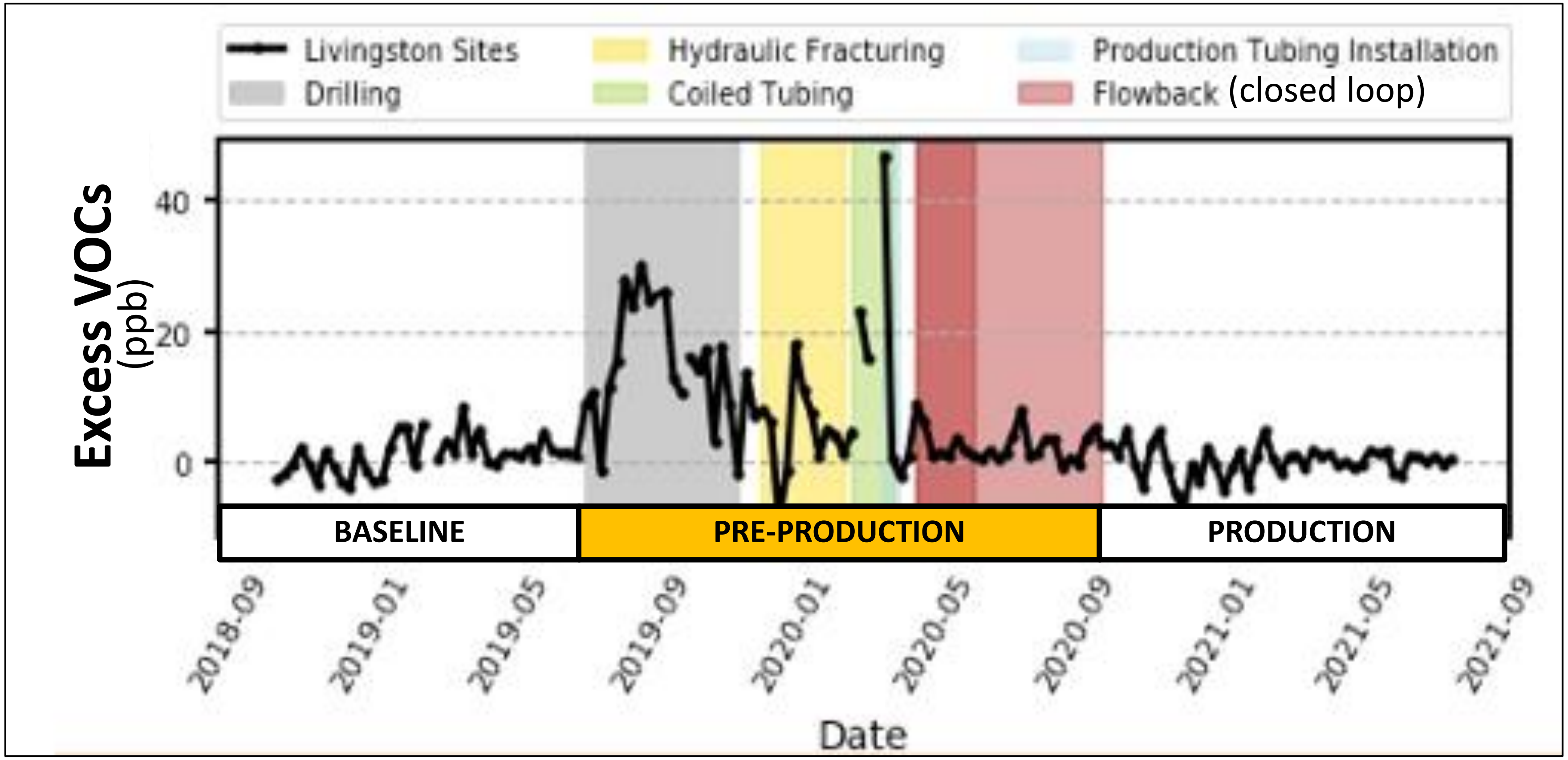
City and County of Broomfield Air Quality Monitoring

Meagan Weisner, PhD
Senior Environmental Epidemiologist
Department of Public Health and Environment

CITY AND COUNTY OF BROOMFIELD • COLORADO •

City & County of Broomfield

Pre-production oil and gas activity is a clear contributor of excess volatile organic compounds (VOCs) which contributes to ozone formation.



- Broomfield has an extensive air monitoring program which pairs understanding toxic air plumes from oil and gas with associated health concerns.
- Data from Broomfield's weekly air canister sample program shows pre-production activity is associated with excess VOCs and air toxics over baseline.
- Known carcinogens have been observed, including benzene.

City & County of Broomfield

Researchers from Colorado State University analyzed 3+ years of Broomfield air monitoring data (Ku et al. manuscript submitted for publication) and found:

- Before well development, VOC gradients were small across Broomfield.
- More than 90 samples were collected of transient plumes associated with specific unconventional oil and gas development (UOGD) operations.
- Weekly benzene concentrations increased around the well pads during pre-production operations, the maximum weekly concentration was 0.8 ppbv, four times above background.

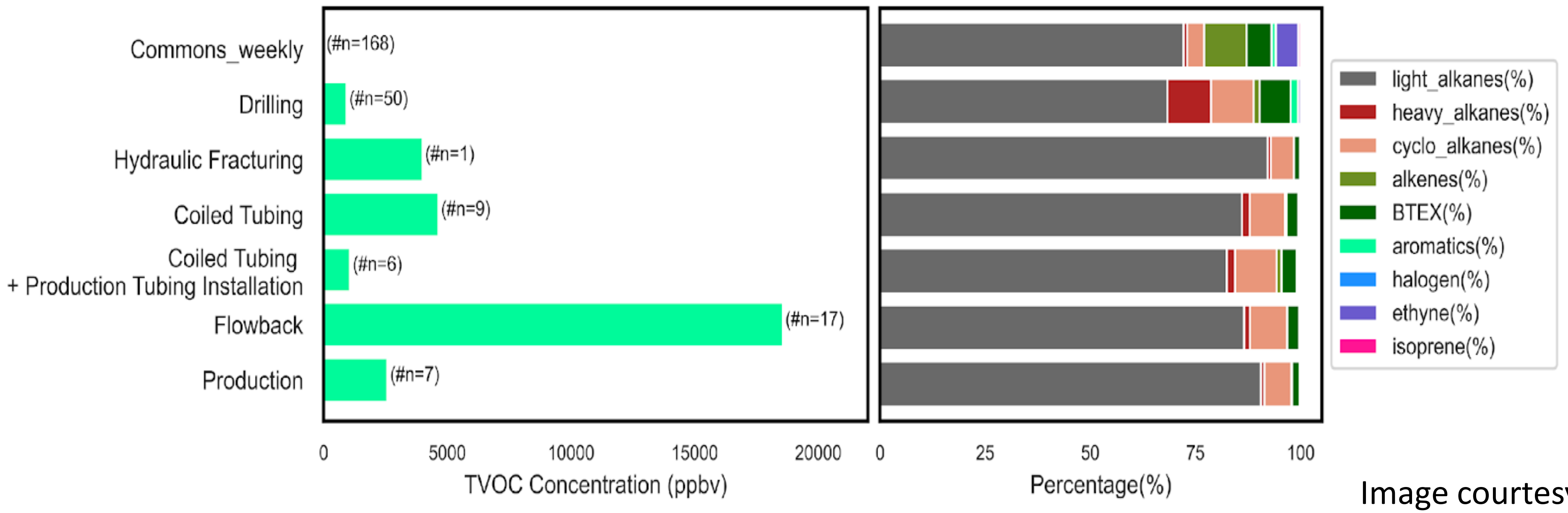
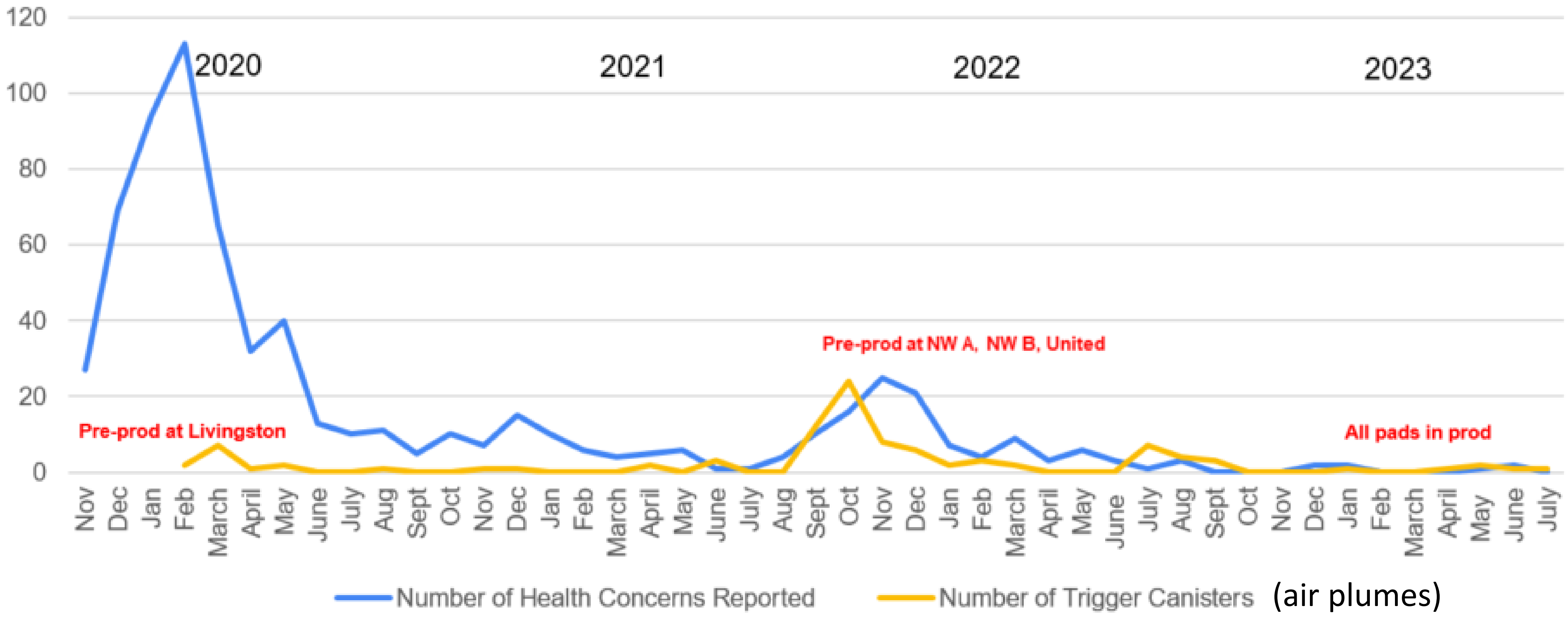


Image courtesy of CSU

Although the UOGD operations in Broomfield use extensive best management practices, better control of emissions is needed to improve air quality.

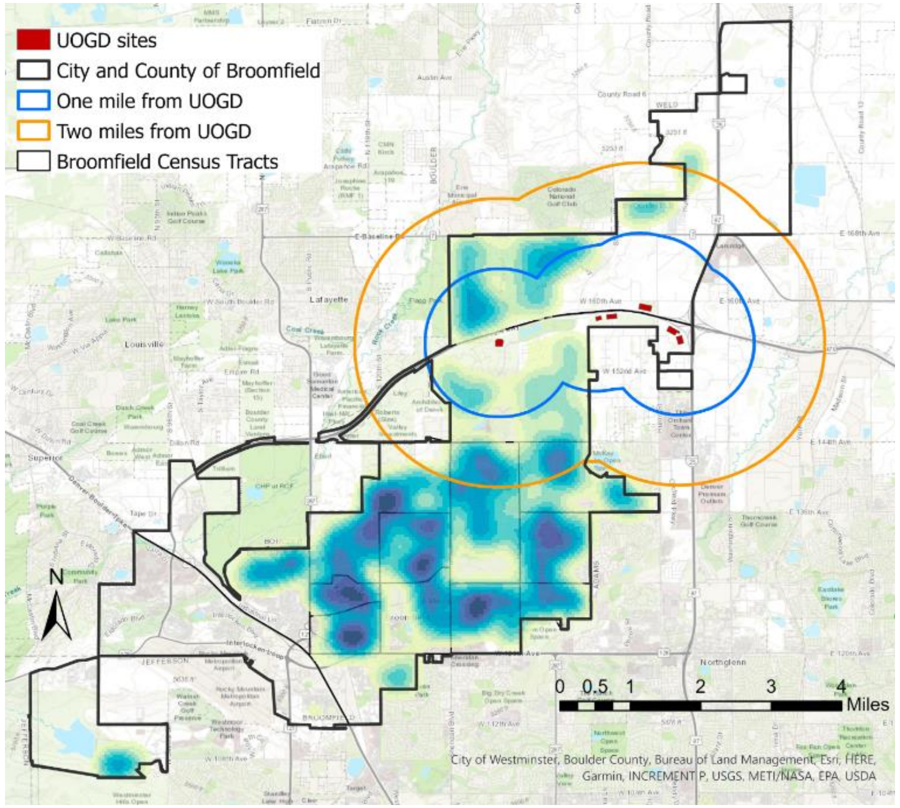
City & County of Broomfield



(air plumes)

City & County of Broomfield

Oil and Gas Health Study



Kernel Density map indicating location densities of 3993 households randomly selected to participate in the health survey. Darker colors indicate a greater number of surveys were sent to that location.

Overall Goal:

- The City and County of Broomfield's Department of Public Health and Environment, along with researchers from the University of Colorado School of Public Health, collected health data from 427 randomly identified Broomfield residents (living in separate households) to better understand self-reported health symptoms associated with living in proximity to unconventional oil and gas development sites.

During the time health data was collected (October-December 2021), 3 UOGD sites were in pre-production phases in Broomfield and the air monitoring network captured dozens of plumes associated with air toxic releases during oil and gas pre-production operations.

City & County of Broomfield

Oil and Gas Health Study

International Journal of
Environmental Research and Public Health

Health Symptoms and Proximity to Active Multi-Well Unconventional Oil and Gas Development Sites in the City and County of Broomfield, Colorado

by Meagan L. Weisner [1,*], William B. Allshouse [2], Benjamin W. Erjavac [2], Andrew P. Valdez [3], Jason L. Vahling [1] and Lisa M. McKenzie [2]

Publication link: https://www.mdpi.com/1660-4601/20/3/2634

Results:

- Adult respondents living within 1 mile of a UOGD site in Broomfield reported greater frequencies of upper respiratory and acute symptoms (nausea, nosebleeds, shortness of breath, cough, throat irritation) than respondents living more than 2 miles from UOGD sites.

- Children living within 2 miles of a UOGD site were reported by their parents to have experienced greater frequencies of lower respiratory, gastrointestinal, and acute response symptoms than children living greater than 2 miles from UOGD sites.

Key Local Government Findings

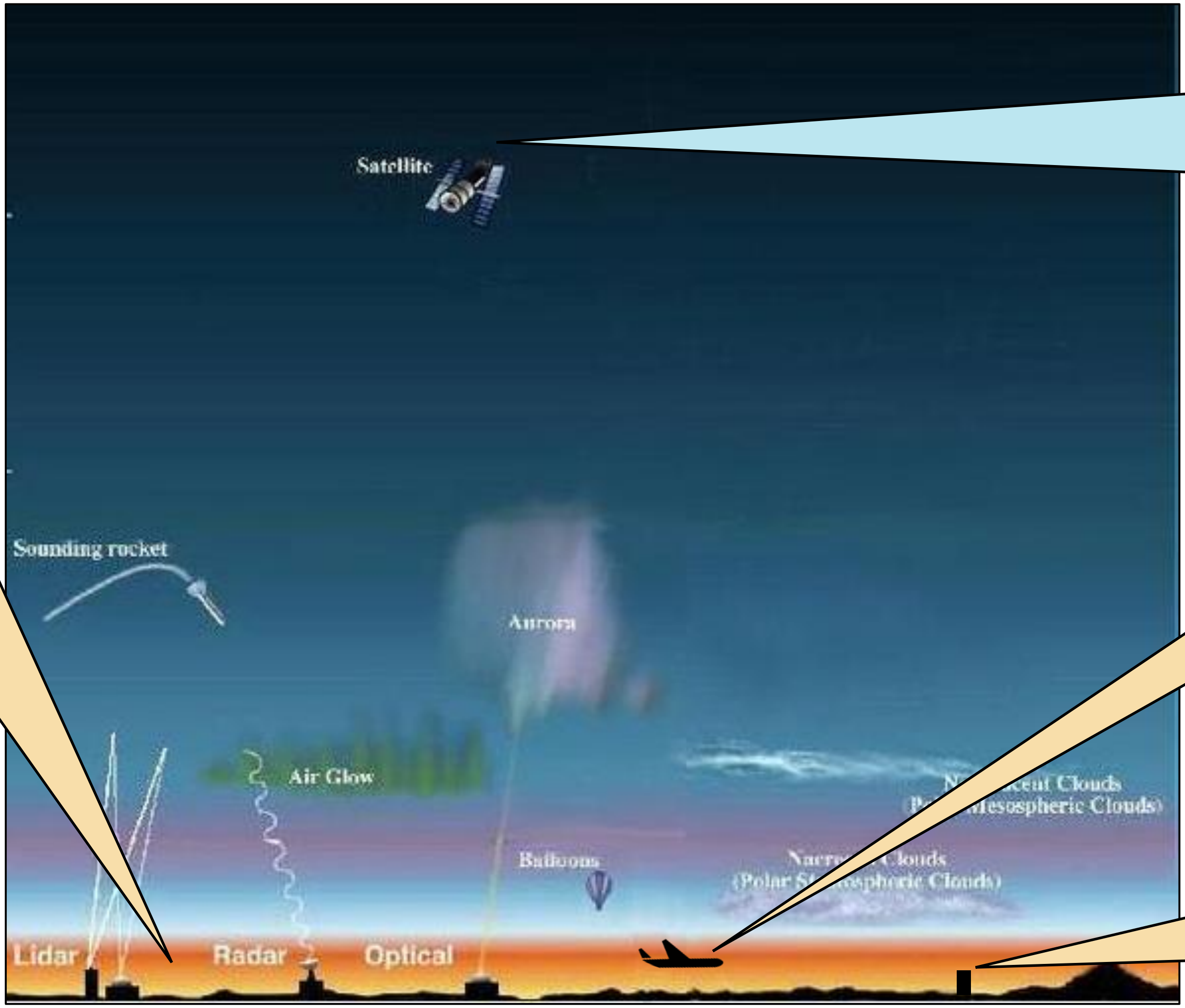
- Ozone concentrations in the DMNFR continue to be heavily influenced by local sources, including oil and gas
- Methane emitted by local sources has not decreased in recent years
  - Local sources of methane are fueling the climate crisis
- Despite newer regulations, oil and gas emissions have not decreased
  - Individual source emissions may have decreased but production has continued to increase
- Broomfield air quality monitoring is paired with health effects research
  - Broomfield has documented numerous releases of oil and gas VOCs and associated health concerns

Backup Slides

The importance of the boundary layer

The **boundary layer** is the layer of air close to the surface (the first few thousand feet above the ground).

This is where air mixes and pollutants are dispersed. Surface-level ozone forms in the boundary layer.



Satellites detect gases through the entire atmosphere and the boundary layer is most important for informing policy.

Aerial air quality studies are flown in the boundary layer

Ground-based instruments are in the boundary layer

Limitations of AIRS satellite data

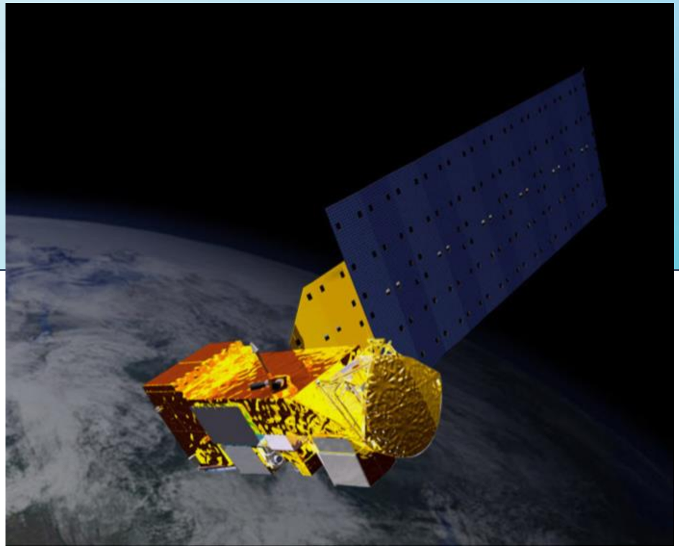


Image credit: airs.jpl.nasa.gov

- NASA's AIRS satellite estimates a daily average concentration of methane over a large area (grid cell)
- Gases are measured through the whole atmosphere with lower sensitivity for pollutants in the boundary layer
- Location specific ground-truthing is required
- NASA's AIRS has uncertain accuracy for methane compared to ground-based instruments, especially at our latitude (Zhang et al., 2021)

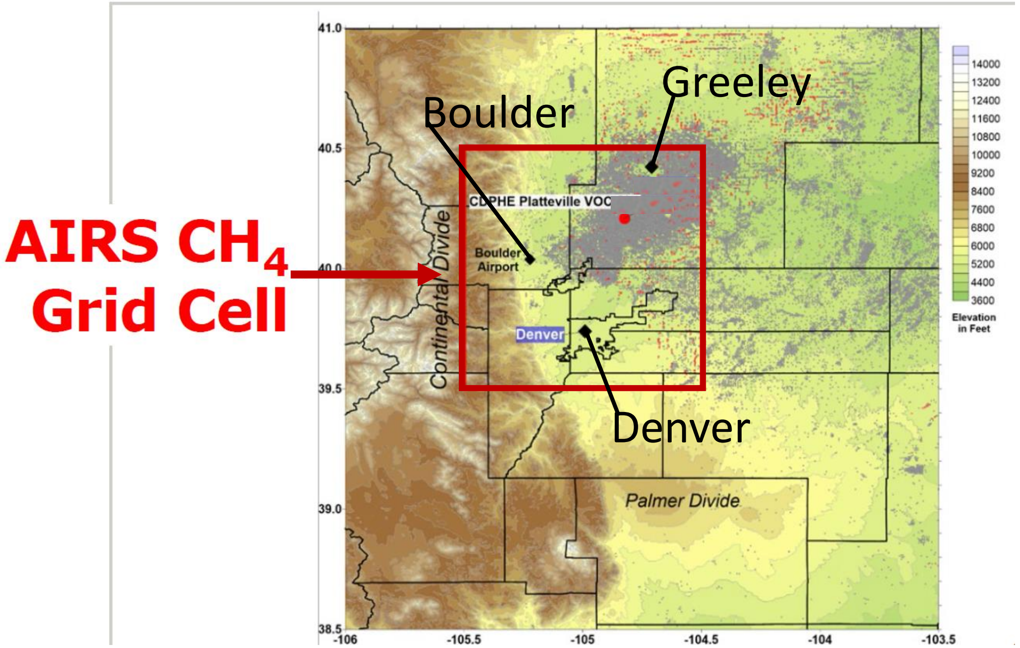


Image adapted from Weld County/Ramboll

Comparison with Other Analyses of Methane

- Others have proposed that methane emissions in the DMNFR are actually decreasing based on satellite data
- Local Government studies contradict these findings

- **Possible reasons for the difference in conclusions:**
  - AIRS satellite data used in analyses was an estimated methane concentration for air at ~10,000 ft. elevation over a large grid cell
  - AIRS satellite trend data has significant uncertainty in correlation with the surface trend
    - Zhang et al. (2021) indicates that for the NOAA Niwot Ridge site, column-integrated AIRS data has a low correlation to data from the Niwot Ridge ground-based instruments
  - Analysis combined satellite data and ground-based data

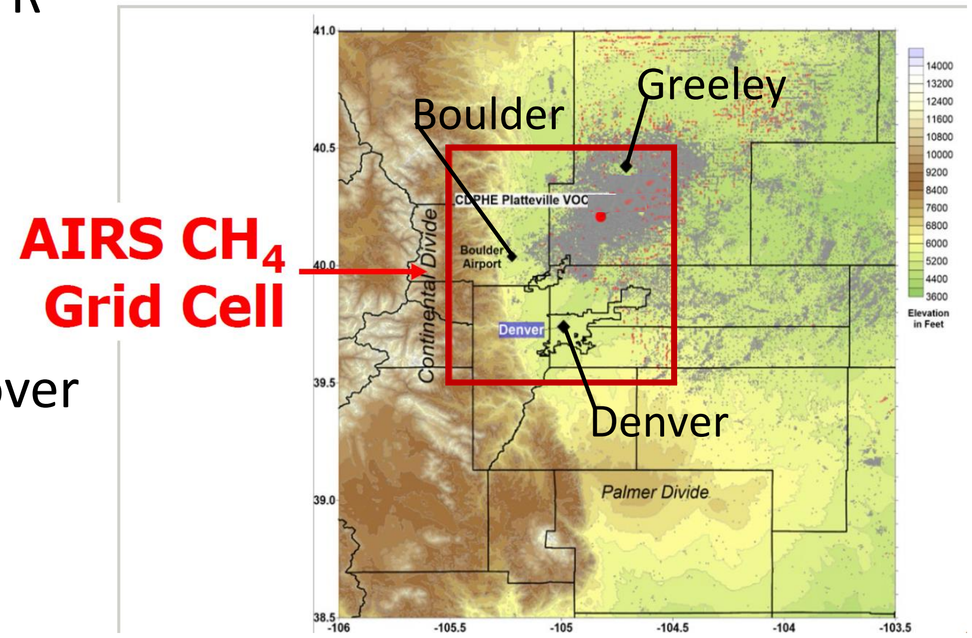


Image adapted from Weld County/Ramboll

Platteville Trend Considerations

Some researchers have highlighted that methane concentrations are decreasing at CDPHE's Platteville Station

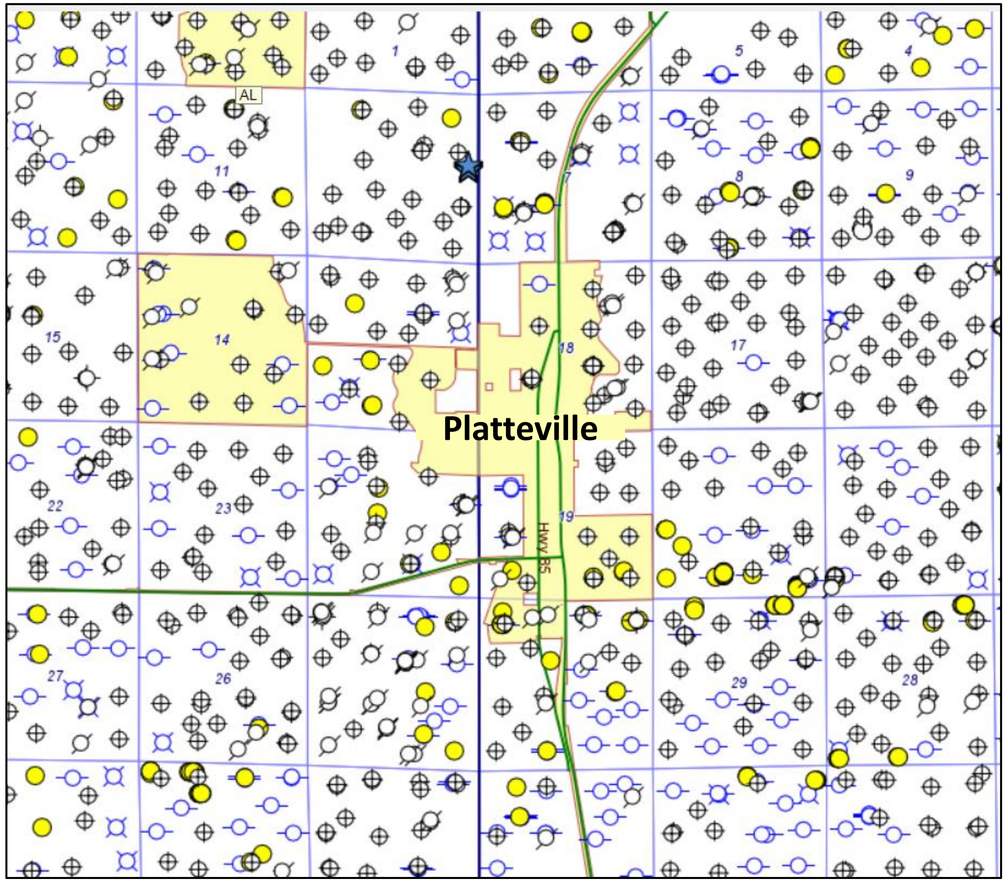
Platteville station is not a good representation of oil and gas development across the DJ Basin:

- Samples are taken once daily from 6-9am
- Early morning conditions are calm meaning samples may only reflect nearby oil and gas operations

CDPHE Platteville monitoring station
Photo credit: cpr.org

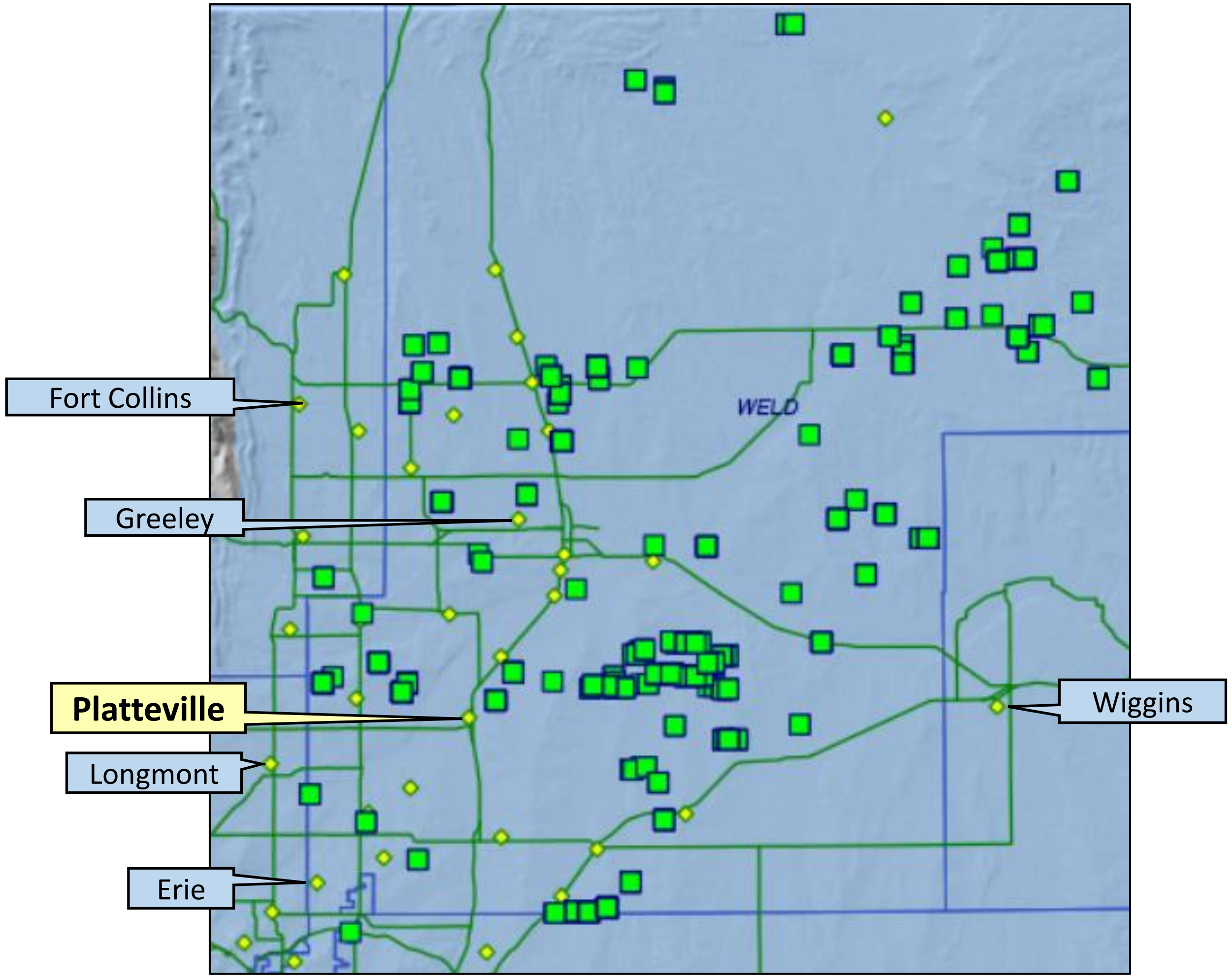
Platteville Trend Considerations

Platteville is not where most new oil and gas development is occurring.



Plugged wells   Producing wells

Non-producing wells (shut in/temporarily abandoned)

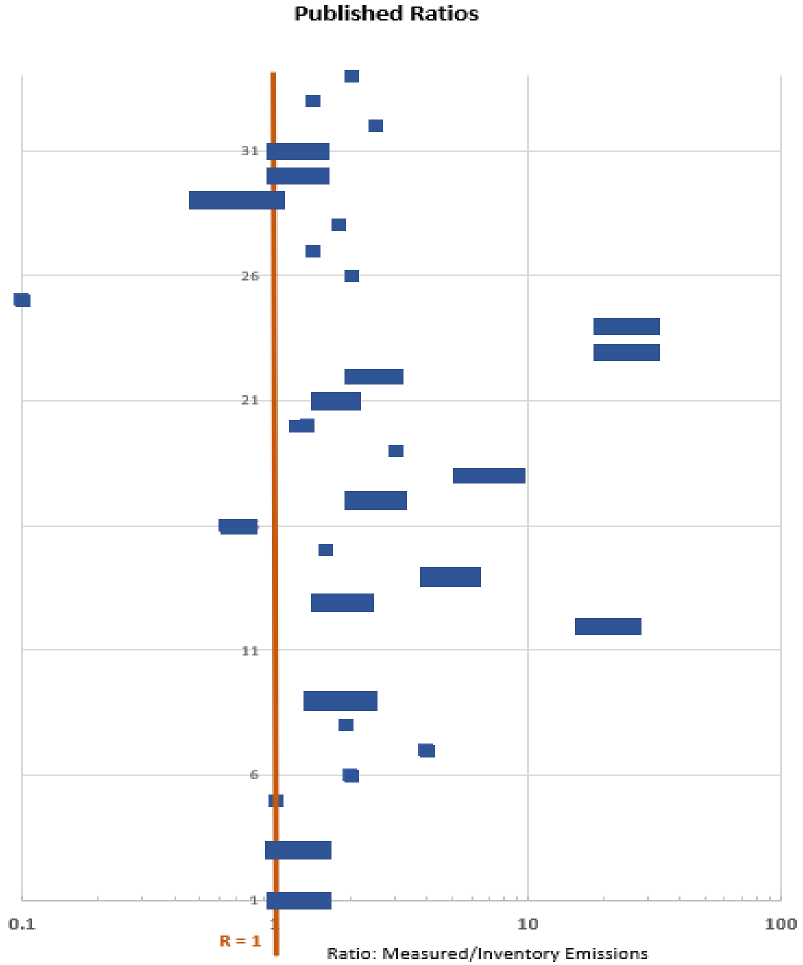


Planned/approved well sites

Source: cogcc.state.co.us

Published studies comparing top-down to bottom-up emissions

Publication and Year	Compound	Equipment/Region	Ratio TD/BU
Lu et al., 2022	Methane	USA, Canada, Mexico	2
Foulds et al., 2022	Methane	Norway	1.42
Helmig et al., 2022	VOCs	Boulder County, Colorado	2.5
Omara et al., 2022	Methane	USA	> 1
Lauvaux et al., 2022	Methane	Worldwide	> 1
Vogt et al., 2022	Methane	Canada	</= 1
Shen et al., 2021a	Methane	USA	1.8
		Canada	1.4
Shen et al., 2021b	Methane	Mexico	2
Zavala-Araiza et al., 2021	Methane	Mexico, off shore	< 0.1
		Mexico, onshore	> 10
		Mexico, satellite	> 20
Neininger et al., 2021	Methane	Australia	2-3
Rutherford et al., 2021	Methane	USA	1.5-2
Maasakkers et al., 2021	Methane	North America	1.22-1.35
Helmig, 2020	Ethane	Colorado	3
Robertson, 2020	Methane	Permian Basin, USA	5.5-9.0
Zhang et al., 2020	Methane	USA	> 2
Pasci et al., 2019	Methane	Western USA	0.64-0.78
Alvarez et al., 2018	Methane	USA	1.6
Pfister et al., 2017	VOCs	Colorado	> 4
Tzompa-Sosa, 2017	Ethane	USA	> 1.5
Johnson et al., 2017	Methane	Alberta, Canada	> 17
Matichuk et al, 2017	NOx	Uintah Basin, USA	inventory too low
	VOCs		4
Peischl et al., 2016	Methane	North Dakota, USA	1.4-2.3
Zavala-Araiza et al., 2015	Methane	Texas, USA	1.9
Ahmadov et al., 2015	Methane	Uintah Basin, USA	4
	VOCs	Uintah Basin, USA	2
Karion et al., 2015	Methane	Texas, USA	agrees with EPA
			> than EDGAR and NGHG
Kort et al., 2014	Methane	Four Corners, USA	> 1
Brandt et al., 2014	Methane	Globally	Majority > 1
Petron et al., 2013	Methane	Colorado, USA	> 1



The ratio of top-down (TD) over bottom-up (BU) emissions is plotted on the x-axis. For the y-axis representation, here we list the papers in order of their publication year, with the most recently published work at the top of the scale. For papers where a numerical value for the ratio was given, it is listed in the fifth column. In several cases, results were given as "greater than a value of x"; those are indicated by the '>' or '<' sign. A graphical representation of the magnitude of the results is provided to the right of the table. The brown vertical line presents the ratio value of 1, where bottom-up and top-down values agree. For cases where results are reported as a range, the range from the maximum to minimum value is indicated by a blue horizontal bar. When results were given as '> x', we chose an upper threshold value of 1.5 times 'x' for the graphical representation. Please note the logarithmic scale of the x-axis.

Cite: Fig 2, Ex. DH 1 to Earthjustice et al.'s comments, comment ID # EPA-HQ-OAR-2021-0668-0758.

Peer Reviewed Studies Associated with Boulder County Data

Helmig, D, et al. 2018. Contrasting behavior of slow and fast photoreactive gases during the August 21, 2017, solar eclipse. Elem Sci Anth, 6: 72. DOI: https://doi.org/10.1525/elementa.322

Asher, E, et al. 2021. Unpiloted Aircraft System Instrument for the Rapid Collection of Whole Air Samples and Measurements for Environmental Monitoring and Air Quality Studies, *Environ. Sci. Technol.* 2021, 55, 9, 5657–5667. https://pubs.acs.org/doi/10.1021/acs.est.0c07213

Pollack, I. B., D. Helmig, K. O'Dell, and E. V. Fischer (2021), Weekend-weekday implications and the impact of wildfire smoke on ozone and its precursors at Boulder Reservoir, Colorado between 2017 and 2019, Journal of Geophysical Research: Atmospheres, 126, e2021JD035221. https://doi.org/10.1029/2021JD035221.

Pollack, I. B., D. Helmig, K. O'Dell, and E. V. Fischer (2021), Seasonality and source apportionment of non-methane volatile organic compounds at Boulder Reservoir, Colorado, between 2017 and 2019 , Journal of Geophysical Research: Atmospheres, 126, e2020JD034234. https://doi.org/10.1029/2020JD034234.

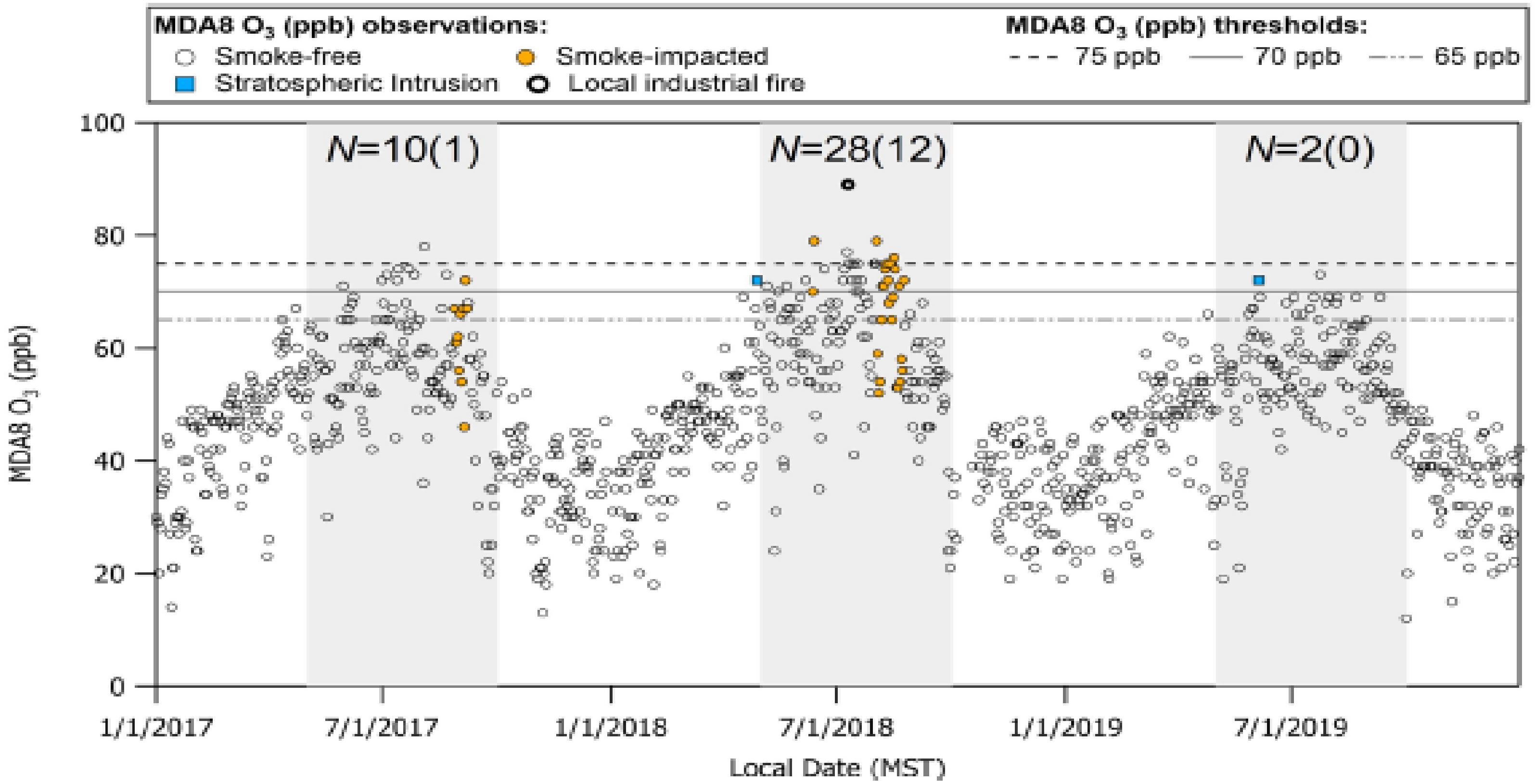
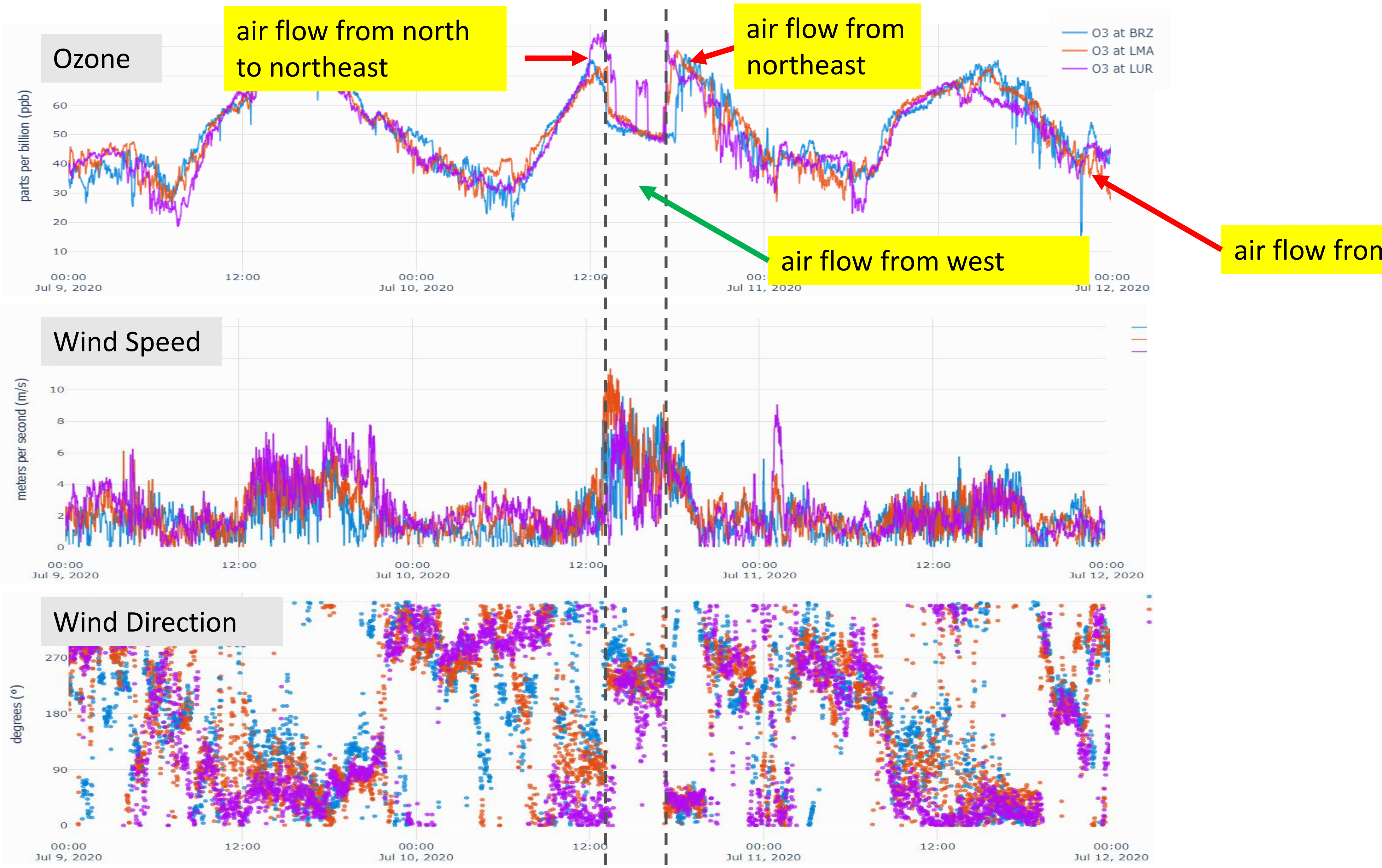


Figure 2. MDA8 O_3 at Boulder Reservoir between January 1, 2017 and December 31, 2019. The orange filled circles represent periods when the monitoring site is considered to be impacted by wildfire smoke, blue squares represent when the site is impacted by a stratospheric intrusion, and the heavy outlined black circle highlights a day that may have been impacted by a local industrial fire. Gray shaded areas represent the May-June-July-August-September (MJJAS) O_3 season. Text within the gray shaded areas indicate the total number of days during the MJJAS study period when MDA8 O_3 exceeds the 70 ppbv National Ambient Air Quality Standard (NAAQS); the number of days when MDA8 O_3 exceeds the 70 ppbv NAAQS that are also impacted by smoke associated with wildfires are shown in parentheses.

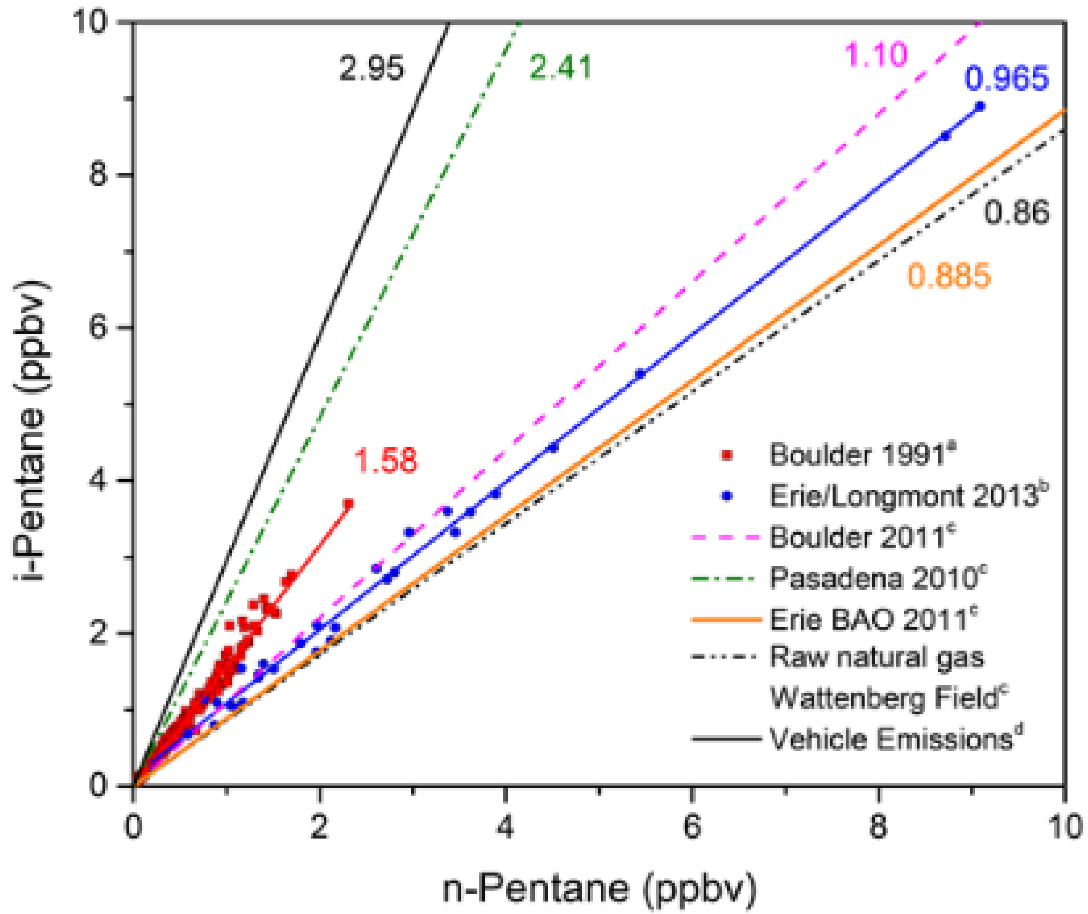
Pollack, I. B., D. Helmig, K. O'Dell, and E. V. Fischer (2021), Weekend-weekday implications and the impact of wildfire smoke on ozone and its precursors at Boulder Reservoir, Colorado between 2017 and 2019, Journal of Geophysical Research: Atmospheres, 126, e2021JD035221. https://doi.org/10.1029/2021JD035221.



Ozone
air flow from north to northeast
air flow from northeast
O3 at BRZ
O3 at LMA
O3 at LUR
parts per billion (ppb)
60
50
40
30
20
10
air flow from west
air flow fron
00:00 Jul 9, 2020
12:00
00:00 Jul 10, 2020
12:00
00:00 Jul 11, 2020
12:00
00:00 Jul 12, 2020
Wind Speed
meters per second (m/s)
10
8
6
4
2
0
00:00 Jul 9, 2020
12:00
00:00 Jul 10, 2020
12:00
00:00 Jul 11, 2020
12:00
00:00 Jul 12, 2020
Wind Direction
degrees (°)
270
180
90
0
00:00 Jul 9, 2020
12:00
00:00 Jul 10, 2020
12:00
00:00 Jul 11, 2020
12:00
00:00 Jul 12, 2020

i/n-Pentane Ratio by source comparison

Figure 12 from Thompson et al. 2015



Emission ratios of i-pentane to n-pentane from several studies in the NFR.

Emission ratios of i-pentane to n-pentane from several studies in the NFR: Boulder 1991, Erie/Longmont 2013 (this study), and Boulder and Erie 2011, compared to the ratio for Pasadena, CA, a site with predominantly urban emissions, the raw natural gas signature from the Greater Wattenberg Field, and the vehicle emissions source signature.

[a]Goldan et al., 1995

[b]This work

[c]Gilman et al., 2013

[d]Broderick and Marnane., 2002

Thompson, C. R., Hueber, J., & Helmig, D. (2014). Influence of oil and gas emissions on ambient atmospheric non-methane hydrocarbons in residential areas of Northeastern Colorado. *Elementa-Science of the Anthropocene*, **3**(35), 4707–4715.

Erie Ajax/CSU Monitoring Stations

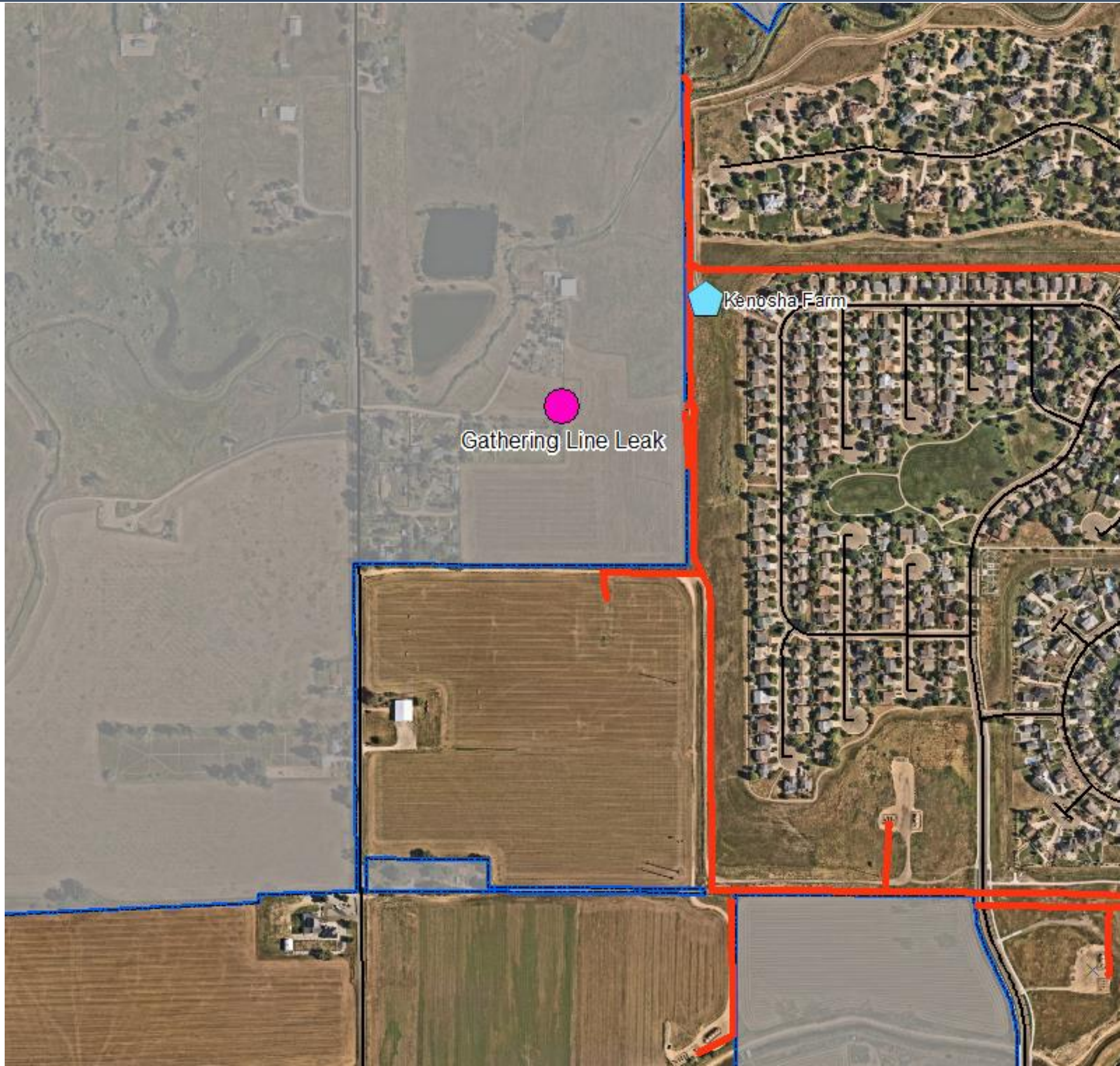
Average 1-week canister catches

TVOC_CSU49 from September 2021 through June 2022

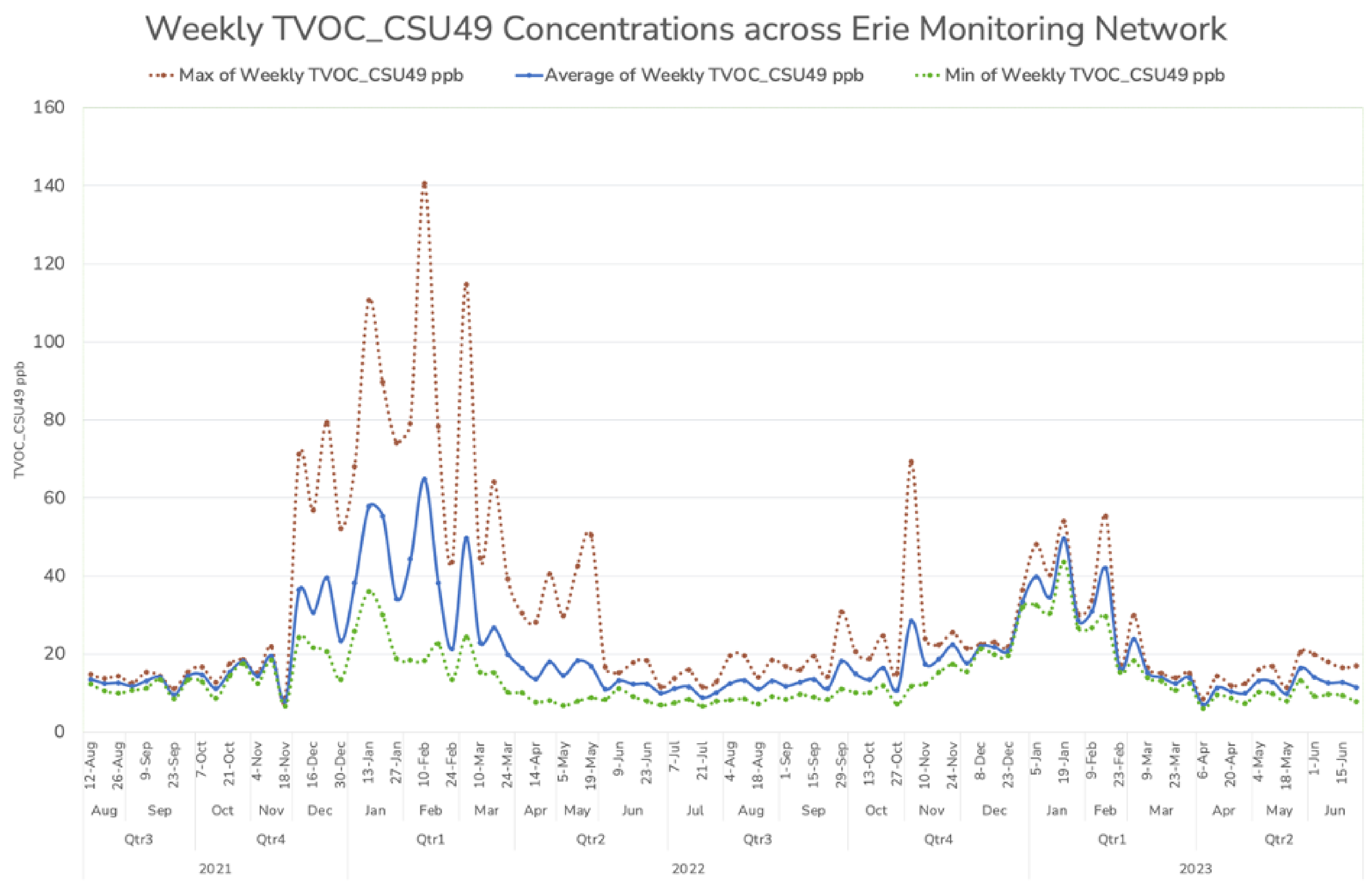
Image credit to Ajax Analytics

Erie Ajax/CSU Kenosha Farms Station

- Installed to establish background air quality
- Average 1-week TVOC_CSU49
  - •prior to 12/2 was 12.5 ppb
  - •12/2 - 5/19 was 61.9 ppb
  - •After 5/19 was 8.7 ppb
- Winds from the SW
- Gathering line leak discovered ~700 ft SW in May 2022
- No plumes detected after pipeline was removed from service and contaminated soils excavated

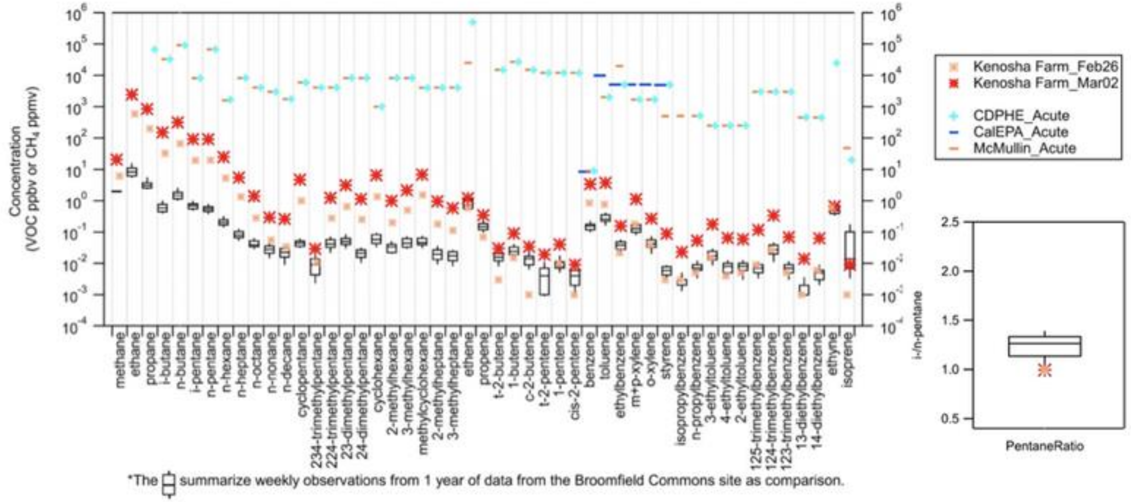


Erie Ajax/CSU Kenosha Farms Station

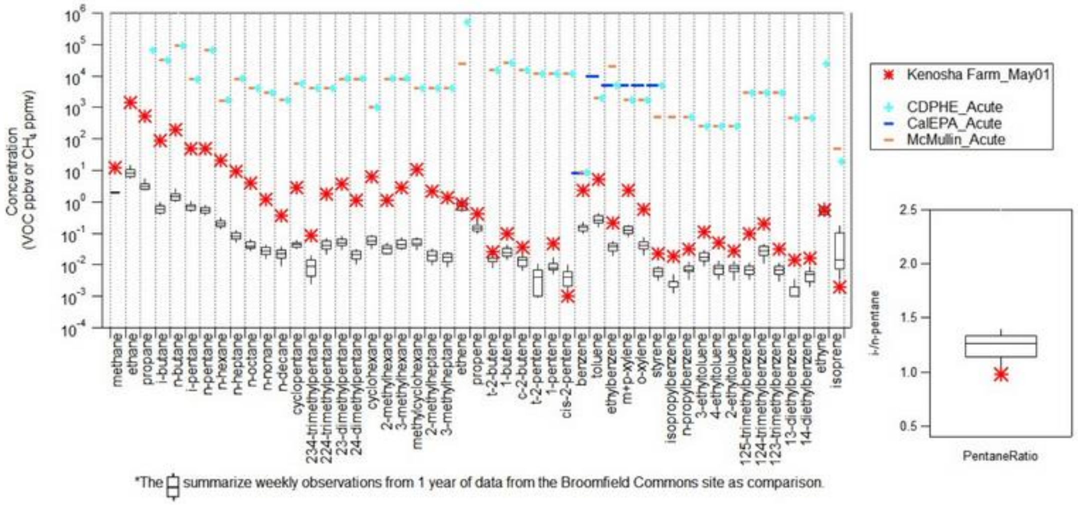


Erie Ajax/CSU Kenosha Farms Station

Erie_Kenosha Farm 02/26 & 03/02



Erie_Kenosha Farm_05/01



Erie Ajax/CSU Kenosha Farms Station

Constraints and Assumptions

In order to quantify the VOC elevations seen in both the PID signal and the weekly canister data in terms of emitted VOC tonnage caused by this leak, we must first identify the constraints and assumptions that limit the inputs of the modeled calculation. The mass of VOC being emitted and the length of time the VOCs were emitting, directly at the break in the flow line, are two critical components of this analysis, however we don't have that level of information. Therefore, we must make 3 main assumptions;

Constraint 1: As methane is the dominant component of the released gas and an important greenhouse gas, we focus on estimating the leak rate of methane. Weekly canister concentrations of methane can help constrain the estimated methane leak rate.

Assumption 1: From our PID data, we can confine the emission duration to a continuous 180-day period between 11/19/21 and 5/18/2022. For this analysis we assume the gathering line had a constant emission rate. In our analysis, we assume a constant methane emission rate at 1g/s from the leaking pipeline and scale this emission rate so that increases in methane concentrations simulated via AERMOD at our monitoring sites best match observed methane concentrations at those locations.

The PID sensor showed a clear pattern of relatively constant VOC elevation at 735' away. There were no extended periods without elevated measurements, and there was distinct clarity in the start and end of the leak episode. Therefore, we are comfortable making this assumption for an initial analysis. We can evaluate whether this assumption is appropriate by looking for any trends between simulated and measured methane concentrations across the lengthy leak period.

Assumption 2: This estimate is calculated using an Ordinary Least Squares (OLS) Linear Regression fit between weekly canister concentrations and monitoring site concentrations simulated using the AERMOD dispersion model.

We will assume that the OLS regression is the best fit for all data points, and that the AERMOD meteorological inputs are most representative of actual conditions. The meteorological data come from a reanalysis of regional meteorology for a location in nearby Broomfield.

Erie Ajax/CSU Kenosha Farms Station

Application of the AERMOD Dispersion Model

In this application of the AERMOD dispersion model, we simulated methane concentrations across Erie and compare them to the real-world weekly methane concentrations from the weekly canister samples collected at the Kenosha Farms (KF) and Upland South (US) monitoring stations. By applying a constant rate of emission of methane in our model, and driving plume transport and dispersion using reanalyzed meteorological field data, we can create an output of simulated methane concentrations that can be scaled to best match our measured weekly methane concentrations.

By assuming a constant methane emission rate of 1 g/s from the leaking pipeline, we can simulate increases in the weekly methane concentration throughout the duration of the leak. Predicted methane concentration increases above background are then compared to methane observations at Kenosha Farms and Upland South. In total, there were 55 valid weekly integrated methane observations to be used in the comparison plotted in Figure 9.

Using an OLS linear regression best-fit line between our simulated and actual methane concentrations, we achieve a relatively strong correlation (r=0.57). The slope of this best-fit line gives us the best-fit emission rate based on the match between the model and real-world data. We can then take the slope of the best-fit line as a constrained emission rate of 13.6 ± 5.4 g/s.

After applying the best-fit emission rate of 13.6 ± 5.4 g/s. throughout the 180-day duration of the leak and applying the quantification ranges for our assumptions, we have calculated a low, best-fit, and high estimate for the total emission tonnage for methane.

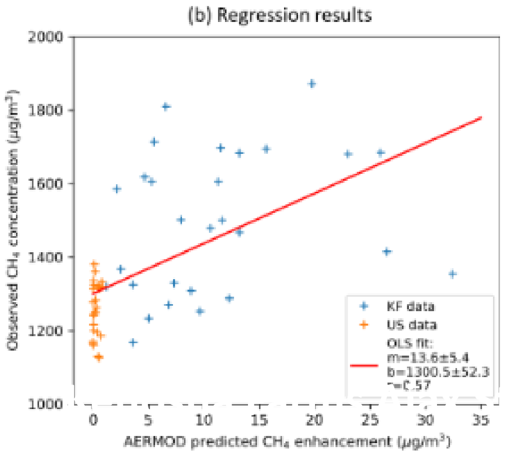


Figure 9: Regression Results from the AERMOD Dispersion Model in comparison to the measured weekly methane concentrations

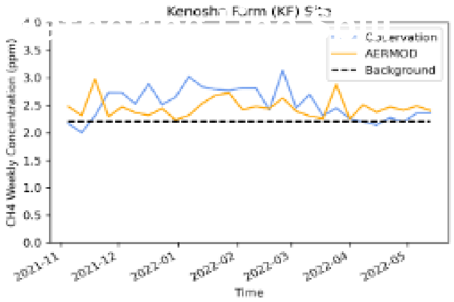


Figure 10: The CH4 time series comparison between observations and AERMOD simulated results for KF site are provided below. The AERMOD simulated time series is based on a constant emission rate (13.6 g/s) with a background concentration of 2.2 ppm.

Low Estimate: ~140 US Tons during the leak period

8.2 g/s = 0.78 tons/day → 0.78 tons/day * 180 days = 140.4 tons

Best-fit Estimate: ~234 US Tons during the leak period

13.6 g/s = 1.30 tons/day → 1.30 tons/day * 180 days = 234 tons during the leak period

High Estimate: ~329 US Tons during the leak period

19 g/s = 1.81 tons/day → 1.81 tons/day * 180 days = 325.8 tons during the leak period

Erie Ajax/CSU Kenosha Farms Station

Perspective on this single routine pipeline leak estimate of ~234 US tons over a 7 month period: Colorado’s permitting thresholds for major stationary sources, according to the Colorado Air Pollution Control Division’s Permitting Section Memo 22-01, a “Moderate” classification of VOCs has a permitting threshold 100 tons per year. On the other end of their classification standards, a “Severe” classification of VOCS has a permitting threshold of 25 tons per year.

Oil and Gas Fingerprint: i/n Pentane Ratio

Pentanes are emitted from gasoline vapors and oil and gas production. Pentanes also contribute to ozone formation.

i/n Pentane Ratio

Oil and gas emissions typically have a ratio of less than 1 (0.8-0.9)

Emissions from vehicles and urban areas have a ratio of greater than 2

Adapted from slide by Dr. Detlev Helmig, Boulder A.I.R.

Alkanes largely from O&G. Ethyne largely from traffic. HAPs – contributions vary.

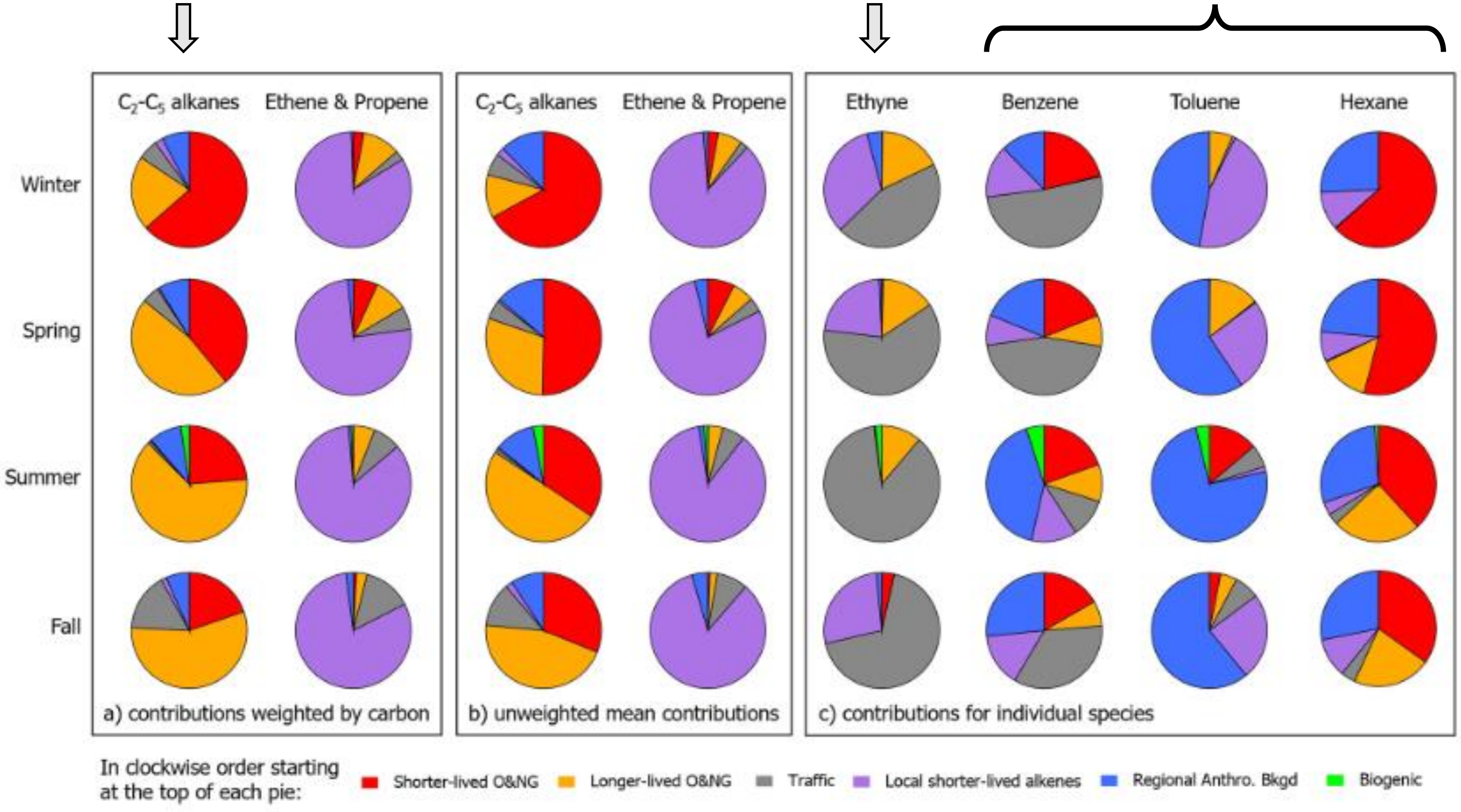
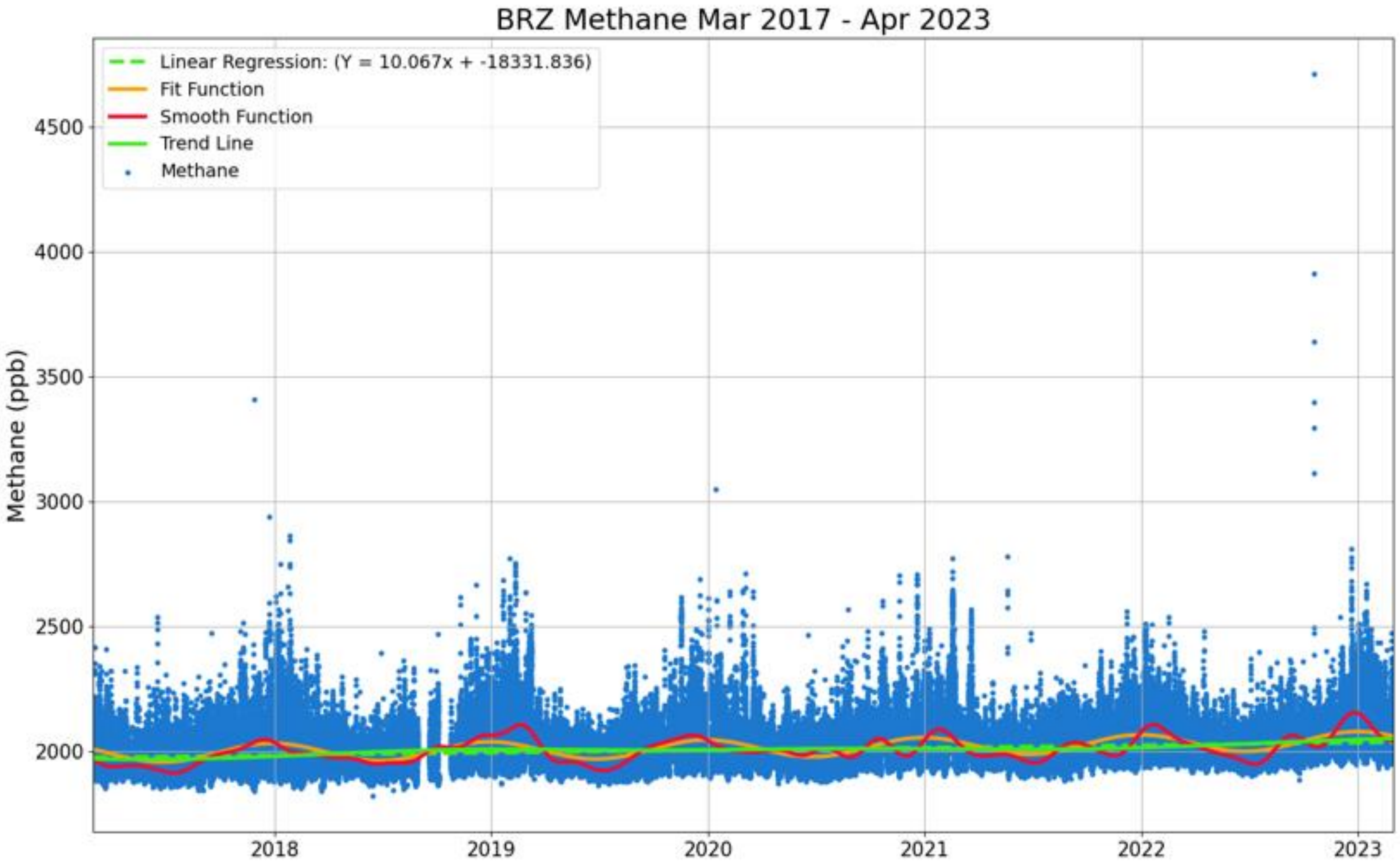


Figure 9. Mean seasonal contributions from the PMF factor profiles for shorter-lived O&NG (red), longer-lived O&NG (orange), traffic (gray), local shorter-lived alkenes (purple), regional anthropogenic background (blue), and biogenics (green; summer only) to C_2-C_5 alkanes, C_2 and C_3 alkenes (i.e., ethene and propene), ethyne, and HAPs (i.e., benzene, toluene, and hexane). Compared to the individual species (c), mean contributions to alkanes and alkenes are illustrated as a weighted mean calculated as the mean seasonal mixing ratio times the number of carbon atoms in each species (a) and as an unweighted mean (b). HAPs, hazardous air pollutants; PMF, Positive matrix factorization.

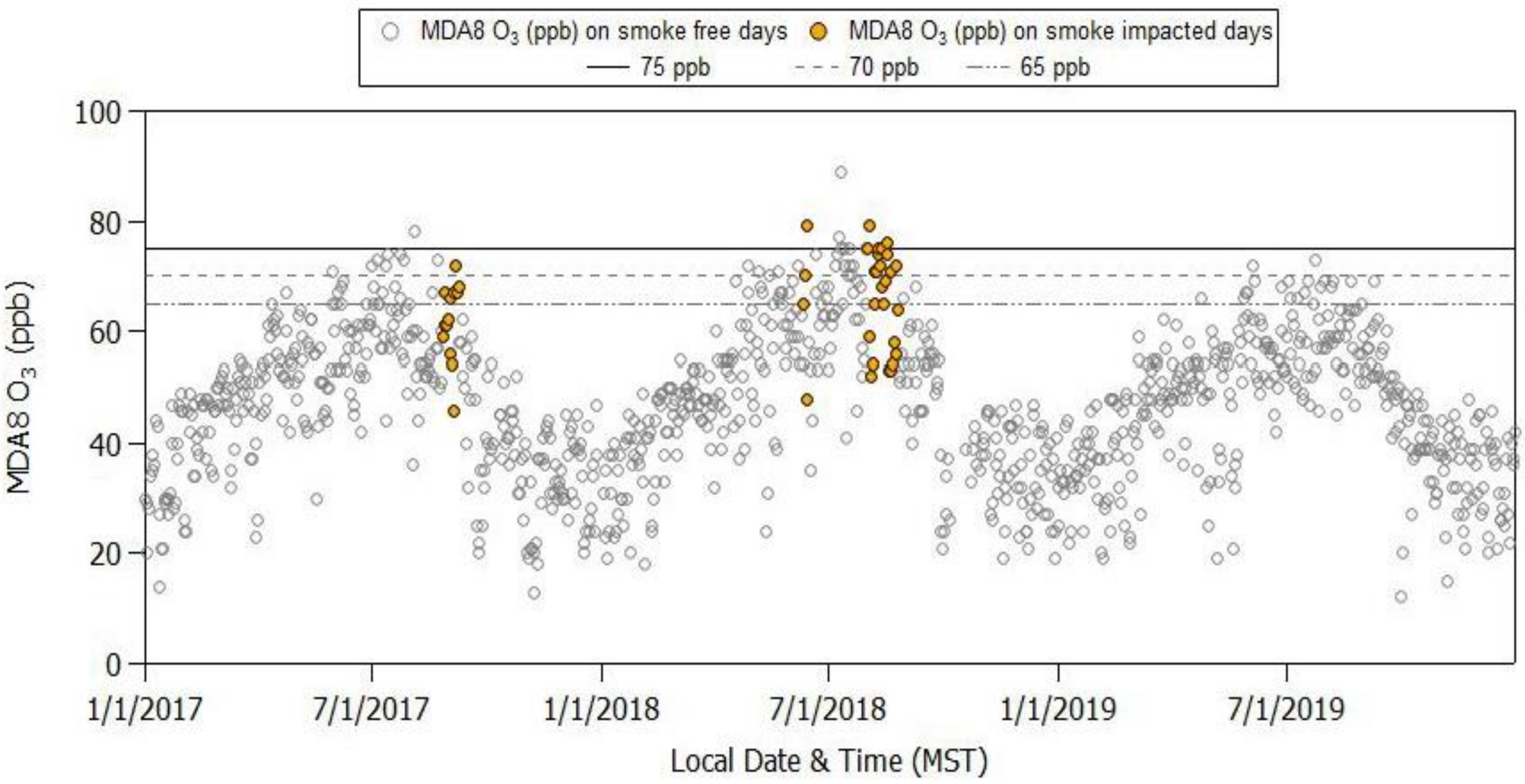
Pollack, I. B., D. Helmig, K. O'Dell, and E. V. Fischer (2021), Seasonality and source apportionment of non-methane volatile organic compounds at Boulder Reservoir, Colorado, between 2017 and 2019 , Journal of Geophysical Research: Atmospheres, 126, e2020JD034234. https://doi.org/10.1029/2020JD034234.

Methane Trends at Boulder Reservoir 2017-2023



Monitoring Data Does Not Show Attainment, Even Without Wildfire Events

- Analysis of Boulder Reservoir 2017-2019 data shows most high ozone summer days aren't smoke impacted.
- Results:
  - Local Sources = majority ozone on high ozone summer days
  - Local NMVOC and NOx sources are main causes
- This means monitoring data will not show attainment even if wildfire events are removed from the data



Credit: Ilana Pollack & Emily Fischer

Oil and Gas NO_X Emissions are a Key Contributor to High Ozone

Oil and gas sector is the largest source of NO_X emissions in the 2023 and 2026 inventories

- Drill rigs and hydraulic fracturing engines alone contribute 20% of NO_X emissions
- At 6.5 tons of NO_X per well, pre-production emissions from drilling and completing just 4 wells would exceed the severe area major source threshold of 25 tons per year
- Modeling shows ozone is sensitive to NO_X as well as VOC emissions
- Oil and gas area sources are estimated to contribute over 5 parts per billion of ozone in 2023 at the state-run monitors in Longmont and Weld County