Boulder Atmosphere Innovation Research

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September 7, 2022

To:

City of Longmont
350 Kimbark Street
Longmont, CO 80501

Attn: Dr. Jane Turner

Re: Longmont Regional Air Quality Study – Year 2022 Quarter 2 Report

Dear Dr. Turner,

Please find included with this letter the April – June (Quarter 2) 2022 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

2022 Quarter 2 (April – June) Report

Longmont Air Quality Study

Longmont Union Reservoir (LUR) during summer 2022. The two roof inlets for the intercomparison of the two GRIMM Particulate Matter instruments can be seen side-by-side on the south side of the building.

Executive Summary

This report summarizes the data and preliminary findings from the Longmont Air Quality Study.

The report includes graphical analyses of all data acquired at the Lykins Gulch (LLG) and Longmont Union Reservoir (LUR) stations during April - June, i.e., Quarter 2 (Q2), 2022. All variables were reported in near-real time on the public *Longmont Air Quality Now* web portal. Data comparisons and analyses of selected events that resulted in enhanced concentrations are presented in this report. LLG and LUR data are compared with each other and also with concurrent observations from the Boulder Reservoir (BRZ), Broomfield Soaring Eagle Park (BSE), Broomfield North Pecos (BNP), the Erie Community Center (ECC), and two sites in Commerce City: the Commerce City Fixed (CCF) site and the Commerce City Mobile (CCM) site. The location of the CCM monitoring site changes approximately every two weeks, but it remains in the vicinity of the Suncor Refinery.

A second GRIMM particulate matter monitor was installed at the LUR station for intercomparison studies and quality control. With the transition to hot, dry summertime weather, there were four days in Q2 when the National Ambient Air Quality Standard (NAAQS) for ozone was exceeded at the LLG monitoring station (June 13th, 16th, 17th, and 22nd), and two days when the ozone NAAQS was exceeded at LUR (June 13th and 16th). In Supplement D, we present some details about the ozone exceedances.

The new analysis introduced last quarter for presenting quarterly comparisons of local increases versus the global growth of the greenhouse gases CO_2 and CH_4 was continued. Results for Q2 2022 indicated that stronger surface winds, relative to other quarters, likely provided stronger than average mixing at the surface to keep the local changes smaller than the global increase in the concentrations of these greenhouse gases.

Increases and changes in the prominent source sector of measured light alkane hydrocarbons at LUR prompted the additional analysis of comparing propane and propane/ethane data for Q2 2022 with the previous 5 quarters to assess the evolution of their transport to LUR. In 2022, it appears that there has been a new or strengthening source of light alkanes to the north of LUR.

For the first time, LUR data are evaluated against NAAQS thresholds for NO_2 (there are two, an annual mean and an hourly average over 3 years' time). The hourly averages of NO_2 in Q2 2022 were well below both thresholds.

There were no exceedances of the NAAQS for PM 2.5 during Q2 2022.

Table of Contents

1. Project Scope and Goals

No changes from the Q1, 2022 report.

2. Overview of the Monitoring Program

No major changes from the Q1, 2022 report.

In May, we changed the layout of the instrument racks at LUR for better access and easier maintenance. We also added another rack for installation of a second Particular Matter (PM) GRIMM monitor that allows us to perform PM instrument comparisons to validate calibrations and further quality control. This also necessitated the addition of a dedicated roof inlet for the second GRIMM (see the cover picture of this report).

Starting on June 8th, there were problems with the climate control (AC units) at both Longmont stations causing overheating of the monitoring equipment, necessitating the shutdown of instrumentation, first at LUR, then at LLG a few days later. The problem was the same at both locations - cottonwood tree cotton clogging the AC coils and fins. Once the AC coils were cleaned out, everything was in working order again. The data outage at LUR lasted from 17:00 MDT on June 8th to 18:00 MDT on June 11th. The data outage at LLG was much shorter, from 15:00 – 19:00 MDT on June 13th.

3. Air Quality Monitoring Study Updates

No changes from the Q1, 2022 report.

4. Data Quality Assurance/Quality Control Process

No changes from the Q1, 2022 report.

A evaluation of the comparison of GRIMM particulate matter data has begun, but the results are too preliminary to present in this report.

5. Website Development

During Q1, 2022, there were 1313 visits to the Longmont Air Quality Now website.

6. Data Archiving

No changes from the Q1, 2022, report.

7. Data for Quarter 2, 2022

The data that were recorded in Q2, 2022, are included in this report in graphical time series format in Supplement A (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.

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 monitoring locations.

8. Selected Data Examples and Preliminary Interpretations

Ozone

The full Q2 ozone records for LLG are presented in Figures SA8 and SA9, and in figures SB8 and SB9 for LUR. With the approach of hot and dry summertime conditions, ground-level ozone began to increase at the end of the quarter, resulting in four days when the 8-hr ozone averages exceeded the National Ambient Air Quality Standard (NAAQS) for ozone of 70 ppb at the LLG station, and two days when the 8-hr NAAQS for ozone was exceeded at the LUR station. (We use 71 ppb as the cutoff point for NAAQS exceedance analysis.) The days were June 13th, 16th, 17th, and the 22nd at LLG, and June 13th and 16th at LUR. The number of hours exceeding the 8-hr ozone NAAQS each day ranged from 1 to 7 hours, depending on the day and the station (see Supplement D for more information).

On May 12, 2022, there was a peak in ozone at BSE of 106 ppb at 11:44 MST. A brief peak in ozone at this time was also measured at all other Boulder AIR monitoring stations, with the 106 ppb peak at BSE the highest value. These ozone peaks can be attributed to a stratospheric intrusion event that can occasionally occur in the Colorado Front Range during the spring. Corroborating evidence of the stratospheric intrusion is seen in the dramatic drop in relative humidity coincident with the abrupt rise in surface ozone, indicating a very dry, ozone-rich air mass was transported downward from above 5000 m above sea level (ASL) to the surface (Supplement E).

Figure 1 presents a statistical analysis of the full Q2 ozone data, comparing the Longmont data with observations from Boulder Reservoir (BRZ), Broomfield Soaring Eagle Park (BSE), Erie Community Center (ECC), and the Commerce City Fixed (CCF) site. During Q2, there was not a lot of variability in the ozone statistics among the stations. Slightly higher ozone was measured at LLG than at LUR.

CO_2

The full Q2 CO_2 records are available in Figures SA6 and SB6 for LLG and LUR, respectively. The statistical comparison of the monitoring data is presented in Figure 2. There were higher values and variability in June relative to the April and May measurements at all stations. Overall, less CO_2 was measured at the stations during Q2 than during Q1 (likely a result of enhanced vertical convective mixing as the earth's surface warmed up with the transition to summer). The wind speed/wind direction analyses are shown in Figure 3. The main source of CO_2 at both LLG and LUR was to the west of east station, similar to what was seen in Q1, 2022.

Table 1 provides comparisons of CO_2 data at LUR between Q2 2021 and Q2 2022 to investigate year-to-year changes. There was a decrease in CO_2 mean values between Q2 2021 and Q2 2022 at LUR of 2 ppm, while the average global change in CO_2 between April 2021 and April 2022 was an increase of 2.6 ppm. Over 120,000 individual 5-min annual data points were considered in the comparison. The CO_2 mean, minimum, and higher percentile values at LUR were all lower in Q2 2022 than in Q2 2021. The most likely explanation is that there were differences in meteorology during these two years that caused lower values in observed concentrations of atmospheric trace gases in 2022 compared to 2021. 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.

The same analysis was done for six consecutive quarters to gain more statistical significance in this analysis. Figure 4 compares the quarter-to-quarter change in the CO_2 measured at LUR (purple bars) with the global change in CO_2 measured in 1 month of the same quarter (obtained from NOAA Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases (noaa.gov)), represented by the green bars. The black line indicates the ratio of the local (LUR) change in CO_2 to that of the global change of CO_2. The blue line represents the differences in the quarterly averages of the surface wind speed, measured at LUR. In four of the six quarter-to-quarter comparisons presented, the measured change at LUR exceeded the increase in the global CO_2 measured by NOAA. The comparison of changes in CO_2 Q4 data between 2021 and 2020 and between Q2 2022 (the current quarter) and Q2 2021 are opposite in sign of the other comparisons. The comparison of the mean wind speed for these two sets of quarters indicates that when the wind speed was higher, there was greater mixing and dilution of pollutants throughout the quarter, leading to a decline in local CO_2 measurements while the global change was positive. Overall, four out of six of these comparisons showed higher CO_2 increases for LUR than in the global data, which makes it appear more likely that regional CO_2 emissions have been increasing rather than decreasing over this time window. This analysis is not yet conclusive, and additional quarter-to-quarter comparisons incorporating future data will be needed to add to the understanding of these data and confidence in their interpretation.

Methane

The full Q2 methane records are available in Figures SA7 and SB7 for LLG and LUR, respectively. During Q1, there were 98 peaks in the LUR one-minute methane data that were > 5000 ppb, but this quarter there were none. The statistical analysis of the full Q2 methane data is shown in Figure 5. The mean values and the variability, as indicated by the percentiles results were greater at LUR than at LLG throughout the quarter.

Table 1 shows the numerical values of the comparison between Q2 2021 and Q2 2022 methane (CH_4) measurements at LUR. The mean values between the datasets showed a 6 ppb increase in Q2 2022 (much smaller than the 43 ppb increase between Q1 2021 and 2022), while the global mean value for March 2021 compared to that of March 2022 had a 20 ppb increase.

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, similar to last quarter. For LUR, the main source of methane was from the north-northeast and, as seen last quarter.

Figure 7 shows quarter-to-quarter comparisons for CH_4 measured at LUR, similar to the analysis shown in Figure 4 for CO_2. The higher wind speeds recorded in Q2 2022 likely led to a lower amount of CH_4

measured at LUR, particularly compared to Q1 2022, but not a reversal in sign as seen in the CO_2 comparison for this quarter. As already discussed above, both quarters where there were methane decreases coincide with relatively high with speed conditions. It is therefore likely that this behavior is largely driven by the difference in winds and dilution. More comparisons will need to be added to this analysis to eventually eliminate the wind influence through averaging over more data and longer time intervals.

VOCs

The full Q2 LUR records for six selected VOCs are available in Figures SB10–SB16. Figure 8 presents a 28-month record of ethane, propane/ethane ratio (new this quarter), benzene, and acetylene from March 2020 – June 2022, measured at LUR. The propane/ethane analysis was added to investigate changes in the natural gas chemical signature as a possible indicator for new natural gas emission sources. The time series of the propane/ethane ratio indicates an increase in the occurrence of plumes with larger ratio values since late 2021/early 2022. Out of 18723 samples, there were 364 measurements where the propane/ethane ratio exceeded 1.0 (1.9% of the time), and 11 times when the ratio exceeded 2.0 (0.06% of the time). For comparison, the 2.0 ratio was exceeded only twice in all of 2020, and 5 times in 2021. Throughout this time period, both, the mean and median of the propane/ethane ratio was 0.53.

The statistical comparison of selected VOCs is plotted in Figure 9. In April and May, more ethane was measured at LUR than at all the other stations. In June, the ethane measurements at BNP were skewed relatively high due to a pipeline leak to the southwest of the station.

In April, the propane measurements at LUR continued the trend from Q1 2022 of having high mean and 95th percentile values, however, overall the propane measurements decreased during the quarter along the typical seasonal cycle where minima are observed in the middle of the summer.

Figure 10 shows the comparison of Q2 2022 statistics for ethane and benzene to those of Q2 2021 and 2020. For ethane and benzene, the mean, median, and the 95th percentile values were less in Q2 2022 than in Q2 2021 (Table 1, Figure 10).

An unusual peak in toluene occurred at LUR on April 21st at 14:05 MDT of 16.49 ppb (Figure SB16) when winds were light and variable. There were peaks at the same time in butane and propane, but not in benzene or acetylene. We are unsure of the origin of this air plume with elevated toluene.

Wind speed/wind direction dependence results of ethane, propane, acetylene, and benzene at LUR are shown in Figure 11. The plots indicate that the strongest ethane, propane, and benzene source was to the north. The propane source to the north is particularly well-defined for all wind speeds. The analysis for Q1 2022 already pointed towards this propane source to the north, whereas the analyses for the previous quarters were more variable in the source direction, ranging from east to north, depending on the quarter. For acetylene, there was a relatively strong source to the south seen at lower wind speeds, and a source to the northwest that was notable at higher wind speeds.

To further investigate the trend in propane measurements are LUR, we re-processed the propane and the propane/ethane ratio data and plotted the bivariate polar plots with the same limits on the color bars to more accurately portray how propane measurements at LUR evolved over time. The propane and propane/ethane ratio plots (Figure 12) show that prior to Q1 2022, the main source of propane measured at LUR was from the east or the northeast, likely a result of emissions from oil and gas operations in this direction within Weld County. In Q1 and Q2 of 2022, the strongest source was from a different direction, i.e. to the north. The increase in the propane/ethane ratio is very apparent in the Q1 2022 data, and a big contrast to the Q1 2021 data analysis.

Further analyses of VOCs signatures, using VOC/VOC ratio values, are shown in Figure 13. The higher ratio of benzene/toluene in stronger winds from the NW results from mostly clean background air that has been photochemically processed. Toluene reacts faster than benzene in the air, decreasing faster. Therefore, the older the air, the higher the benzene/toluene ratio. The propane/ethane ratio is quite different from the north than from the east, where natural gas signatures from the Denver-Julesburg Basin in Weld County are observed. It is remarkable that the source persists through all wind speeds. At the very lowest wind speeds propane levels are relatively modest, indicating that the source(s) is (are) further away from the station.

Similar to previous quarters, 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).

Nitrogen Oxides (NO, NO_x)

The Q2 LUR record for nitric oxide (NO) is available in Figure SB17, and the record for total nitrogen oxides (NO_x) in Figure SB18. Figure 14 shows the statistical analyses for NO (A) and NO_x (B). The mean NO and NO_x values at all stations were skewed high by occasionally occurring very high values. The measurement data were lower than in Q1 2022. In May and June, the highest overall NO_x was measured at LUR within the network. A time series of hourly-averaged NO_2 is shown in Figure 14 (C). The 1-hour NAAQS for NO_2 is defined such that the 98th percentile of the 1-hour daily maximum mole fraction, averaged over 3 years, cannot exceed 100 ppb. There is also an annual mean NAAQS of 53 ppb. The hourly-averaged NO_2 results shown in Figure 13 indicate that NO_2 did not exceed 30 ppb during Q2, staying well below both NO_2 NAAQS thresholds throughout the quarter. Dependency of NO and NO_x on wind direction and wind speed is presented in Figure 15. The strongest sources of NO were to the south and to the southeast of LUR.

Particulate Matter (PM)

PM 10 and PM 2.5 LUR Q2 monitoring results are presented in Figures SB19 and SB20. The 24-hour averaged PM 2.5 data are available in Figure SB21. There were no exceedances of the 35 $\mu g\ m^{-3}$ PM 2.5 NAAQS this quarter. There were three days with large, brief peaks in PM 10 measurements exceeding 1000 $\mu g\ m^{-3}$ (June 9th, June 19th, and June 30th). In all cases there was a wind direction shift associated with the PM 10 peaks. These wind shifts could possibly be due to gusts front or cold front passages, but we have not confirmed this. In two cases (June 9th and 19th), there were coincident peaks in NO_x, a dip in ozone, and a slight increase in CO_2. On June 9th the winds were from the north-northwest before they shifted to southwesterly, and on the 19th the winds were from the west-northwest before they shifted to southeasterly. In both cases, there is the possibility that agricultural operations on the field to the west of LUR resulted in machinery emissions or/and stirred up the soil, contributing to increases in PM 10 and NO_x.

The statistical comparison of LUR data with BSE, ECC, and CCF data is presented in Figure 16.

9. Summary

A second GRIMM for measurement of particulate matter was installed at the LUR for measurement intercomparison and quality control studies.

With the transition to hot, dry summertime weather, there were four days in Q2 when the National Ambient Air Quality Standard (NAAQS) for ozone was exceeded at the LLG (June 13th, 16th, 17th, and 22nd), and two days when the ozone NAAQS was exceeded at LUR (June 13th and 16th). In Supplement D we present some details about the ozone exceedances.

The new analysis introduced last quarter for presenting quarterly comparisons of local changes to global changes in CO_2 and CH_4 was continued this quarter. Results for Q2 2022 indicated that stronger surface winds, relative to other quarters, likely provided stronger mixing at the surface that resulted in local changes of these greenhouse gases that are smaller than the trends seen in the global data.

Frequent spikes and changes in the prominent source sector of measured propane at LUR prompted the additional analysis, comparing propane and propane/ethane data for Q2 2022 with the previous 5 quarters to assess the evolution of propane transport to LUR. These analyses provide compelling argument that there has been an increase in natural gas emissions that are relatively rich in propane within the north sector of LUR.

For the first time, this report provides an evaluation of the measurement data with the NAAQS thresholds for NO_2 (there are two, an annual mean and an hourly average over 3 years' time). The hourly averages of NO_2 in Q2 2022 were well below both thresholds.

There were no exceedances of the NAAQS for PM 2.5 during Q2 2022.

Tables

Table 1: Comparison of the statistics of CO_2 and CH_4 data (5-min averages) and ethane and benzene (10-min data once every hour) at LUR during Q2 of 2021 and Q2 of 2022. "Abs Diff" is the 2022 value minus the 2021 value. % Diff shows the relative change between the two years. The Local/Global column shows the relative ratio of the increase seen in the Longmont data in comparison to the global background.

Species	Stat	2021	2022	Abs Diff	% Diff	Local/Global
CO_2	count	129494	128677	-817	-0.63	
(ppm)	mean	432.0	430.0	-2.0	-0.5	-0.8
	std	20.6	15.8	-4.8	-23.3	
	min	403.0	377.5	-25.5	-6.3	
	5%	413.2	415.3	2.1	0.5	
	25%	418.8	420.3	1.5	0.3	
	50%	424.6	424.7	0.0	0.0	0.0
	75%	438.4	434.0	-4.4	-1.0	
	95%	476.0	465.7	-10.3	-2.2	
	max	567.5	547.9	-19.6	-3.5	
	Global mean	*415.8*	*418.4*	*2.6*	*1.0*	
CH_4	count	129494	128677	-817	-0.6	
(ppb)	mean	2051	2057	6	0.3	0.3
	std	120	133	13	10.7	
	min	1908	1924	16	0.8	
	5%	1945	1957	12	0.6	
	25%	1985	1992	7	0.4	
	50%	2024	2027	2	0.1	0.1
	75%	2084	2086	2	0.1	
	95%	2234	2236	1	0.0	
	max	7571	12409	4838	63.9	
	Global mean	*1889*	*1909*	*20*	*1.0*	
Ethane	count	2037	1939	-98	-4.8	
(ppb)	mean	7.2	6.6	-0.6	-8.8	
	std	6.2	9.3	3.1	50.4	
	min	0.8	0.7	-0.1	-11.9	
	5%	1.6	1.6	0.0	2.2	
	25%	3.5	2.8	-0.7	-20.4	
	50%	5.7	4.7	-1.0	-17.8	
	75%	9.0	8.0	-1.1	-11.8	
	95%	17.8	16.5	-1.3	-7.1	
	max	100	228	127	127	
Benzene	count	2042	1940	-102	-5.0	
(ppb)	mean	0.08	0.06	-0.02	-20.5	
	std	0.07	0.06	-0.01	-14.9	
	min	0.01	0.01	0.00	7.6	
	5%	0.02	0.02	-0.01	-26.4	
	25%	0.04	0.03	-0.01	-29.1	
	50%	0.06	0.05	-0.01	-23.4	
	75%	0.10	0.08	-0.02	-17.1	
	95%	0.20	0.16	-0.04	-20.6	
	max	1.31	1.26	-0.05	3.7	

Figures

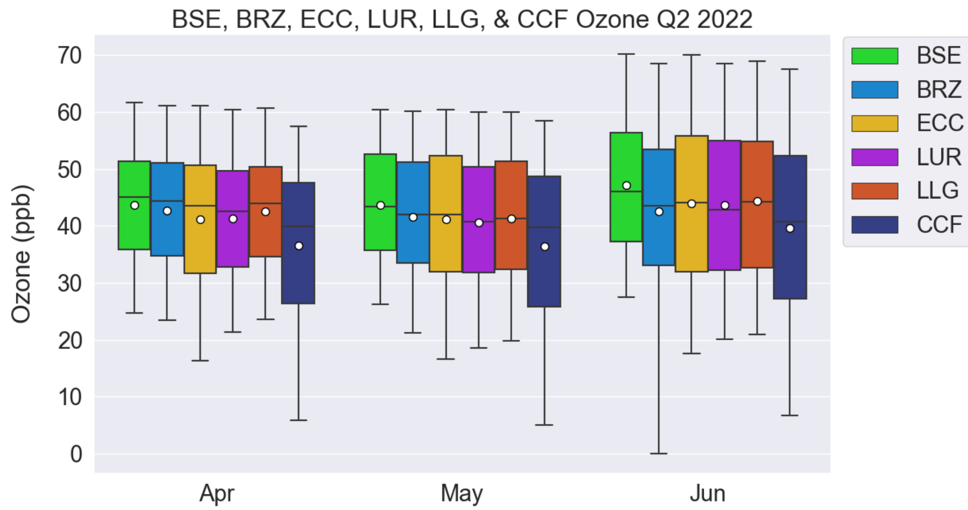


Figure 1:
Comparison of the ozone distribution at BSE, BRZ, ECC, LUR, LLG, and CCF, during April – June 2022. These box whisker plots show the median value as the center line, the 25-75 percentile distribution as the colored boxes, and the 5-percentile and 95-percentile values as the whiskers. The white dot on each box illustrates the mean value at each site.

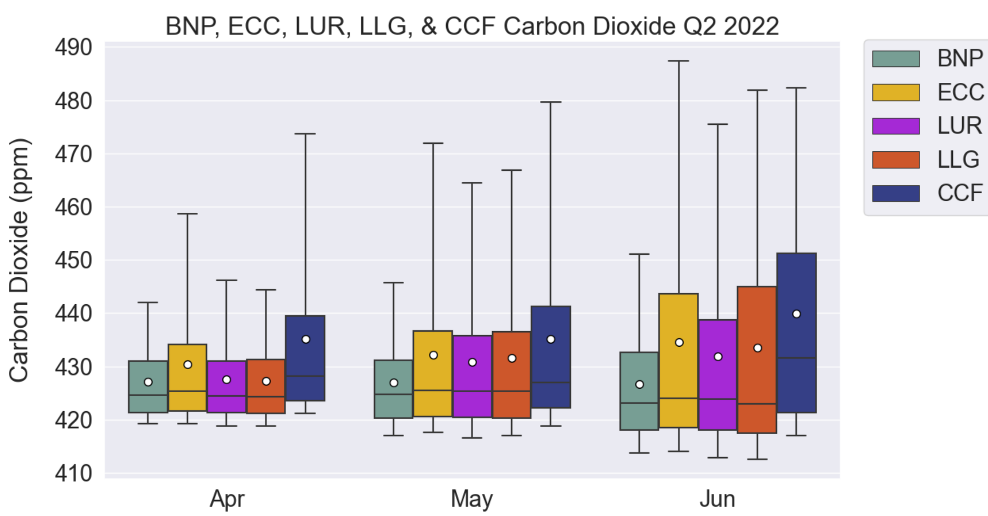


Figure 2:
Comparison of the CO_2 distribution at BNP, ECC, LUR, LLG, and CCF, during April – June 2022. See Figure 1 for explanation of the box whisker plot format.

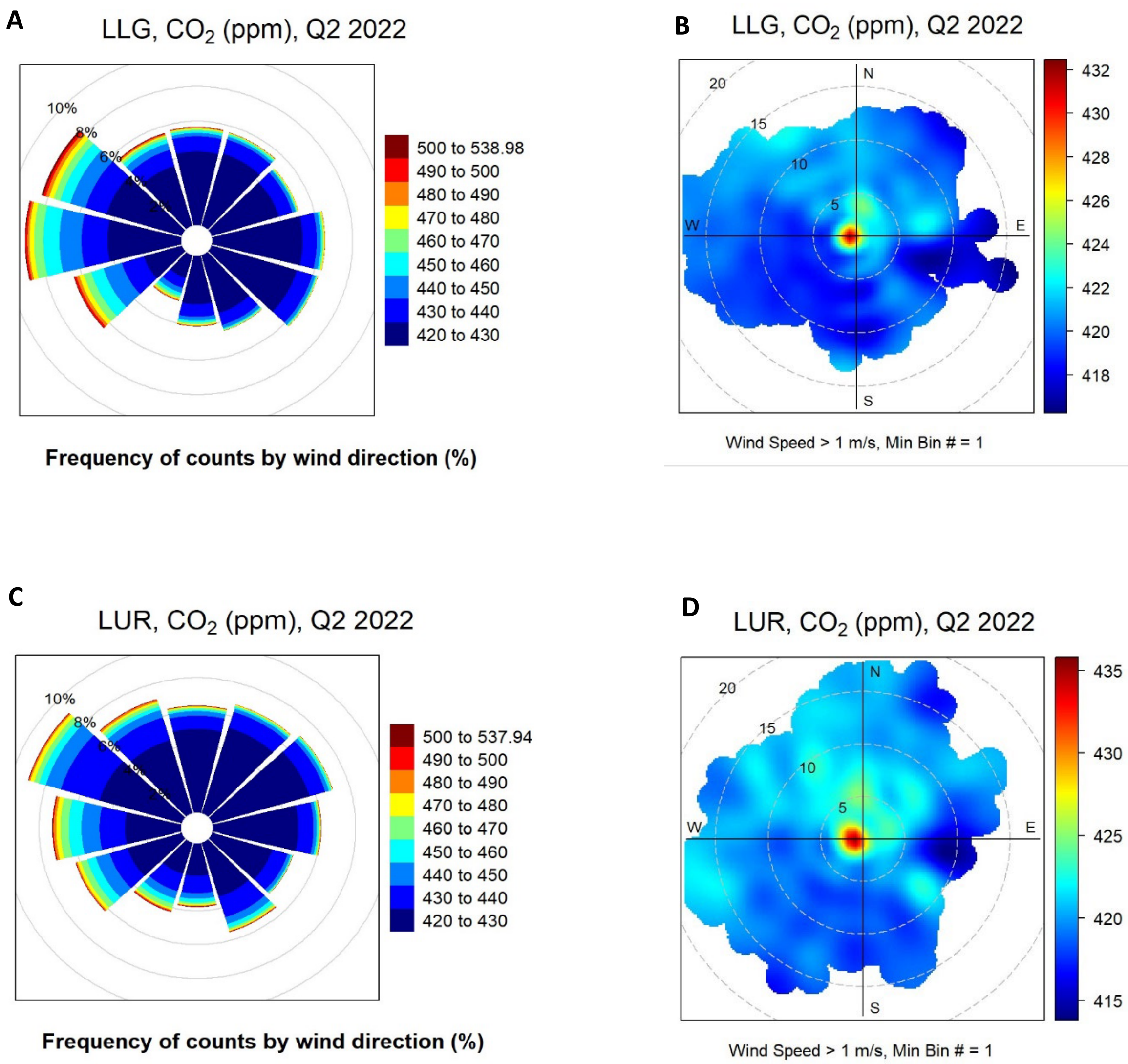


Figure 3:
Wind rose (left) and wind heat map analysis showing the dependency of CO_2 mole fractions at LLG (top, A, B) and LUR (bottom, C, D) during April – June 2022. The LUR site is east of the City of Longmont. These analyses suggests that the city is the primary source for enhanced CO_2 observed at LUR.

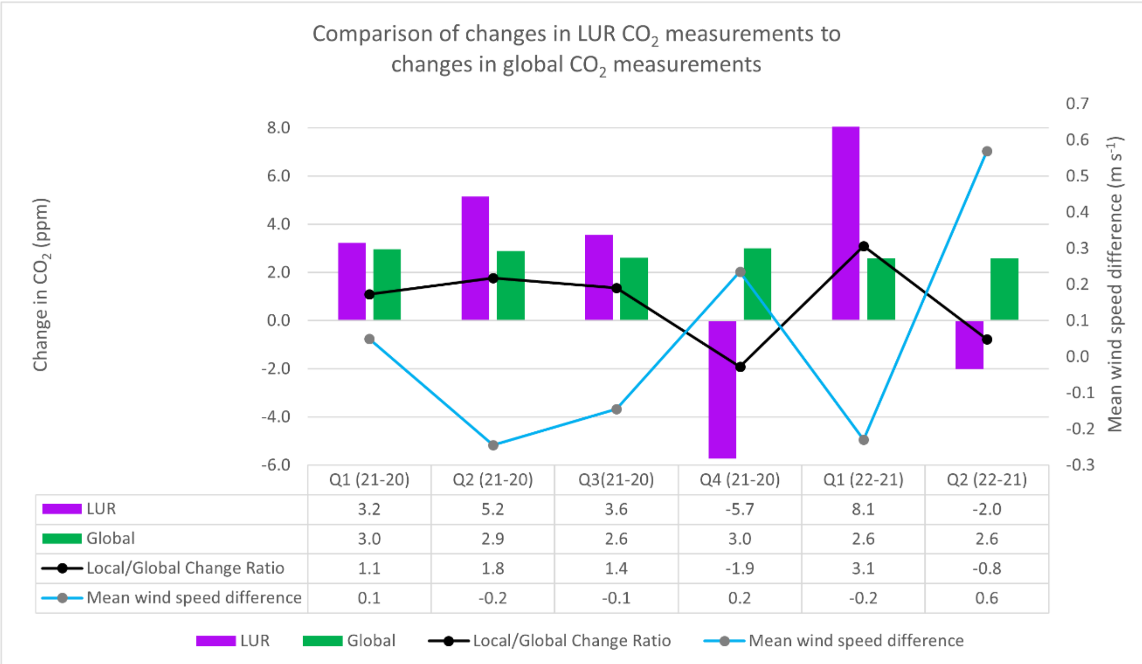


Figure 4:
Comparisons of the quarter-to-quarter change in the CO_2 measured at LUR with the global change in CO_2 measured in 1 month of the same quarter (obtained from Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases (noaa.gov)). The quarter and years being compared are noted in the top row of the table. Purple bars represent LUR data, green bars represent global data. The black line indicates the ratio of the local (LUR) change in CO_2 to that of the global change of CO_2. The blue line represents the differences in the quarterly averages of the surface wind speed, measured at LUR.

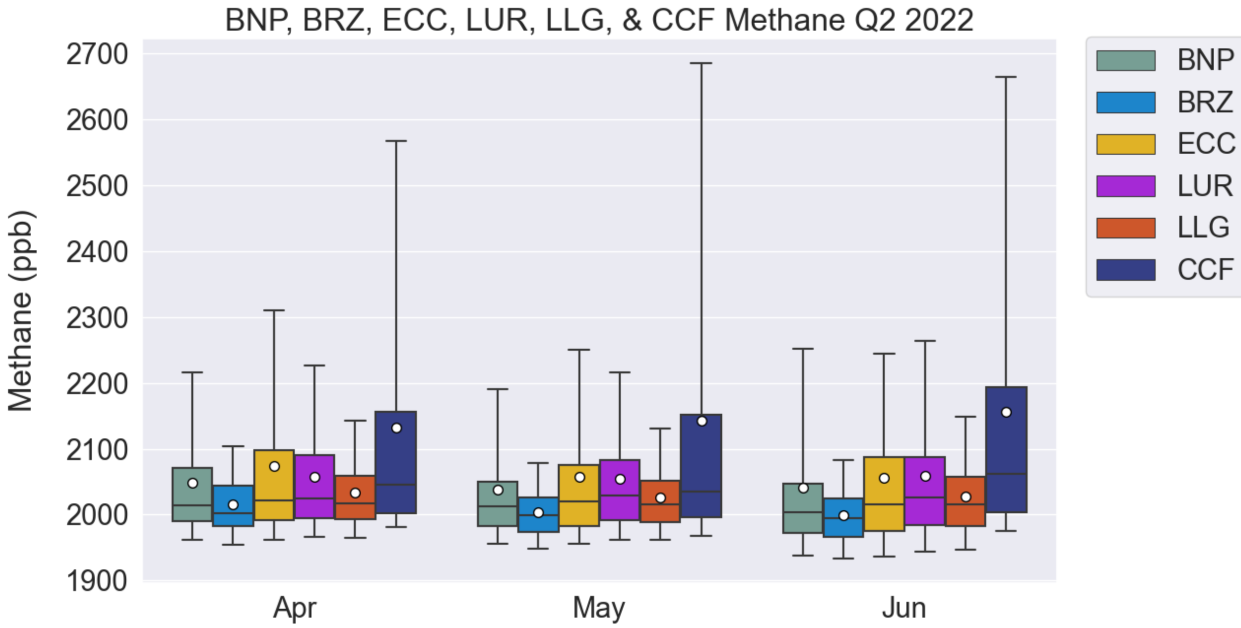


Figure 5:
Comparison of the methane distribution at BNP, BRZ, ECC, LUR, LLG, and CCF, during April – June 2022. See Figure 1 for explanation of the box whisker plot format. Between the two Longmont sites, LUR has higher absolute values and variance.

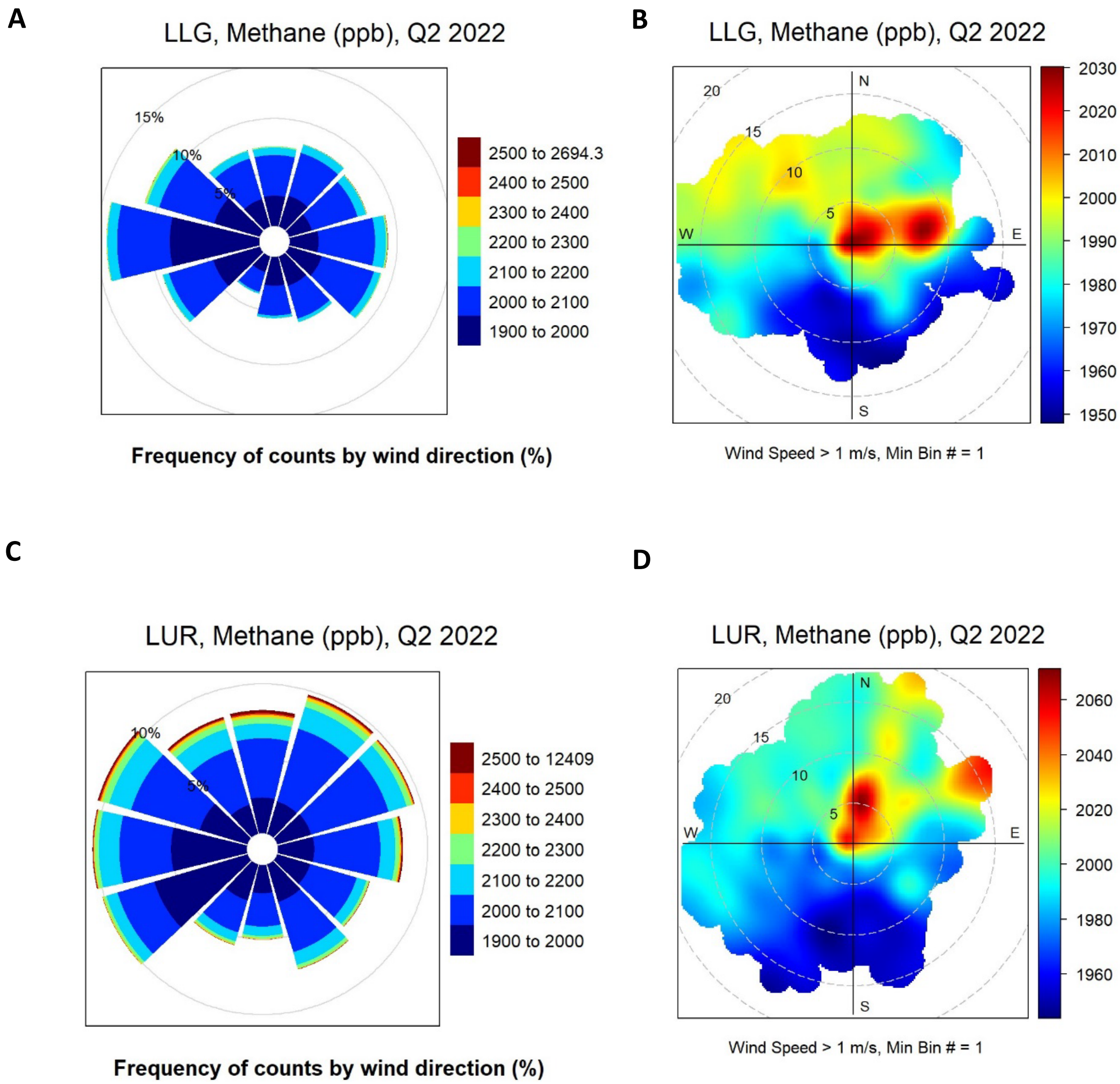


Figure 6:
Wind rose (left) and wind heat map analysis showing the dependency of CH_4 mole fractions at LLG (top, A, B) and LUR (bottom, C, D) during April – June 2022.

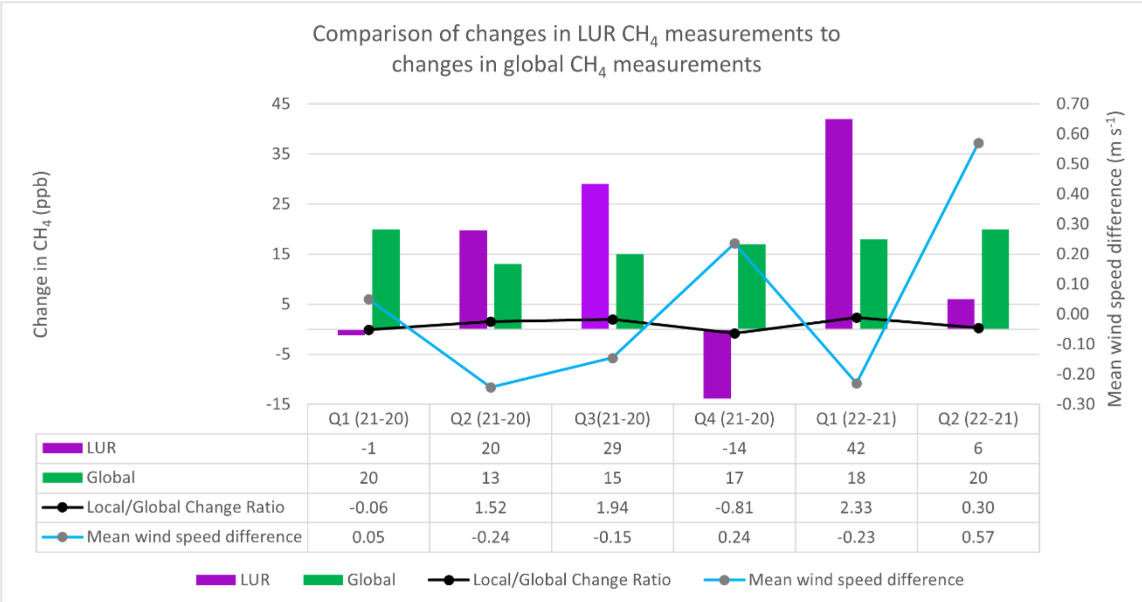
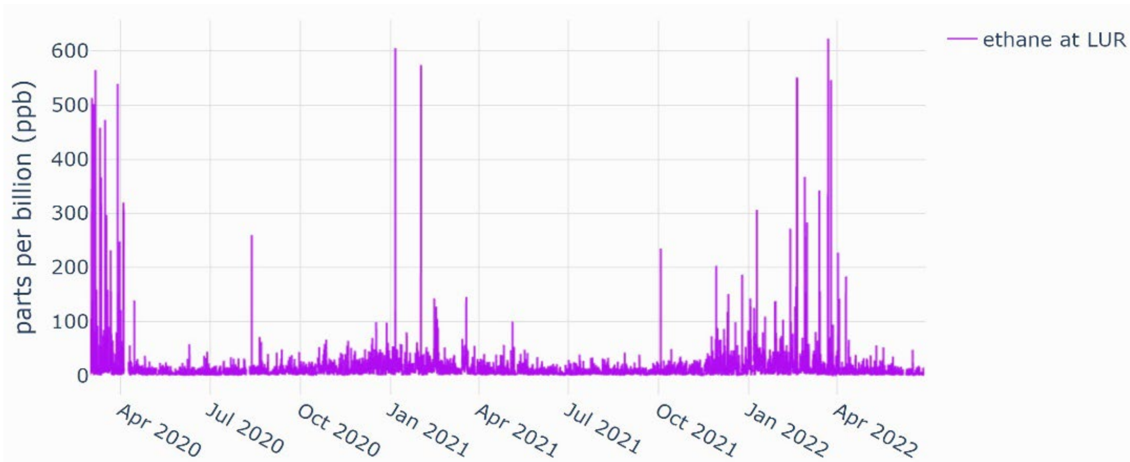


Figure 7:
Same as in Figure 4, except for methane (CH_4).

A



B

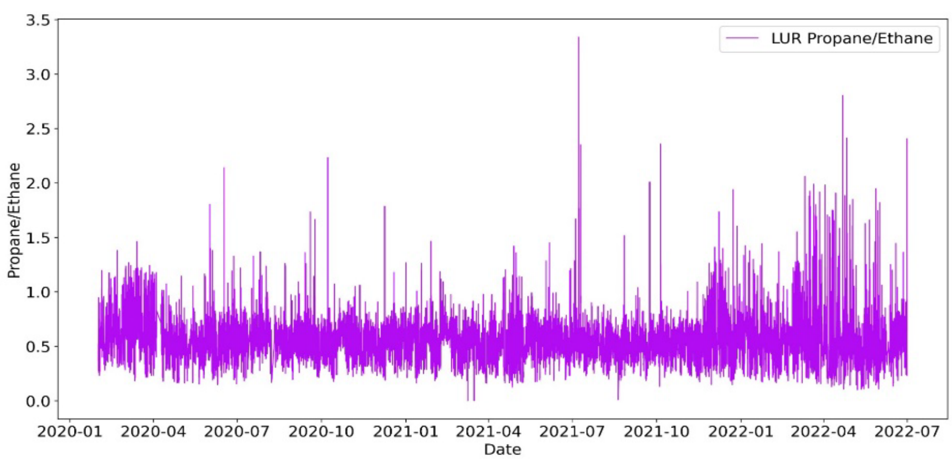
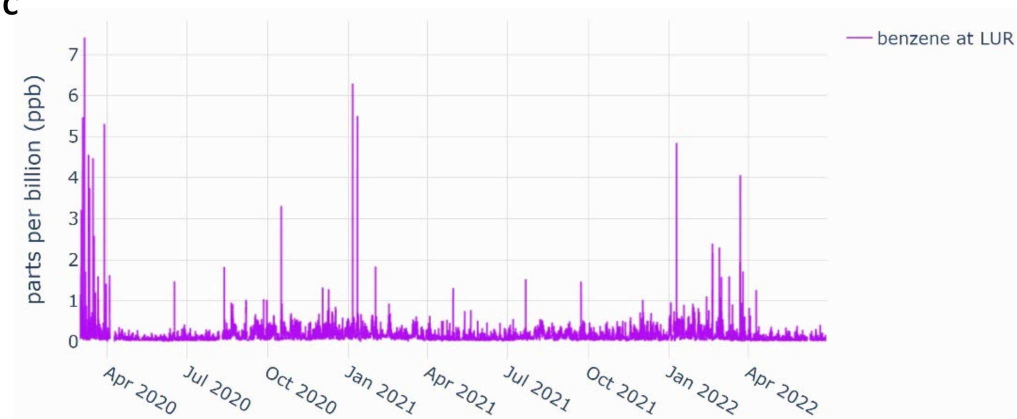
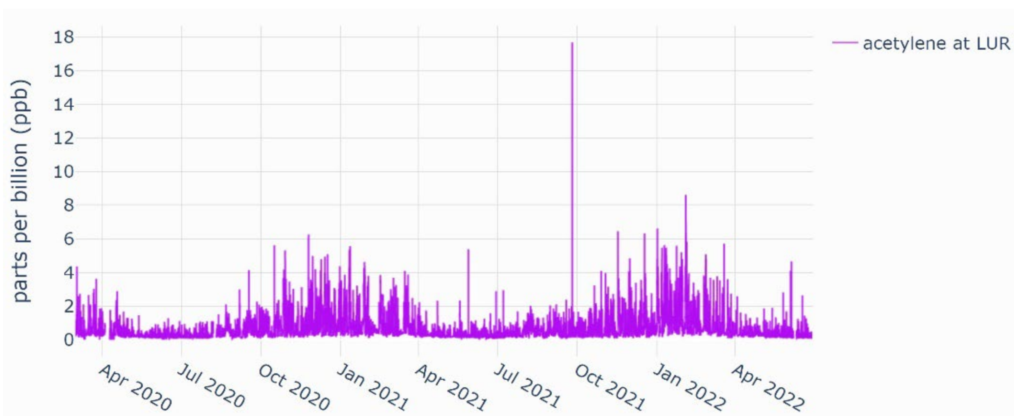


Figure 8:
Time series analyses of ethane (A), the propane/ethane ratio (B), benzene (C, next page), and acetylene (D, next page) at LUR between March 1, 2020 and June 30, 2022. Lower frequency and lower maximum values of concentration spikes during the summer are observed for all compounds. These summer 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. The ethane time series suggests an increase of oil and gas emissions during the last year. The propane/ethane ratio time series indicates that a new source of propane appeared late last year or early this year.

C


benzene at LUR
parts per billion (ppb)
0
1
2
3
4
5
6
7
Apr 2020
Jul 2020
Oct 2020
Jan 2021
Apr 2021
Jul 2021
Oct 2021
Jan 2022
Apr 2022

D


acetylene at LUR
parts per billion (ppb)
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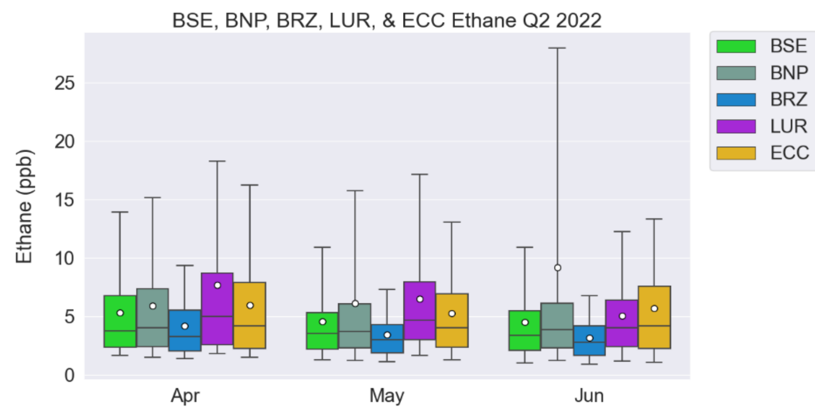
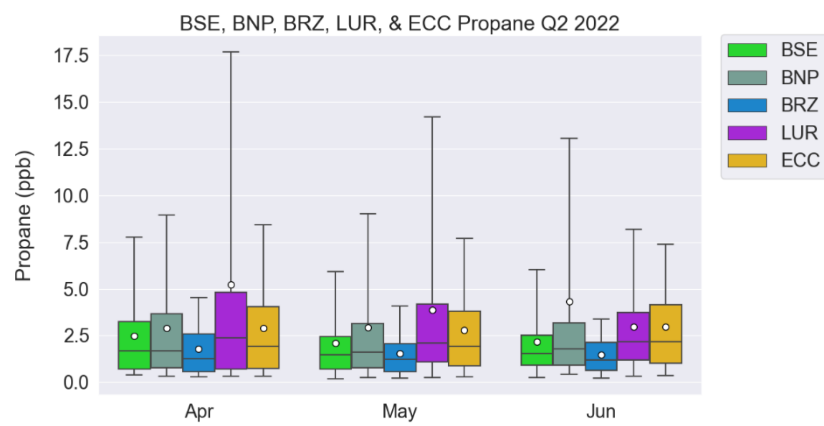
2
4
6
8
10
12
14
16
18
Apr 2020
Jul 2020
Oct 2020
Jan 2021
Apr 2021
Jul 2021
Oct 2021
Jan 2022
Apr 2022

A



B



C

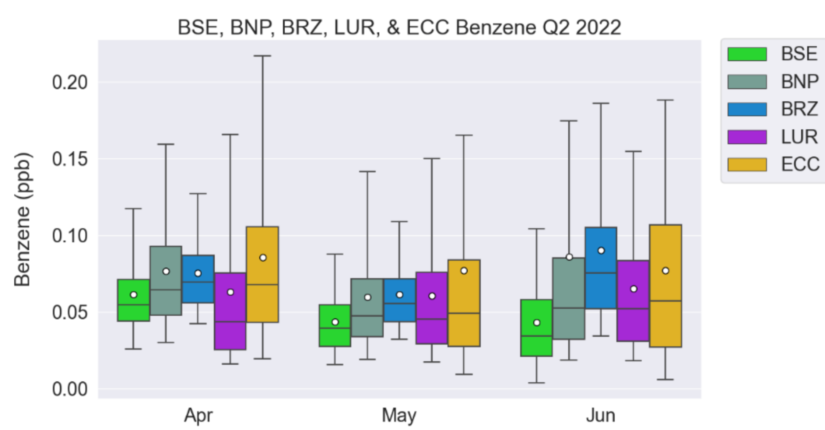
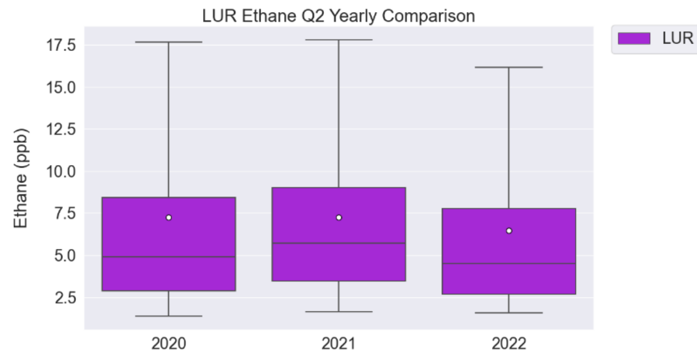


Figure 9:
Comparison of the distribution of ethane (A), propane (B), and benzene (C) at BSE, BNP, BRZ, LUR, and ECC during Q2. See Figure 1 for explanation of the box whisker plot format.

A



B

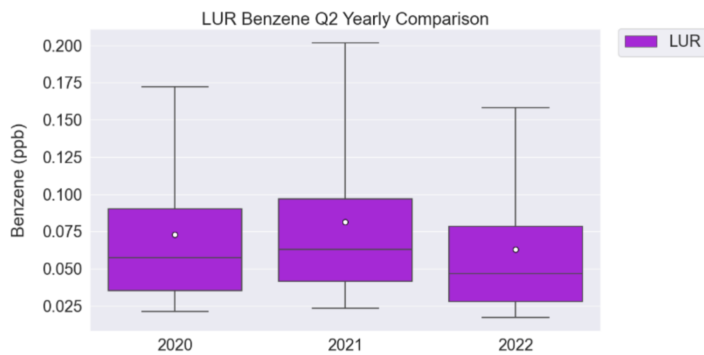


Figure 10:
Comparison of the ethane distribution (top, A) and the benzene distribution (bottom, B) at LUR during Q2 of 2020, 2021, and 2022. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions for Q2 2021 and 2022 are presented in Table 1.

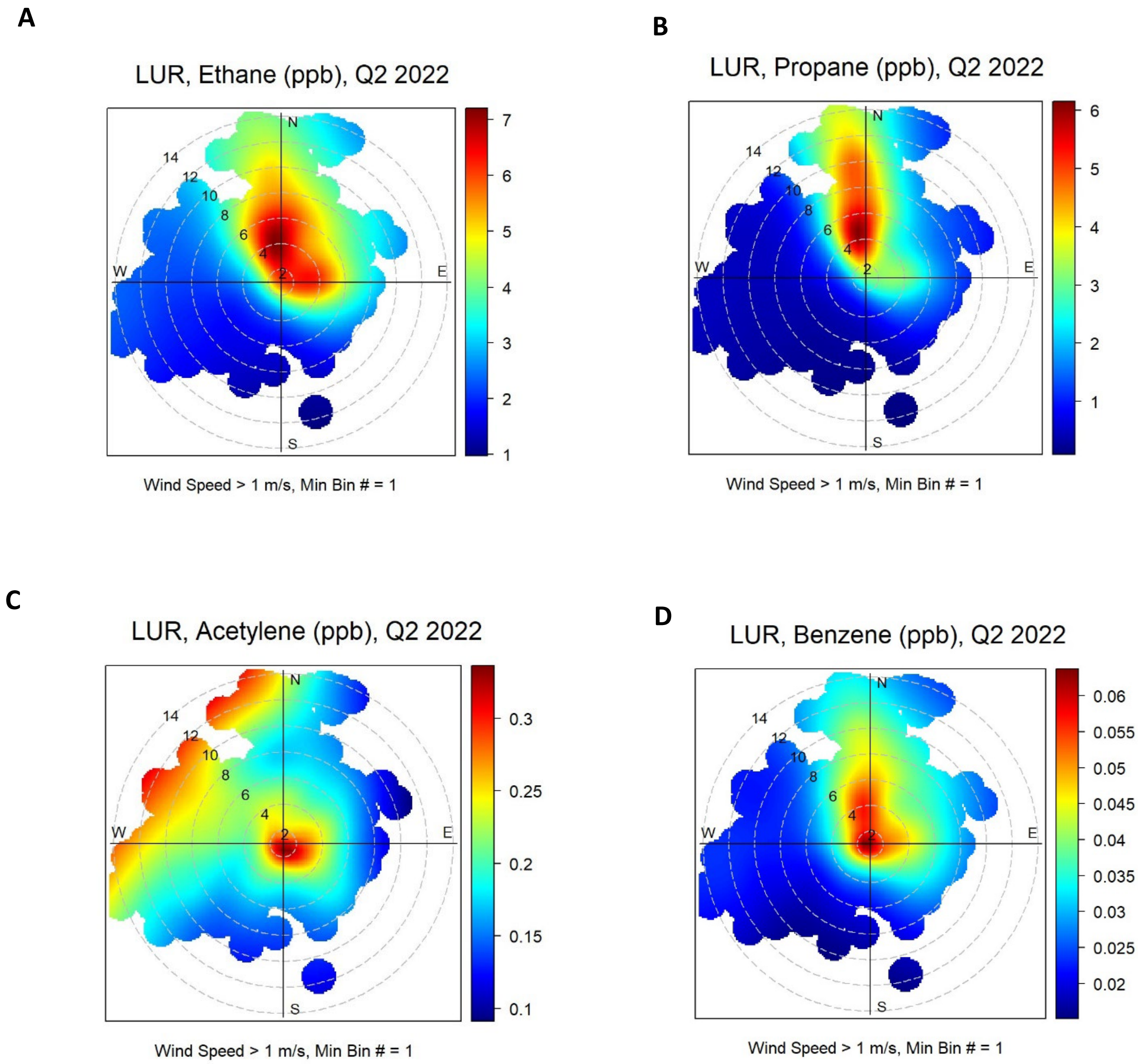


Figure 11:
Comparison of ethane (A), propane (B), acetylene (C), and benzene (D) occurrences as a function of wind speed and direction at LUR during Q2 2022.

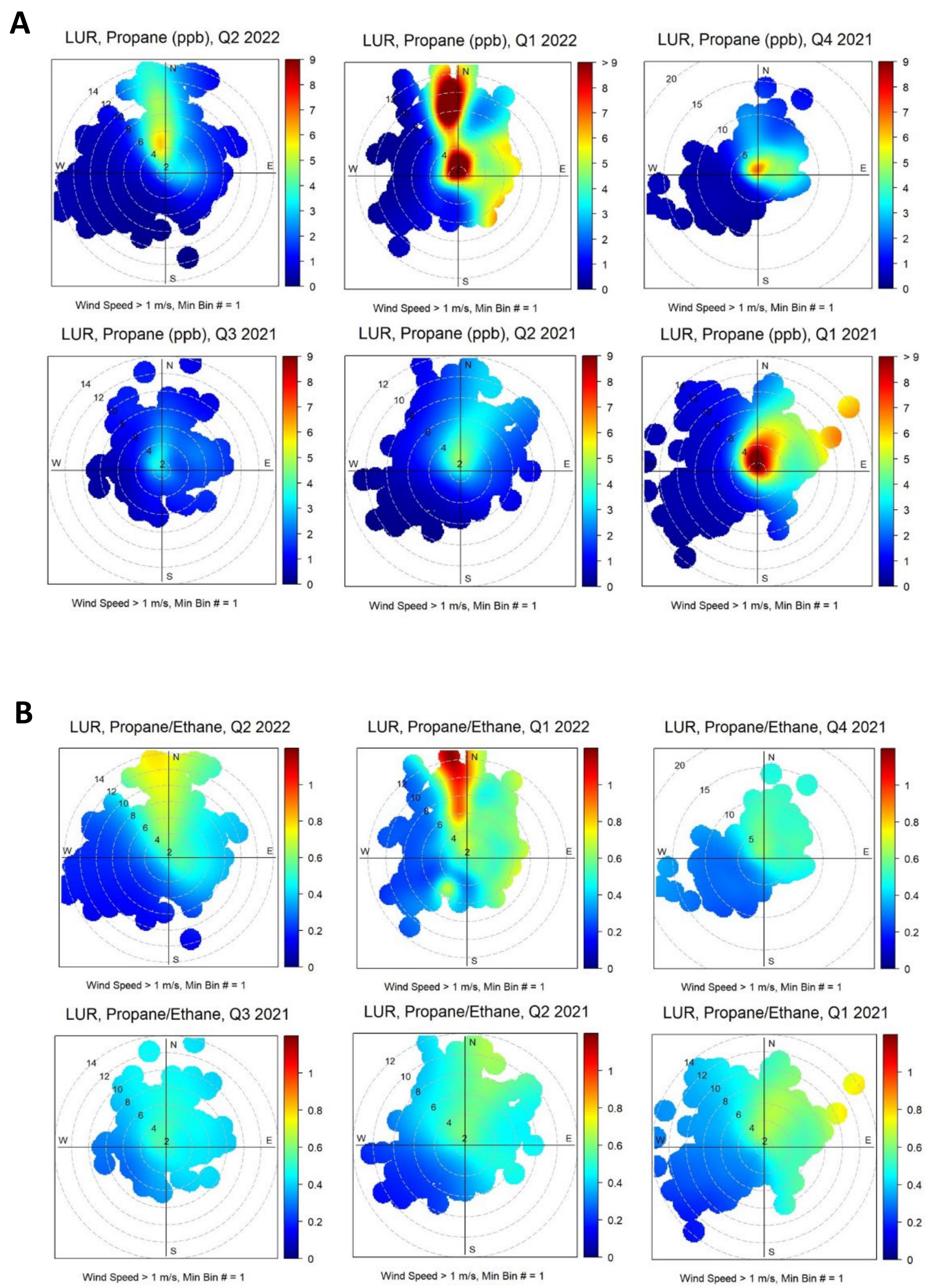


Figure 12:
6-panel A: Propane bivariate polar plots from Q1 2021 – Q2 2022, in reverse chronological order. Bottom 6-panel B: Propane/ethane ratio plots for the same time period. Prior to Q1 2022, the main propane source for emissions detected at LUR was to the east or the northeast of LUR. In Q1 and Q2 of 2022, the main source was to the north.

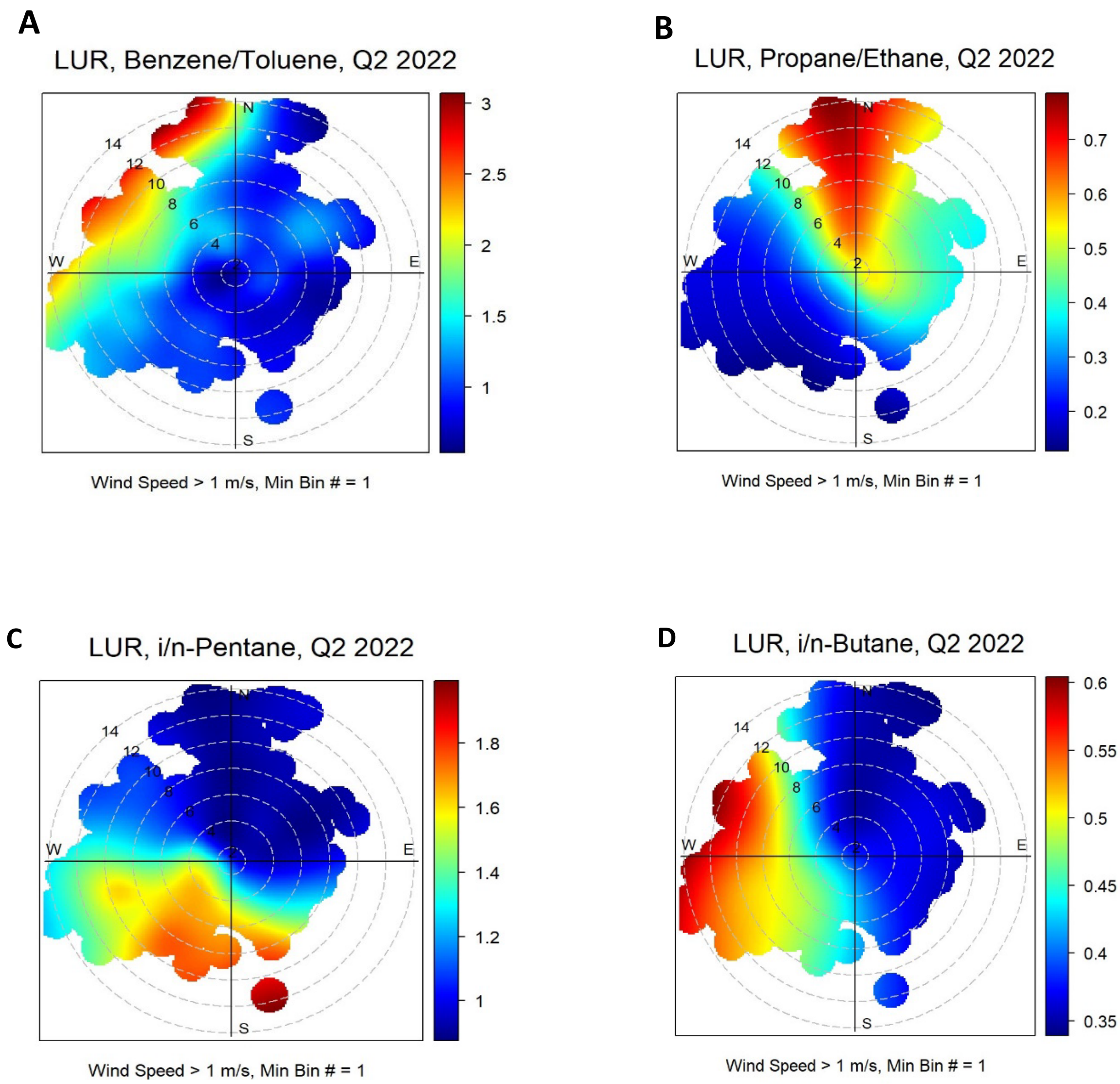


Figure 13:
Ratios of selected VOC pairs as a function of wind direction and wind speed during Q2 2022. These analyses show clear differences in the chemical signatures in air transported from different directions to the monitoring station.

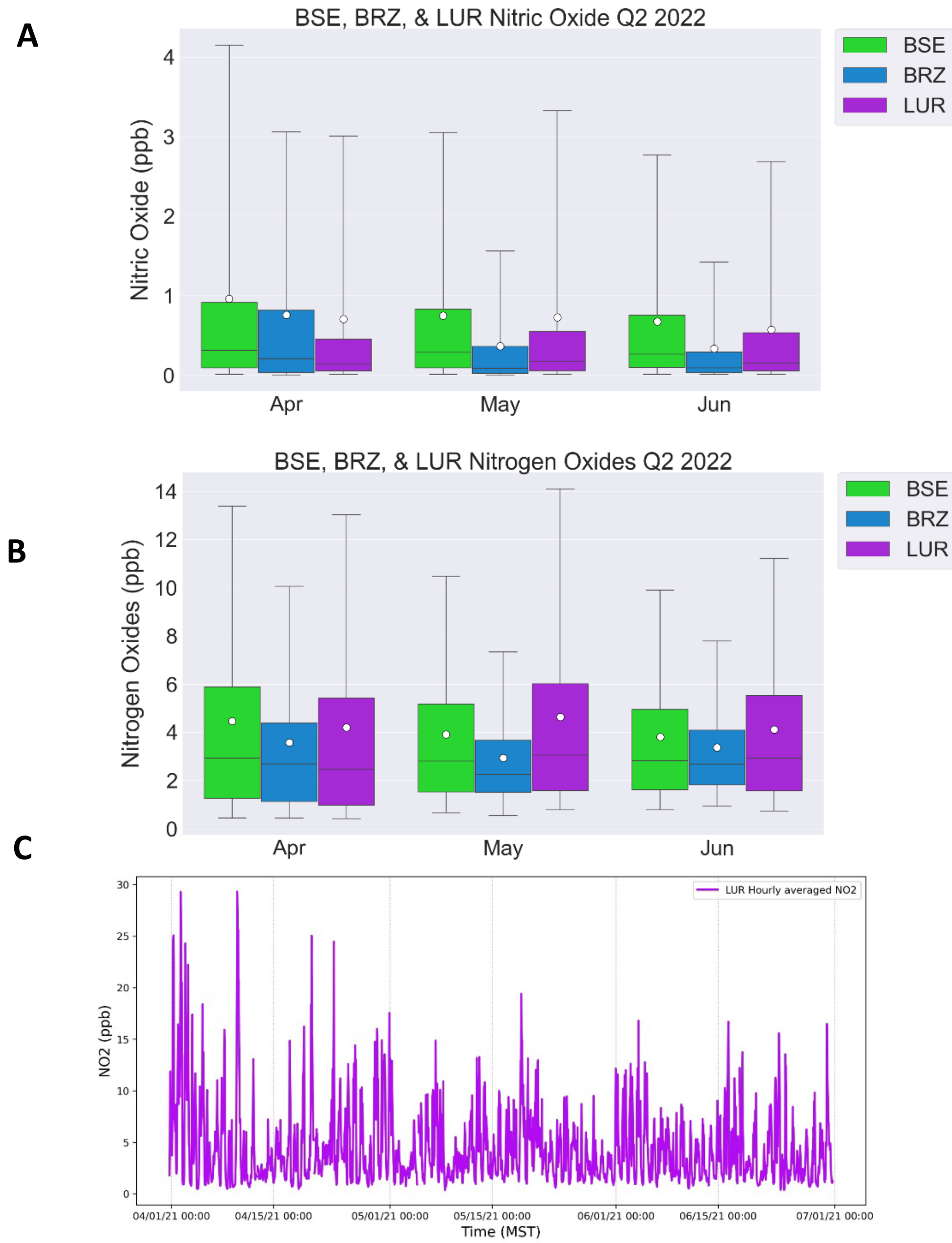


Figure 14:
Comparison of nitric oxide (A) and nitrogen oxides (B) at BSE, BRZ, and LUR during April – June 2022. See Figure 1 for explanation of the box whisker plot format. (C) LUR hourly-averaged NO_2.

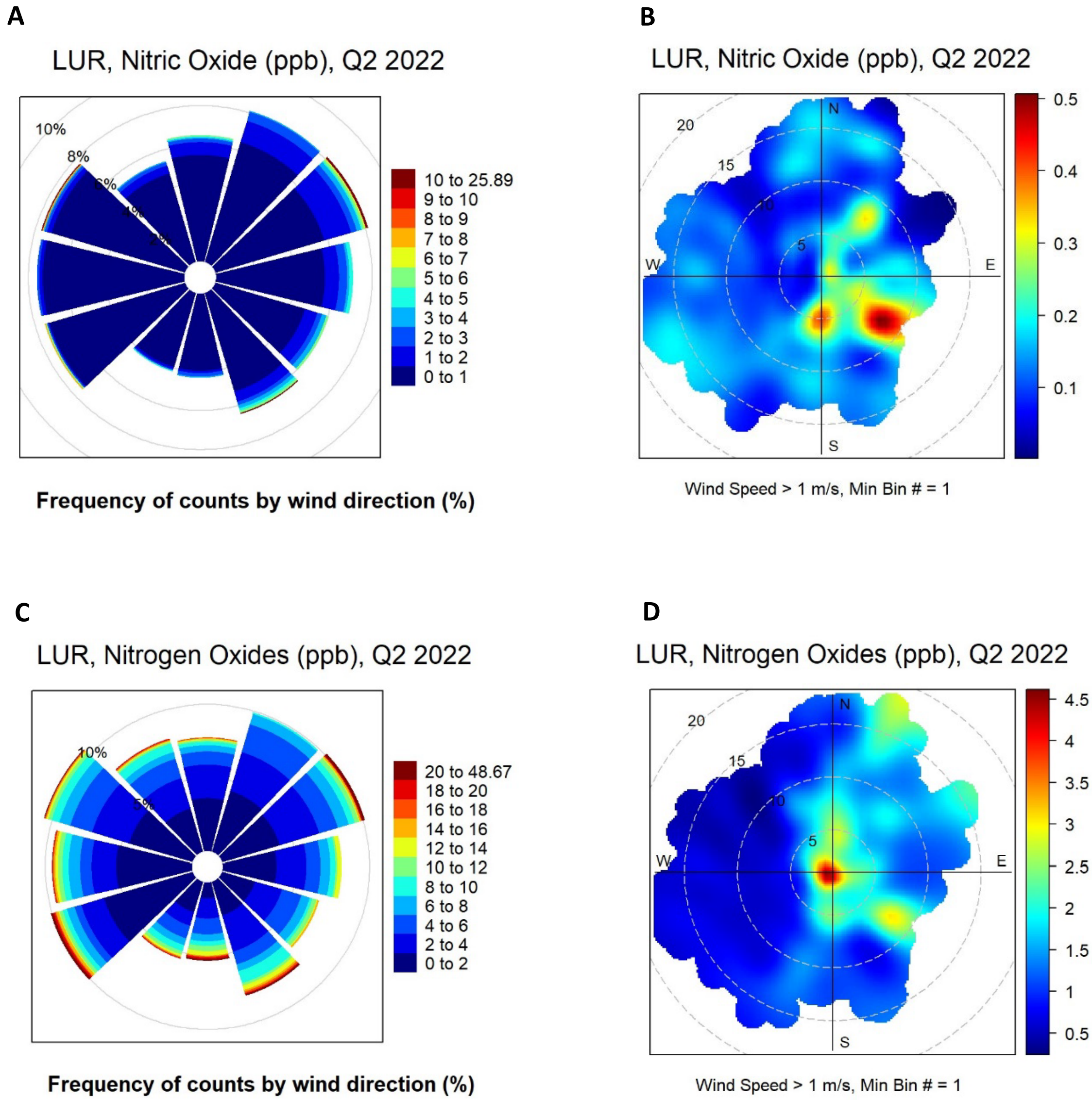
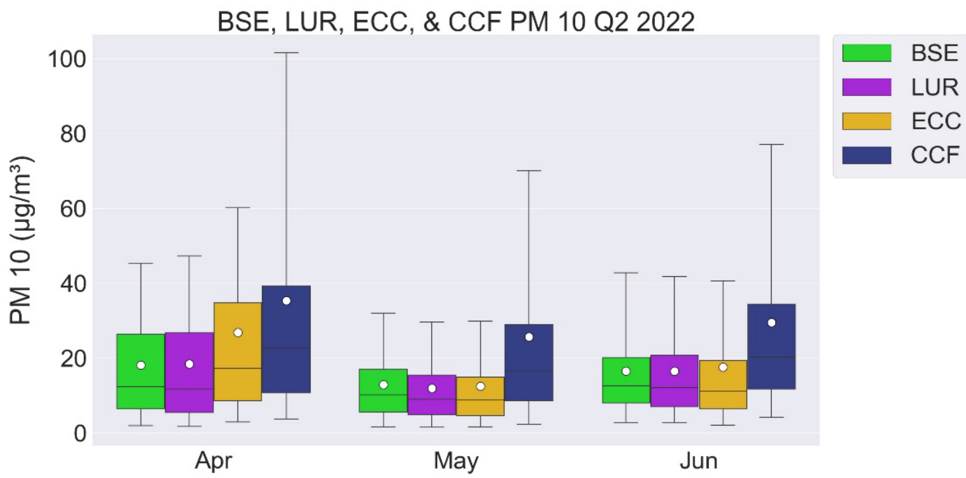


Figure 15:
Dependence of nitric oxide (A, B) and nitrogen oxides (C, D) as a function of wind speed and direction at LUR during April – June 2022. As seen in the prior data, the City of Longmont, located to the west, appears to be the strongest upwind source for NO_x.

A



B

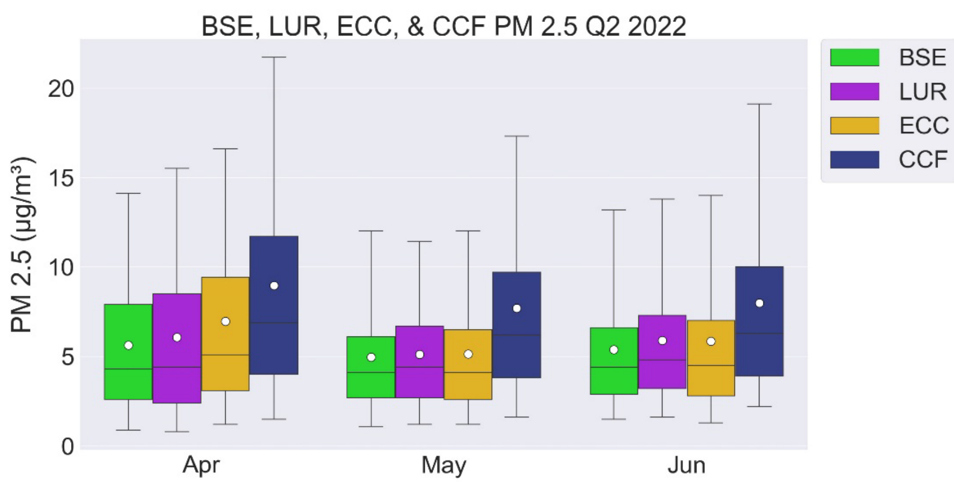


Figure 16:
Comparison of PM 10 (A, top) and PM 2.5 (B, bottom) at BSE, LUR, ECC, and CCF during April – June 2022. See Figure 1 for explanation of the box whisker plot format.