Boulder A.I.R. L.L.C; 2820 Lafayette Dr., Boulder, CO 80305, U.S.A.; dh.bouldair@gmail.com

February 28, 2022

To:

City of Longmont
350 Kimbark Street
Longmont, CO 80501

Attn: Dr. Jane Turner

Re: Longmont Regional Air Quality Study – Year 2021 Quarter 4 Report

Dear Dr. Turner,

Please find included with this letter the October – December (Quarter 4) 2021 report for our work on the Longmont Air Quality Study. The monitoring data and data interpretations are presented.

Thank you for providing this opportunity for air quality monitoring to Longmont citizens and the City of Longmont. We would be happy to discuss any questions that you, other City staff or Longmont citizens may have.

Sincerely,

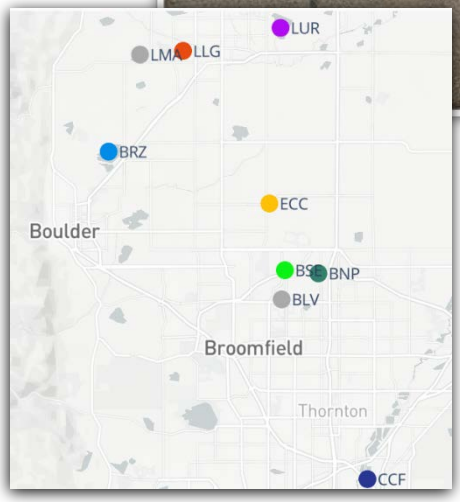
Detlev Helmig

Boulder AIR LLC

2021 Quarter 4 (October – December) Report

Longmont Air Quality Study

LLG after installation (photo by Jacques Hueber)



Updated map of Boulder A.I.R. monitoring stations. Colored dots represent active stations.

Executive Summary

This report summarizes the data and preliminary findings from the Longmont Air Quality Study during October through December of 2021. All variables were reported in near-real time on the public *Longmont Air Quality Now* web portal.

This report includes graphical analyses of all data acquired at the Longmont Municipal Airport (LMA) station before the site was moved to Lykins Gulch (LLG) between Oct. 26th and Nov. 1st, and the Longmont Union Reservoir (LUR) station during October - December, i.e. Quarter 4 (Q4), 2021. In addition, data comparisons and analyses of selected events that resulted in enhanced concentrations are presented. LMA/LLG and LUR data are compared with each other and also with concurrent observations from the Boulder Reservoir (BRZ), the Broomfield sites Broomfield Soaring Eagle Park (BSE), and Broomfield North Pecos (BNP). For the first time, measurements from a newly commissioned site at the Erie Community Center, CO (ECC) are included in the comparisons.

Overall, Q4 2021 was less eventful than the summer quarter. With the absence of wildfires and hot, summer days that enhance photochemical pollutants, there were no exceedances of the particulate matter National Ambient Air Quality Standard (NAAQS) or the ozone NAAQS. Meteorology can account for the brief increase in ozone seen at LUR and other stations and in the large spikes in particulate matter measured at LUR, as explained in the report. The analyses of a large methane peak and a large benzene peak at LUR are included in the supplements.

Since the station at LMA was moved to LLG, this ended our longer-term comparisons of some species, such as methane and CO_2, at that site. Analyses of LLG data from November and December began a new baseline of such measurements for future comparisons. The addition of the new ECC data provided additional context for all of the Boulder A.I.R. monitoring station data.

Table of Contents

1. Project Scope and Goals

No changes from Q3, 2021 report.

2. Overview of the Monitoring Program

A major change from the Q3, 2021 report is the relocation of the monitoring station from the Longmont Municipal Airport (LMA) to Lykins Gulch (LLG). There was a data gap between Oct. 26th and Nov. 1st , during the station move.

3. Air Quality Monitoring Study Updates

No changes from Q3, 2021 report.

Boulder A.I.R. is now calculating a current Air Quality Conditions (AQC) conditions index based on ozone and particulate matter (PM) measurements. The AQC indices are currently published on the Erie (ECC, AirLive Erie (bouldair.com)) and Commerce City (CCF, AirLive Commerce City (bouldair.com)) web sites. The Commerce City website is still under construction as new measurements come online.

4. Data Quality Assurance/Quality Control Process

As reported in the Q3 report for faster dissemination, the Colorado Department of Public Health & Environment (CDPHE) conducted an audit of the nitrogen oxides monitoring, PM analyzer, and the ozone analyzer at LUR on October 8th. All systems passed the audit and fall within the state regulatory guidelines.

The CDPHE conducted an audit of the LLG meteorology tower instrumentation and ozone analyzer on Nov. 19th. The ozone analyzer passed the federal regulatory requirements. Wind speed and temperature passed the federal regulatory requirements. The wind direction failed the audit; however, the cross-arm of the anemometer was adjusted using the guidance received during the audit and the pre-audit wind direction data were corrected.

The meteorology tower at LUR was audited by CDPHE on February 7th, 2022 and wind and temperature measurements passed the federal regulatory requirements.

The audit reports are included in Supplement E.

5. Website Development

During Q4, 2021, there were 1285 visits to the Longmont Air Quality Now website.

6. Data Archiving

No changes from the Q3, 2021, report.

7. Data for Quarter 4, 2021

The data that were recorded in Q4, 2021, are included in this report in graphical time series format in Supplement A (LMA/LLG) and Supplement B (LUR). These graphs provide the records of the completeness of the data coverage and general features in the dynamic, diurnal, and seasonal changes. Some of the data (e.g. wind direction) are difficult to interpret when 3 months of data are included in the same plot. In these instances, the primary objective is to show general trends and that the data are nearly continuous – not to point out individual features. Data coverage for all variables is more than 95% for the full quarter, except for the station move from the airport to Lykins Gulch. The webcam at LUR started experiencing intermittent failures during October, and then failed completely during November 11-18, and from December 1 to the end of the quarter. A new camera was purchased and installed in Q1, 2022.

In Supplement C, the variables that are measured at all sites are shown together in a set of time series graphs. These graphs are presented to highlight similarities and differences between the two locations.

8. Selected Data Examples and Preliminary Interpretations

Ozone

The full Q4 ozone records for LMA and LUR are presented in Figures SA8 and SA9 for LMA/LLG and SB8 and SB9 for LUR. As a warmer and drier than normal fall transitioned into winter, strong cold fronts started passing through the region, at times causing vertical mixing of pollutants and particulate matter, rapidly changing pollutant concentrations near the surface.

At LMA, LLG, and LUR there were no exceedances of the NAAQS 8-hour ozone limit during Q4. On Dec. 15th, with the passage of a strong cold front/snowsquall, ozone briefly jumped above 70 ppb at BRZ, LLG, LUR, and BSE at approximately 11 am, probably a result of vertical mixing associated with the cold front passage. This elevated ozone was not a pollution event, but most likely due to rapid transport of high-ozone containing air from the mid- to upper-troposphere to the surface.

Figure 1 presents a statistical analysis of the full Q4 ozone data, comparing the Longmont data with observations from Boulder Reservoir (BRZ), Broomfield Soaring Eagle Park (BSE), and Erie (ECC). With the addition of the ECC ozone data, it is no longer necessarily the case that less ozone is measured at LUR than at the rest of the Boulder A.I.R. monitoring stations. Ozone at ECC was slightly less ozone in October than at LUR. Since Boulder A.I.R. is not monitoring NO and NO_x at ECC, we cannot make a comparison of the NO_x levels with that station. However, as in previous quarters, more NO_X was measured at LUR than at BRZ and BSE (Figure 11). The continued higher NO_x levels measured at LUR cause more ozone depletion at night, resulting in overall lower ozone at night and in the early morning at the LUR station. This lower ozone morning starting value can, under calm air circulation conditions, result in an overall delayed ozone production at LUR and slightly lower ozone afternoon maximum values.

CO_2

The full Q4 CO_2 records are available in Figures SA6 and SB6 for LMA/LLG and LUR, respectively. The statistical comparison of the monitoring data is presented in Figure 2. The CO_2 measured at LUR was more than what was measured at the other Boulder A.I.R. stations. LUR CO_2 measurements were also more variable, with higher 95th percentile values than seen at the other stations. The wind speed/wind direction analyses are shown in Figure 3. During November and December, winds at LLG were predominantly from the west. The main source of CO_2 at LLG appeared to be just to the west of LLG under light winds, with sources also to the north, east, and south associated with stronger winds and therefore more dilution. AT LUR, the main source of CO_2 continued to be from the west (i.e., the city of Longmont).

Table 1 provides comparisons of CO_2 data at LUR between Q4 2020 and Q4 2021. The decrease in CO_2 mean values between Q4 2020 and Q4 2021 was 5.7 ppm, while the average global change in CO_2 between November 2020 and November 2021 was approximately a 3 ppm increase. Over 120,000 individual 5-min annual data points were considered in the comparison. In Q4 2021, CO_2 mean values and all percentile values were smaller than in Q4 2020. As always, there could have been differences in meteorology during these two years that drove the differences in observed concentrations of atmospheric trace gases. For atmospheric trace gases with high variability in their mole fractions, as observed here, longer time records and application of sophisticated trend analysis tools are required for an accurate trend analysis.

Methane

The full Q4 methane records are available in Figures SA7 and SB7 for LMA/LLG and LUR, respectively. In the statistical comparisons among the stations, higher values of methane were measured at ECC in Q4, outpacing LUR where in the past more methane had been measured at LUR among the Boulder A.I.R. stations (Figure 4). Mean, 75th percentile, and 95th percentile values were greater at ECC; however, the lower percentile values of methane were slightly lower at ECC than at LUR.

There was a large peak in methane measurements at LUR on Nov. 29th, 2021, at 16:15 MST. The peak value measured in the one-minute data was 27,843 ppb. Winds were from the east-southeast around the time of the peak. Peaks in other VOCs were also measured. A detailed analysis of this event is available in Supplement D.

Wind rose and heat map analyses for LLG and LUR data are shown in Figure 6. The data indicate that there were relatively strong methane sources to the east of LLG and also to the north. As for LUR, there the strongest methane source sector was to the northwest of the station.

VOCs

The full Q4 LUR records for six selected VOCs are available in Figures SB10–SB16. Figure 7 presents a 19-month record of ethane, benzene, and acetylene from March 2020 – December 2021. These graphs show declines in the oil and gas tracers ethane and benzene relative to March 2020, until late November 2021, when pollution plume occurrences and measured ethane values began to increase compared to the previous several months, ending the steady decline in elevated ethane measurements. Acetylene values peaked in the colder months as seen in the previous year.

The statistical comparison of the VOCs is plotted in Figure 8. Ethane measurements (Figure 8, top) show that more ethane was measured at LUR than at the other stations, and there was a month-to-month increase of ethane at LUR. The jump in the higher values measured in December coincide with colder mornings and stronger temperature inversions that suppressed mixing (and dilution) of pollutants that are emitted from nearby sources at the surface. As already mentioned above, the time series of ethane shown in Figure 7 also showed an overall jump in ethane measurements, indicating an increase in ethane emissions toward the end of 2021. At the new ECC station, the second highest values of ethane were measured throughout the quarter. The statistical analysis of propane (Figure 8, middle) was similar to that of ethane, with more propane measured at LUR than at the other stations, measurements at ECC coming in as second highest among the other stations, and month-to-month increases. There was a big increase in propane measurements at LUR in December, outpacing increases at the other stations, especially when looking at the 95th percentile values. Overall, more benzene was measured at ECC and either LUR or BNP measured the second highest amounts of benzene, depending on the month (Figure 8, bottom). BNP benzene statistics tend to be skewed by very large short-lived spikes.

There was a peak in benzene of 1.03 ppb measured at LUR at 19:05 MST on Dec. 2nd, 2021. The wind direction was changing from northwest to southwest during this time and winds were from 253° at the same time as the methane peak. For more details on this benzene peak see Supplement D.

Figure 9 and Table 1 show the comparison of Q4 2020 statistics for ethane and benzene compared to those of Q4 2021. For ethane, the mean value and percentile values were all less in Q4 2021 (Table 1, Figure 9); however, the maximum value was greater. For benzene, the Q4 mean value and percentile values were lower than the Q4 2020 values.

Wind speed/wind direction dependence results of ethane, propane, acetylene, and benzene are shown in Figure 10. Compared to the Q3 2021 analyses, the heat map transport patterns were similar.

The analysis of VOCs signatures, using VOC/VOC ratio values, are shown in Figure 11. The i-pentane/n-pentane ratio plot clearly shows that air associated with oil and gas production to the northeast of LUR was advected to LUR (ratio values < 1.5), and background/urban air was advected to LUR from the southwest (ratio values > 1.5).

Nitrogen Oxides (NO, NO_x)

The Q4 LUR record for nitric oxide (NO) is available in Figure SB17, and the record for total nitrogen oxides (NO_x) in Figure SB18. Figure 12 shows the statistical analyses for NO (top) and NO_x (bottom). LUR had the highest mean and 95th percentile values for NO. At all stations, the mean values were skewed to higher values because of spikes in the NO measurements. Overall, values of NO were higher than measured in Q3, likely because of suppressed mixing at the surface in the mornings due to colder temperatures. NO_x measurements at LUR were highest in all metrics, except the 5th percentile measurements. Dependency of NO and NO_x on wind direction and wind speed is presented in Figure 13. In Q4, there was a well-defined source of NO to the southeast of LUR, and NO_x source to the west.

Particulate Matter (PM)

PM10 and PM2.5 LUR Q4 monitoring results are presented in Figures SB19 and SB20. The 24-hour averaged PM2.5 data are available in Figure SB21. There were no exceedances of the PM 2.5 NAAQS this quarter. There were, however, two large, brief peaks in PM 2.5 measured at LUR, both associated with a wind shift. One occurred on November 17th, with PM 2.5 values up to 239 µg m^{-3} as the winds shifted

from upslope (northeasterly) to downslope (westerly). The other occurred at 13:20 MST on December 10th when the wind shifted from light northeasterly upslope to gusty westerly downslope and PM 2.5 measurements jumped up to 396 µg m^{-3}. A brief episode with highly elevated PM2.5 originating from the Marshall fire was observed at BSE in the afternoon on December 30. No such enhancements were seen in the LUR PM data, indicating the site was not subjected to the Marshall Fire pollution as with the further northern location of the LUR station it was outside of the fire smoke plume.

The statistical comparison of LUR data with BSE data is presented in Figure 14. For Q4 comparisons, we now have data from the Erie station (ECC). Mean LUR PM 2.5 and PM 10 measurements were similar to those taken at BSE. ECC had higher particulate matter measurements than either station, likely from been ongoing construction activities near the ECC station throughout the quarter. Overall, for BSE and LUR, there were lower PM 2.5 measurements in Q4 compared to Q3, probably because there were few, if any, wildfires in the region that can elevate PM 2.5 measurements.

9. Summary

Overall, Q4 2021 was less eventful than the summer and fall quarters in terms of air pollution episodes. With the absence of wildfires and hot, summer days that enhance pollutants, there were no exceedances of the particulate matter NAAQS or the ozone NAAQS. Meteorology can account for the brief increase in ozone seen at LUR and other stations and in the large spikes in particulate matter measured at LUR, as explained in the report. The analyses of a large methane peak and a large benzene peak at LUR are included in the supplements.

Since the station at the Longmont Municipal Airport (LMA) was moved to Lykins Gulch (LLG), this ended our longer-term comparisons of some species, such as methane and CO_2. Analyses of LLG data from November and December began a baseline of such new measurements for future comparisons. The addition of the new Erie (ECC) data provides additional context for all of the Boulder A.I.R. monitoring station data.

Tables

Table 1:
Comparison of the statistics of CO_2 and CH_4 data (5-min averages) and ethane and benzene at LUR during Q4 of 2020 and Q4 of 2021. "Abs Diff" is the 2021 value minus the 2020 value.

Species	Stat	2020	2021	Abs Diff. (vs 2020)	% Diff.
CO_2	count	127429	130260	2831	2.2
ppm	mean	440.3	434.6	-5.7	-1.3
	std	28.1	20.8	-7.4	-26.2
	min	408.0	405.1	-2.9	-0.7
	5%	412.0	414.6	2.6	0.6
	25%	419.0	419.5	0.5	0.1
	50%	431.0	427.9	-3.1	-0.7
	75%	455.0	443.0	-12.0	-2.6
	95%	497.0	477.2	-19.8	-4.0
	max	692.0	588.8	-103.2	-14.9
	Global mean	413.0	416.0	3.0	1.0
CH_4	count	127429	130260	2831	2.2
ppb	mean	2131	2118	-13	-0.6
	std	166	185	19	10.3
	min	1910	1940	30	1.5
	5%	1960	1963	3	0.2
	25%	2010	2013	3	0.1
	50%	2090	2086	-4	-0.2
	75%	2200	2190	-10	-0.5
	95%	2450	2357	-93	-3.9
	max	4830	27843	23013	476
	Global mean	1890	1907	17	1.0
Ethane	count	1943	2118	175	9.0
ppb	mean	13.85	11.40	-2.45	-17.7
	std	11.82	13.07	1.25	10.6
	min	0.97	0.81	-0.17	-17.0
	5%	1.87	1.41	-0.45	-24.3
	25%	5.58	3.98	-1.60	-28.7
	50%	11.03	8.22	-2.81	-25.4
	75%	18.48	15.31	-3.17	-17.2
	95%	35.15	28.90	-6.26	-17.8
	max	99.24	235.20	135.96	137.0
Benzene	count	1943	2118	175	9.0
ppb	mean	0.19	0.12	-0.07	-36.2
	std	0.18	0.09	-0.08	-46.3
	min	0.02	0.01	-0.01	-32.8
	5%	0.04	0.03	-0.02	-40.9
	25%	0.08	0.05	-0.03	-33.6
	50%	0.15	0.09	-0.06	-37.4
	75%	0.25	0.16	-0.09	-35.5
	95%	0.43	0.30	-0.13	-29.8
	max	3.31	1.03	-2.28	-69.0

Figures

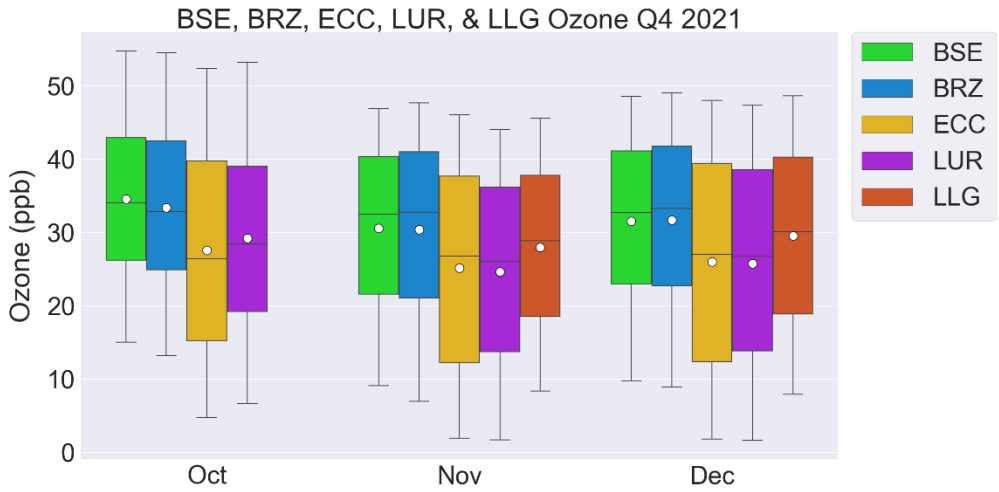


Figure 1:
Comparison of the ozone distribution at BSE, BRZ, ECC, LUR, and LLG during October – December 2021. Note that since the monitoring station was moved from the Longmont Municipal Airport (LMA) to Lykins Gulch (LLG) in late October, we only show November and December data at LLG. These box whisker plots show the median value as the center line, the 25-75 percentile distribution as the colored boxes, and the 5-percentile and 95-

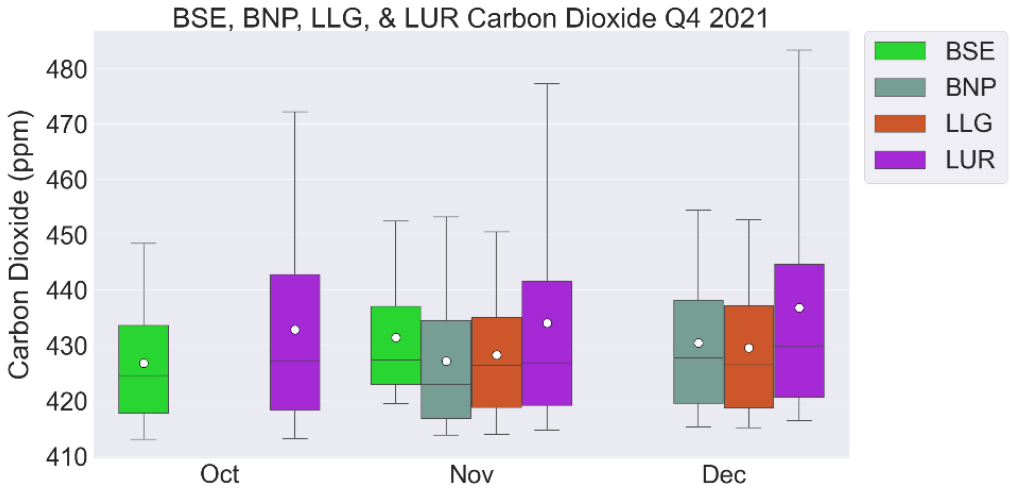


Figure 2:
Comparison of the CO_2 distribution at BSE, BNP, LLG, and LUR during October – December 2021. Note that since the monitoring station was moved from the Longmont Municipal Airport (LMA) to Lykins Gulch (LLG) in late October, we only show November and December data at LLG. See Figure 1 for explanation of the box whisker plot format.

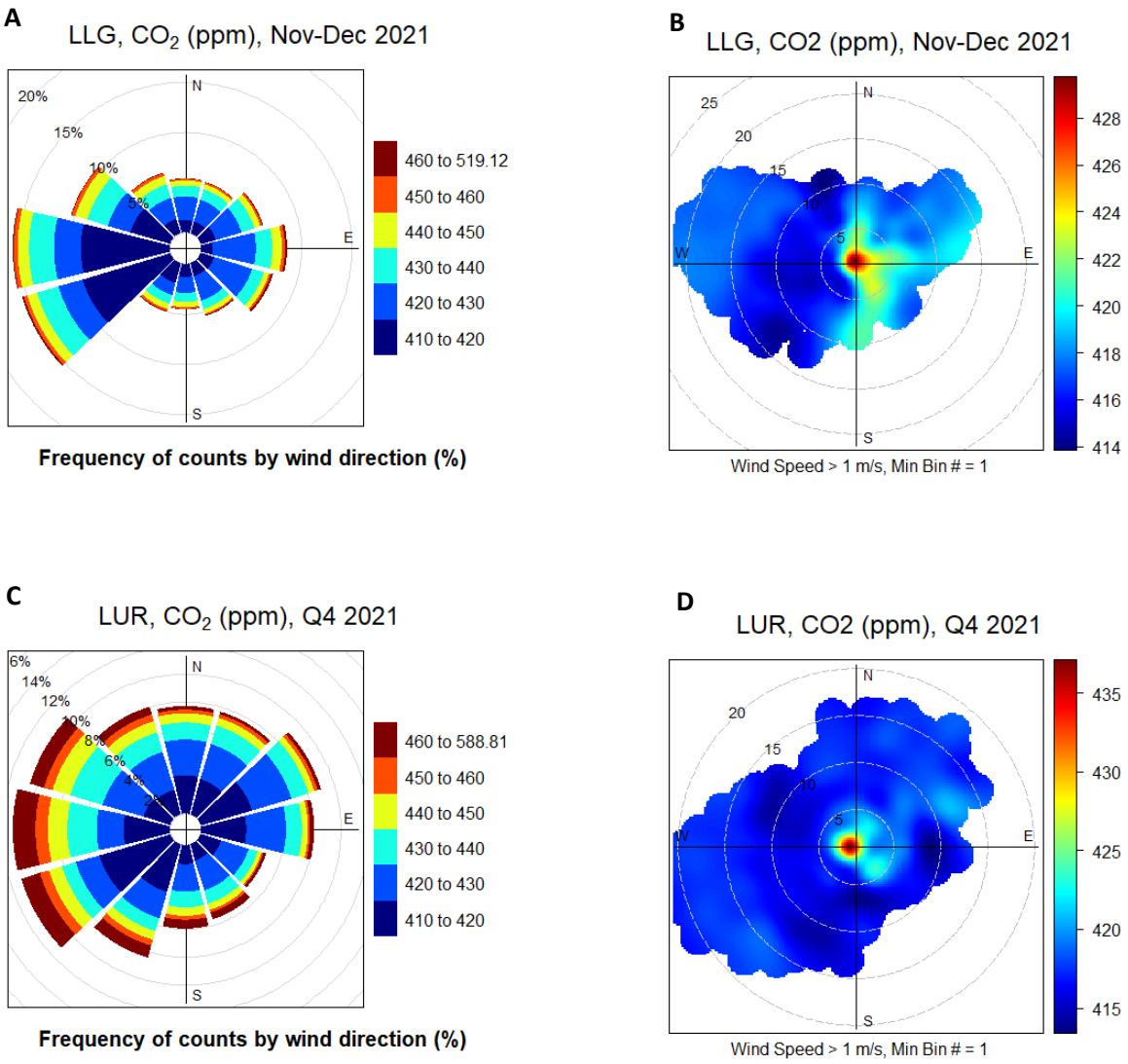


Figure 3:
Wind rose (left) and wind heat map analysis showing the dependency of CO_2 mole fractions at LLG (top, A, B) and LUR (bottom, C, D) during November – December 2021. Note that since the monitoring station was moved from the Longmont Municipal Airport (LMA) to Lykins Gulch (LLG) in late October, we only show November and December data at LLG, rather than data from the full quarter. The LUR site is east of the City of Longmont. These analyses suggests that the city is the primary source for enhanced CO_2 observed at LUR.

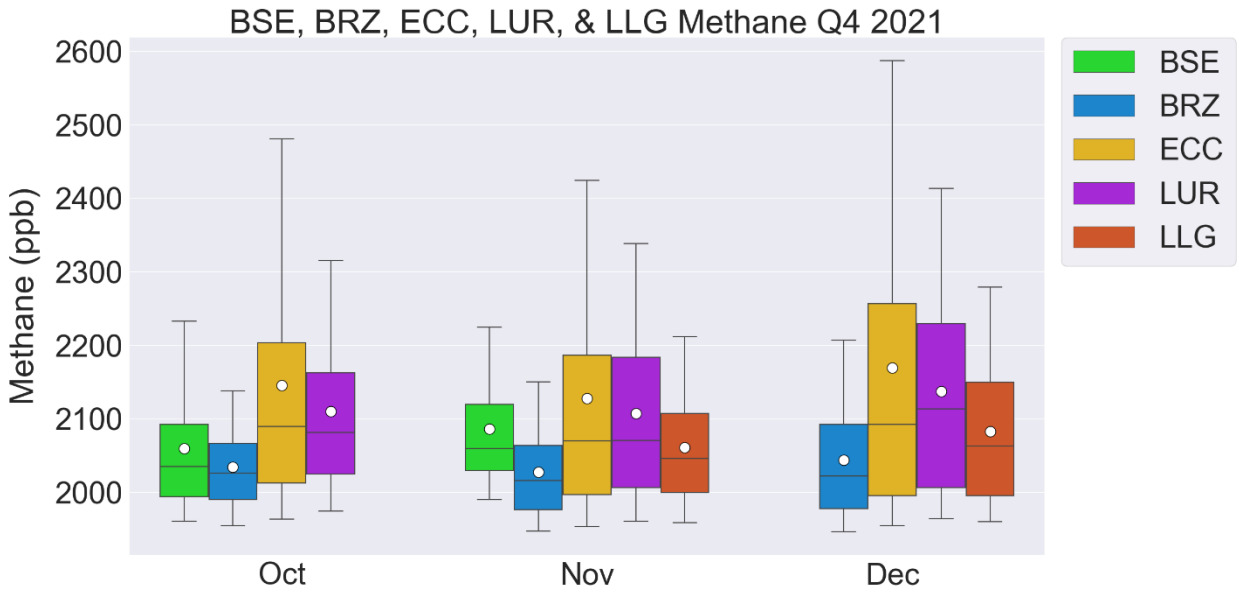
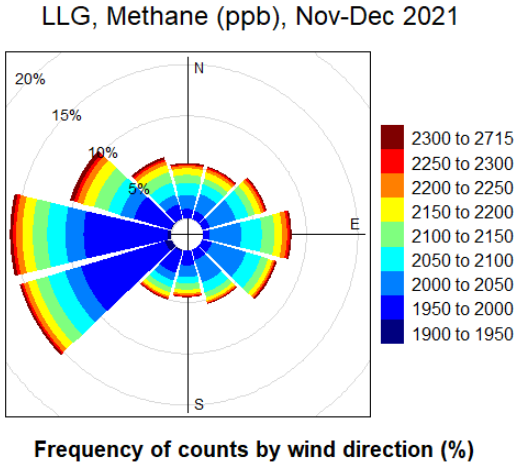
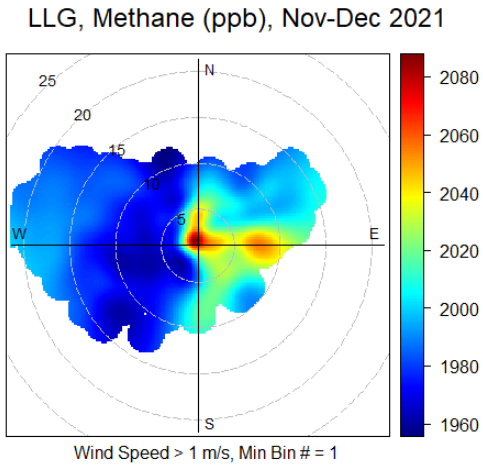


Figure 4:
Comparison of the methane distribution at BSE, BRZ, ECC, LLG, and LUR during October – December 2021. Note that since the monitoring station was moved from the Longmont Municipal Airport (LMA) to Lykins Gulch (LLG) in late October, we only show November and December data at LLG, rather than data from the full quarter. See Figure 1 for explanation of the box whisker plot format. Between the two Longmont sites, LUR has higher absolute values and variance.

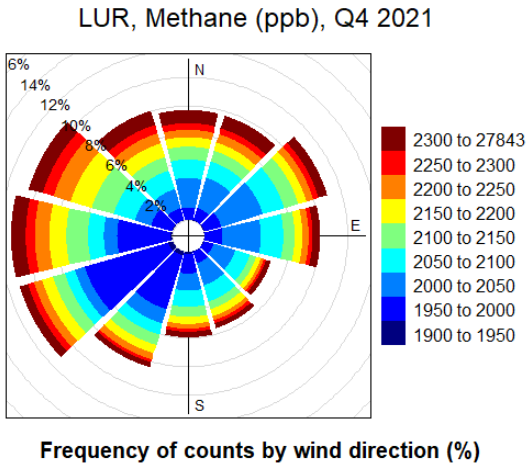
A



B



C



D

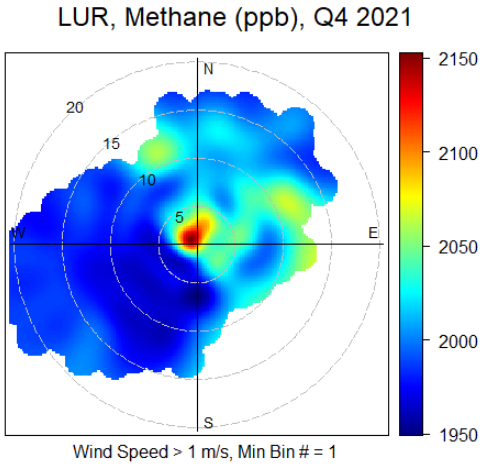
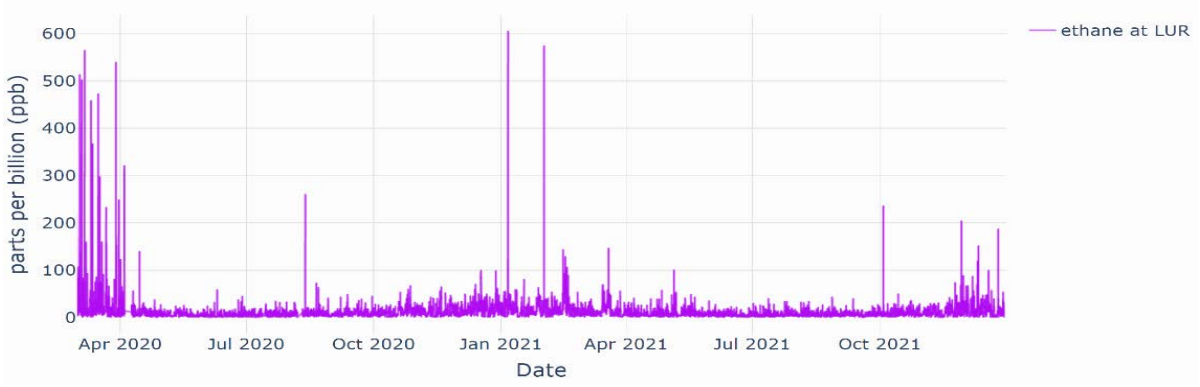
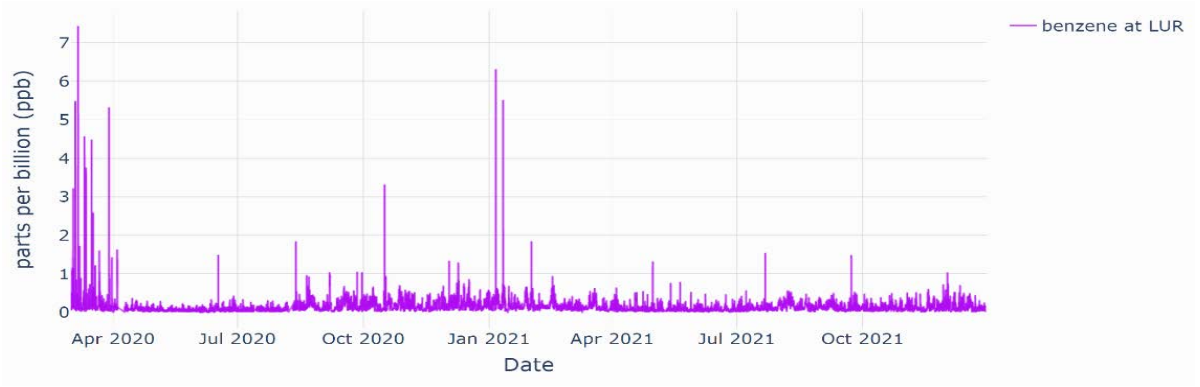


Figure 5:
Wind rose (left) and wind heat map analysis showing the dependency of CH_4 mole fractions at LLG (top, A, B) and LUR (bottom, C, D) during October – December 2021. Note that since the monitoring station was moved from the Longmont Municipal Airport (LMA) to Lykins Gulch (LLG) in late October, we only show November and December data at LLG, rather than data from the full quarter.

A



B



C

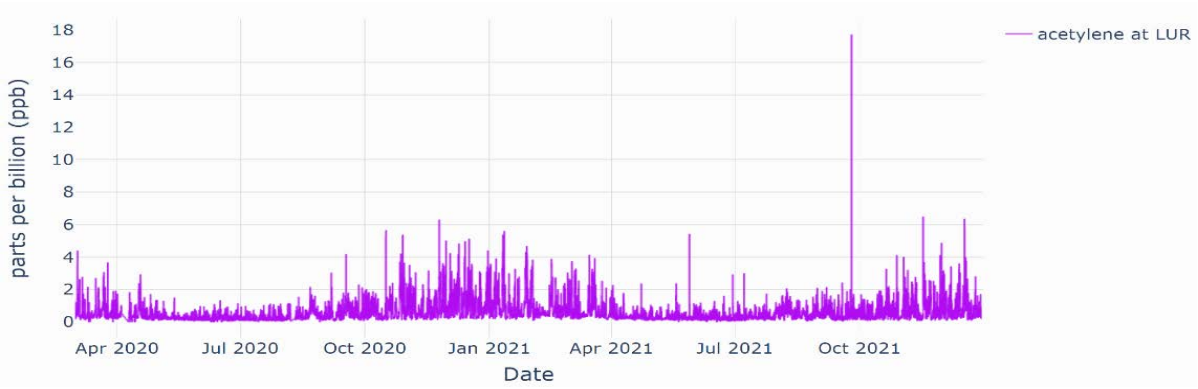


Figure 6:
Ethane (A, top), benzene (B, middle), and acetylene (C, bottom) at LUR between March 1, 2020 and December 31, 2021. Lower frequency and lower maximum values of concentration spikes during the summer are observed for all three compounds. These summer minima are mostly caused by the stronger mixing (dilution) of surface air from thermal convection. For acetylene, a compound that is mostly the result of combustion, similar peak patterns are observed for the spring, fall, and winter months for the two years of the record. These time series suggest that there was a decline in the source strength for ethane and benzene from the earliest measurements, however, in late November 2021, measurements of ethane at LUR started to increase compared to previous months.

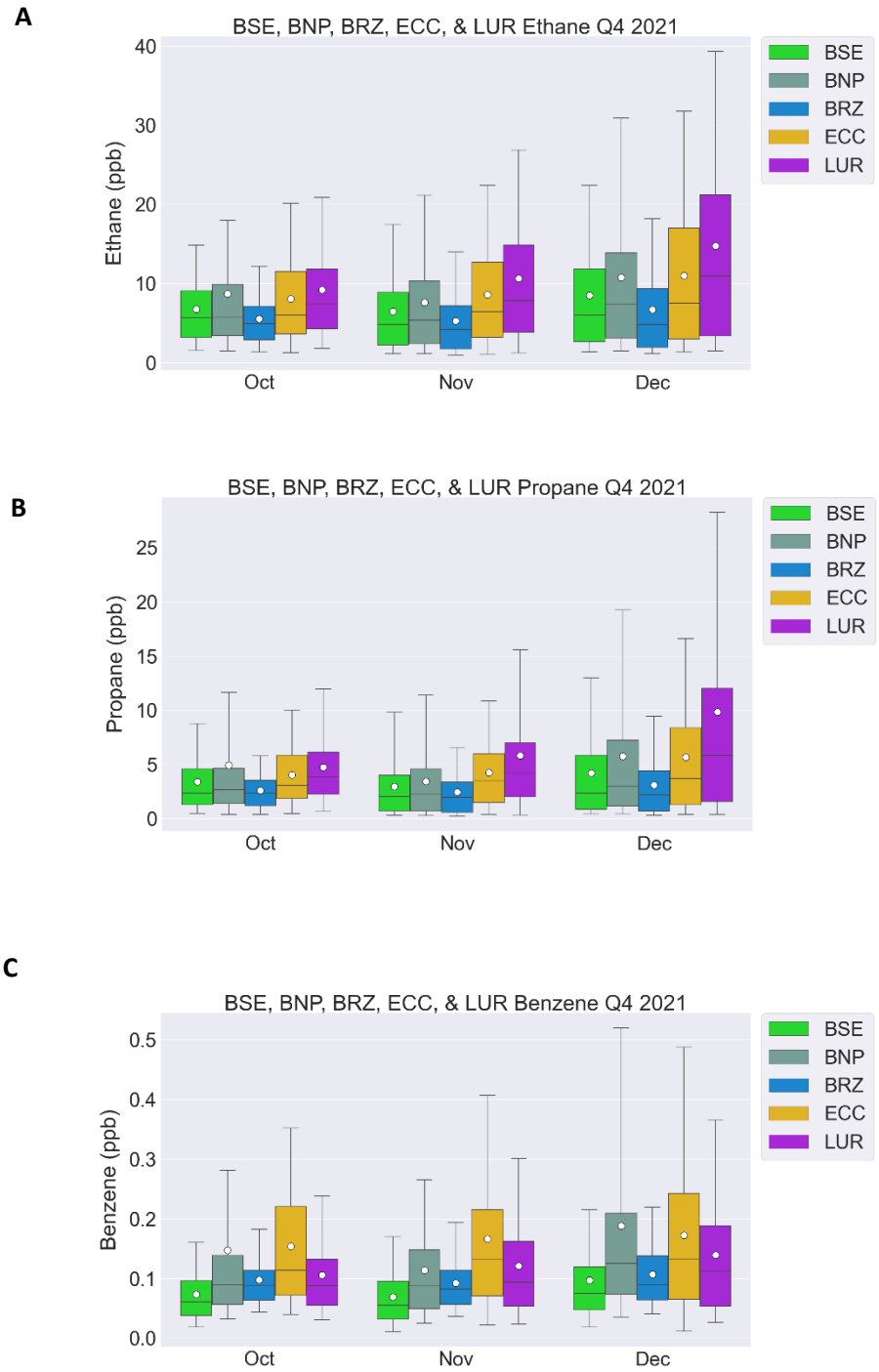
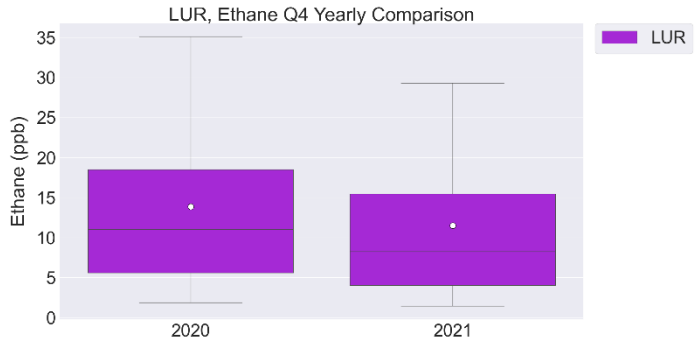


Figure 7:
Comparison of the distribution of ethane (A), propane (B), and benzene (C) at BSE, BNP, BRZ, ECC, and LUR during Q4. See Figure 1 for explanation of the box whisker plot formats. For the first time, we include measurements from the new Erie station (ECC). On average, more benzene was detected at ECC than any other station.

A



B

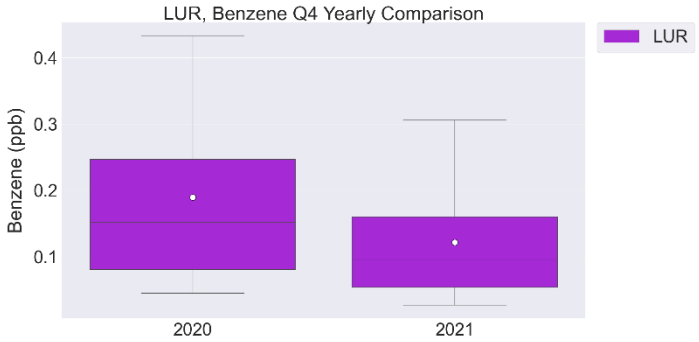
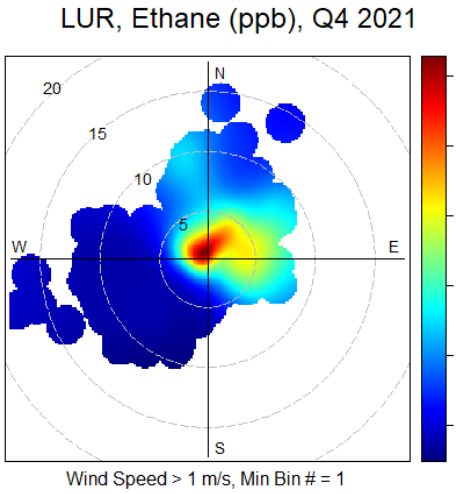
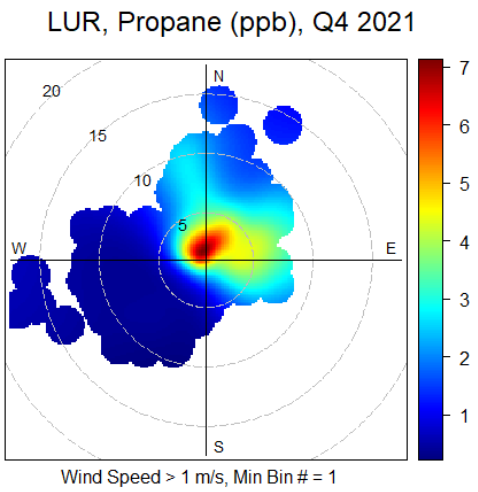


Figure 8:
Comparison of the ethane distribution (top, A) and the benzene distribution (bottom, B) at LUR during Q4 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions are presented in Table 1. The mean, median, and values 95th percentile values were lower for Q4 in 2021.

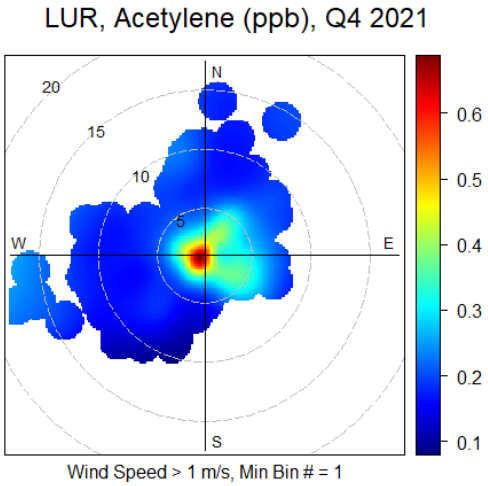
A



B



C



D

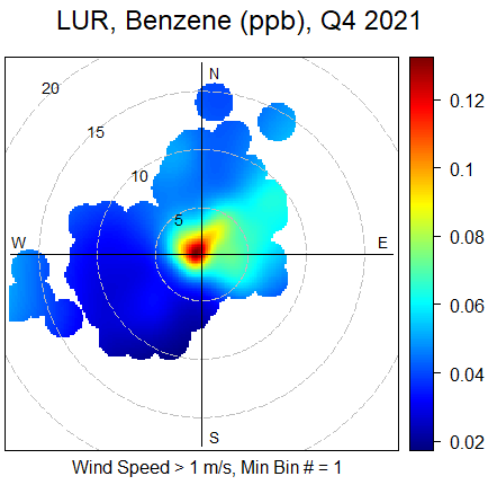


Figure 9:
Comparison of ethane (A), propane (B), acetylene (C), and benzene (D) occurrences as a function of wind speed and direction at LUR during Q4 2021.

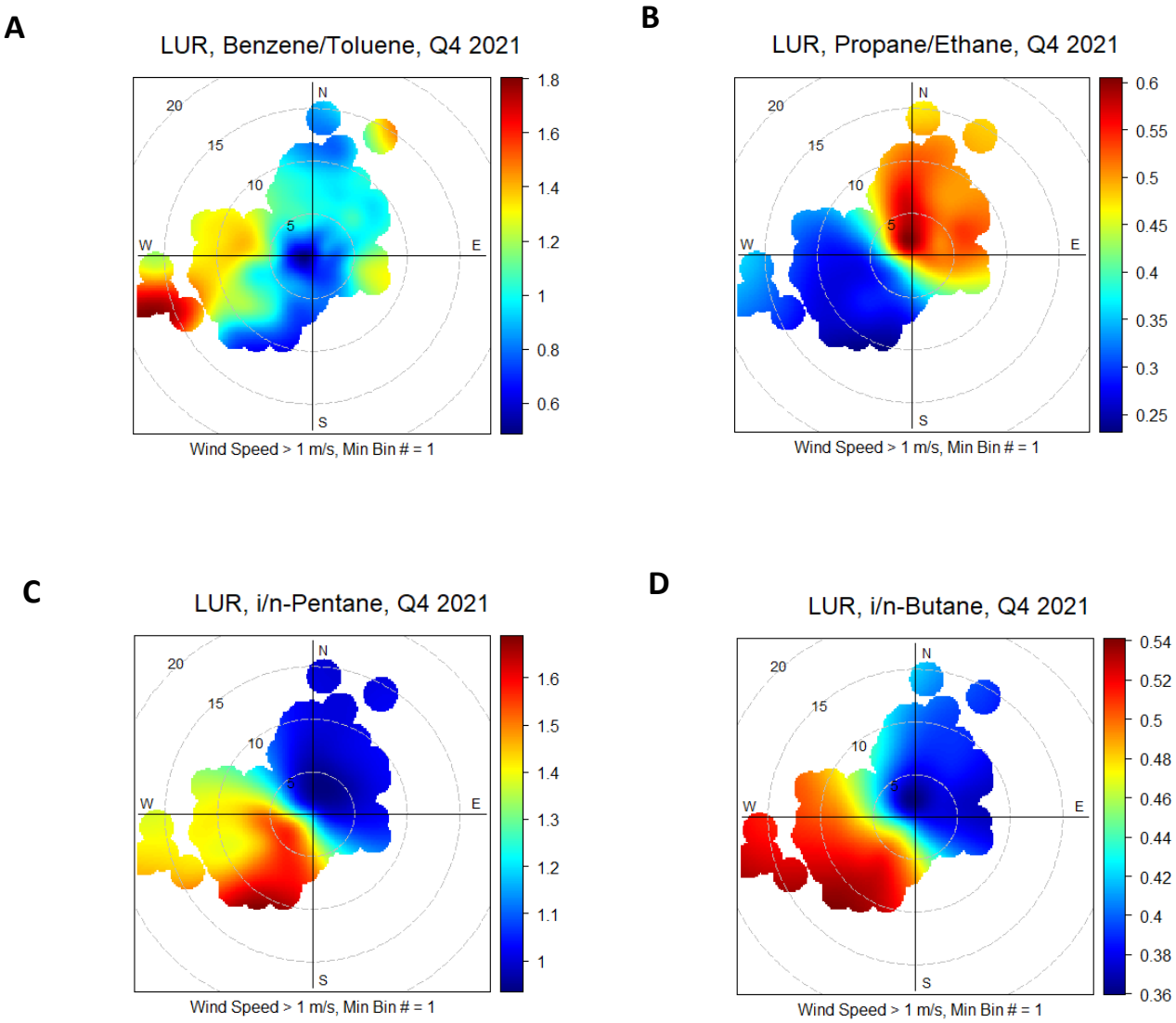
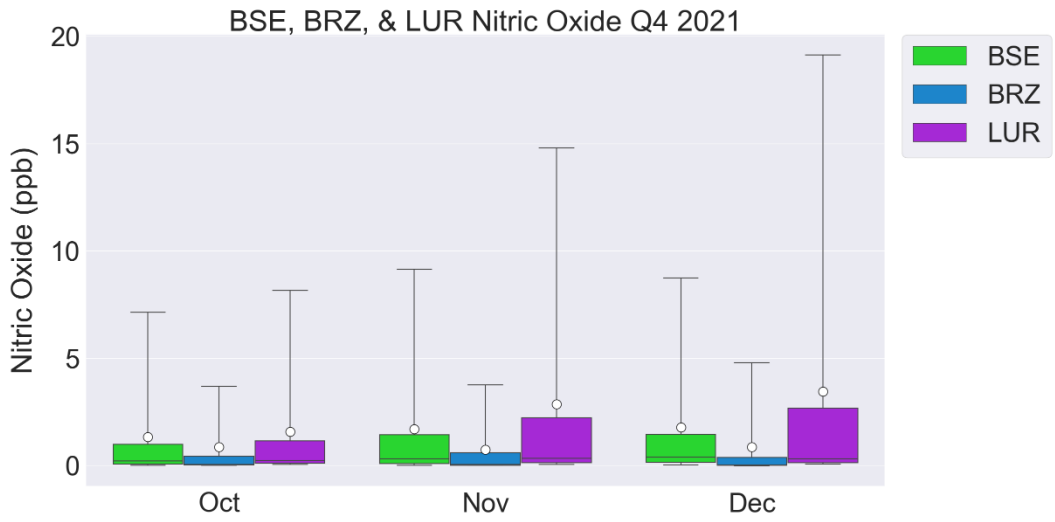


Figure 10:
Ratios of selected VOC pairs as a function of wind direction and wind speed during Q4. These analyses show clear differences in the chemical signatures in air transported from different directions to the monitoring station.

A



B

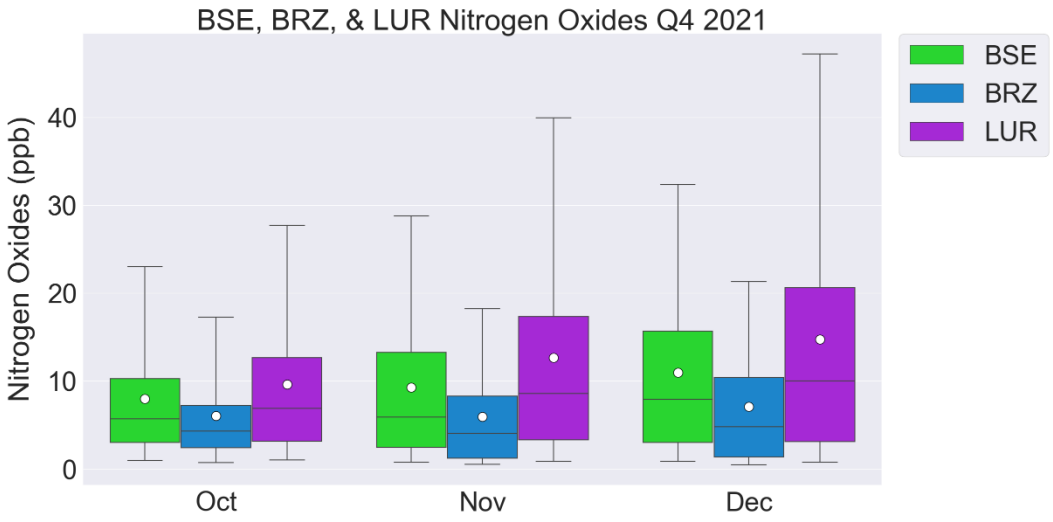
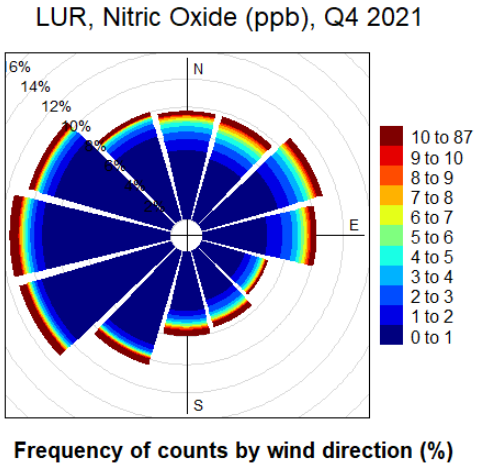
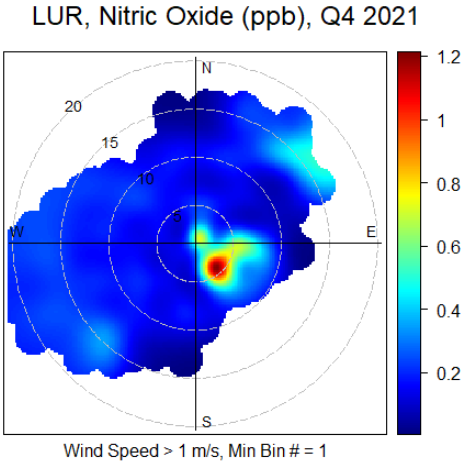


Figure 11:
Comparison of nitric oxide (A) and nitrogen oxides (B) at BSE, BRZ, and LUR during October – December 2021. See Figure 1 for explanation of the box whisker plot formats.

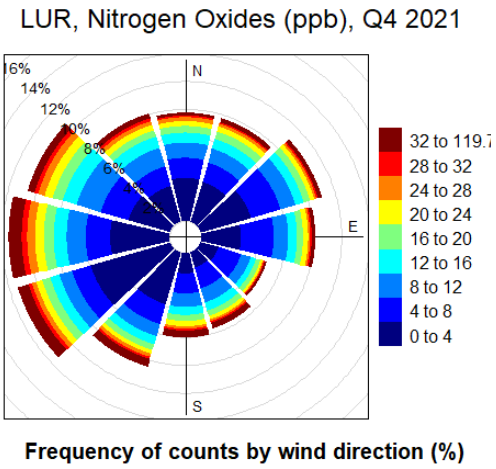
A



B



C



D

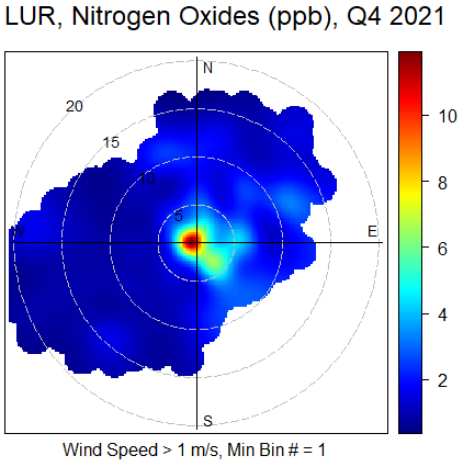
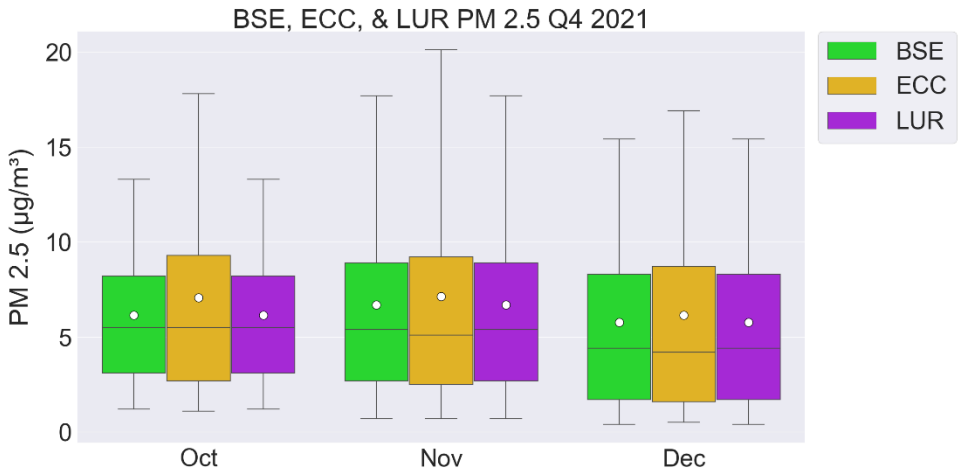


Figure 12:
Dependence of nitric oxide (A, B) and nitrogen oxides (C, D) as a function of wind speed and direction at LUR during October – December 2021. As seen in the prior data, the City of Longmont, located to the west, appears to be the strongest upwind source for NO_x.

A



B

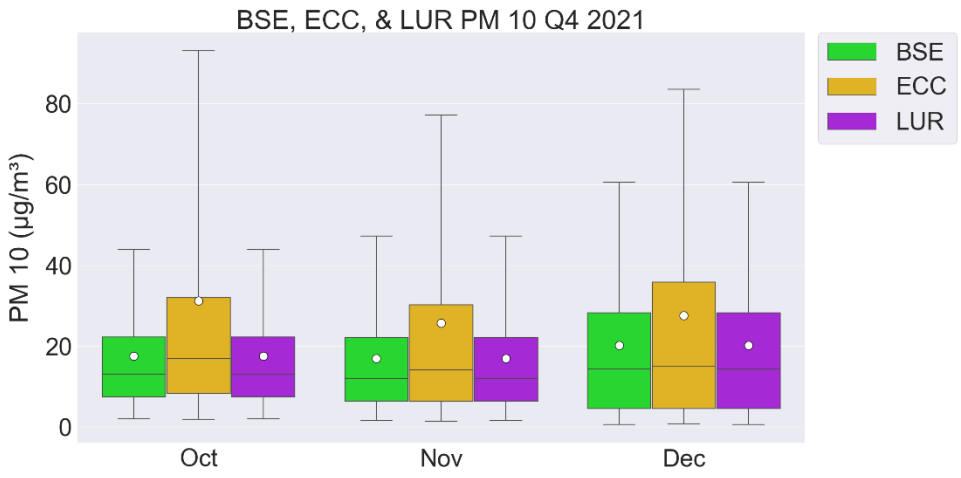


Figure 13:
Comparison of PM 2.5 (A) and PM 10 (B) at LUR, BSE, and for the first time, ECC, during October - December 2021. See Figure 1 for explanation of the box whisker plot formats.