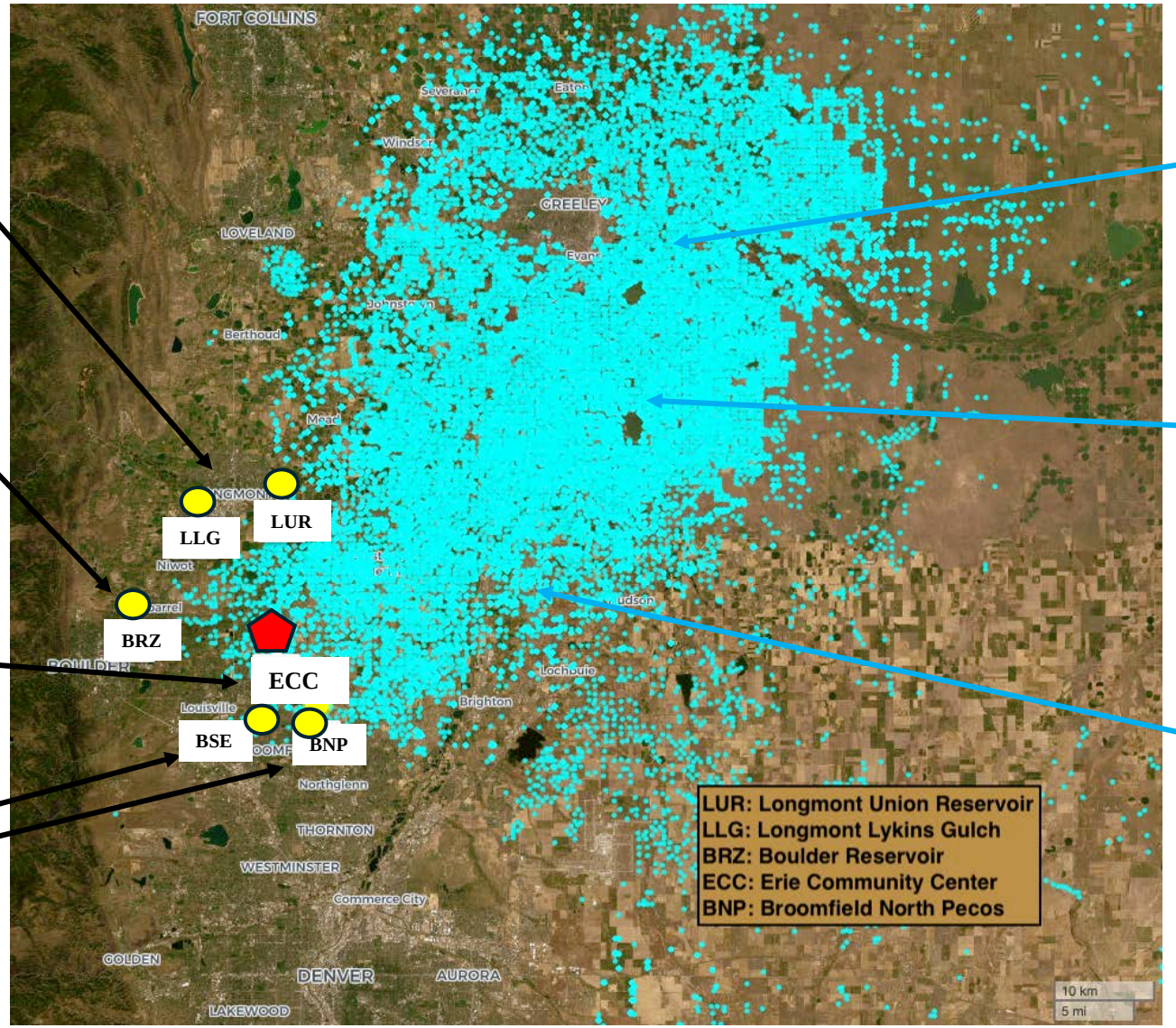
Selected Findings and Outcomes from the Air Quality Monitoring at the Erie Community Center

Detlev Helmig

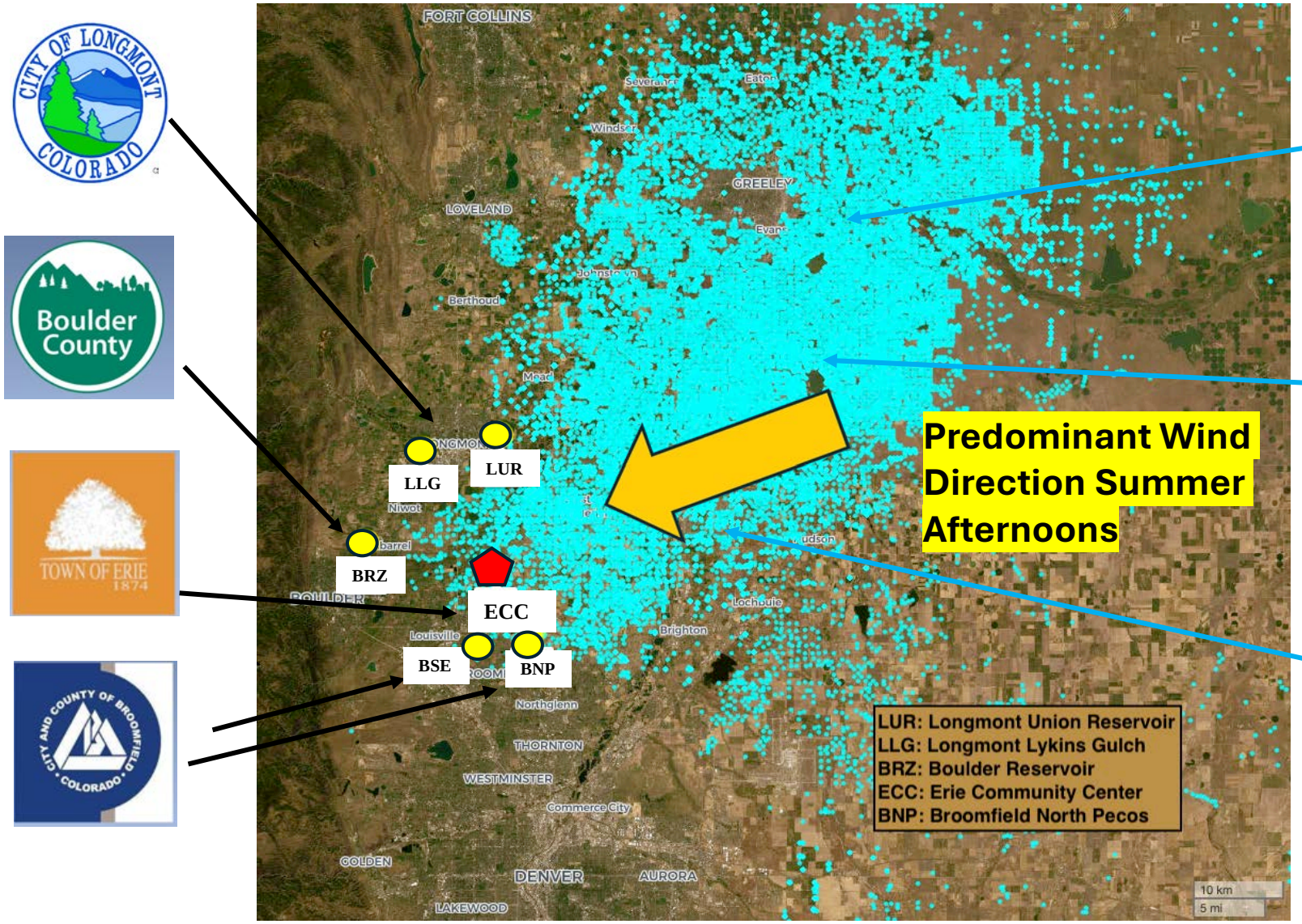
Dani Caputi, Jacques Hueber, Gabriel Greenberg, Kat Potter,
Susan Simoncic, Michel Stahli

1. Monitoring Program Introduction
2. Data Examples and Highlights
3. Impact

Local Government Air Quality Monitoring Programs and Oil and Gas Operations



Local Government Air Quality Monitoring Program and Oil and Gas Operations

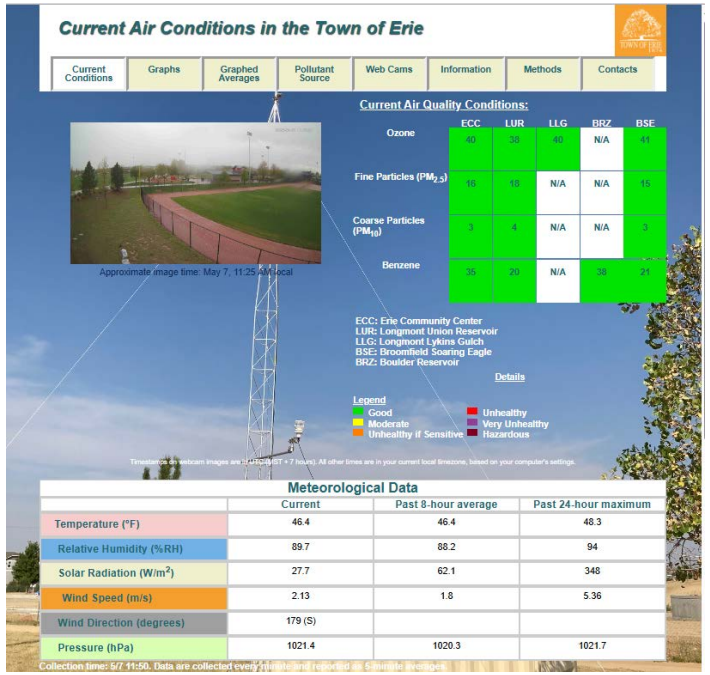


Erie Community Center (ECC) Air Monitoring Station

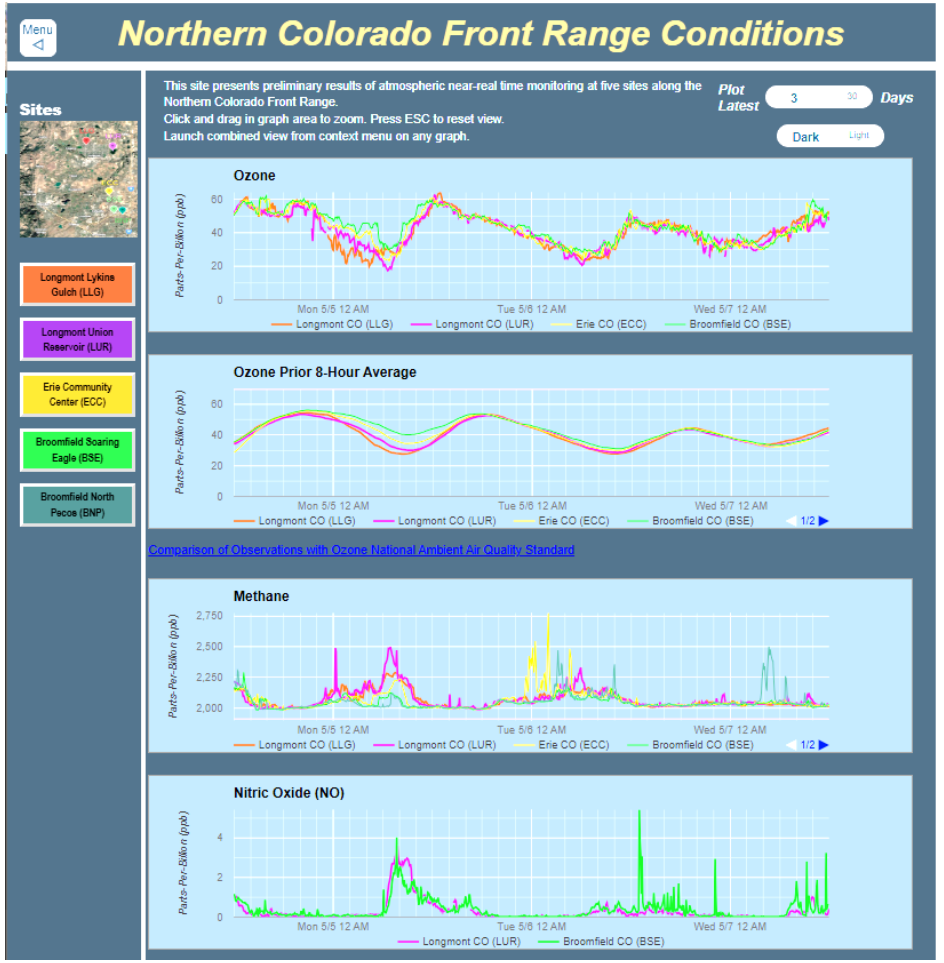
Monitored Variables:

- Methane
- Ozone
- Volatile Organic Compounds (Ethane, propane, .., acetylene, benzene,…. 20 VOCs total)
- Airborne small particles (PM2.5, PM10)
- Webcam Images
- Wind Speed
- Ambient Temperature
- Relative Humidity
- Solar Radiation

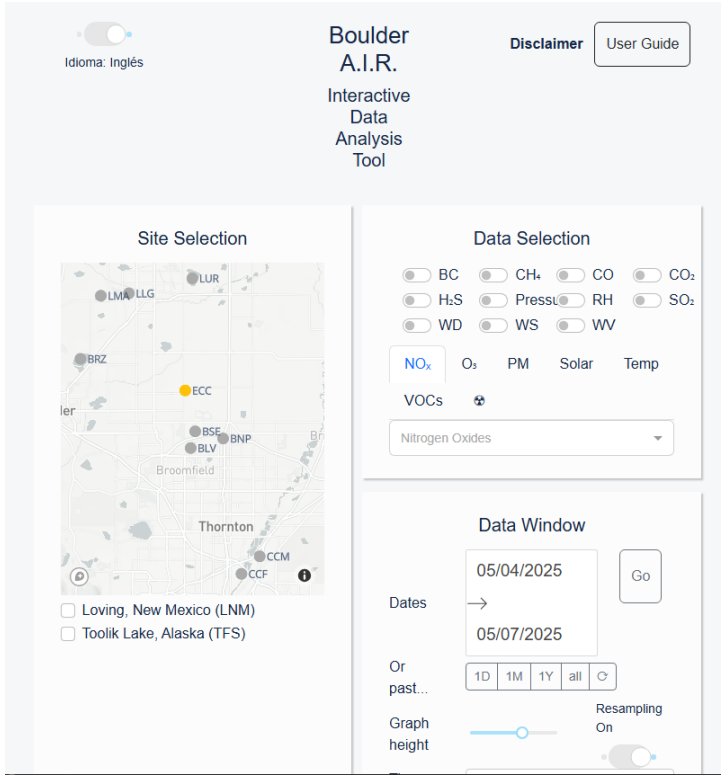
Real-Time Data Reporting and Data Access



https://www.bouldair.com/erie.htm;
6,958 website visits

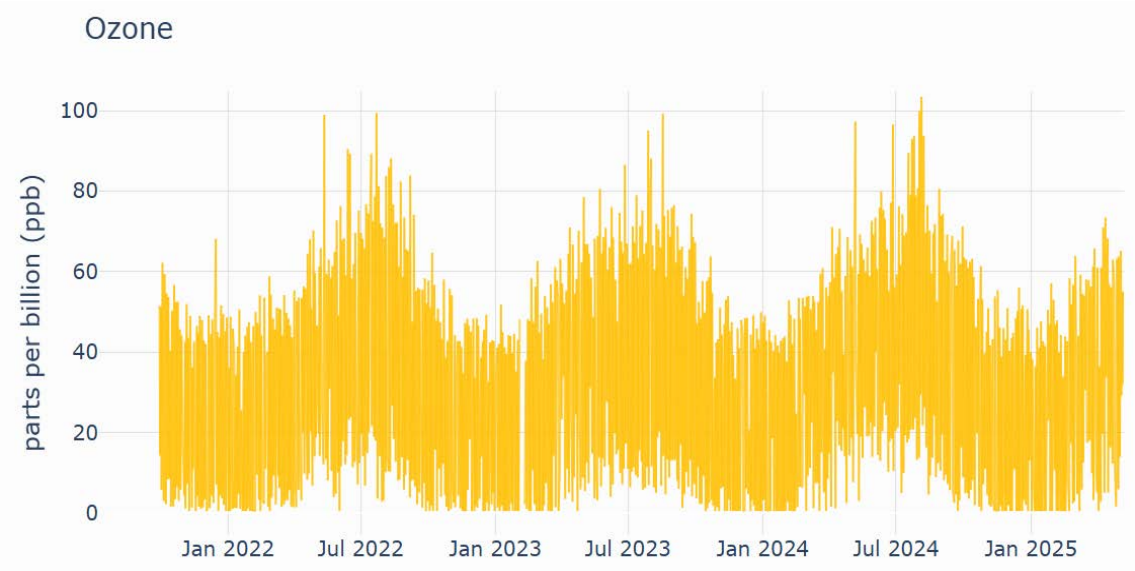


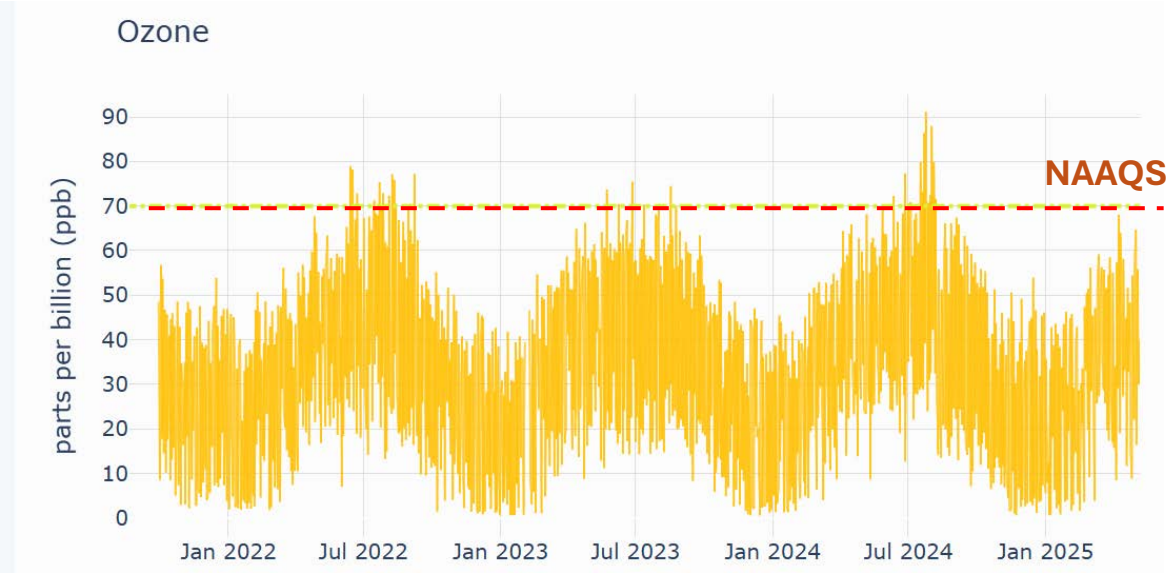
https://www.bouldair.com/NoCoFrontRange.htm;
19,013 website visits



https://bouldairtools.com/interactive/

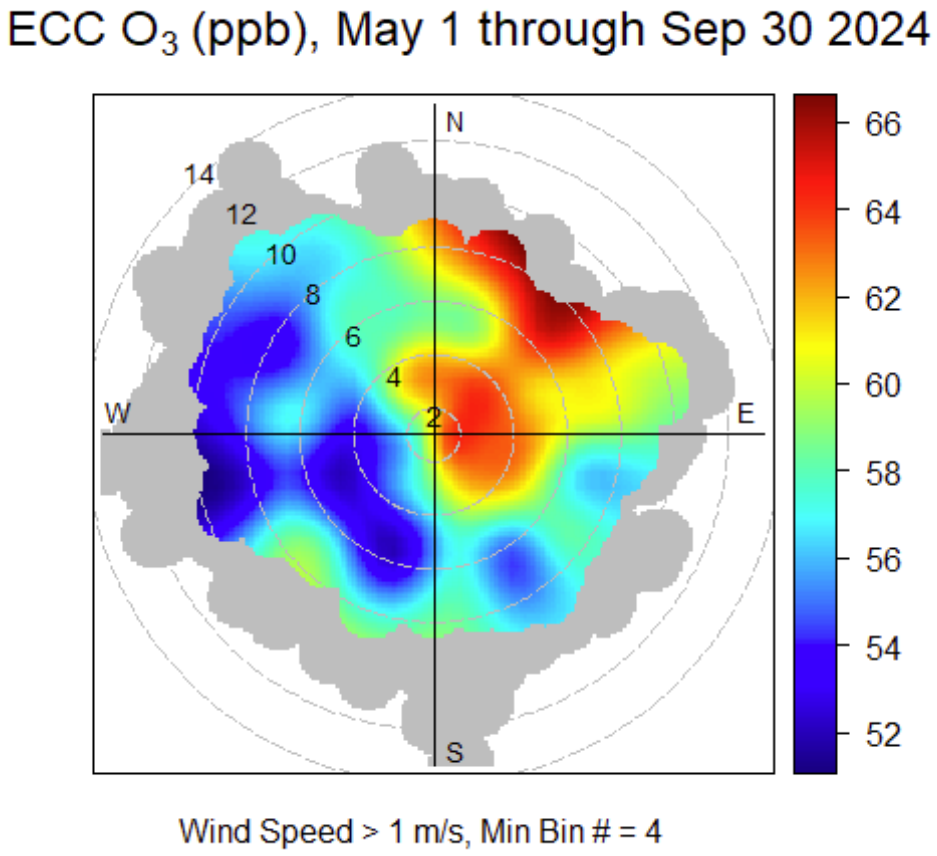
Ozone Monitoring at the Erie Community Center



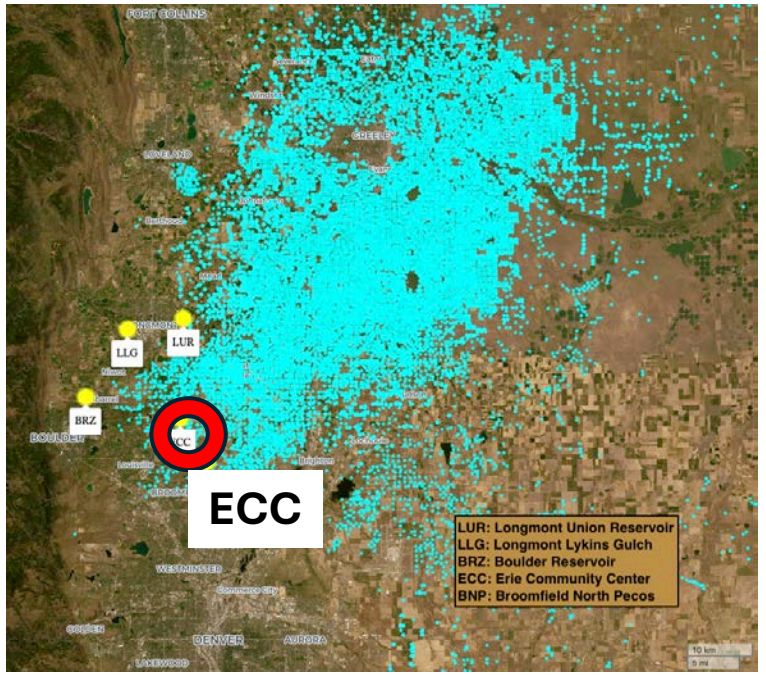


- Ozone is an EPA-classified priority pollutant.
- Northern Colorado Front Range has been downgraded to a severe ozone health standard non-attainment area. One of the ten most polluted ozone areas in the U.S.
- Elevated ozone is estimated to cause 84,000 emergency department visits every year.
- A 2021 study estimated 14,000 annual premature deaths in the US due to elevated ozone.
- The US National Ambient Air Quality Standard (NAAQS) is one of the least protective compared to other developed countries.
- In Erie, the NAAQS has been exceeded 13, 3, 20 times per year since 2022.

Ozone Monitoring at the Erie Community Center



- High ozone occurrences in Erie are most commonly associated with air transport from the north to southeast air sector.



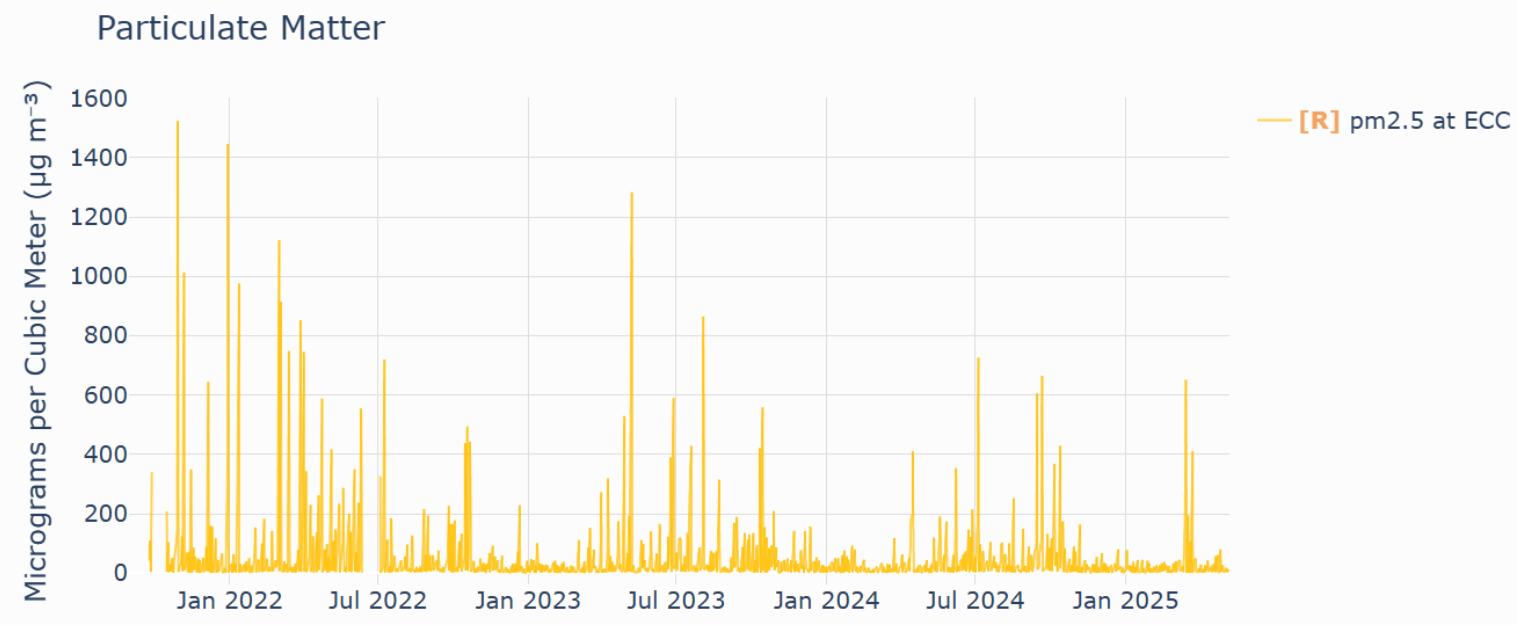
Occurrences of High Loadings with Airborne Particulate Matter at the Erie Community Center

National Ambient Air Quality Standard for 24-hour averaged PM2.5 exposure.

May 17, 2023, at 12:13 p.m. with PM 2.5 at 4 µg/m^3.

May 19, 2023, at 12:13 p.m. with PM 2.5 at 117.6 µg/m^3.

Occurrences of High Levels of Airborne Particulate Matter at the Erie Community Center Compared to Neighbor Communities



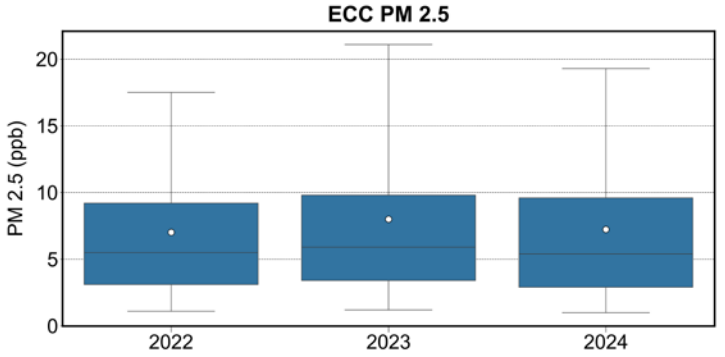
- Occurrences with high PM loading are observed throughout the year, though wildfire events have been the most long-lasting ones.
- Erie consistently sees the highest levels in small (PM2.5) and coarse (PM10) particle pollution compared to Broomfield and Longmont.
- Pollution from particulates shows signs of improvement for most extreme events, but other than that hasn't changed much.

Number of hours PM > 100 µg/m^3

	PM 2.5			PM 10		
Year	ECC	LUR	BSE	ECC	LUR	BSE
2021 [a]	1.2	0.3	0.2	63.8	13.0	7.6
2022	3.1	0.6	0.3	57.9	36.2	13.4
2023	9.6	2.4	2.4	79.6	15.5	15.7
2024	1.7	5.5	0.2	74.7	42.2	13.4
2025 [b]	0.5	0.4	0.0	13.9	5.1	0.9
Total	16.0	9.2	3.0	289.9	112.0	50.9

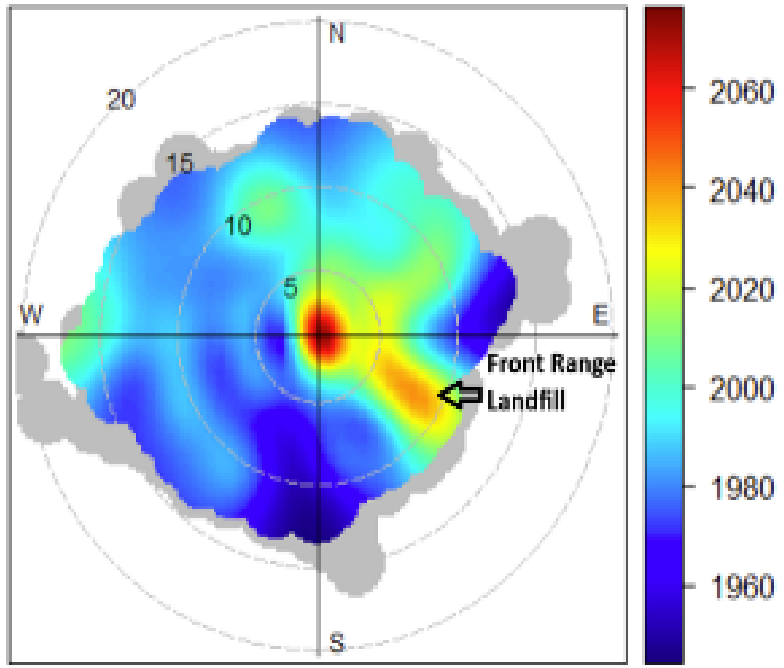
[a] 1 Oct - 31 Dec

[b] 1 Jan - 30 Apl



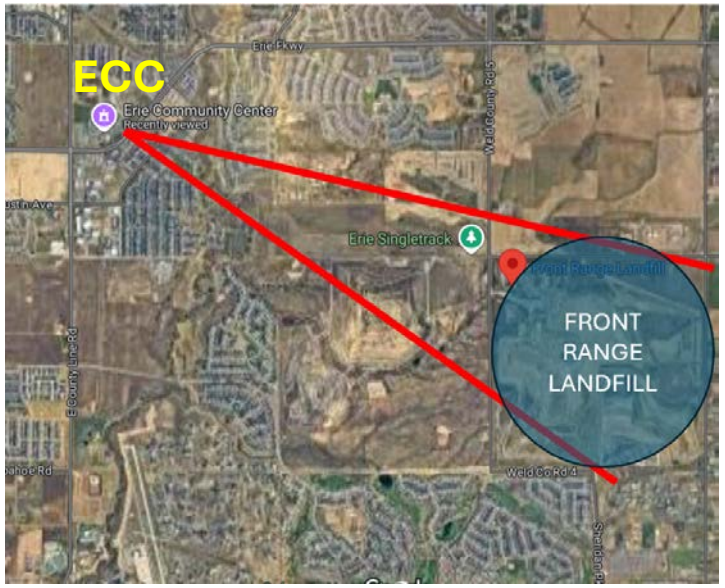
Methane at the Erie Community Center

ECC CH_4 (ppb), Oct 2021 through Aug 2024



Wind Speed > 1 m/s, Min Bin # = 2

- Methane is a strong greenhouse gas, about 40 times more potent per molecule than CO_2.
- Atmospheric methane has more than doubled from human-caused emissions.
- Erie data show two main source types: 1. Oil and gas production regions in Weld Country. 2. Erie landfill.
- High methane plumes at Erie more frequent than at other sites.



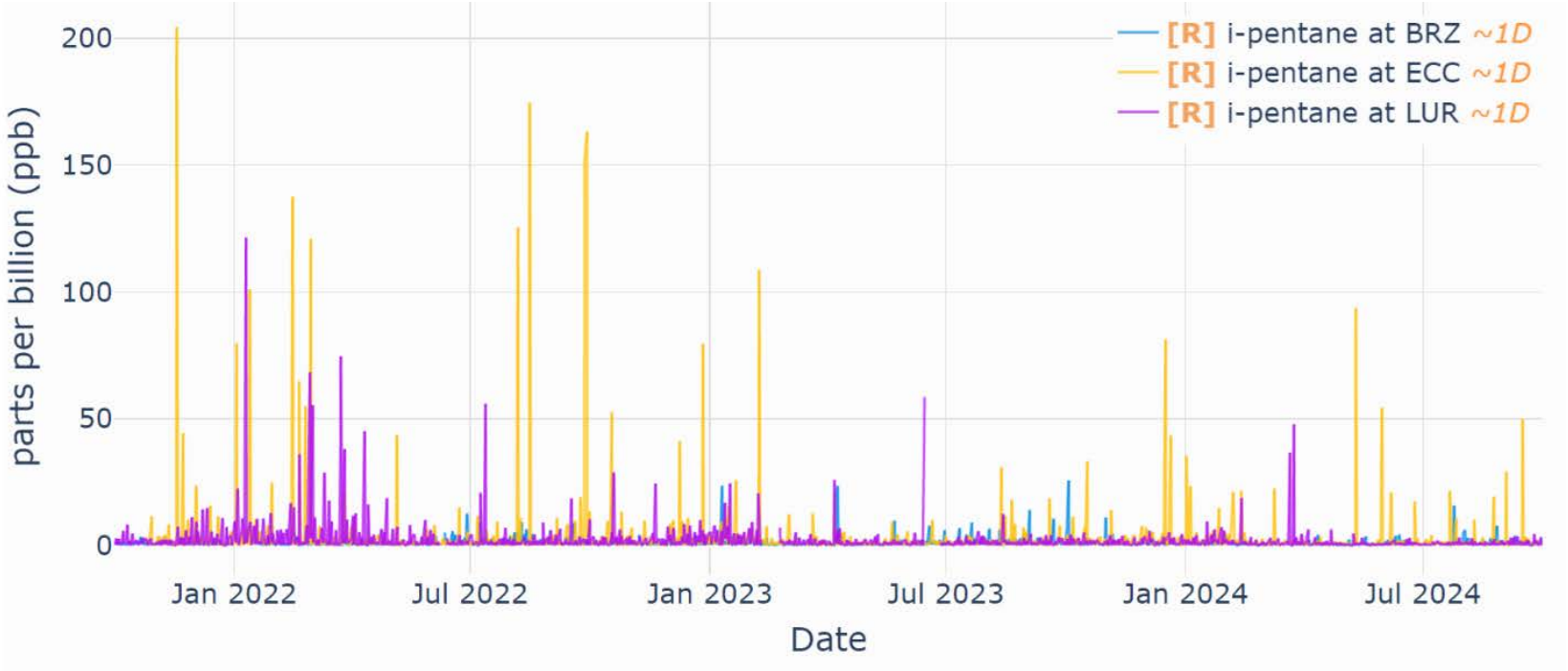
Number of hours methane > 4 ppm

Year	ECC	LUR	LLG	BRZ	BNP
2021 [a]	6.6	1.0	0.0	0.0	2.6
2022	22.0	4.6	0.0	0.3	6.0
2023	28.9	3.1	0.0	0.0	11.8
2024	13.5	1.1	0.5	0.0	1.9
2025 [b]	5.3	0.4	0.0	-	2.6
Total	76.3	10.2	0.5	0.3	24.9

[a] 1 Oct - 31 Dec

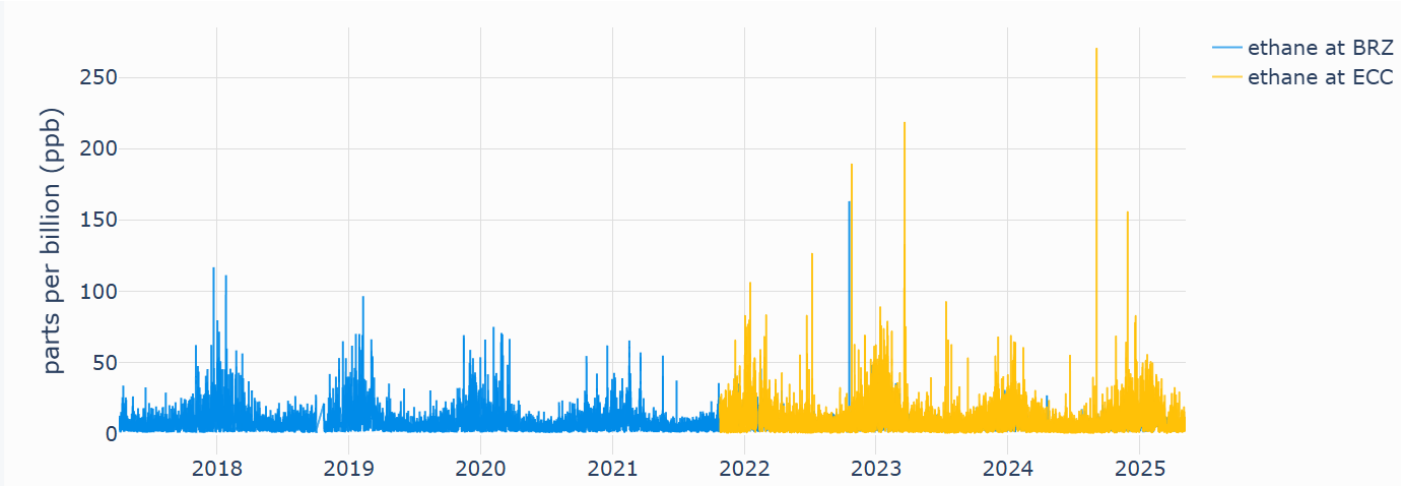
[b] 1 Jan - 30 Apl

Volatile Organic Compounds as Indicators of Petroleum Hydrocarbon Emissions

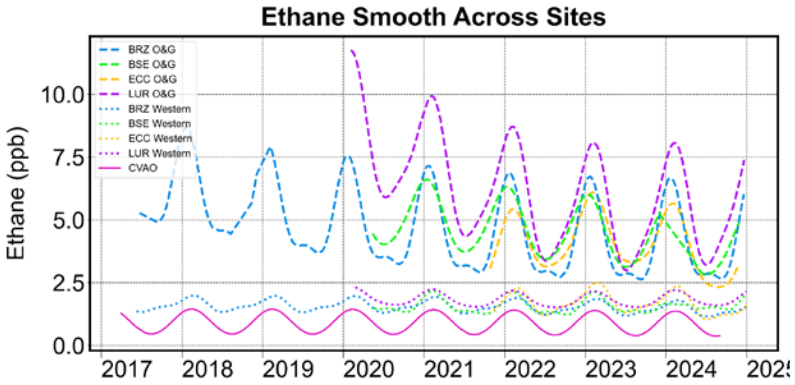


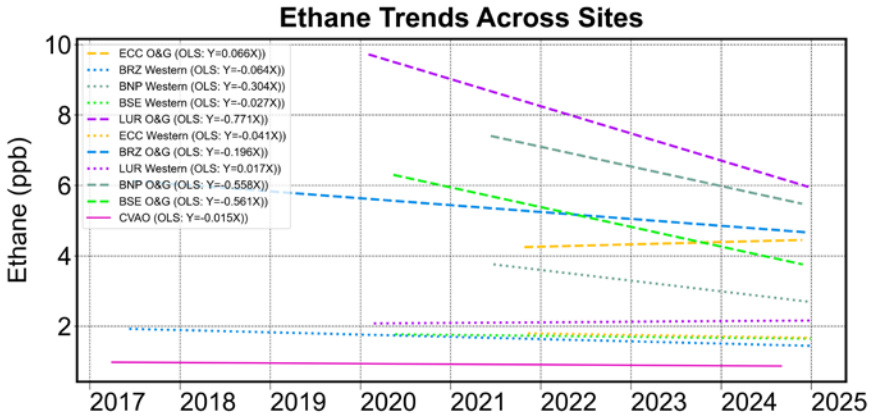
- Erie consistently sees higher frequency and higher maximum concentrations of volatile organic compounds, iso-pentane here as an example, than at the Longmont and Boulder Reservoir comparison sites.
- Frequency and maximum levels of pollution plumes appear to be slowly declining.

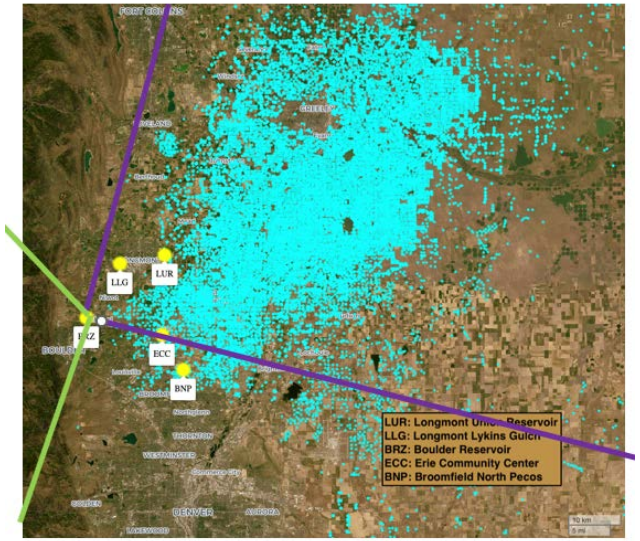
Results from Trends Analysis Project



- Ehane is a selective tracer for oil and gas emissions.
- Trend analyses show that ethane has been declining at Boulder, Longmont, Broomfield sites in air flow from oil and gas sector. Only exemption is Erie, where thus far the data do not show a downwards trend.







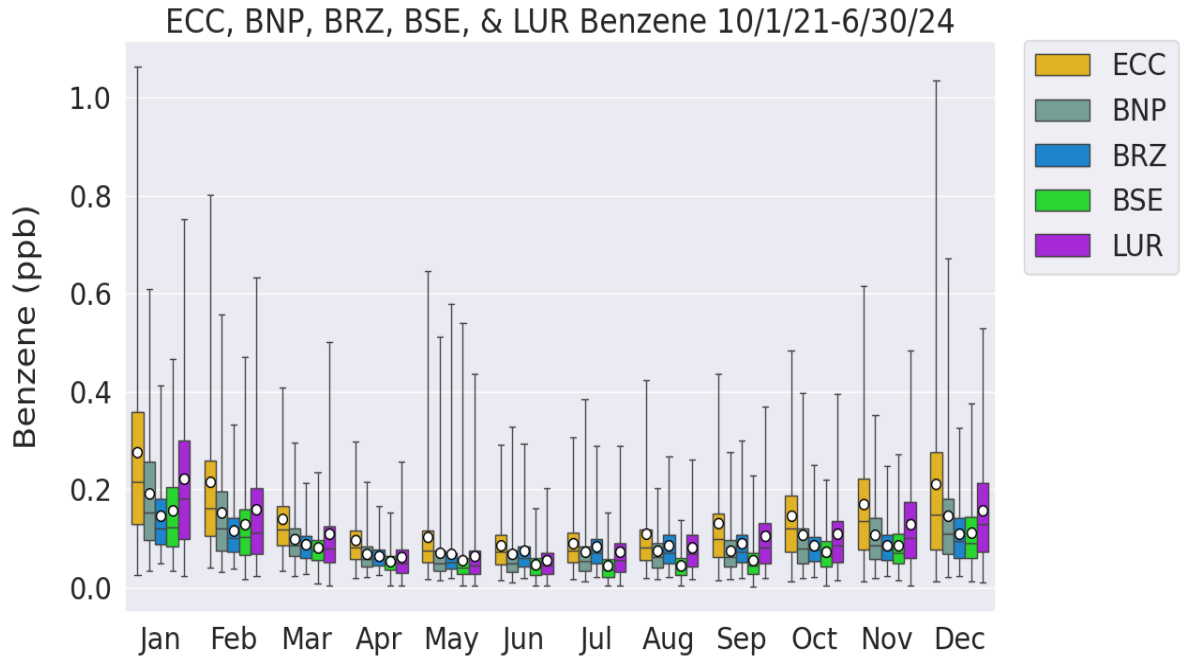
Benzene in Erie Air Monitoring Data

Number of times benzene > 0.9 ppb

Year	ECC	LUR	BRZ	BNP	BSE
2021 [a]	5	1	0	**9**	3
2022	**55**	28	4	9	1
2023	**51**	4	4	15	1
2024	**16**	10	2	0	0
2025 [b]	1	2	-	0	1
Total	128	45	10	33	6

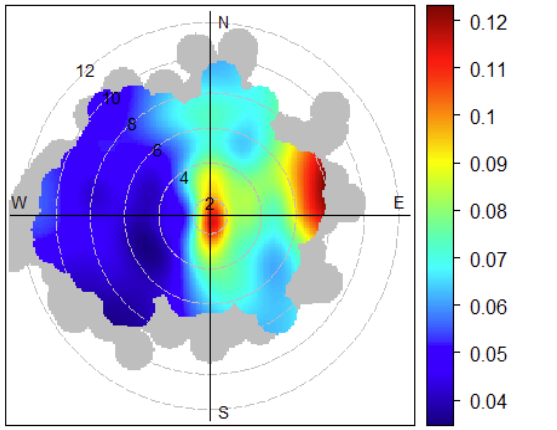
[a] 1 Nov - 31 Dec

[b] 1 Jan - 30 Apl



- Benzene is an airborne carcinogen, e.g. can cause leukemia.
- No safe lower threshold level.
- Benzene levels in Erie are higher throughout the year than at comparison sites.
- Higher benzene is transported in air flow from the north to south sector than from the west.

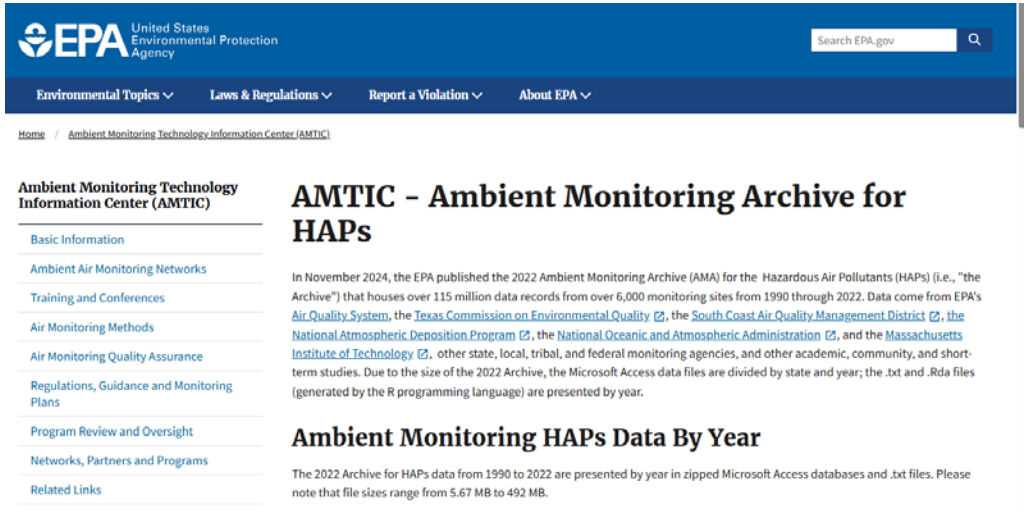
ECC benzene (ppb), Oct 2021 through Aug 2024



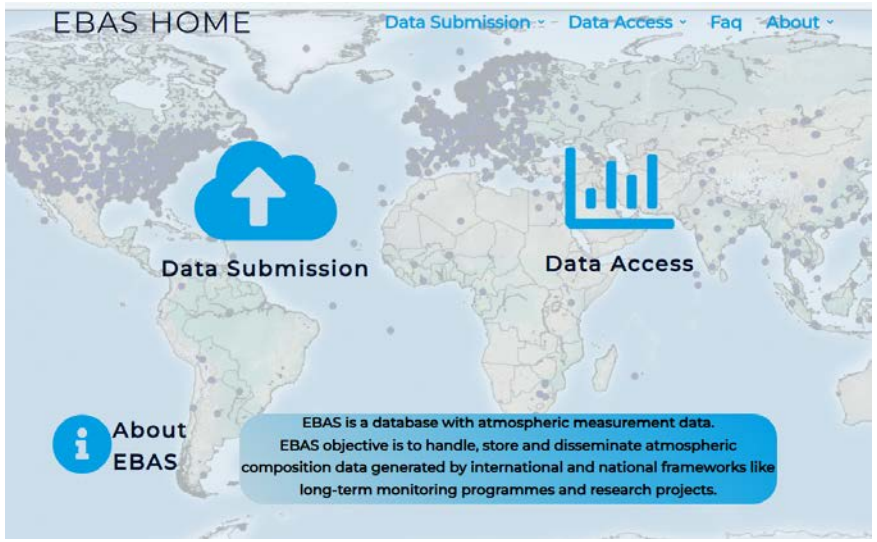
Wind Speed > 1 m/s, Min Bin # = 2

Dissemination and Use of Erie Air Monitoring Data

EPA



Global



National Labs and Universities

NOAA

NCAR

Colorado State University

University of Colorado Boulder

State

Peer-Reviewed Publications Building on Local Government Coalition Air Monitoring

2025

Helmig, D., and Caputi, D. (2025) Top-Down versus Bottom-Up Atmospheric Emission Estimates from Oil and Natural Gas Operations. Manuscript submitted for publication.

Caputi D., Helmig D., Darby L. S., Greenberg G., Hueber J. Ortega J., and Simoncic S. (2025) Late Winter Ozone and PM 2.5 NAAQS Exceedance in the Northern Colorado Front Range in Relation to Oil and Natural Gas Emissions. Geophys. Res. In press.

Helmig D., Greenberg G., Hueber J., Blanchard B., Chopra J., Simoncic S., Angot H., Darby L. S., Ortega J., and Caputi D. (2025) Methane and volatile organic compounds and their influence on air quality in Boulder, Colorado. Elem Sci Anth. 12, DOI: https://doi.org/10.1525/elementa.2023.00117.

2024

Langford A. O., Alvarez II R. J., Aikin K. C., Baidar S., Brewer W. A., Brown S. S., Coggan M. M., Cullis P. D., Gilman J., Gkatzelis G. I., Helmig D., Johnson B. J., Knowland K. E., Kumar R., Lamplugh A. D., McClure-Begley A., McCarty B. J., Middlebrook A. M., Pfister G., Peischl J., Petropavlovskikh I., Rickley P. S., Rollins A. W., Sandberg S. P., Senff C. J., and Warneke C. (2024) An unusual winter ozone event in Colorado. EGUsphere. DOI: https://doi.org/10.5194/egusphere-2024-1938.

Helmig D., Nobel J., Caputi D., Brown D., Daly R. W., Darby L. S., Doe P. T., Gonzalez O., Greenberg G., Hueber J., Potter K., Schade G. W., Simoncic S., Stahli M., and Subra W. (2024) Elevated airborne radioactivity downwind of a Colorado oil refinery. J. Air&Waste Manag. Assoc. 1-12, DOI: https://doi.org/10.1080/10962247.2024.2393194.

2022

Helmig D., Fangmeyer J., Fuchs J., Hueber J., and Smith K. (2022) Evaluation of selected adsorbents for passive sampling of atmospheric oil and natural gas non-methane hydrocarbons. J. Air & Waste Management Association 72, 235-255, DOI: 10.1080/10962247.2021.2000518.

2021

Rossabi S., Hueber J., Wang W., Milmoe P., and Helmig D. (2021) Spatial distribution of atmospheric oil and natural gas volatile organic compounds in the Northern Colorado Front Range. Elem. Sci. Anthro. 9, DOI: 10.1525/elementa.2019.00036.

Pollack I.B., Helmig D., O'Dell K., and Fischer E.V. (2021) Weekend-weekday implications and the impact of wildfire smoke on ozone and its precursors at Boulder Reservoir, Colorado between 2017 and 2019. J. Geophys. Res. 126, DOI: 10.1029/2021JD035221.

Oltmans S.J., Cheadle L.C, Helmig D., Angot H., Petron G., Montzka S.A., Dlugokencky E.J., Miller B., Hall B., Schnell R.C., Kofler J., Wolter S., Crotwell M., Siso C., Tans P. and Andrews A. (2021) Atmospheric oil and natural gas hydrocarbon trends in the Northern Colorado Front Range are notably smaller than inventory emissions reductions. Elem. Sci. Anthro. 9, DOI: 10.1525/elementa.2020.00136.

Darby L.S., Senff C.J., Alvarez R.J. II, Banta R.M., Bianco L., Helmig D., and White A.B. (2021) Spatial and temporal variability of ozone along the Colorado Front Range occurring over two days with contrasting wind flow. Elem. Sci. Anthro. 9, DOI: 10.1525/elementa.2020.00146.

Pollack I.B., Helmig D., O'Dell K., and Fischer E.V. (2021) Seasonality and source apportionment of non-methane organic compounds at Boulder Reservoir Colorado, between 2017-2019. J. Geophys. Res., DOI: 10.1029/2020JD034234.

Asher E., Hills A.J., Hornbrook R.S., Shertz S., Gabbard S., Stephens B.B., Helmig D., and Apel E.C. (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., doi:10.1021/acs.est.0c07213.

2020

Pozzer A., Schultz M.G., Helmig D. (2020) Impact of U.S. oil and natural gas emission increases on surface ozone is most pronounced in the Central United States. Environ. Sci. Technol. 54, 12423–12433. https://dx.doi.org/10.1021/acs.est.9b06983

Helmig D. (2020) Air quality impacts of oil and natural gas development in Colorado. Elem. Sci. Anth. 8, 1-33. http://doi.org/10.1525/elementa.398

2019

Tzompa-Sosa Z. A., Henderson B. H., Keller C. A., Travis K., Mahieu E., Franco B., Estes M., Helmig D., Fried A., Richter D., Weibring P., Walega J., Blake D. R, Hannigan J. W., Ortega I., Conway S., Strong K., Fischer E. V. (2019) Atmospheric implications of large C2-C5 alkane emissions from the US oil and gas industry. J. of Geophys. Res. 124, 1148-1169. DOI: 10.1029/2018JD028955

Oltmans S. J., Cheadle L. C., Johnson B. J., Schnell R. C., Sterling C., Thompson A. M., Helmig D., Cullis P., Hall E., Jordan A., McClure-Begley A., Sullivan J. T., McGee T. P., and Wolfe D. (2019) Boundary layer ozone in the Northern Colorado Front Range in July-August 2014 during FRAPPE and DISCOVER-AQ from vertical profile measurements. Elem. Sci. Anth. 7, 1-14.

2018

Tzompa-Sosa Z., Richter D., Henderson B., Travis K., Keller C., Mahieu E., Franco B., Estes M., Helmig D., Fried A., Weibring P., Walega J., Blake D., Hannigan J., Ortega I., Conway S., Strong K., and Fischer E. (2018) Atmospheric implications of large light alkane emissions from the U.S. oil and gas industry. J. Geophys. Res. 124, 1148-1169.

Bien T. and Helmig D. (2018) Changes in the summertime ozone chemistry in Colorado during 2000 – 2015. Elem. Sci. Anth. 6, 1-25, doi: 10.1525/elementa.300.

Monks S. A., Wilson C., Emmons L. K., Hannigan J., Helmig D., Blake N. J., and Blake D. R. (2018) Using an inverse model to reconcile differences in simulated and observed global ethane concentrations and trends between 2008 and 2014. J. Geophys. Res. 123, 11,262-11,282, doi:10.1029/2017JD028112.

Rossabi S., Choudoir M., Helmig D., Hueber J., and Fierer N. (2018) Volatile organic compound emissions from soil following wetting events. J. Geophys. Res. Biogeosciences, 123, 1988-2001, doi:10.1029/2018JG004514.

McKenzie L. M., Blair B., Hughes J., Allshouse W. B., Blake N. J., Helmig D., Milmoe P., Halliday H., Blake D. R., and Adgate J. L. (2018) Ambient nonmethane hydrocarbon levels along Colorado's Northern Front Range: Acute and chronic health risks, Environ. Sci. Technol. 52, 4514-4525, doi:10.1021/acs.est.7b05983.

Rossabi S., and Helmig D. (2018) Changes in atmospheric butanes and pentanes and their isomeric ratios in the Continental United States. J. Geophys. Res. 123, 3772-3790, doi:10.1002/2017JD027709.

Dalsøren S.B., Myhre G., Hodnebrog Ø., Myhre C.L., Stohl A., Pisso I., Schwietzke S., Höglund-Isaksson L., Helmig D., Reimann S., Sauvage S., Schmidbauer N., Read K.A., Carpenter L.J., Lewis A.C., Punjabi S., and Wallasch M. (2018) Discrepancy between simulated and observed ethane and propane levels explained by underestimated fossil emissions. Nature Geosci. 11, 178–184.

Research Building on Erie Data and Supported by External Sources

"Air quality trends in Texas and Colorado as associated with unconventional oil and gas development (UOG)"; submitted by Texas A&M University and Boulder AIR, awarded by the Health Effects Institute (HEI), 2024.

"Comprehensive Ozone Source Location Analysis"; prepared by the Local Governments Air Monitoring Coalition and awarded by the Colorado Air Quality Enterprise, 2024.

"How much of the Denver Metro Northern Front Range Ozone is Produced from Isoprene?"; prepared by Boulder AIR and awarded by the Colorado Air Quality Enterprise, 2024.

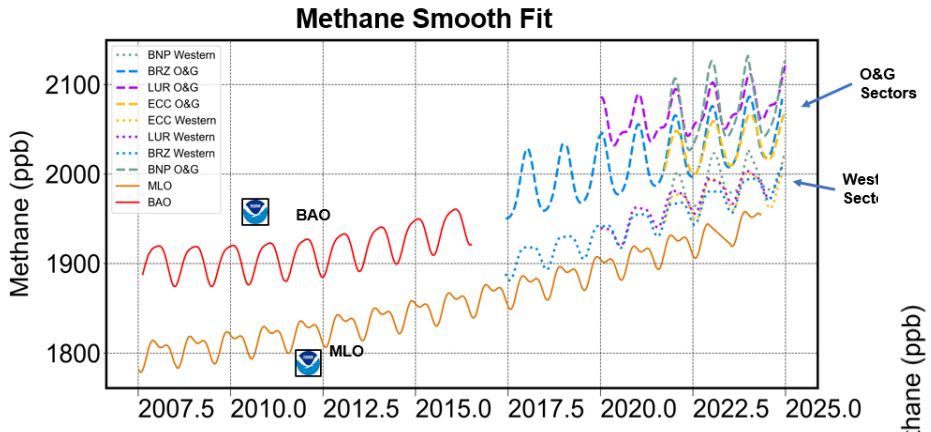
"Erie Landfill Air Emissions and Community Exposure Study", prepared in partnership by Town and Erie and Boulder Air. Submitted in April 2025 to the Mountains and Plains Environmental Justice Program. Proposal was rejected and funding program was withdrawn by federal government.

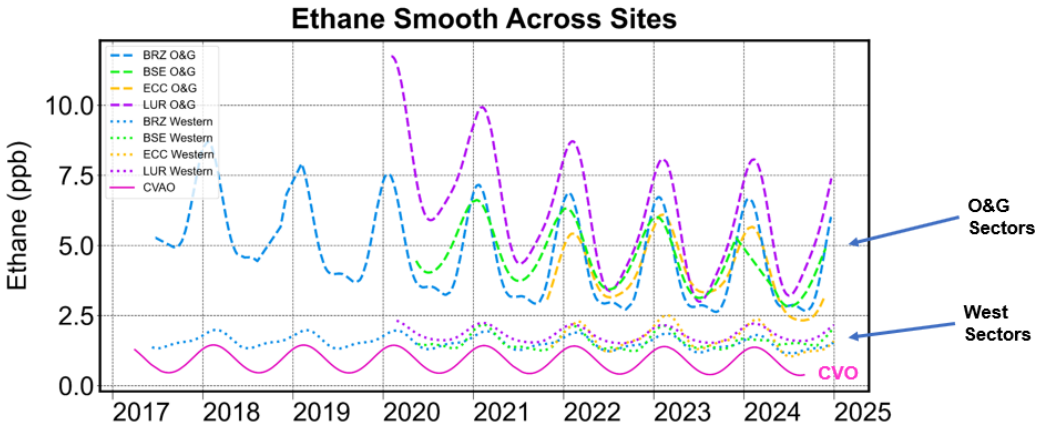
Impact - Colorado Legislations Targeting Oil and Gas Industry Emissions

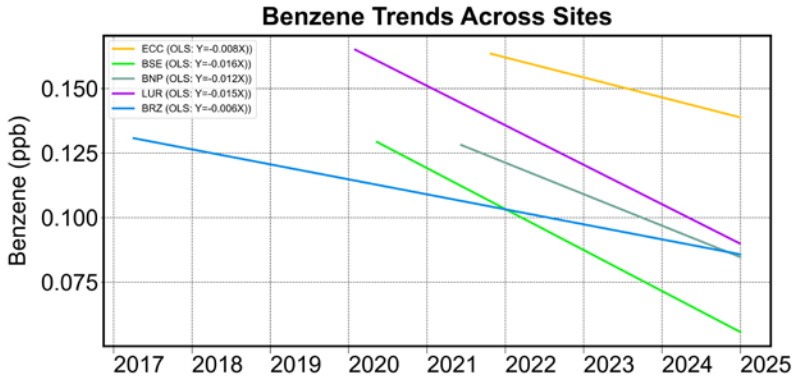
Year Introduced	Bill or Commission	Effective Date	Policy/Action
2007	HB07-1298	May 1, 2009	Suite of new regulations passed which included requirements for emission control devices on certain equipment near communities.
2007	HB07-1341	Jul. 1, 2007	Reconstructs the Colorado Oil and Gas Conservation Commission (COGCC) to have more representation from outside of the oil and gas industry.
2011	COGCC	Apr. 1, 2012	Hydraulic fracturing sites must disclose all chemicals used in a public database.
2013	SB 13-202	Jul. 1, 2014	Requires a greater frequency of inspections at oil and gas wellheads, prioritized based on risk level of a wellhead experiencing excess emissions based on its phase of development.
2013	COGCC	Jan. 9, 2013	Setbacks for drilling increased to 500 feet for homes and 1000 feet for high occupancy buildings such as schools and hospitals.
2014	CDPHE AQCC	Feb. 23, 2014	Colorado Air Quality Control Commission adopts a series of policies to reduce methane emissions, making Colorado the first state to do so.
2015	COGCC	Feb. 14, 2015	Penalties increased for all emission violations.
2019	SB19-181	Jan. 15, 2021	Enables local governments to have HB1041 powers over oil and gas mineral extraction areas without restriction, including the ability to inspect any facility. Setbacks increased from 500 to 2000 feet.
2019	HB19-1261	May. 30, 2019	Colorado implements a goal to reduce greenhouse gas emissions by 26% and 50% of what was observed in 2005, by 2025 and 2030, respectively.
2020	SB20-204	Jan. 1, 2021	Air Quality Enterprise established to conduct high-quality scientific studies on air pollution in Colorado.
2021	HB21-1189	Jan. 1, 2023	“Regulate Air Toxics Act” implements fenceline monitoring requirement for hydrogen sulfide, hydrogen cyanide, and benzene at four major facilities. Community monitoring is also now required.
2022	HB22-1244	Jan. 1, 2023	Allows the Air Quality Control Commission to designate "toxic air contaminants" to be regulated more stringently than the Clean Air Act and requires these emissions to be reported.
2022	SB22-193	Jun. 30, 2022	Clean Air Grant Program funds public and private entities $25M for projects to reduce industry-related air pollution.
2023	CHPHE AQCC REG 7	Jun. 14, 2025	Operators must directly measure GHG emissions and comply with facility-level standards using approved monitoring technologies.

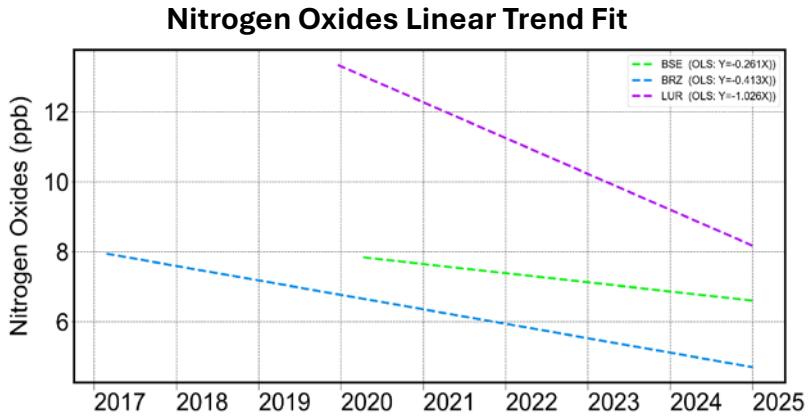
Legislation co-directed by Front Range Local Government Coalition Air Monitoring and Research Program

Summary: Impact, the Big Picture, and Some Good News





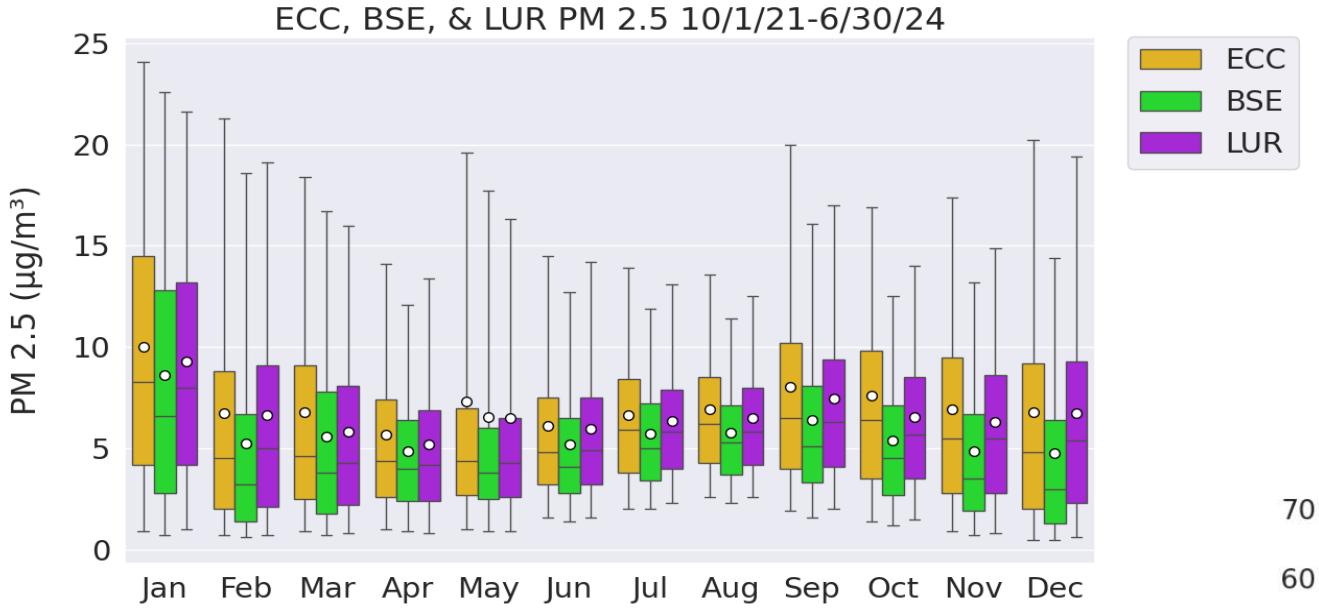


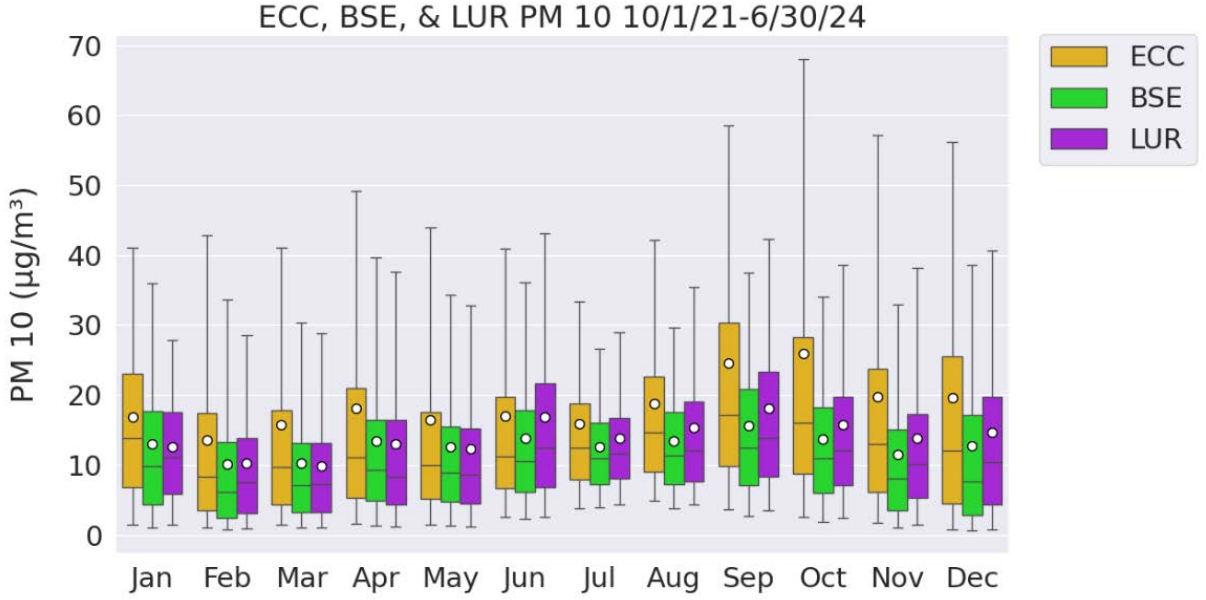


- Methane increase is slower than in the global background –> sign for declining methane emissions.
- Ethane levels are declining at most sites (except ECC) -> sign for declining O&G VOCs emissions.
- Nitrogen Oxides levels are dropping -> pathway for improving ozone pollution.
- Erie remains the most pollution impacted community in the Front Range.

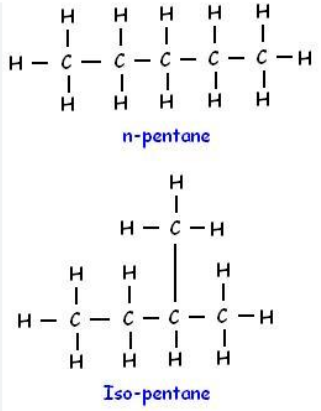
Q&A Slides

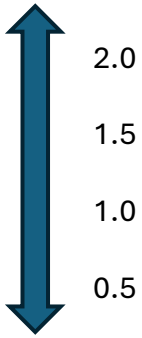
PM2.5 and PM10 Sites Comparison

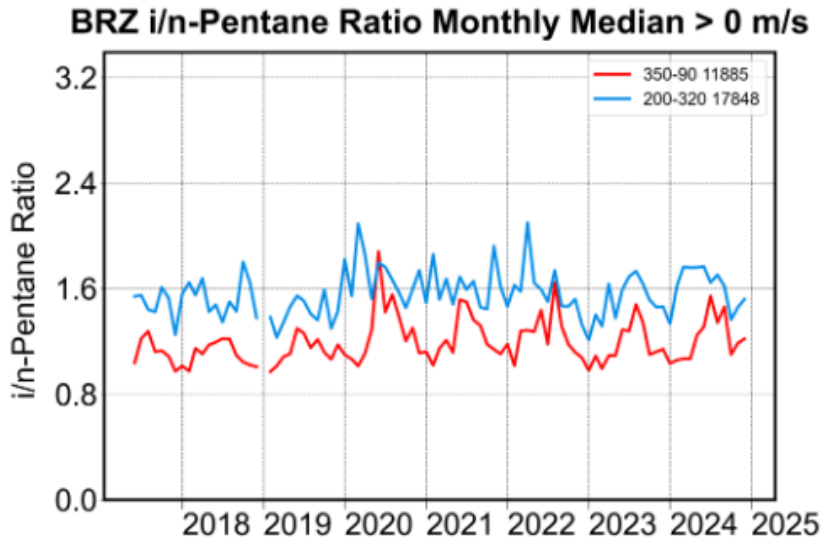


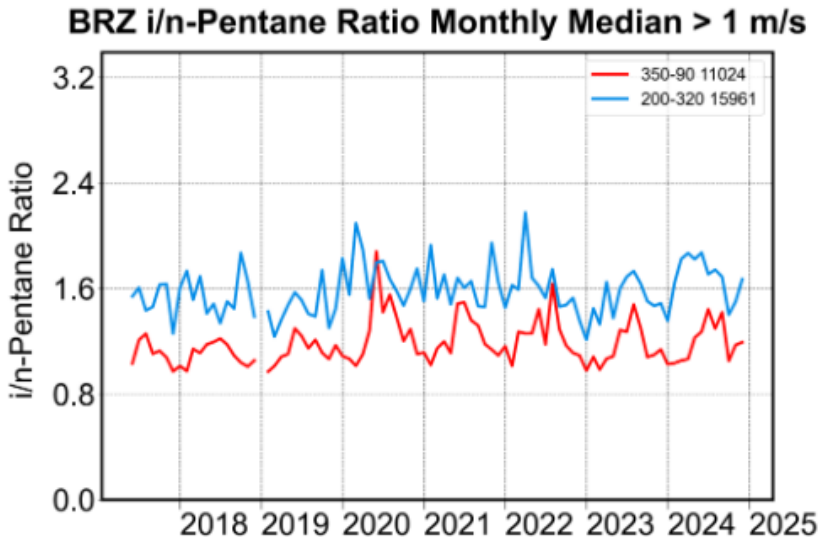


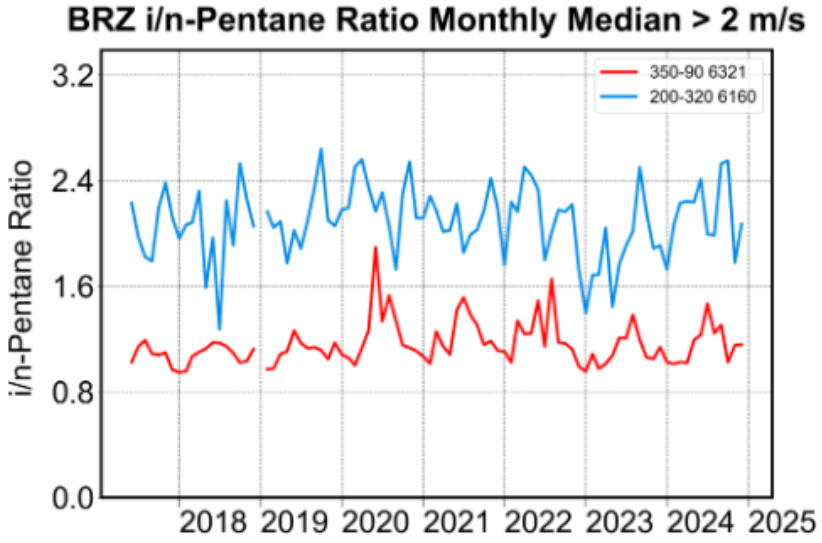
Trend Analyses – Isomeric Pentane Ratio Differentiated by Wind Speed

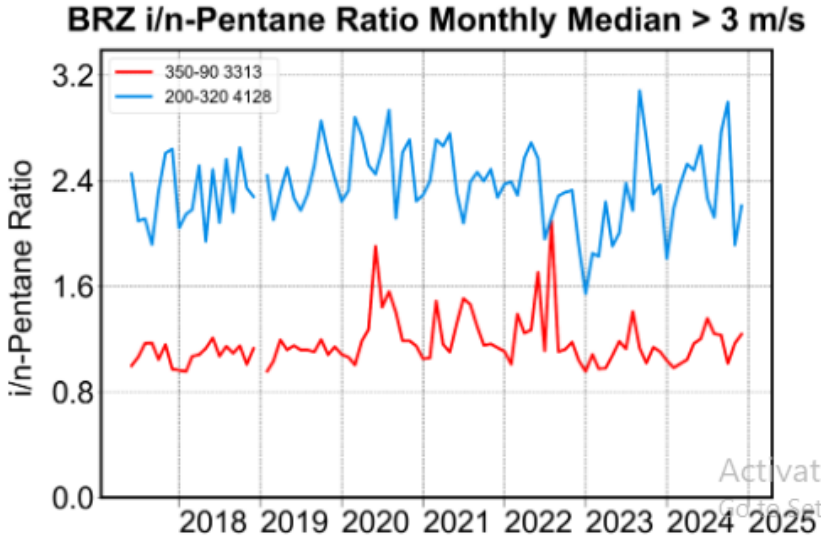




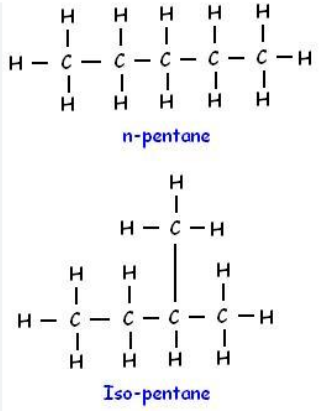


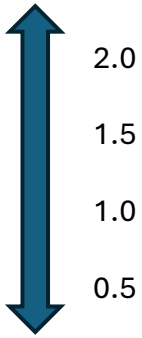


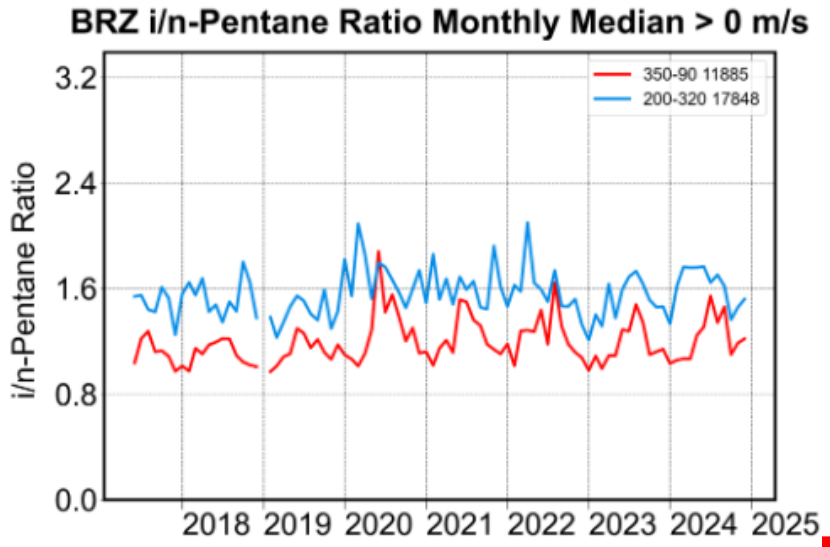


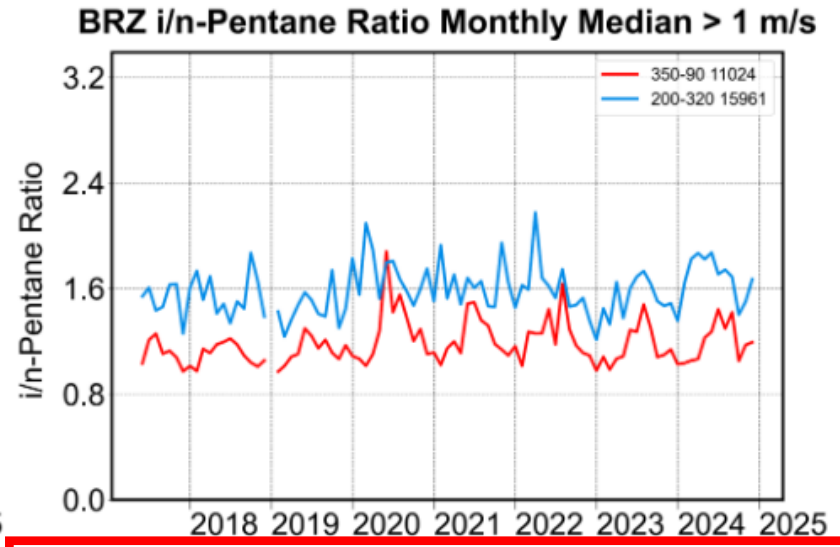


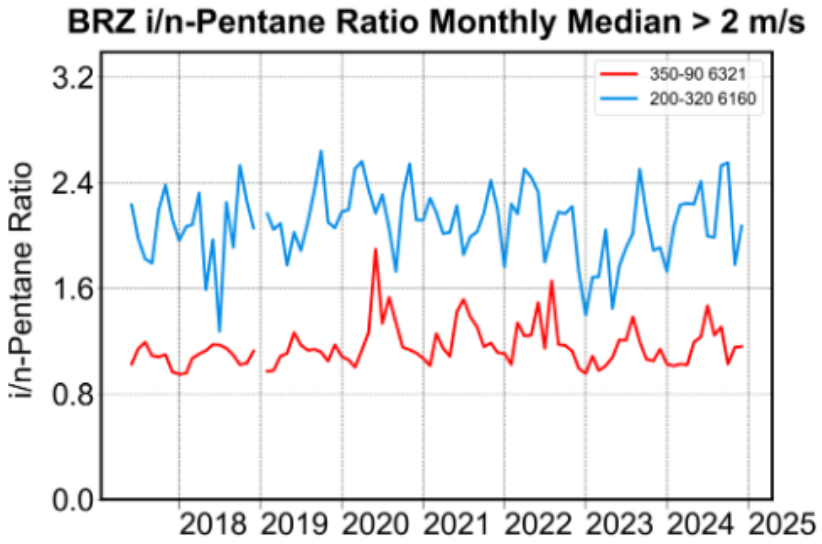
Trend Analyses – Isomeric Pentane Ratio Differentiated by Wind Speed

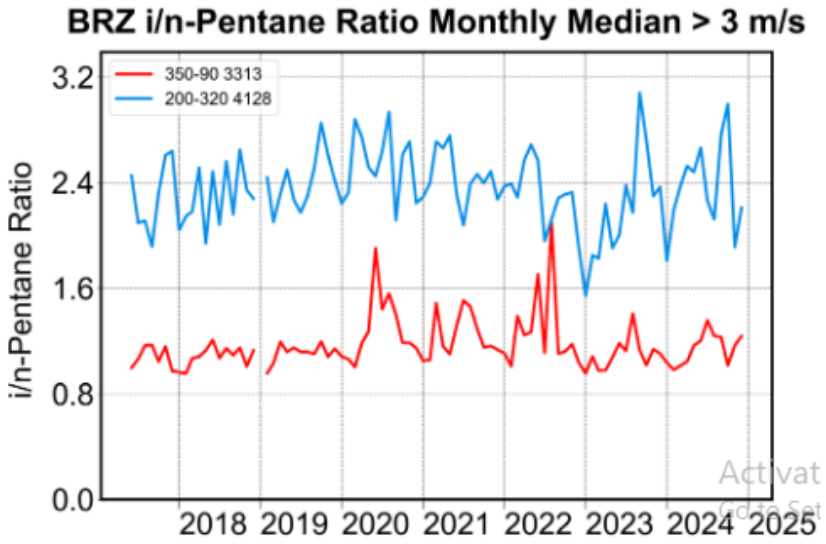












Plus 2/3 of data in prior and post hour from within same sector

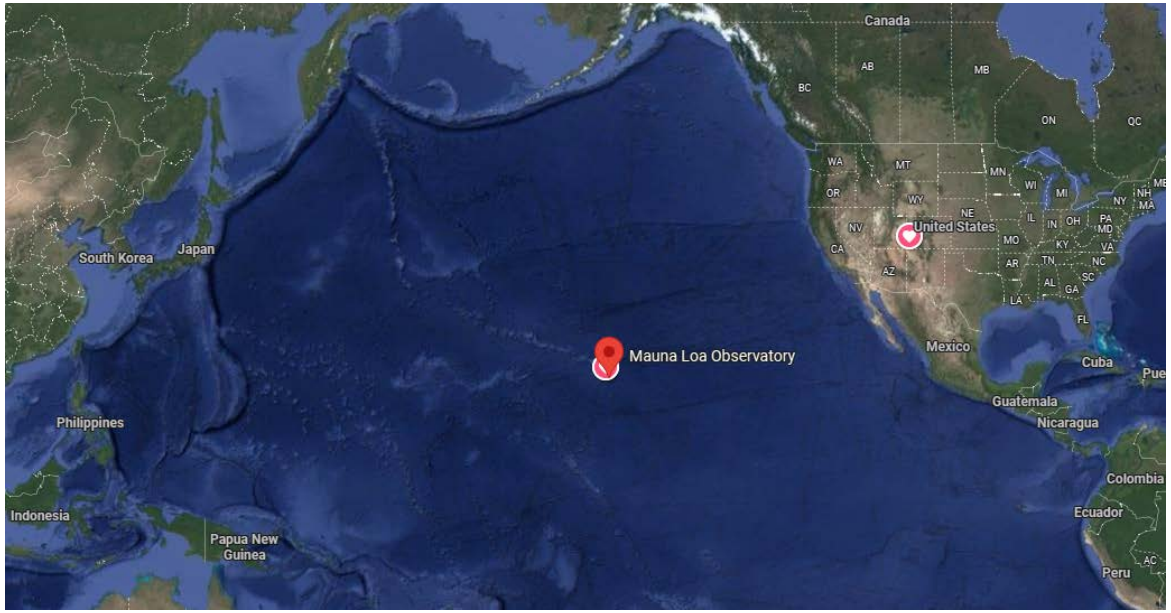
Trend Analyses – Background Reference Data

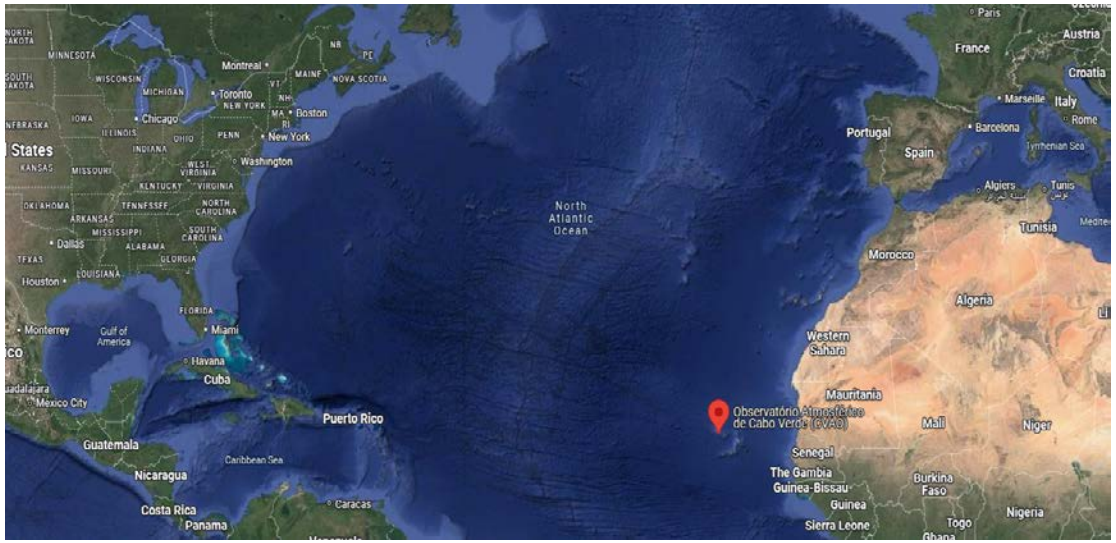
Mauna Loa Observatory (MLO)

(Methane)

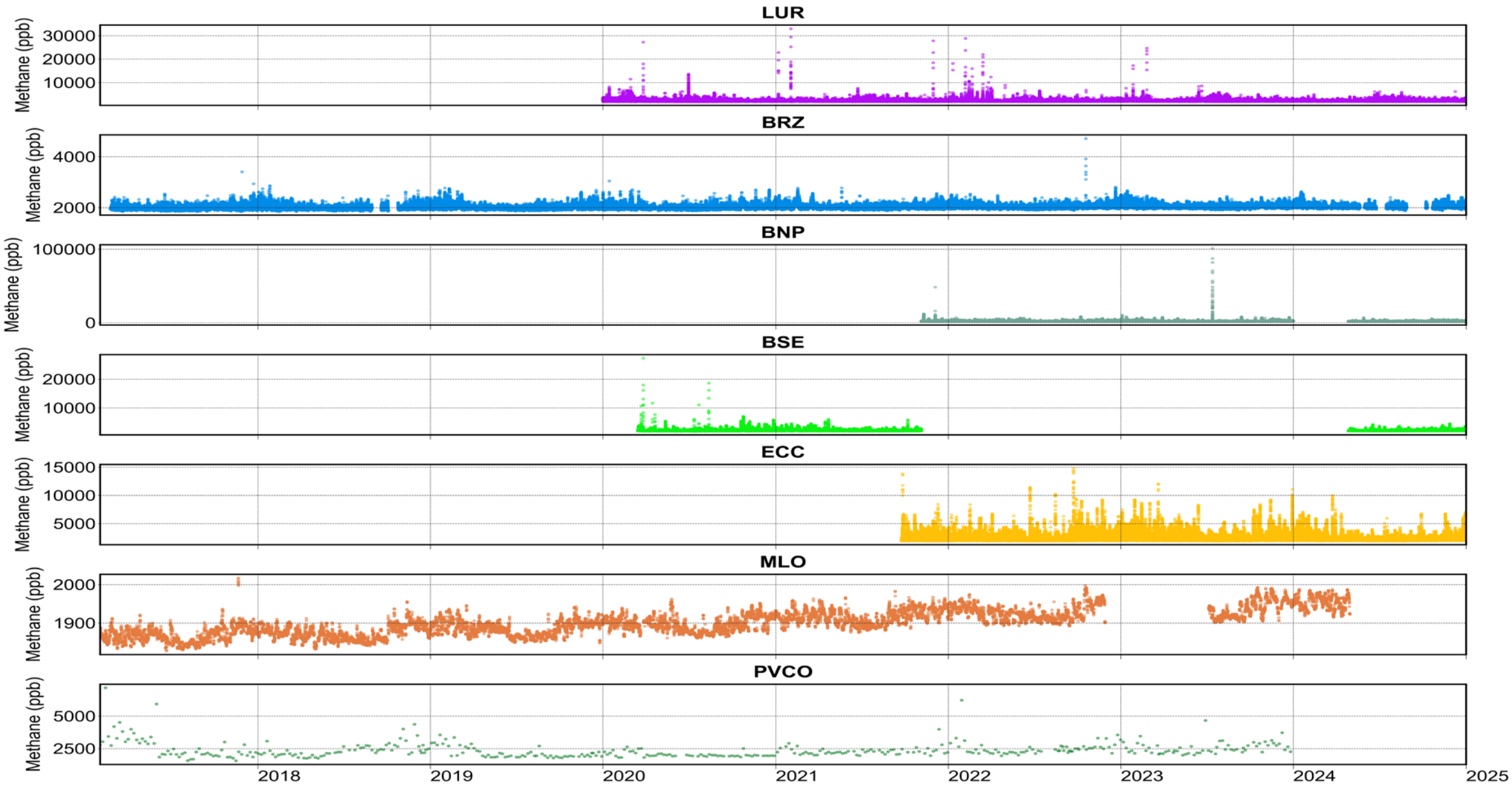
Cape Verde Observatory (CVO)

(Ethane)

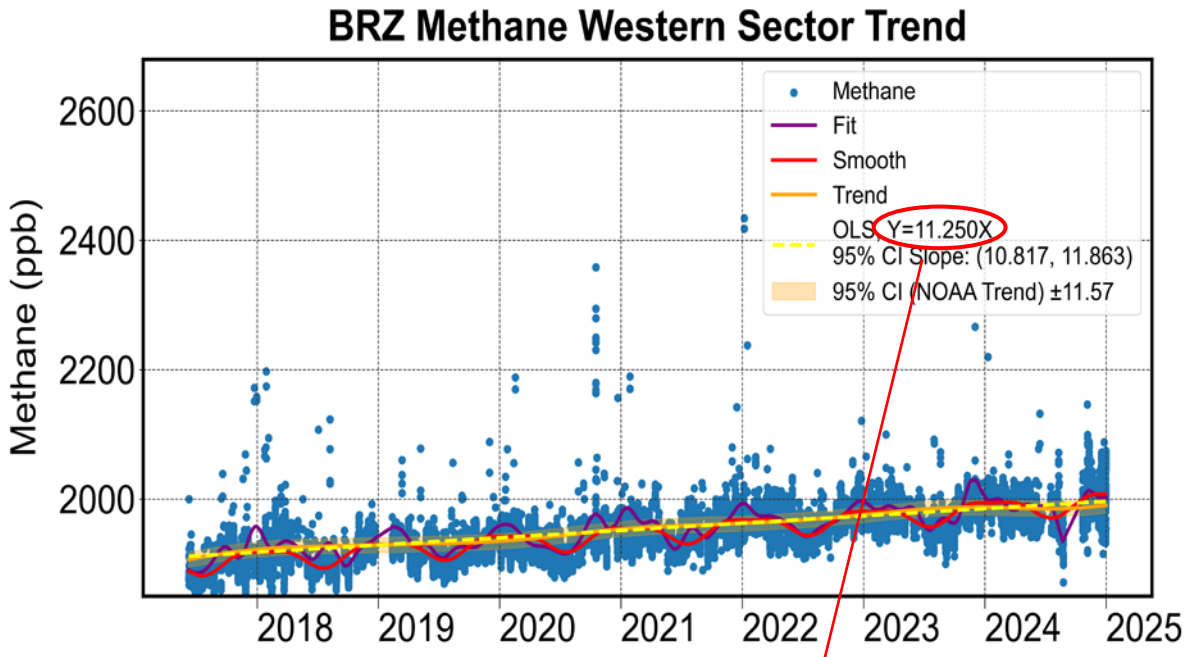




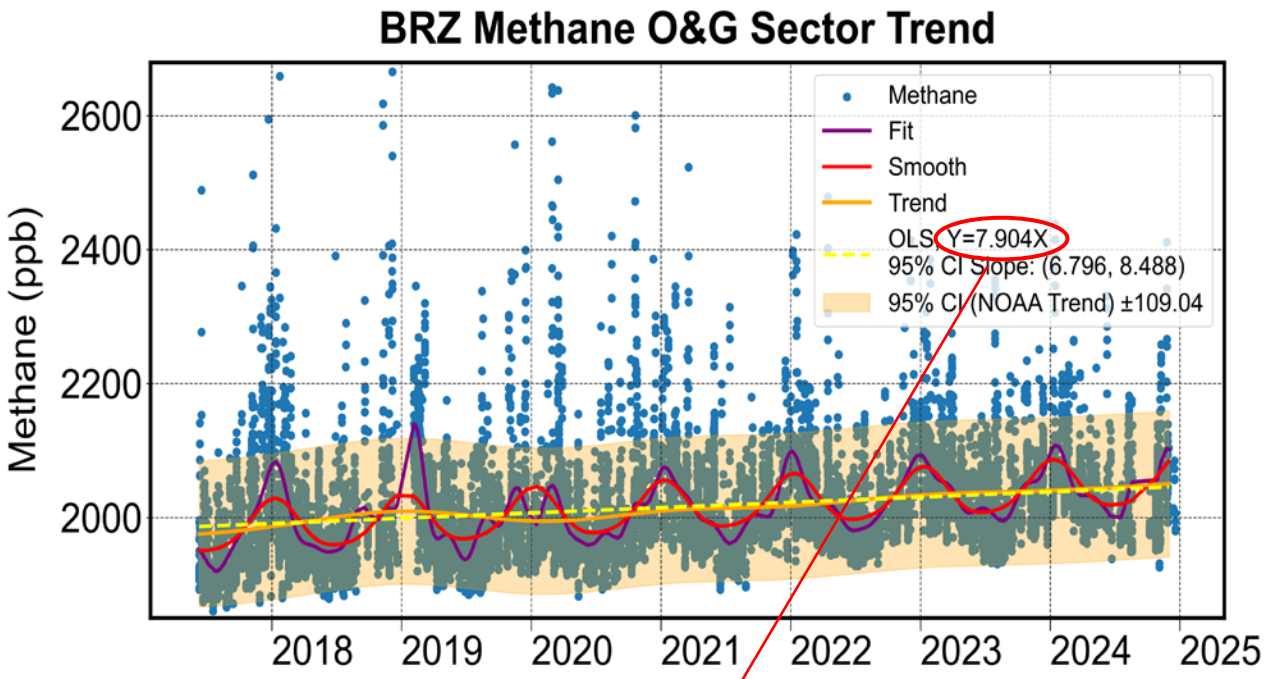
Methane Data Records



Methane Trend Analyses Results – Boulder Reservoir

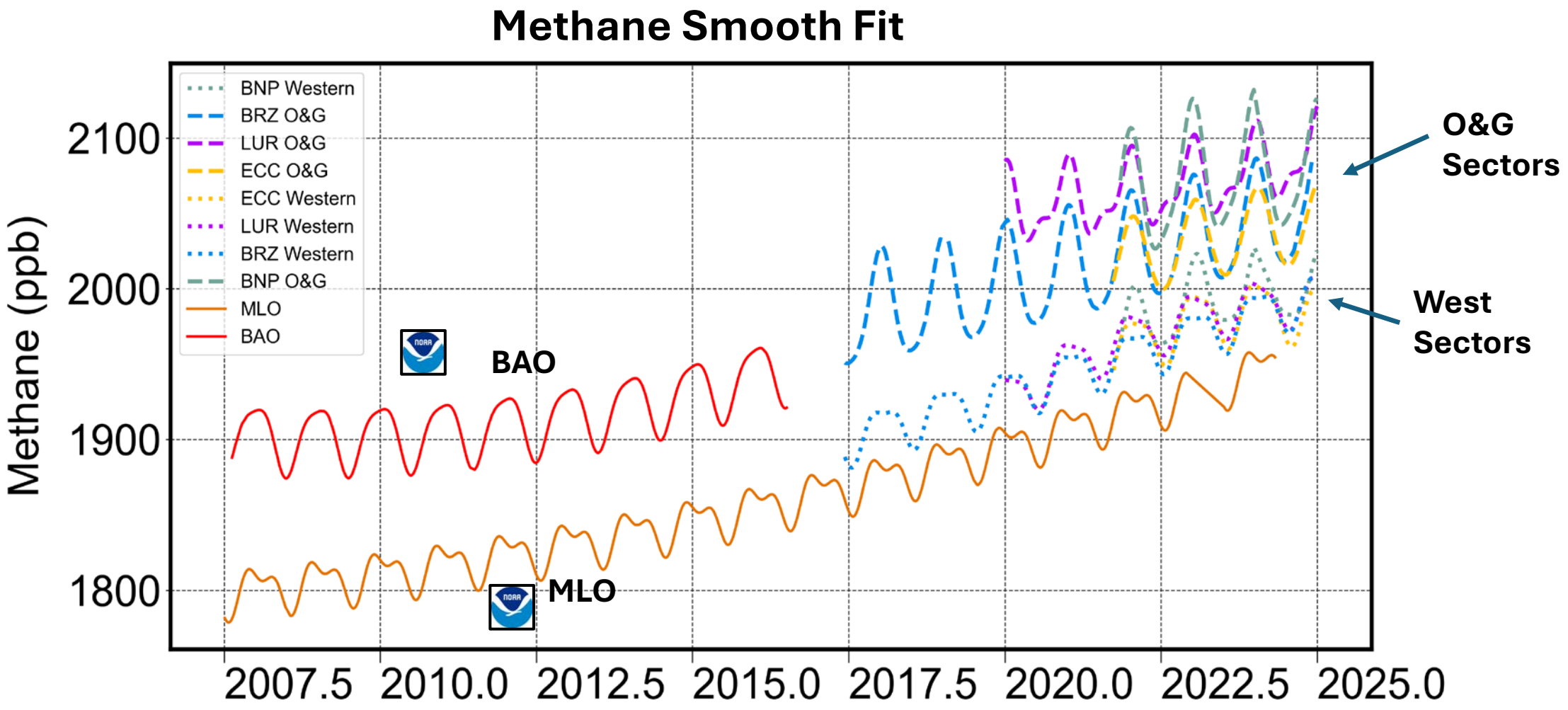


Growth Rate: 11.25 ppb/yr

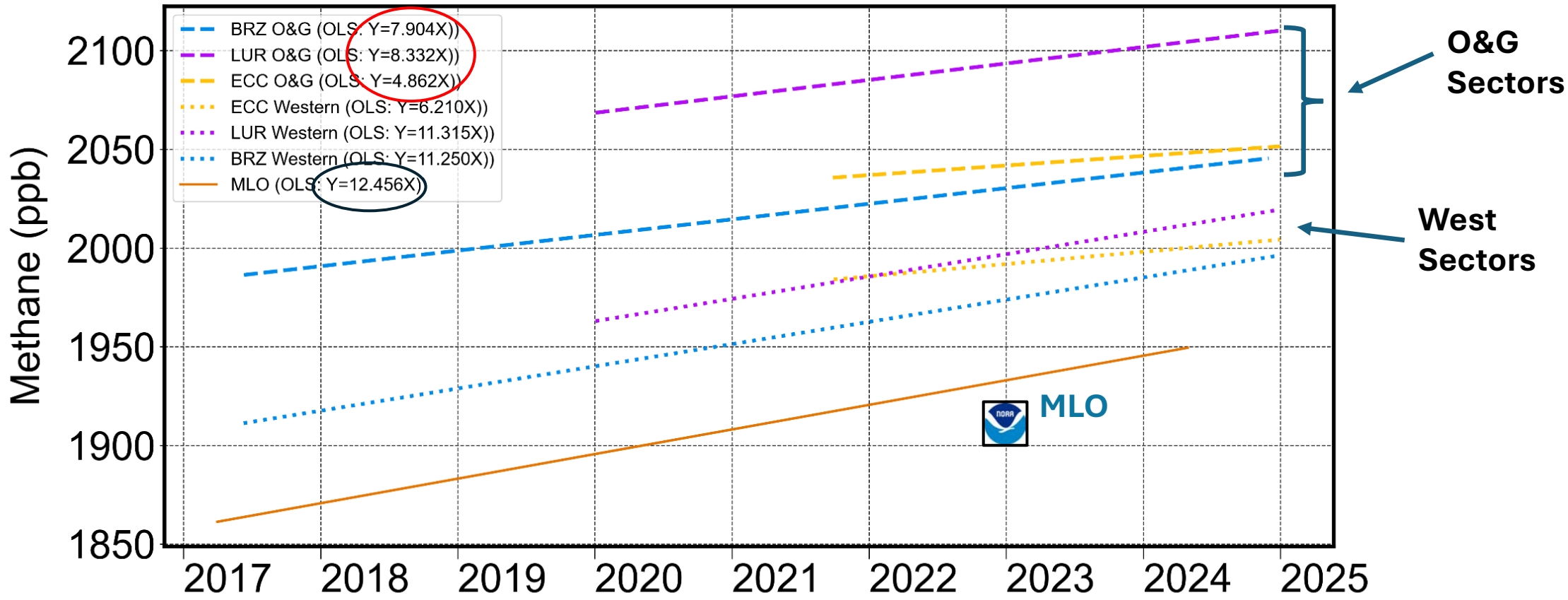


Growth Rate: 7.90 ppb/yr

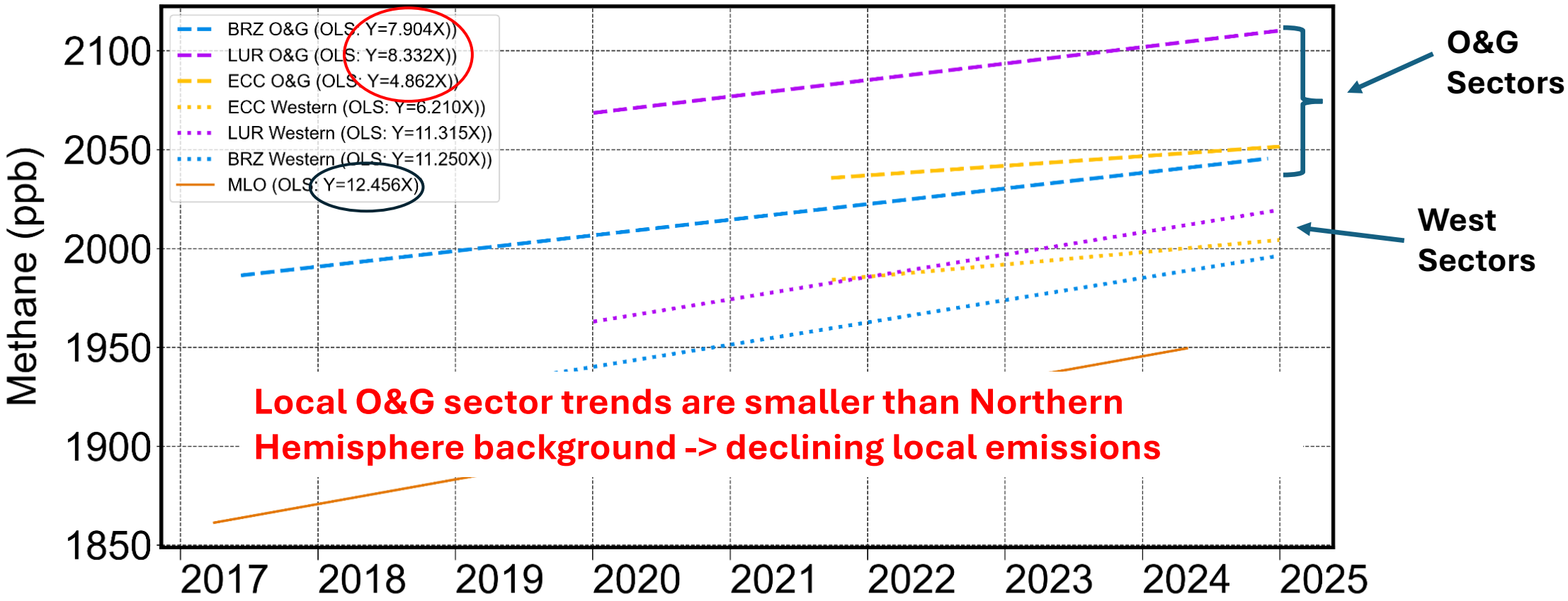
Methane Trend Analysis Results – All Sites



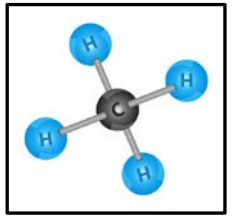
Methane Trend Analyses – Linear Fits all Sites



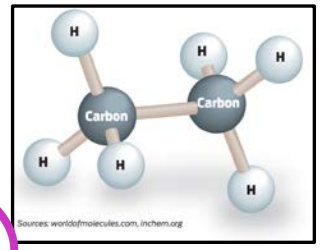
Methane Trend Analyses – Linear Fits all Sites



Trend Analyses – Ethane as Oil and Natural Gas Tracer



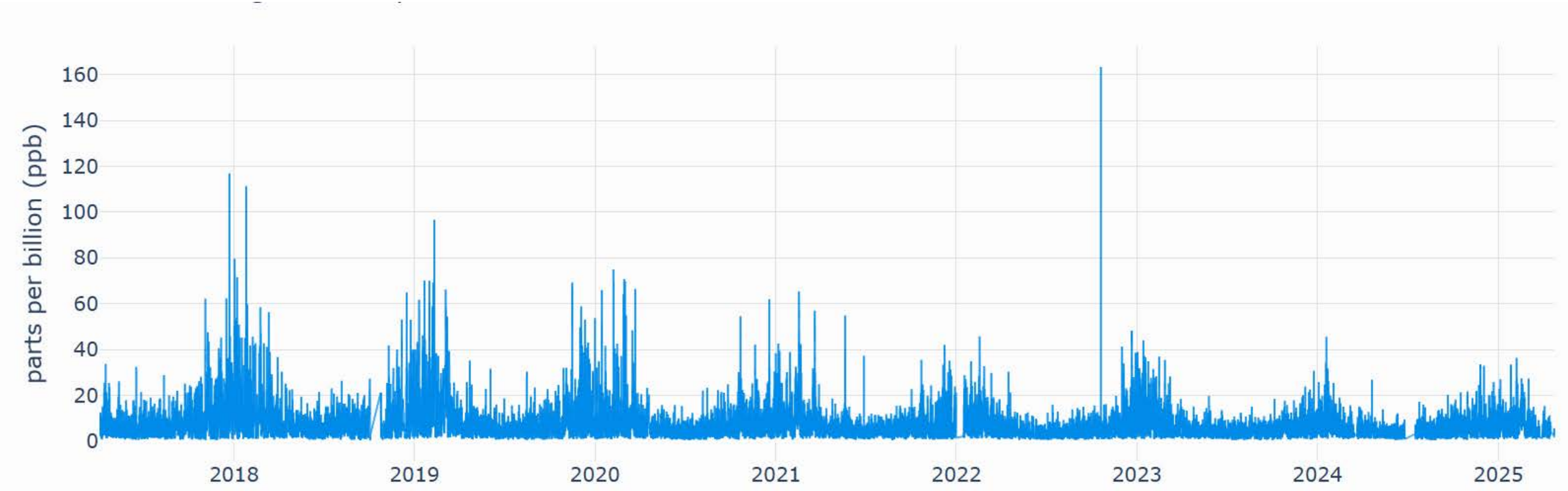
Ethane



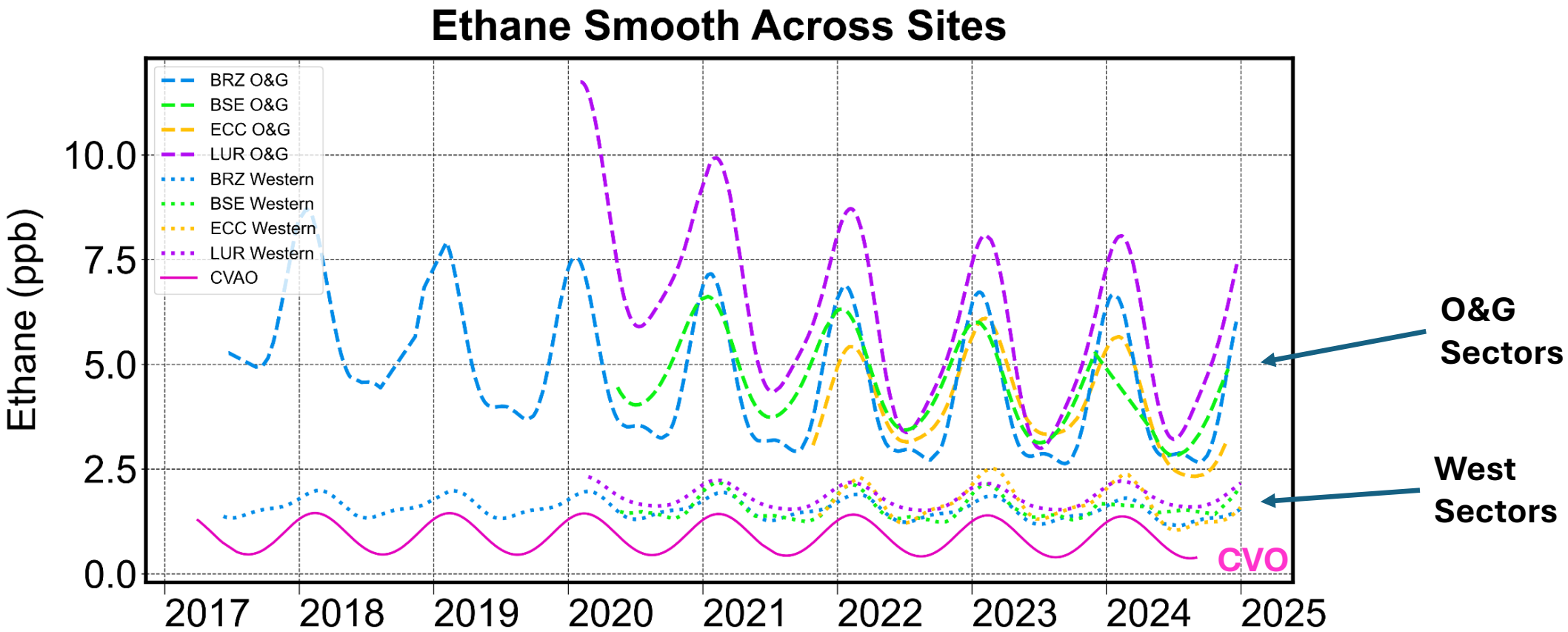
Methane

Nitrogen Oxides (NOx)

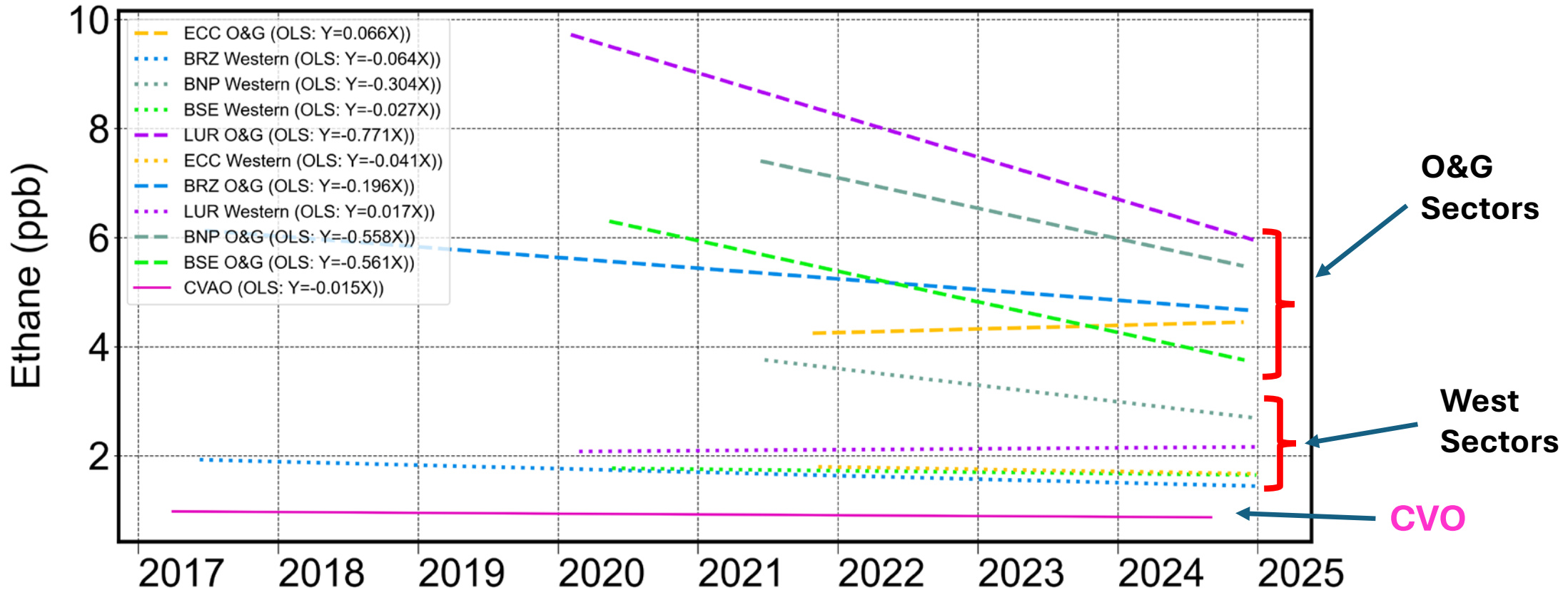
Ethane Trend Analysis – Boulder Reservoir Data Record



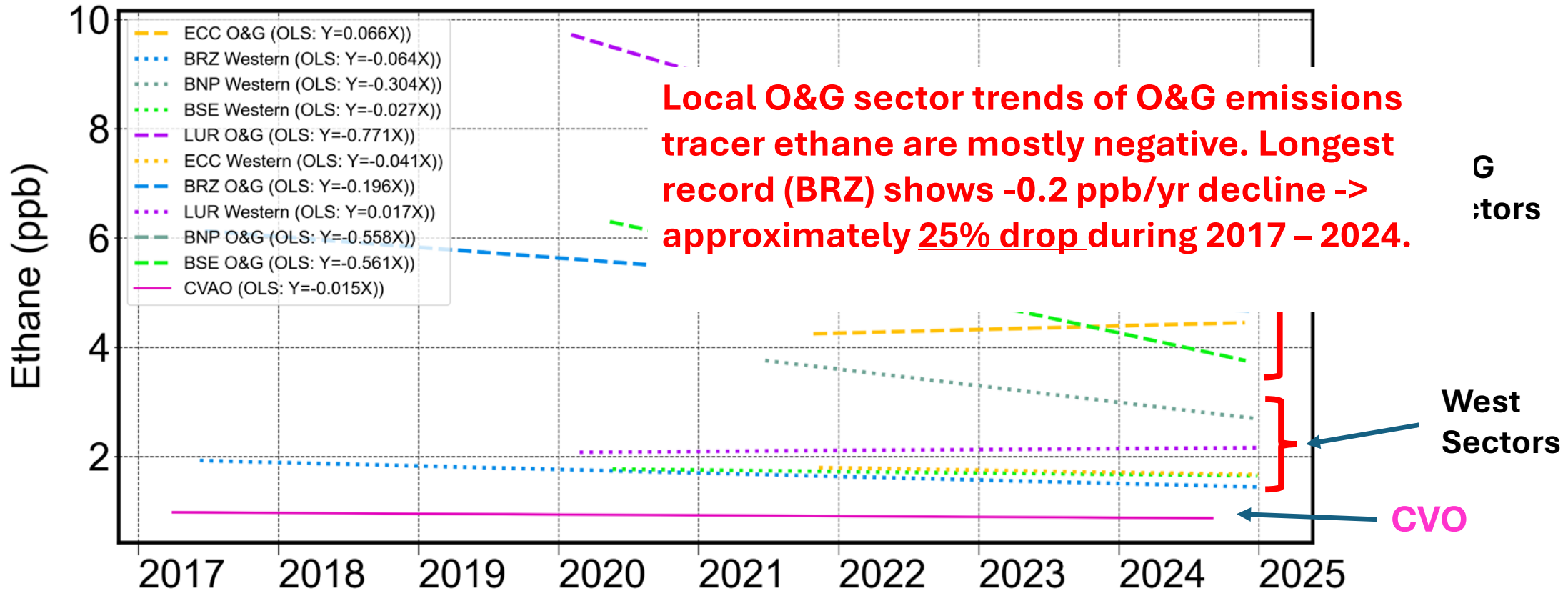
Ethane Trend Analyses



Ethane Linear Trend Analysis Results

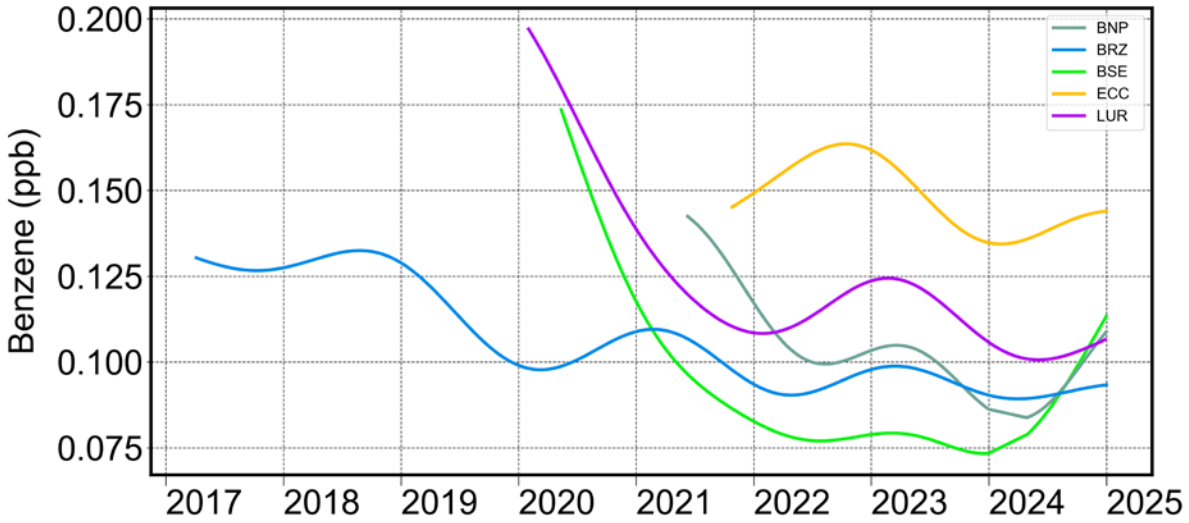


Ethane Linear Trend Analysis Results

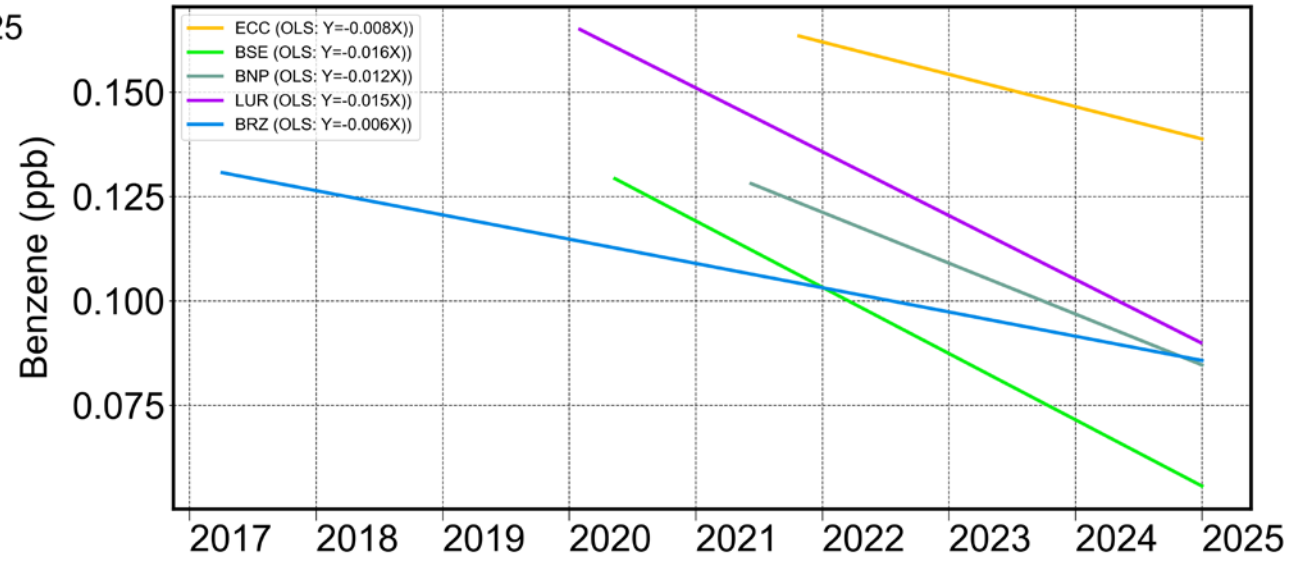


Benzene Trend Analyses Results

Benzene Trend Curves

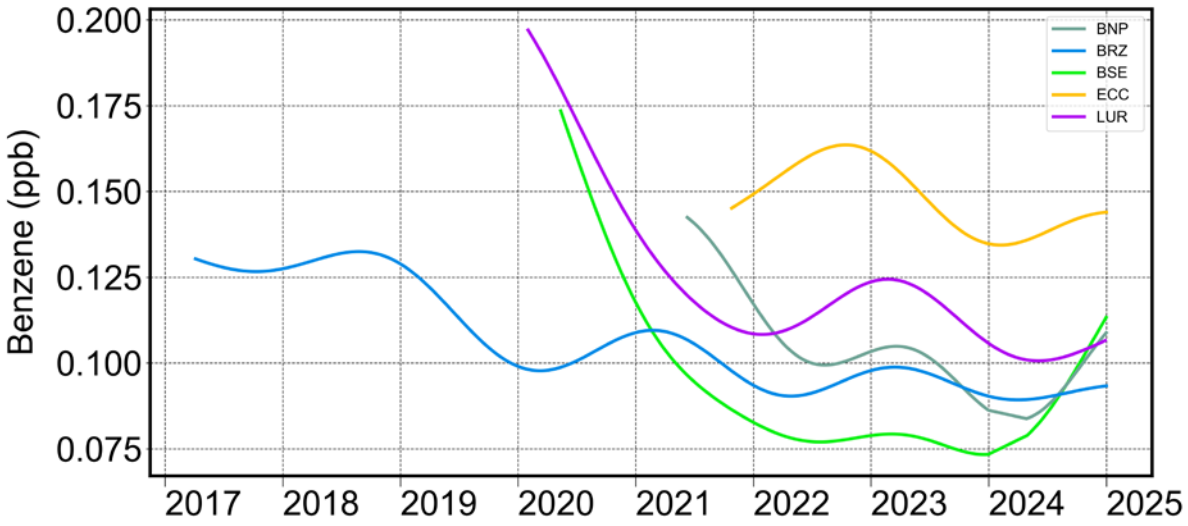


Benzene Linear Trend Lines



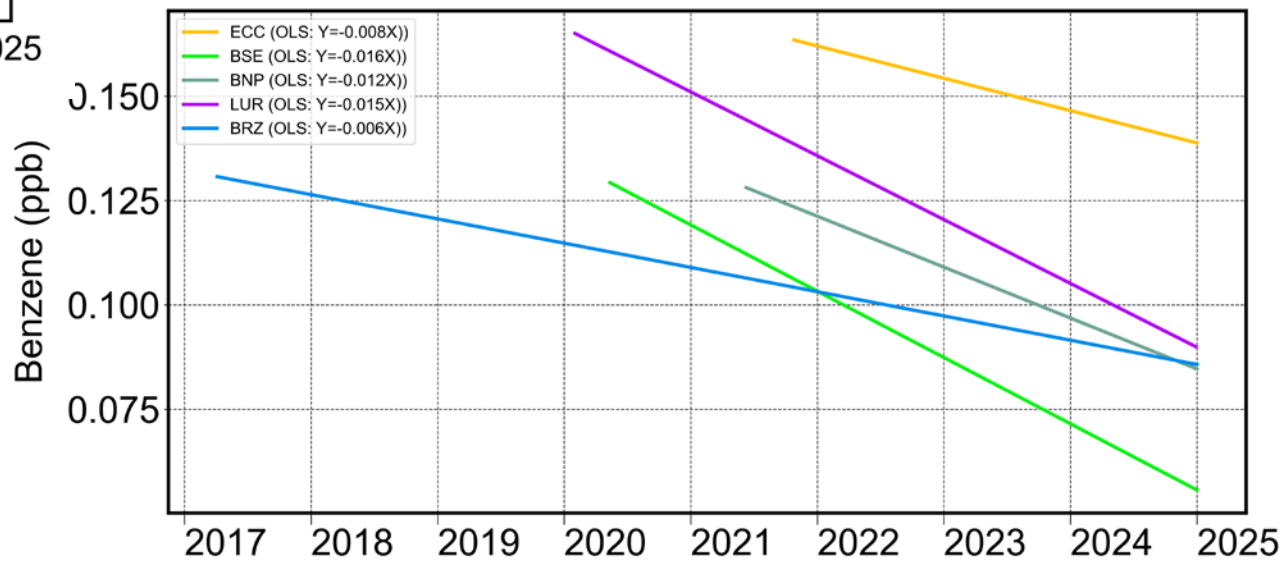
Benzene Trend Analyses Results

Benzene Trend Curves

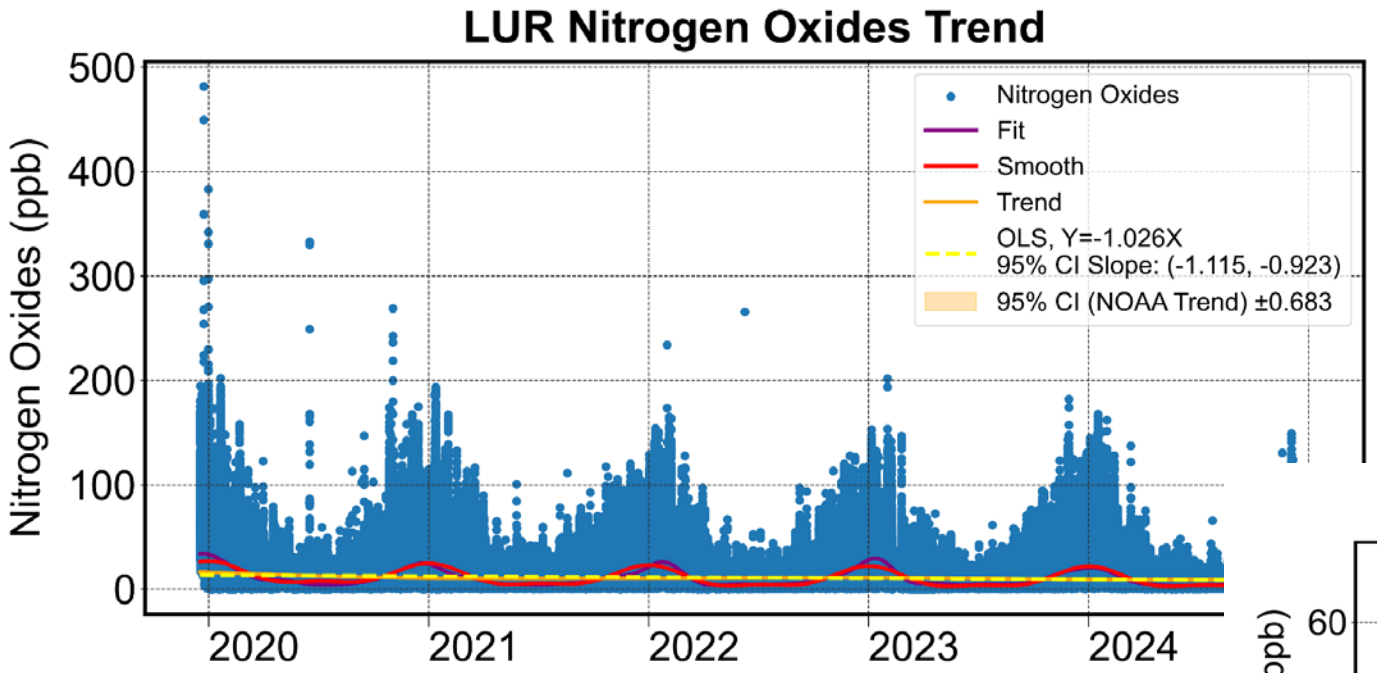


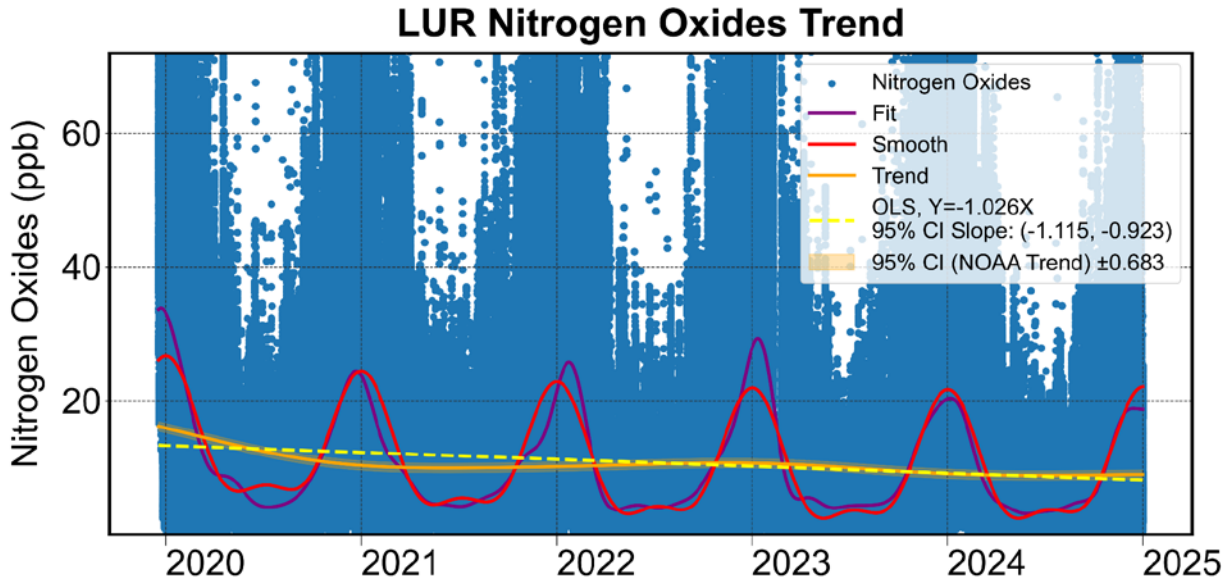
Benzene has been declining at all sites. Longest record (BRZ) shows -0.006 ppb/yr decline -> approximately 30% drop during 2017 – 2024.

Benzene Linear Trend Lines



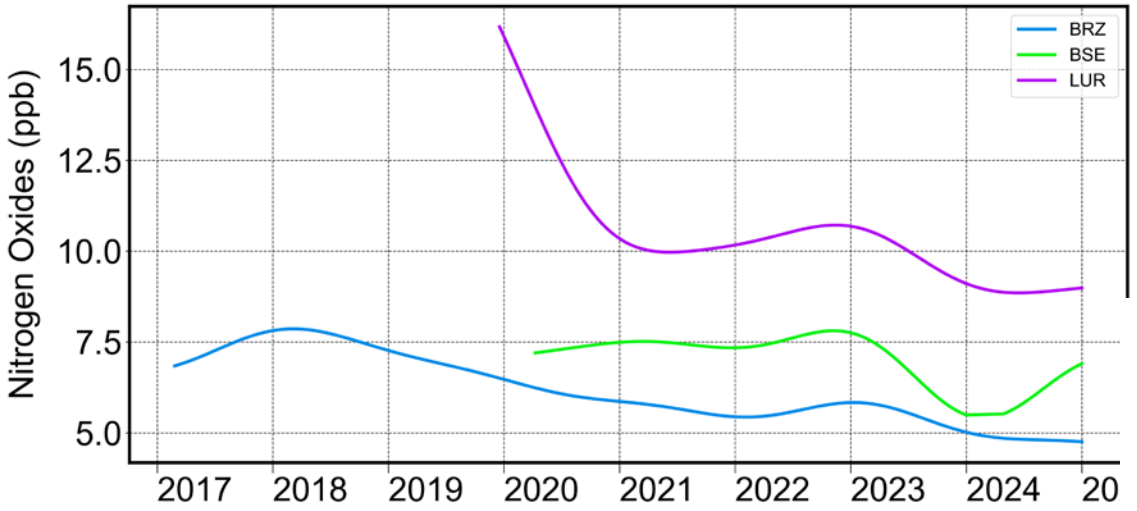
Nitrogen Oxides Trend – Longmont Union Reservoir



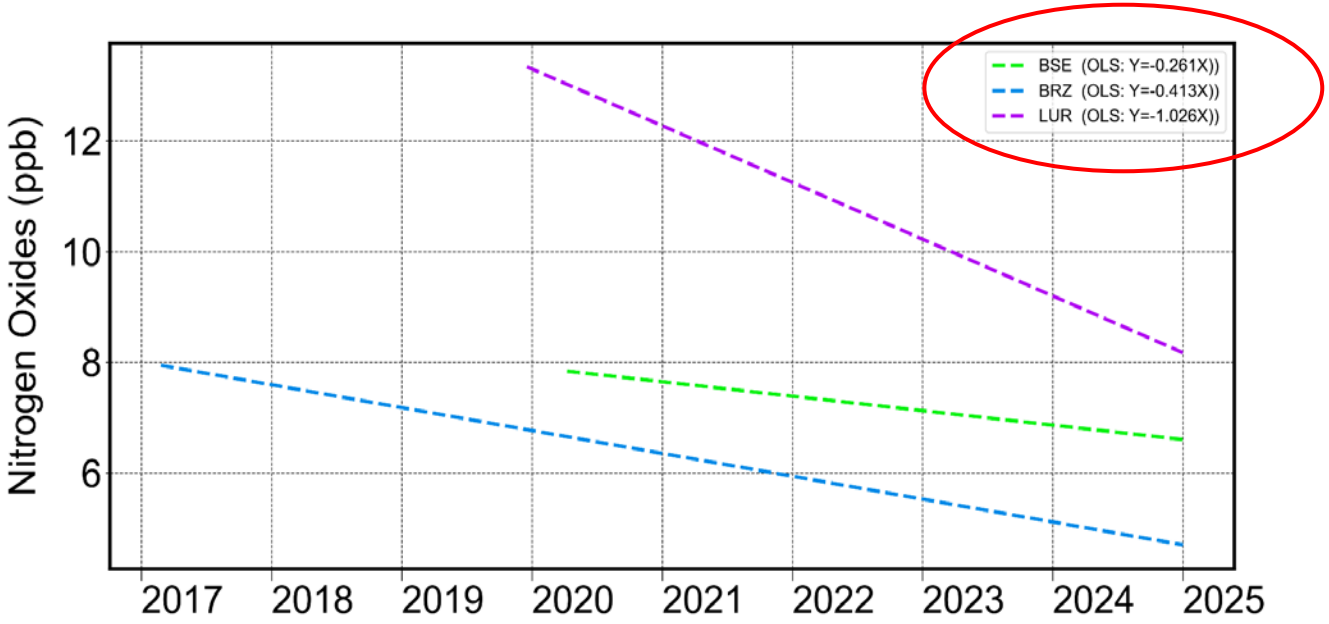


Nitrogen Oxides Results

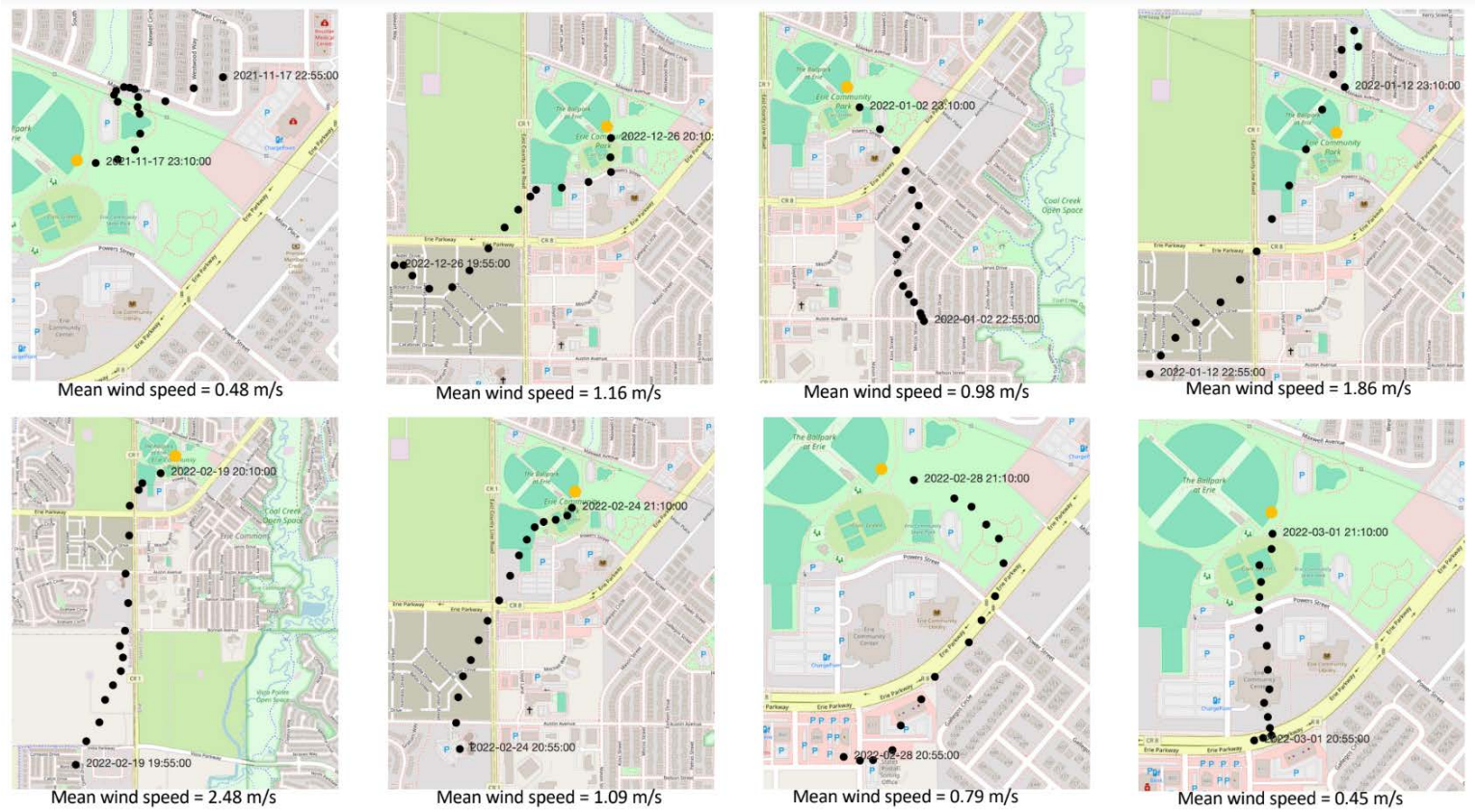
NOx Trend Curves



NOx Linear Trend Lines

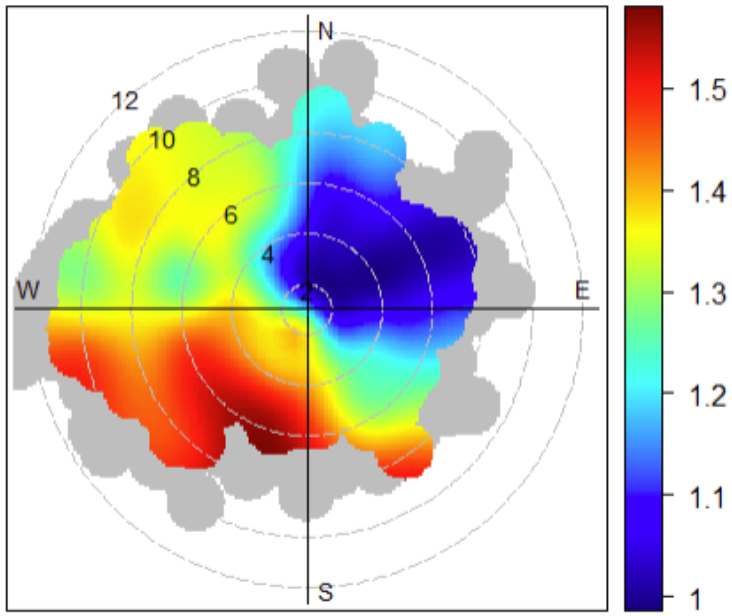


Transport Path of VOCs Plumes



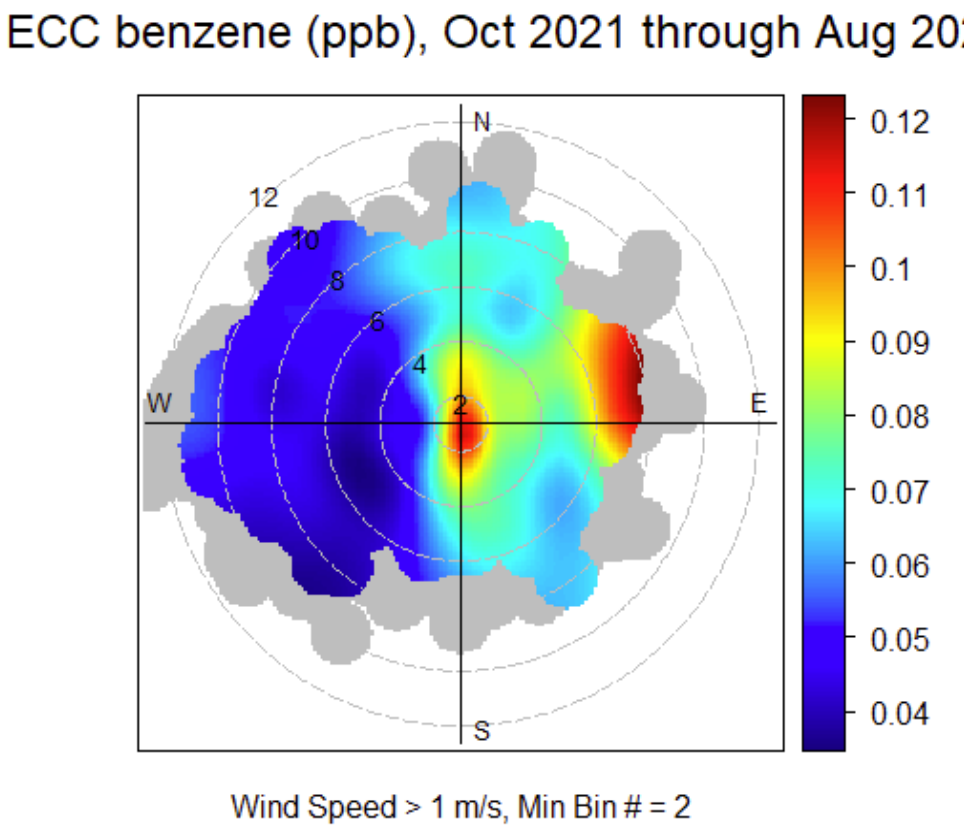
15-minute back-trajectories for 8 selected events of nocturnal spikes of heavy alkanes (butane, pentane, and/or hexane). Each black dot represents a 1-minute increment on the inferred pathway that the air parcel took before arriving at ECC.

ECC i/n Pentane Ratio, Oct 2021 through Aug 2024



Wind Speed > 1 m/s, Min Bin # = 2

Bivariate polar plot showing the dependency of the isomeric pentane ratio at ECC as a function of wind speed (m/s) and wind direction. Ratio values consistent with oil and natural gas (O&NG) sources are observed when winds are blowing from the northeast, and ratio values consistent with mobile sources are observed from the south and southwest.



Bivariate polar plot showing the dependency of benzene at ECC as a function of wind speed (m/s) and wind direction. The highest benzene is observed when winds are blowing from the north to south, and at higher wind speeds from the east.