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December 8, 2022

To:

City of Longmont
350 Kimbark Street
Longmont, CO 80501

Attn: Dr. Jane Turner

Re: Longmont Regional Air Quality Study – Year 2022 Quarter 3 Report

Dear Dr. Turner,

Please find included with this letter the July – September (Quarter 3) 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 3 (July – September) Report

# Longmont Air Quality Study

# 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 July - September, i.e., Quarter 3 (Q3), 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.

8-hr ozone averages exceeded the National Ambient Air Quality Standard (NAAQS) for ozone of 70 ppb at the LLG station during 6 days in Q3 (July 25$^{th}$, August 8$^{th}$ – 10$^{th}$, and Sept 6$^{th}$ and 7$^{th}$). 8-hr ozone exceedances also occurred at LUR on these days, plus on August 11$^{th}$. (We use 71 ppb as the cutoff point for NAAQS exceedance analysis.) The number of hours exceeding the 8-hr ozone NAAQS each day ranged from 1 to 5 hours, depending on the day and the station. These high ozone days were associated with hot summer temperatures and stagnant meteorological conditions. See Supplement D for more information and a more detailed look at the August ozone exceedance days.

There were a few brief periods during Q3 when methane measured at LUR exceeded 5000 ppb, mostly late in the evening of July 12$^{th}$. Peaks in some VOCs occurred at the same time as the methane peaks, indicating that a natural gas release was likely observed at LUR at this time. A detailed analyses is shown in Supplement E. There were no instances of methane measurements greater than 5000 ppb at LLG during Q3.

High values of acetylene were measured at LUR on September 5$^{th}$ and 8$^{th}$. See analysis in Supplement E for more information.

There were no exceedances of the NAAQS for PM 2.5 or $NO_2$ during Q3 2022.

An issue with unreasonably low (< 400 ppm) $CO_2$ measurement results at LUR and LLG was investigated. It was found that $H_2O$ that likely accumulated in the sampling line may have been responsible for a measurement artifact causing these values. A data filtering was applied to remove these data. Options for remediation in the measurement system are being explored, as well as further analysis of the $CO_2$ measurements in order to better characterize and understand the issue.

## Table of Contents

## 1. Project Scope and Goals

No changes from the Q2, 2022 report.

## 2. Overview of the Monitoring Program

No major changes from the Q2, 2022 report.

## 3. Air Quality Monitoring Study Updates

Boulder AIR is increasing security measures across all sites and security cameras were installed at both LLG and LUR in July. At each station there is one camera mounted on the tower and one inside the station. The cameras are motion-activated and an email is sent to a Boulder AIR staff member each time a camera is activated. The email includes a short video clip of the motion. This function has been tested and been found to respond properly during staff site visits.

## 4. Data Quality Assurance/Quality Control Process

***Particulate Matter***

A second "reference" GRIMM particulate matter (PM) instrument was installed at LUR in the spring for the purpose of instrument validation. Bi-annual maintenance was performed on both instruments in September which included cleaning of the inlet stacks and tests with synthetic aerosols. Subsequently, the instruments were run side-by-side for a two-week period in October. The readings between the instruments agreed for PM 2.5 with an R-squared value of 0.97 and slope of 0.96 (after removal of a small fraction of high values that likely corresponded to dynamic air composition changes between the two separate inlets). This is a very good agreement for field conditions where there will be inherent environmental variation between the air masses reaching the separate instrument inlets.

The agreement for PM 10 was not as good with an R-squared of 0.80 and slope of 0.71. The inferior PM 10 comparison is similar to what we have seen at other stations when doing side-by-side measurements and we think indicative of the greater propensity for the larger particles to be influenced while traveling through the inlet. Plots for the instrument comparison are included in Supplement F. Further testing is currently ongoing to further characterize and understand the PM 10 measurement agreement.

***Picarro $CO_2$ measurements***

In the analysis of the Q3 data, it was noted that at times the $CO_2$ measurements at LUR and LLG occasionally dipped below 400 ppm, which is not realistic. This was much more likely to occur at LUR than at LLG. These measurements were investigated, and it was found that there was a relationship between the low $CO_2$ values and higher $H_2O$ measurements. Boulder AIR staff consulted with Picarro experts who confirmed that when water condenses in the line, $CO_2$ can dissolve into the water, thus lowering the measurements.

To address the issue, Picarro scientists recommend:

- Look for dips in the line where water can accumulate. Boulder AIR staff checked the line at LUR and there were no clear dips in the line where water would accumulate.
- Lightly heat the line inside the trailer, or at least insulate it. "Picarro recommends that all tubing between the walls of a sample shelter and the ZRM or Picarro instrument be heated to a temperature higher than the outside ambient dew point, typically 45°C."
- Consider directing the sample air through Nafion tubing for water removal to dry the air sample.

All historical LUR $CO_2$ data were checked for values below 400 ppb. Low values were found only in Q3 2020, Q3 2021, and Q3 2022. For the analyses shown in this report, the LUR and LLG $CO_2$ data were filtered to remove all values < 400 ppm, plus all data 30 minutes before and after these low values. These filtered data are also shown in the Supplements. The files that are used to plot data on the IDAT website have not been filtered as of the writing of this report. Boulder AIR is continuing to investigate the relationship between the Picarro $CO_2$ and $H_2O$ measurements, and the remediation recommendations listed above.

## 5. Website Development

During Q3, 2022, there were 2029 visits to the Longmont Air Quality Now website.

## 6. Data Archiving

No changes from the Q2, 2022, report.

## 7. Data for Quarter 3, 2022

The data that were recorded in Q3, 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 Q3 ozone records for LLG are presented in Figures SA8 and SA9, and in figures SB8 and SB9 for LUR. 8-hr ozone averages exceeded the National Ambient Air Quality Standard (NAAQS) for ozone of 70 ppb at the LLG station during 6 days in Q3 (July 25$^{th}$, August 8$^{th}$ – 10$^{th}$, and Sept 6$^{th}$ and 7$^{th}$). 8-hr ozone exceedances also occurred at LUR on these days, plus August 11$^{th}$ (we use 71 ppb as the cutoff point for NAAQS exceedance analysis.). The number of hours exceeding the 8-hr ozone NAAQS each day ranged from 1 to 5, depending on the day and the station. These high ozone days were associated with hot summer temperatures and stagnant meteorological conditions. See Supplement D for more information and a more detailed look at the August ozone exceedance days.

Figure 1 presents a statistical analysis of the full Q3 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. After the higher amounts of ozone measured in July and August, there was a drop in the ozone measurements at all stations in September as the days grew shorter, resulting in lower rates of ozone production. The statistics for LLG and LUR were similar during July and August and LLG had a slightly greater mean and median than LUR in September.

***$CO_2$***

The full Q3 $CO_2$ 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. More $CO_2$ was measured at LLG than at LUR, as indicated by the mean values. There was more variability in the measurements in August than in July or September. The wind speed/wind direction analyses are shown in Figure 3. The main source of $CO_2$ at both LLG and LUR was from the west of the station, similar to what was seen in previous quarters.

Table 1 provides comparisons of $CO_2$ data at LUR between Q3 2021 and Q3 2022 to investigate year-to-year changes. There was an increase in $CO_2$ mean values between Q3 2021 and Q3 2022 at LUR of 2.7 ppm. This is higher than the average global $CO_2$ growth rate between August 2021 and August 2022, which was an increase of 2.2 ppm. Over 120,000 individual 1-min data points were considered in the comparison. The $CO_2$ 95th percentile and maximum values at LUR were lower in Q3 2022 than in Q3 2021, indicating a lower frequency of occurrences with high $CO_2$ pollution events. 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 completed for seven 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. All $CO_2$ data shown in this analysis were filtered for values < 400 ppm, as explained in Section 4. In five of the seven 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 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, five out of seven 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 because of the relatively low number of data points, 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 Q3 methane records are available in Figures SA7 and SB7 for LLG and LUR, respectively. There were two brief periods in Q3 when the 1-minute methane data from LUR exceeded 5000 ppb. Late on July 12$^{th}$ there were 11 relatively short spikes between 22:46 and 23:00 MST when the methane exceeded 5000 ppb, and then there was a one-minute spike on July 14$^{th}$ (6:16 MST). This is a much lower number of occurrences compared to what was measured in Q1 of this year. There were no times during Q3 2022 when methane exceeded 5000 ppb at the LLG station. Supplement E contains an analysis of the high methane values measured on July 12$^{th}$.

The statistical analysis of the full Q3 methane data is shown in Figure 5. In July, more methane was measured at LUR than at any other station, as indicated by the mean, the median, and the 95$^{th}$ percentile values. LUR and LLG methane measurements were eclipsed by CCF methane measurements in the two months they were available in Q3. In all months of Q3, more methane was measured at LUR than at LLG.

Table 1 shows the numerical values of the comparison between Q3 2021 and Q3 2022 methane measurements at LUR. The mean values between the datasets showed a local 10 ppb *decrease* in Q3 2022 compared to Q3 2021, while the global mean value for July 2021 compared to that of July 2022 *increased* 18 ppb.

Wind rose and heat map analyses for LLG and LUR data are shown in Figure 6. Measurements at LLG indicated a source to the north at weak winds and a source to the north-northeast associated with higher wind speeds. The source seen to the east in the Q2 analysis did not appear in the Q3 analysis. The LUR measurements were similar in that there was also a source at higher wind speeds to the north-northeast, along with a source just to the north at lower wind speeds. The agreement in the heat map analysis results between the two monitoring sites is remarkable and provides high confidence of a relatively strong methane emissions source to the northeast of Longmont. With ethane results from LUR (Figure 11) showing a similar wind dependency, i.e., also showing a strong source to the north, it appears likely that these methane increases are resulting from natural gas emissions.

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 Q3 2022 methane and wind speed measurement comparison with Q3 2021 show that the average wind speeds for Q3 2021 and 2022 were nearly the same (a difference of 0.04 m s$^{-1}$), yet the local (LUR) methane measurements decreased while the global methane measurements increased. 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 Q3 LUR records for six selected VOCs are available in Figures SB10–SB16. Figure 8 presents a 31-month record of ethane, propane/ethane ratio, benzene, and acetylene from March 2020 – September 2022, measured at LUR. The long-term ethane time series (Figure 8a) shows that the Q3 2022 measurements were relatively low compared to the previous two quarters, excluding the high values measured on July 12th, discussed below. The propane/ethane analysis (Figure 8b) was added last quarter to investigate changes in the natural gas chemical signature as a possible indicator for new natural gas emission sources. The percentage of time that the propane/ethane ratio exceeded 1 or 2 did not change significantly from the Q2 report (1.9% and 0.06 %, respectively). Throughout this time period, both the mean and median of the propane/ethane ratio was 0.53, same as reported last quarter, indicating there was little change in the ratio with the inclusion of Q3 2022 data.

There were large peaks in VOCs at LUR on July 12th, 2022 (Figure 8 and time series shown in Supplement B) and in the acetylene measurements during September 2022 (Figure 8d), relative to the long-term measurements. The analysis of the data for the July 12th VOC and methane event (shown in Supplement E) indicated that this likely due to a natural gas plume as indicated by the combination of pollution species that peaked together late in the evening (e.g., ethane, propane, and methane). Time series that are zoomed in to the time of the peaks are shown in Figures SE1, SE2, and SE3 (Supplement E). The peaks in the measurements occurred after a wind direction shift from westerly to northerly (Figure SE2b and SE3b). Table SE1 compares the number of times (and percentage of time) that selected VOCs exceeded a given threshold at each station, for all measurements, providing historical context. The Table SE1 shows that the high values of ethane and propane (> 300 ppb) were most likely to occur at LUR, and, in fact, ethane and propane measurements this high have never been measured at the BRZ and ECC stations. The ethane/methane scatter plot shown in Figure SE4 shows what an outlier these July 12th measurements were, with ethane and methane measurements well above typical values measured during Q3 2022 (Figure 9a).

Acetylene exceeded 10 ppb two times in September 2022 (on the 5th and the 8th). Figures SE6 – SE10 in Supplement E detail this event. These values were rare for LUR, with acetylene exceeding 10 ppb only 3 times in all of the historical LUR measurements. Other VOCs had peaks in their measurements at the same time (e.g., benzene and toluene, Figure SE10), however, they were not as extreme. There was no coincident peak in the LUR methane measurements, thus the acetylene peaks were not likely to be natural gas related. It is possible that the peaks were from vehicle emissions from the parking areas south and southeast of the station (~ 30 m away). During the VOC sampling times for both of these peaks, the wind direction was variable, but both cases included times with wind from the southeast. There was also a very large, but brief, peak in PM 10 measurements on September 8th at the same time as the acetylene peak, which could also be due to vehicle emissions in the dirt parking area. September 5th was Labor Day this year, so it was likely there were more people using the reservoir on this day than normal.

The statistical comparison of selected VOCs is plotted in Figure 9. Looking at the mean, median, and 95th percentile values, more ethane and propane were measured at LUR than at any of the other stations during Q3 2022. The 95th percentile values in LUR propane data were quite high. In July and August, more benzene was measured at BRZ than at the other stations, but in September higher benzene was measured at LUR. The year-to-year ethane and benzene comparisons shown in Figure 10 indicate that less ethane and benzene were measured at LUR in Q3 2022 than during Q3 the previous two years.

Wind speed/wind direction dependence results of ethane, propane, acetylene, and benzene at LUR are shown in Figure 11. In the last quarterly report (Q2 2022), it was highlighted that there was an indication of a well-defined source of ethane, propane, and benzene to the north of LUR. This quarter, the bivariate polar plots still indicate a source of these species to the north, but a source to the east also stands out, especially for ethane and propane.

The updated propane and propane/ethane ratio plots in (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, and now Q3 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 analysis.

Further analyses of VOCs signatures, using VOC/VOC ratio values, are shown in Figure 13. The benzene/toluene ratio plot indicates a characteristic source to the north-northeast rather than to the northwest as last quarter. The propane/ethane plot still indicates a source with a distinct signature to the north, as previously noted. The i-butane/n-butane plot still indicate higher values to the west.

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 Q3 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 NO and $NO_x$ measurements indicate that more NO was measured at LUR than at BRZ, but less than what was measured at BSE. More $NO_x$ was measured at LUR than at the other stations. A time series of hourly-averaged $NO_2$ is shown in Figure 14 (C). The 1-hour 100 ppb NAAQS for $NO_2$ is defined as the 98$^{th}$ percentile of the 1-hour daily maximum mole fraction, averaged over 3 years. There is also an annual mean NAAQS of 53 ppb. The hourly-averaged $NO_2$ results shown in Figure 14 indicate that $NO_2$ did not exceed 30 ppb during Q3, 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. As seen last quarter, 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 Q3 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 was a large peak in PM measured at LUR on September 8$^{th}$, at the same time the acetylene peaked (see analysis in Supplement E).

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

Results from GRIMM instrument comparisons at LUR are shown in Supplement F.

## 9. Summary

8-hr ozone averages exceeded the National Ambient Air Quality Standard (NAAQS) for ozone of 70 ppb at LLG during 6 days in Q3 (July 25$^{th}$, August 8$^{th}$ – 10$^{th}$, and Sept 6$^{th}$ and 7$^{th}$). 8-hr ozone exceedances also occurred at LUR on these days, plus on August 11th. (We use 71 ppb as the cutoff point for NAAQS exceedance analysis.) The number of hours when the 8-hr ozone NAAQS was exceeded each day ranged from 1 to 5 hours, depending on the day and the station. These high ozone days were associated with hot summer temperatures and stagnant meteorological conditions. See Supplement D for more information and a more detailed look at the August ozone exceedance days.

There were a few brief periods during Q3 when methane measured at LUR exceeded 5000 ppb, mostly late in the evening of July 12th. Peaks in some VOCs occurred at the same time as the methane peaks, indicating that a natural gas release was measured at LUR at this time. A detailed analyses is shown in Supplement E. There were no instances of methane measurements greater than 5000 ppb at LLG during Q3.

High values of acetylene were measured at LUR on September 5th and 8th. See analysis in Supplement E for more information.

There were no exceedances of the NAAQS for PM 2.5 or $NO_2$ during Q3 2022.

An issue with unrealistic low (< 400 ppm) $CO_2$ measurement data at LUR and LLG was investigated and identified as an artifact from water accumulation in the sampling line. The data were removed from the record shown in this report. Options for remediation in the measurement system are being explored, as well as further analysis of the $CO_2$ measurements in order to better understand the issue.

# Tables

**Table 1:** Comparison of the statistics of $CO_2$ and $CH_4$ one-minute data, and ethane and benzene (10-min data once every hour) at LUR during Q3 of 2021 and Q3 of 2022. "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 | Diff | % Diff | Local/Global |
|---|---|---|---|---|---|---|
| **$CO_2$** | count | 126971 | 128665 | 1694 | 1.3 | |
| **(ppm)** | mean | 433.5 | 436.2 | 2.7 | 0.6 | 1.2 |
| | std | 24.7 | 23.3 | -1.4 | -5.6 | |
| | min | 400.0 | 400.2 | 0.2 | 0.0 | |
| | 5% | 408.1 | 411.7 | 3.6 | 0.9 | |
| | 25% | 413.8 | 417.9 | 4.2 | 1.0 | |
| | 50% | 425.4 | 428.6 | 3.2 | 0.8 | 1.5 |
| | 75% | 448.0 | 449.6 | 1.5 | 0.3 | |
| | 95% | 483.4 | 482.5 | -0.9 | -0.2 | |
| | max | 564.8 | 559.0 | -5.8 | -1.0 | |
| | Global mean | 412.2 | 414.4 | 2.2 | 1.0 | |
| **$CH_4$** | count | 129888 | 131631 | 1743 | 1 | |
| **(ppb)** | mean | 2090 | 2080 | -10 | -0.5 | -0.6 |
| | std | 165 | 140 | -25 | -15.0 | |
| | min | 1906 | 1918 | 12 | 0.6 | |
| | 5% | 1948 | 1955 | 7 | 0.4 | |
| | 25% | 1999 | 1996 | -2 | -0.1 | |
| | 50% | 2050 | 2044 | -6 | -0.3 | -0.3 |
| | 75% | 2129 | 2121 | -8 | -0.4 | |
| | 95% | 2360 | 2325 | -34 | -1.5 | |
| | max | 4965 | 6615 | 1650 | 33.2 | |
| | Global mean | 1886 | 1905 | 18 | 1.0 | |
| **Ethane** | count | 2109 | 2009 | -100 | -4 | |
| **(ppb)** | mean | 6.5 | 5.9 | -0.6 | -9.7 | |
| | std | 4.6 | 9.7 | 5.1 | 110.3 | |
| | min | 0.6 | 0.7 | 0.0 | 6.8 | |
| | 5% | 1.7 | 1.4 | -0.3 | -15.5 | |
| | 25% | 3.5 | 2.7 | -0.8 | -21.7 | |
| | 50% | 5.4 | 4.4 | -1.1 | -19.8 | |
| | 75% | 8.1 | 7.0 | -1.2 | -14.3 | |
| | 95% | 14.6 | 14 | -0.6 | -4.2 | |
| | max | 43 | 382 | 339 | 787 | |
| **Benzene** | count | 2109 | 2009 | -100 | -4 | |
| **(ppb)** | mean | 0.13 | 0.09 | -0.04 | -28.99 | |
| | std | 0.10 | 0.10 | 0.01 | 8.06 | |
| | min | 0.01 | 0.01 | 0.00 | 15.15 | |
| | 5% | 0.04 | 0.03 | -0.01 | -26.14 | |
| | 25% | 0.07 | 0.05 | -0.02 | -31.59 | |
| | 50% | 0.10 | 0.07 | -0.03 | -30.90 | |
| | 75% | 0.17 | 0.11 | -0.06 | -33.61 | |
| | 95% | 0.31 | 0.22 | -0.10 | -30.42 | |
| | max | 1.53 | 3.21 | 1.68 | 110.14 | |

# Figures

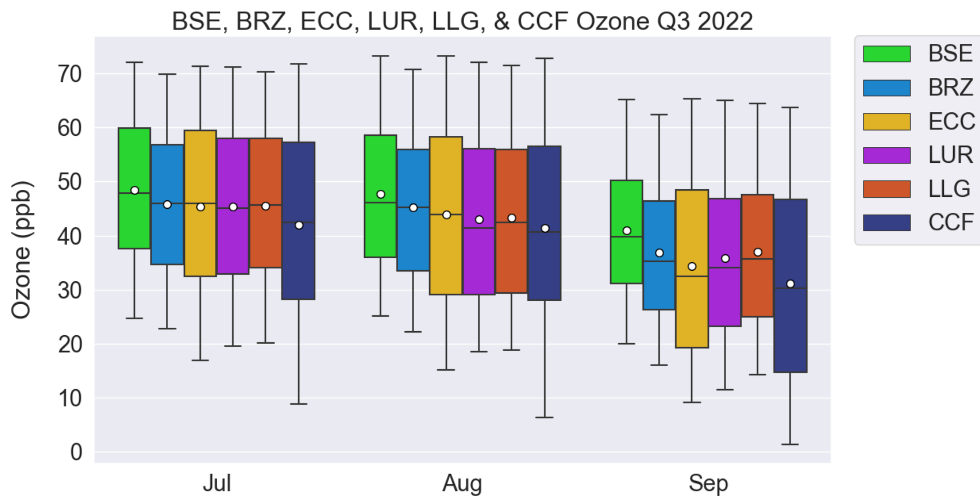



**Figure 1:**
Comparison of the ozone distribution at BSE, BRZ, ECC, LUR, LLG, and CCF, during July – September 2022. These box whisker plots show the median value as the center line, the 25-75 percentile distribution as the colored boxes, and the 5-percentile and 95-percentile values as the whiskers.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

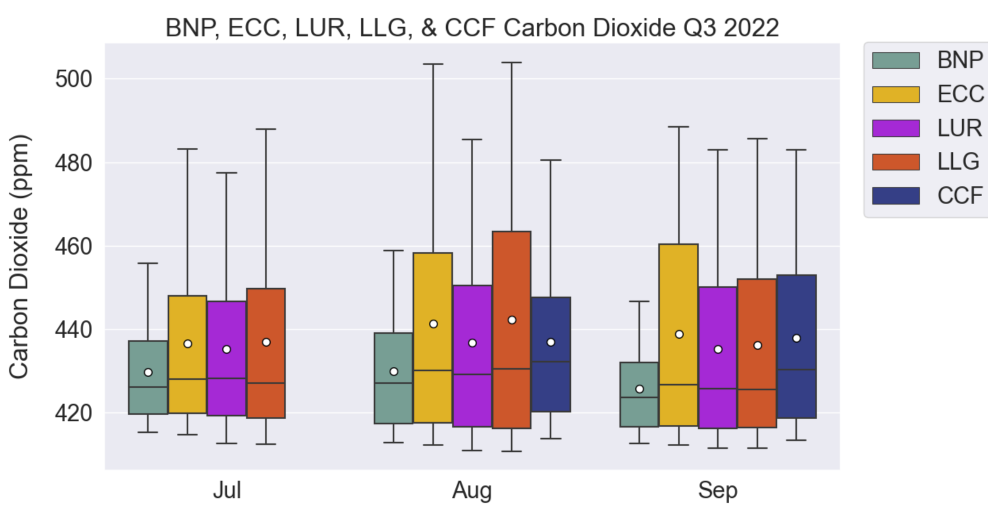



**Figure 2:**
Comparison of the $CO_2$ distribution at BNP, ECC, LUR, LLG, and CCF, during July – September 2022. See Figure 1 for explanation of the box whisker plot format.

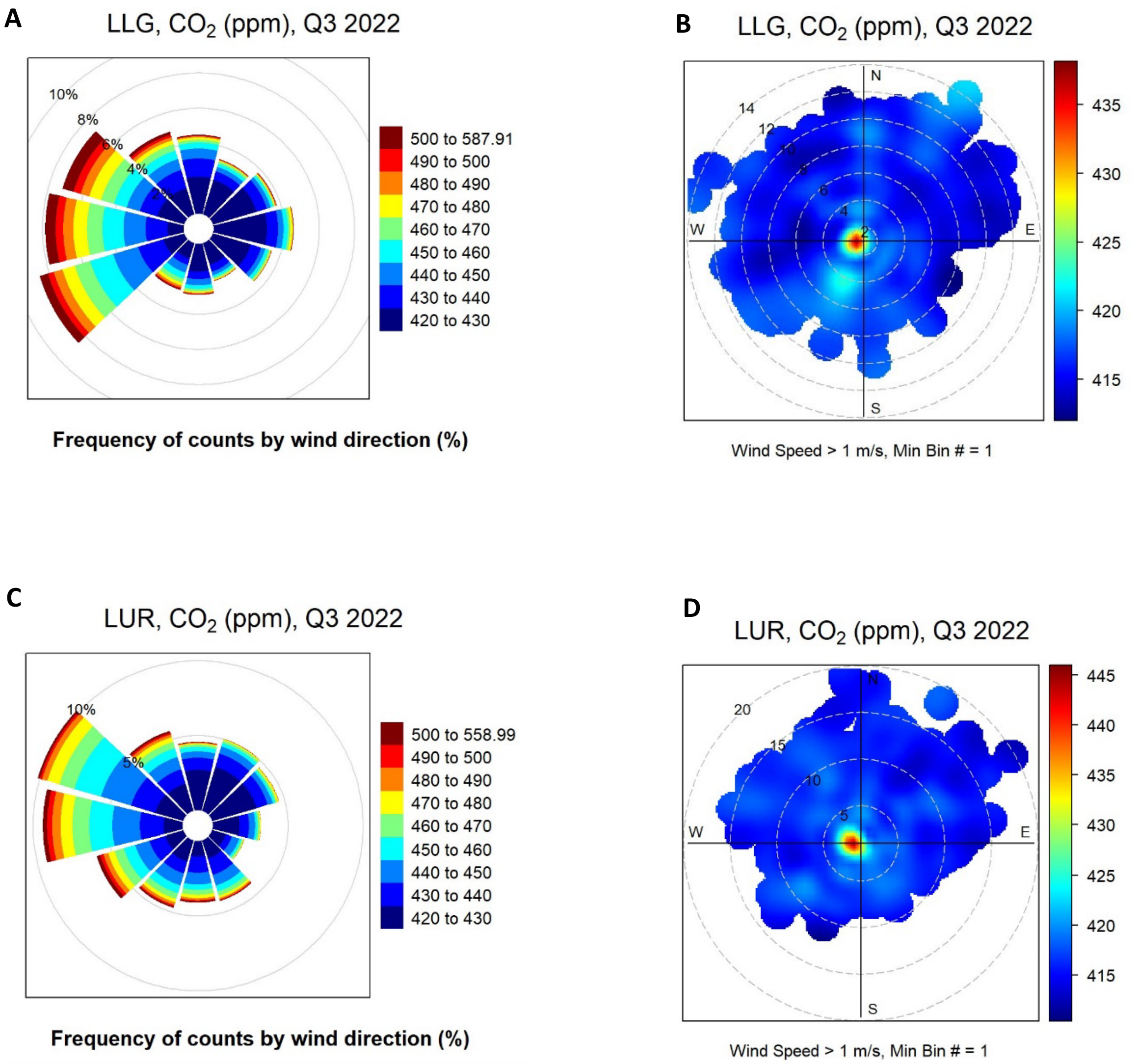
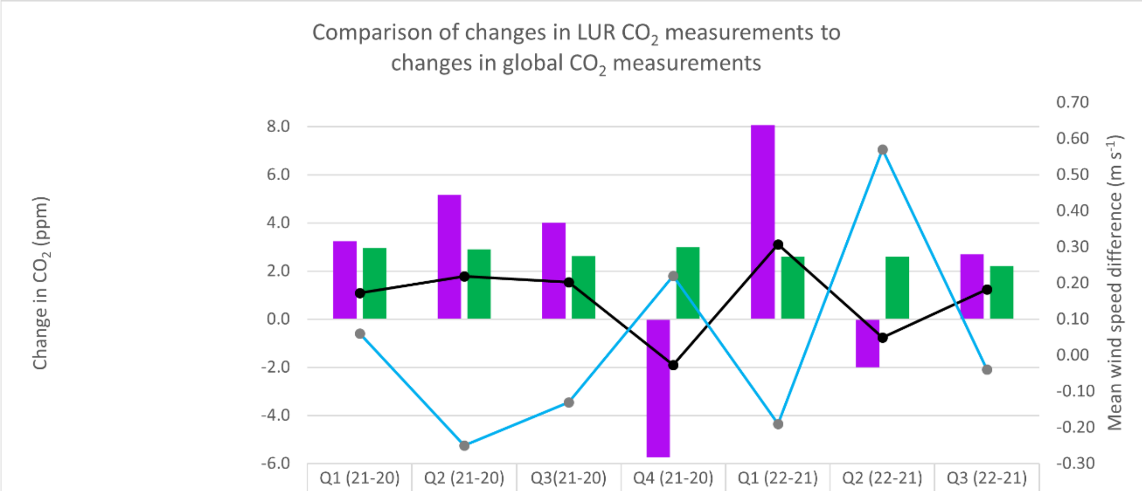



**Figure 3:**
Wind rose (left) and wind heat map analysis showing the dependency of $CO_2$ mole fractions at LLG (top, A, B) and LUR (bottom, C, D) during July – September 2022. The LUR site is east of the City of Longmont. These analyses suggests that the city is the primary source for enhanced $CO_2$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




| | Q1 (21-20) | Q2 (21-20) | Q3(21-20) | Q4 (21-20) | Q1 (22-21) | Q2 (22-21) | Q3 (22-21) |
|---|---|---|---|---|---|---|---|
| LUR | 3.2 | 5.2 | 4.0 | -5.7 | 8.1 | -2.0 | 2.7 |
| Global | 3.0 | 2.9 | 2.6 | 3.0 | 2.6 | 2.6 | 2.2 |
| Local/Global Change Ratio | 1.1 | 1.8 | 1.5 | -1.9 | 3.1 | -0.8 | 1.2 |
| Mean wind speed difference | 0.06 | -0.25 | -0.13 | 0.22 | -0.19 | 0.57 | -0.04 |

**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.

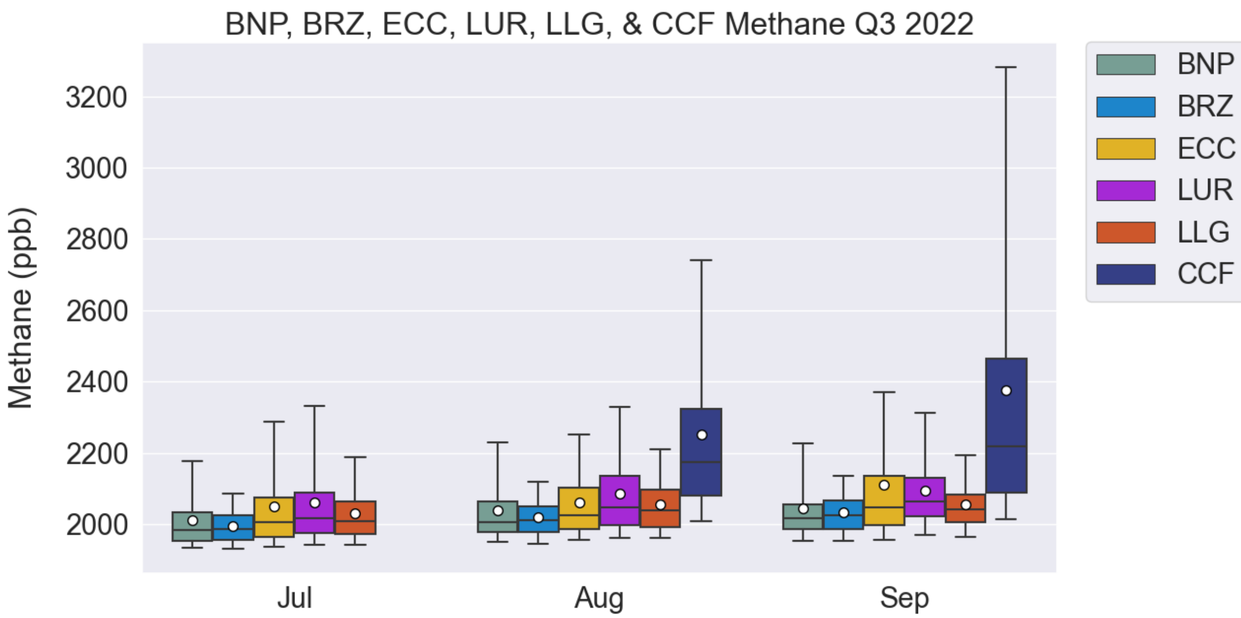



**Figure 5:**
Comparison of the methane distribution at BNP, BRZ, ECC, LUR, LLG, and CCF, during July – September 2022. See Figure 1 for explanation of the box whisker plot format. Between the two Longmont sites, LUR has higher absolute values and variance.

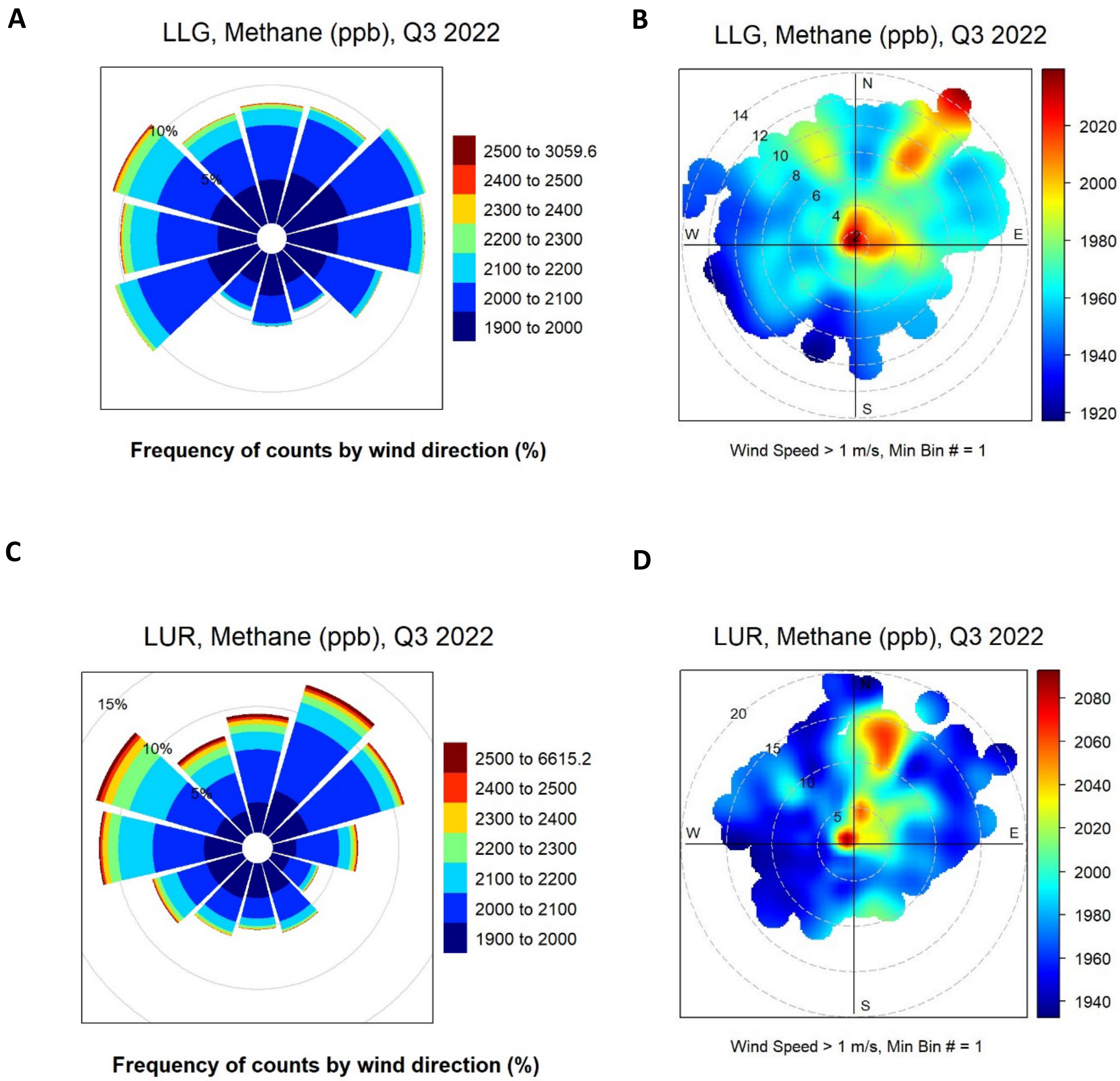
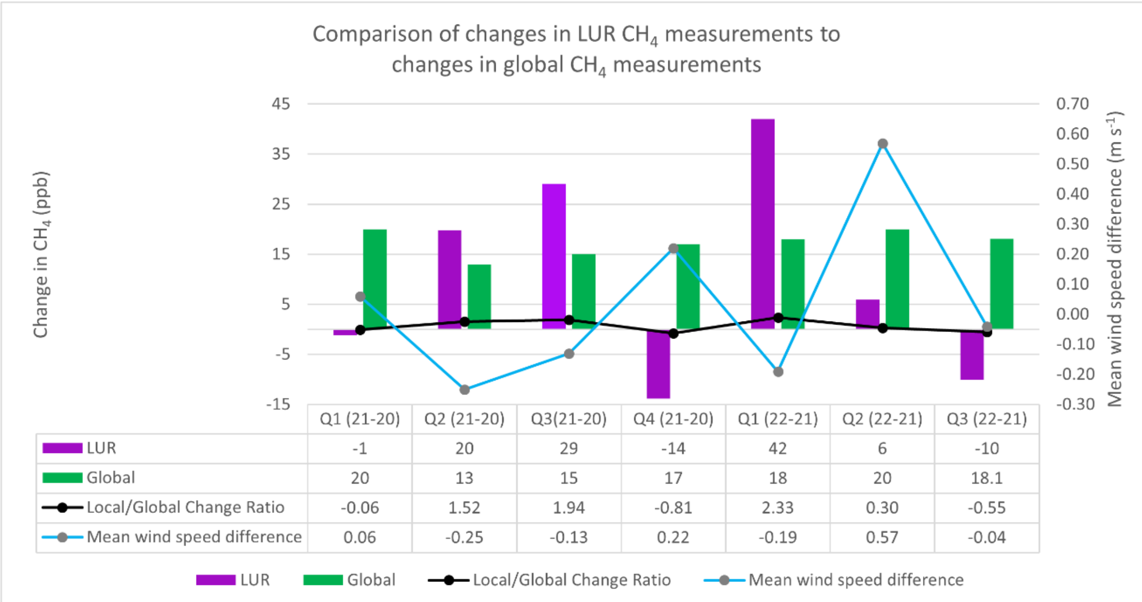


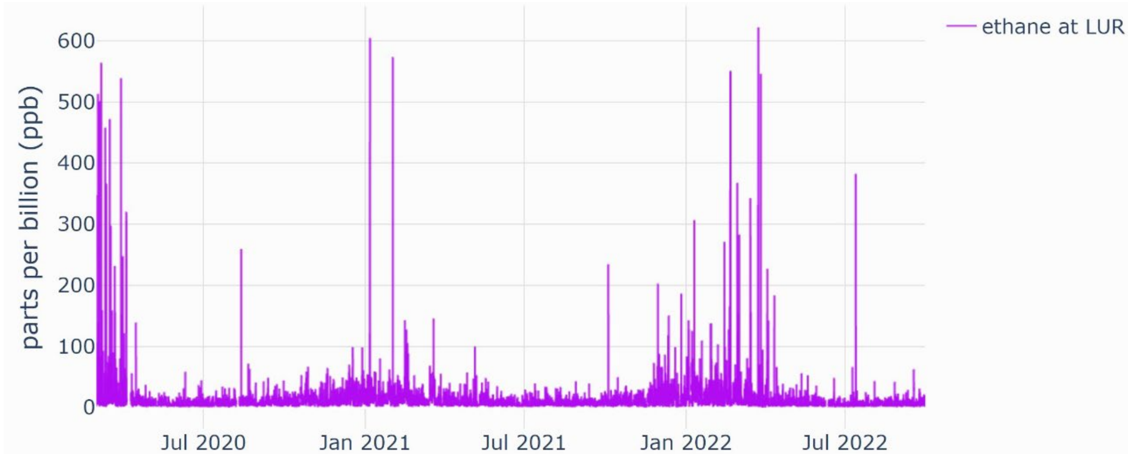

**Figure 6:**
Wind rose (left) and wind heat map analysis showing the dependency of $CH_4$ mole fractions at LLG (top, A, B) and LUR (bottom, C, D) during July – September 2022.




| | Q1 (21-20) | Q2 (21-20) | Q3(21-20) | Q4 (21-20) | Q1 (22-21) | Q2 (22-21) | Q3 (22-21) |
|---|---|---|---|---|---|---|---|
| LUR | -1 | 20 | 29 | -14 | 42 | 6 | -10 |
| Global | 20 | 13 | 15 | 17 | 18 | 20 | 18.1 |
| Local/Global Change Ratio | -0.06 | 1.52 | 1.94 | -0.81 | 2.33 | 0.30 | -0.55 |
| Mean wind speed difference | 0.06 | -0.25 | -0.13 | 0.22 | -0.19 | 0.57 | -0.04 |

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

**A**




**B**

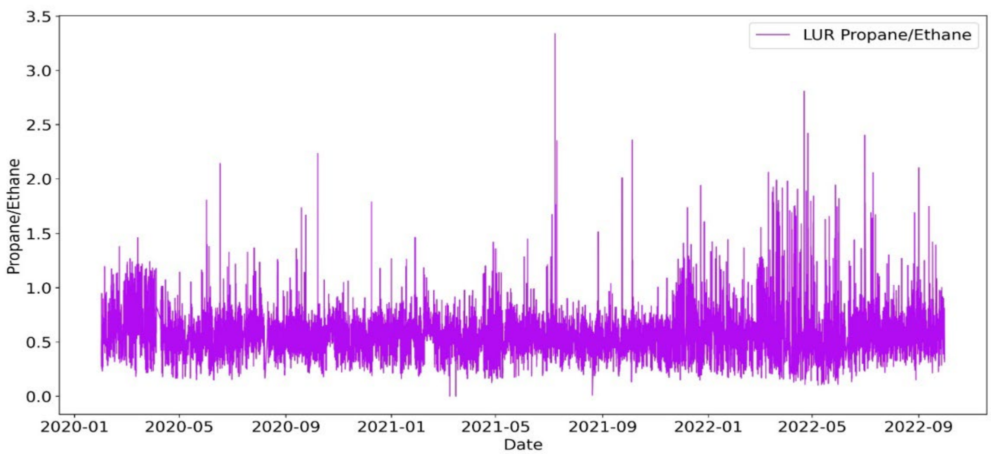
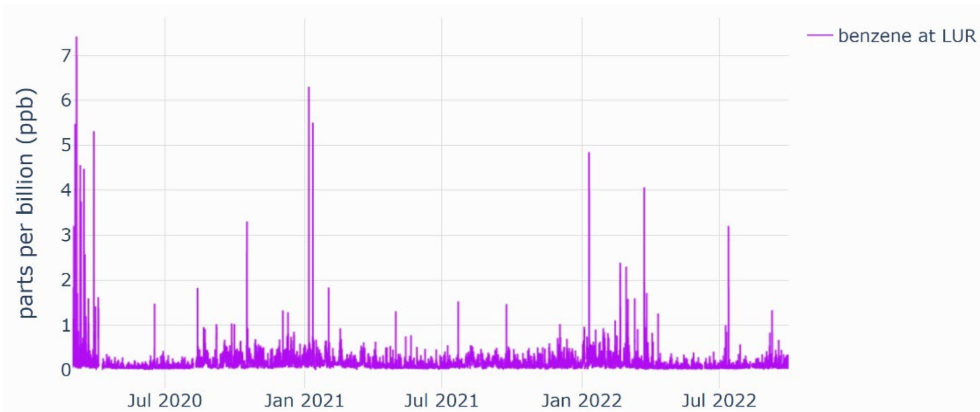
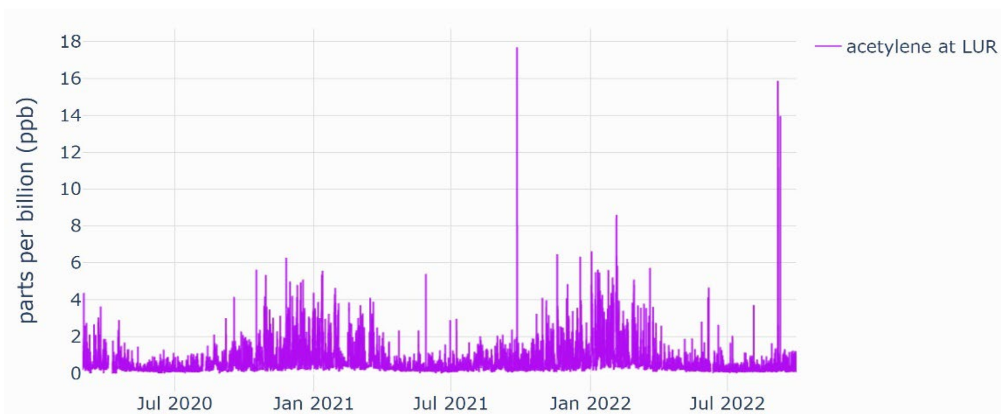



**Figure 8:**
Time series analyses of ethane (A), the propane/ethane ratio (B), benzene (C, next page), and acetylene (D, next page) at LUR between March 1, 2020 and September 30, 2022. Lower frequency and lower maximum values of concentration spikes during the summer are observed for all compounds. 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.

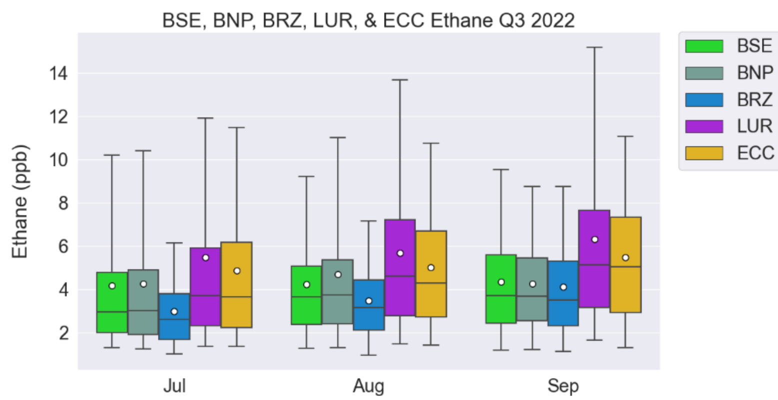
**C**


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

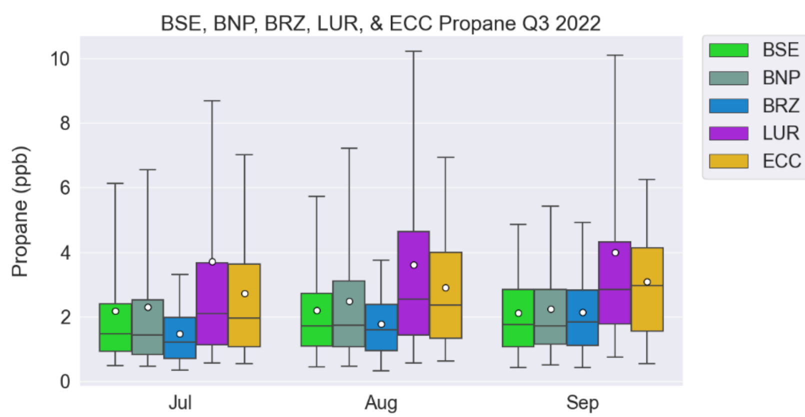
**D**


acetylene at LUR
parts per billion (ppb)
0
2
4
6
8
10
12
14
16
18
Jul 2020
Jan 2021
Jul 2021
Jan 2022
Jul 2022

**A**




**B**




**C**

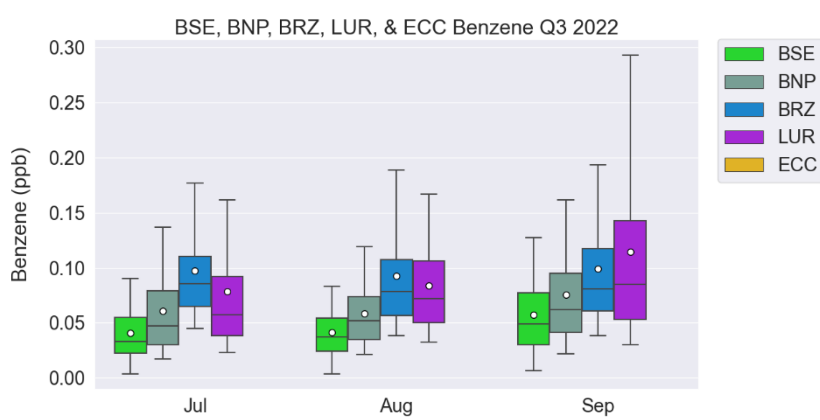
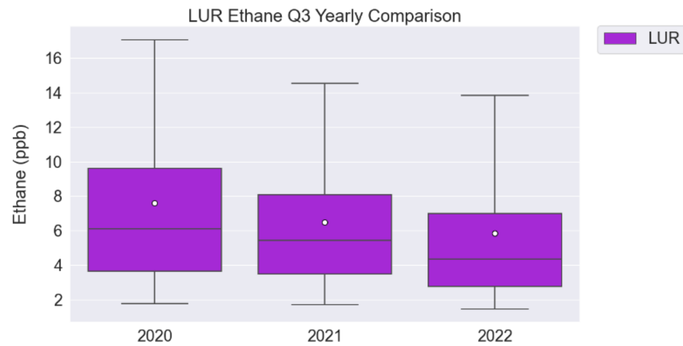



**Figure 9:**
Comparison of the distribution of ethane (A), propane (B), and benzene (C) at BSE, BNP, BRZ, LUR, and ECC during Q3. See Figure 1 for explanation of the box whisker plot format.

**A**




**B**

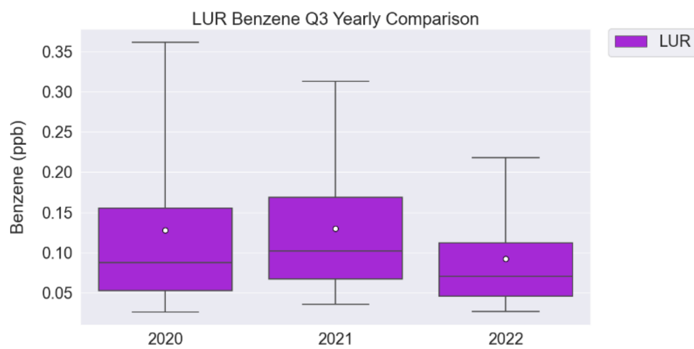



**Figure 10:**
Comparison of the ethane distribution (top, A) and the benzene distribution (bottom, B) at LUR during Q3 of 2020, 2021, and 2022. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions for Q3 2021 and 2022 are presented in Table 1.

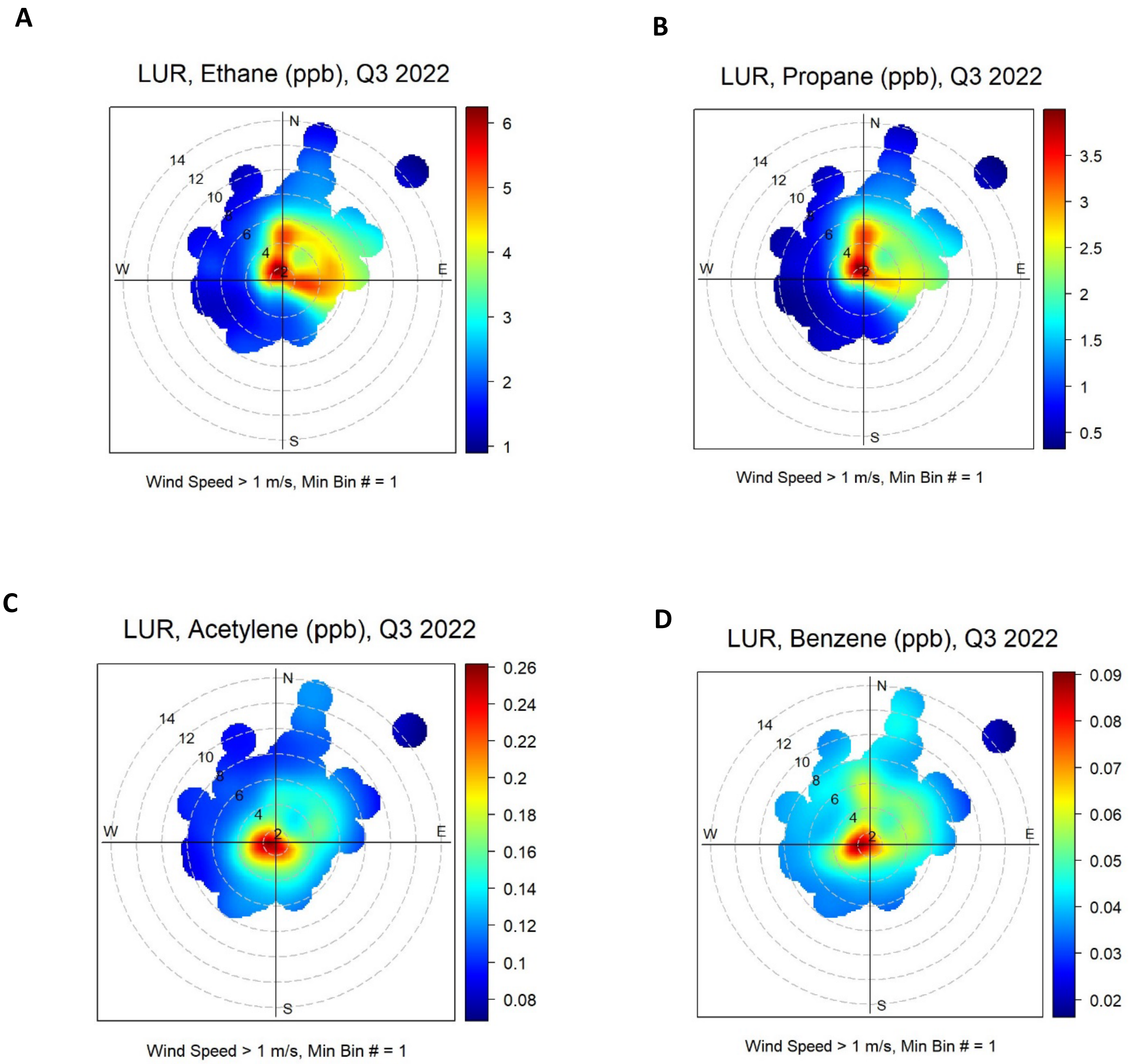



**Figure 11:**
Comparison of ethane (A), propane (B), acetylene (C), and benzene (D) occurrences as a function of wind speed and direction at LUR during Q3 2022.

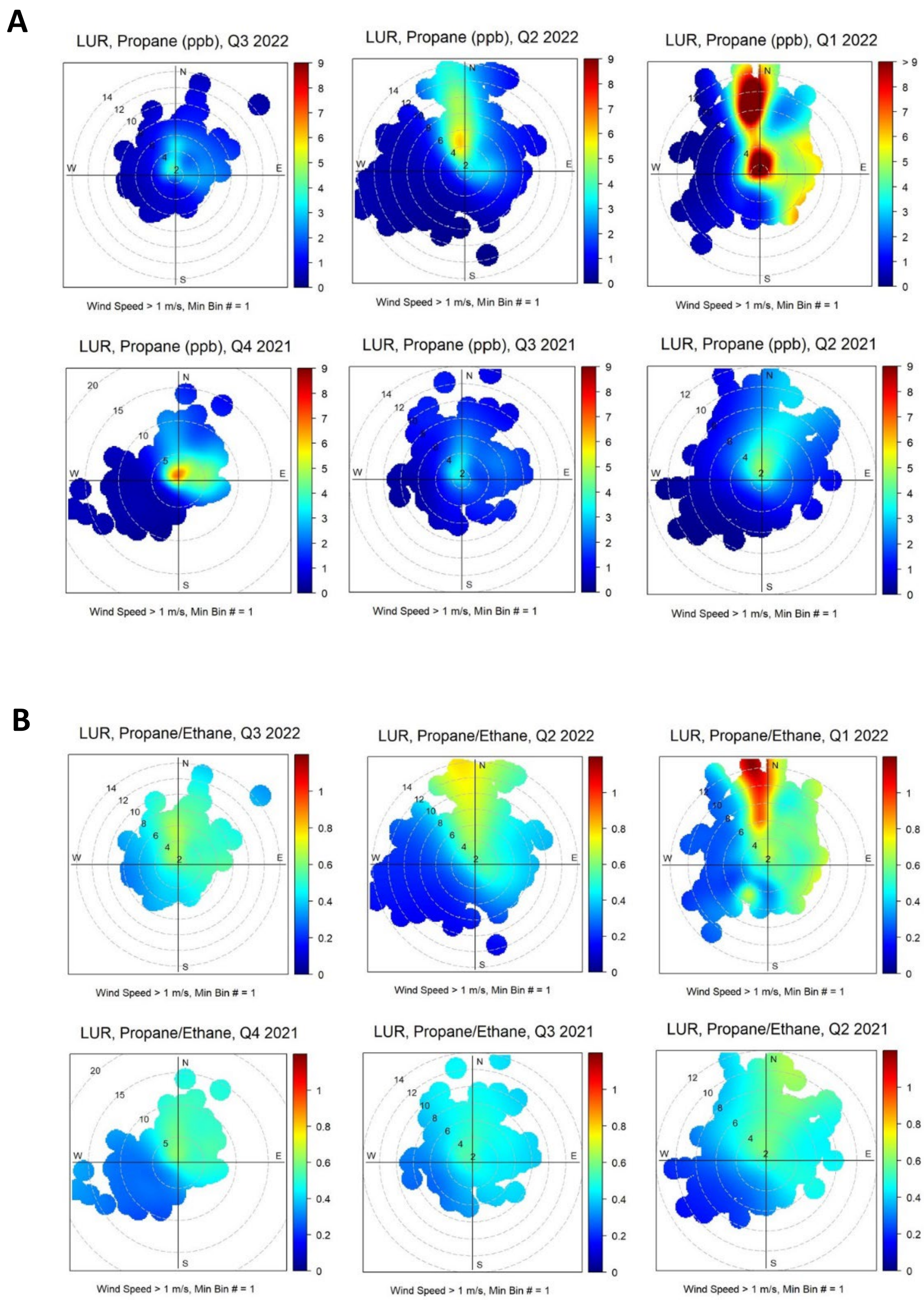



**Figure 12:**
6-panel A: Propane bivariate polar plots from Q2 2021 – Q3 2022, in reverse chronological order. Bottom 6-panel B: Propane/ethane ratio plots for the same time period. Prior to Q1 2022, the main propane source for emissions detected at LUR was to the east or the northeast of LUR. In Q1, Q2, and Q3 of 2022, air transported from the north had a characteristic signature of high propane/ethane values, indicating unusual propane-rich emissions.

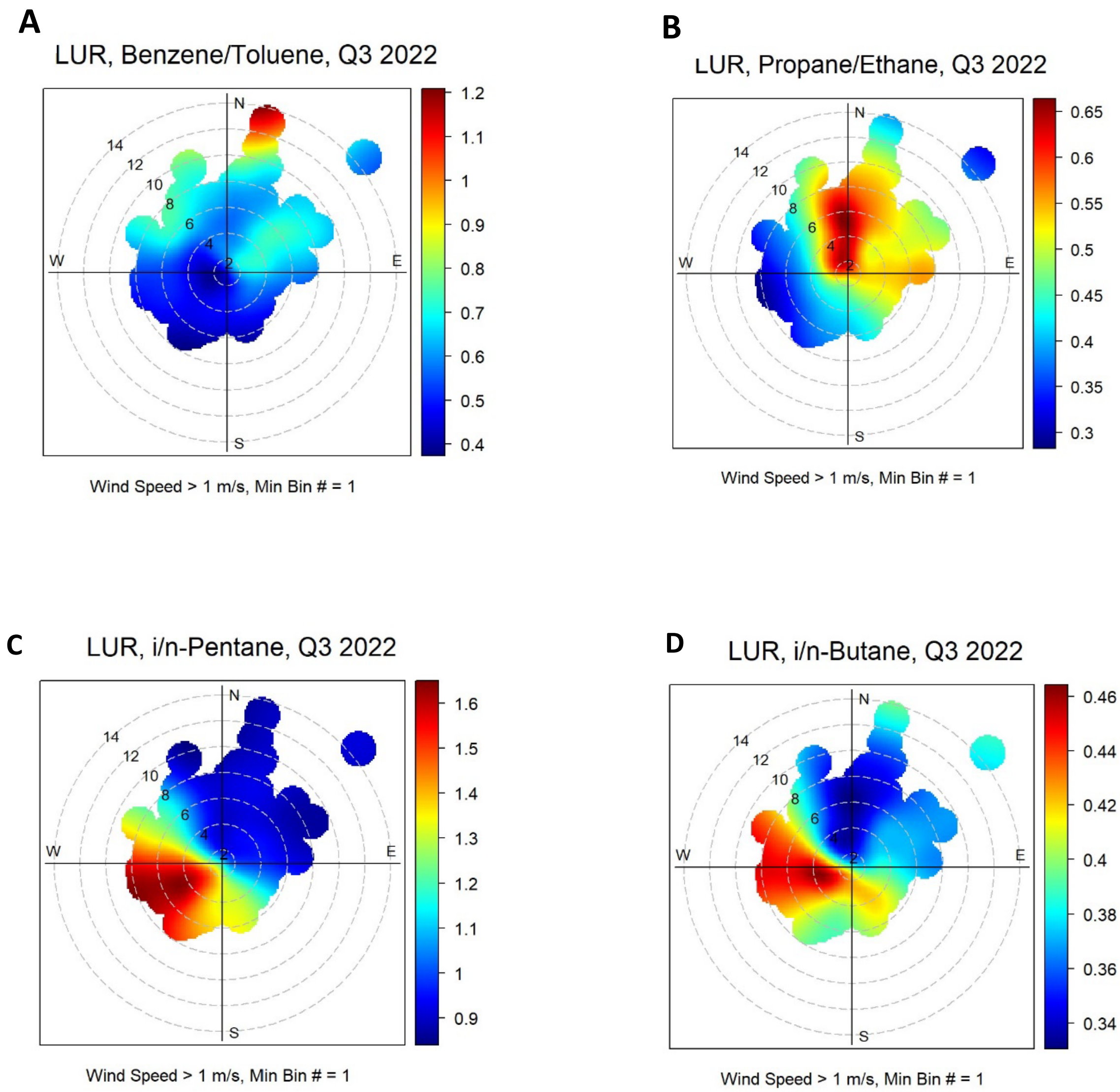



**Figure 13:**
Ratios of selected VOC pairs as a function of wind direction and wind speed during Q3 2022. These analyses show clear differences in the chemical signatures in air transported from different directions to the monitoring station.

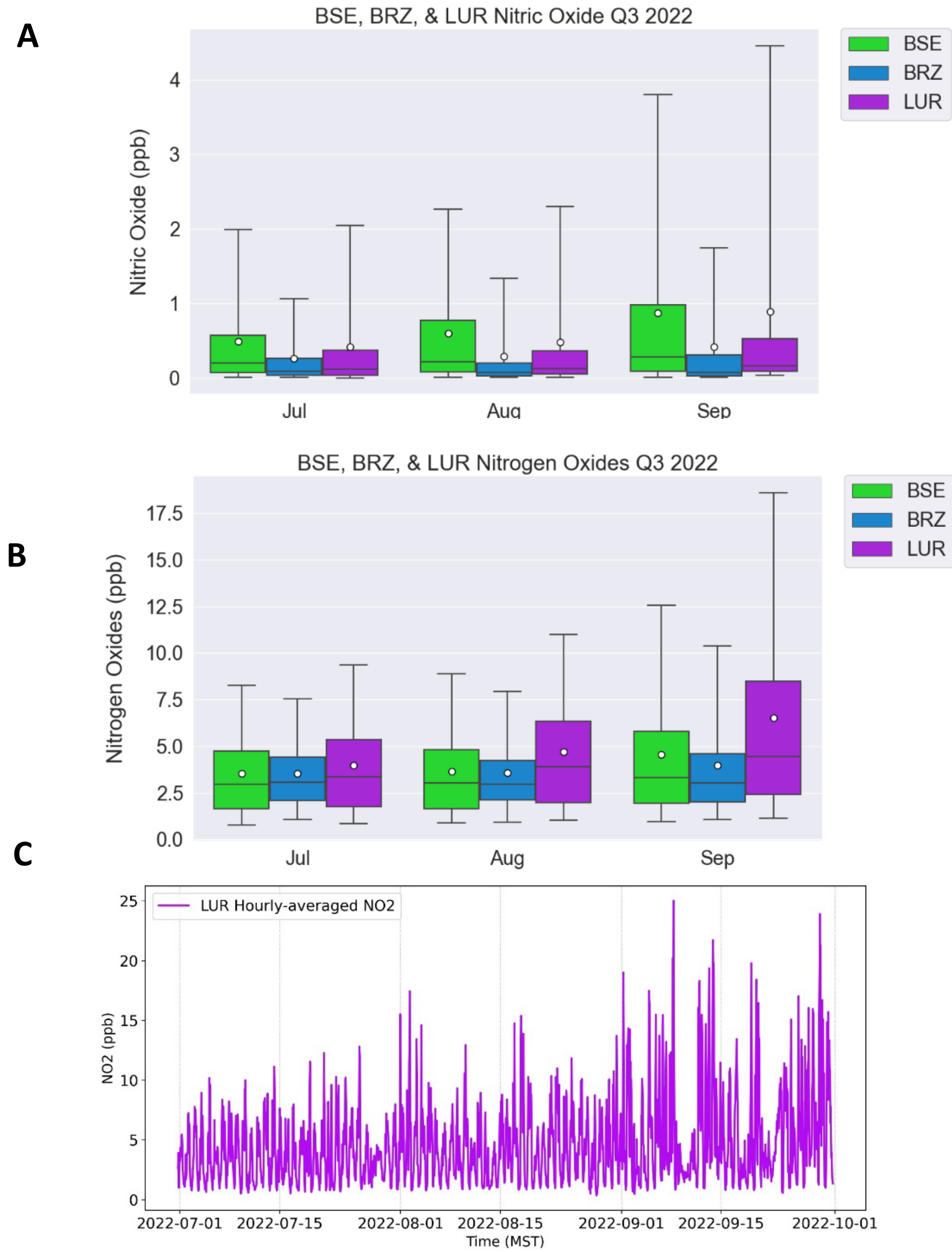



**Figure 14:**
Comparison of nitric oxide (A) and nitrogen oxides (B) at BSE, BRZ, and LUR during July – September 2022. See Figure 1 for explanation of the box whisker plot format. (C) LUR hourly-averaged $NO_2$.

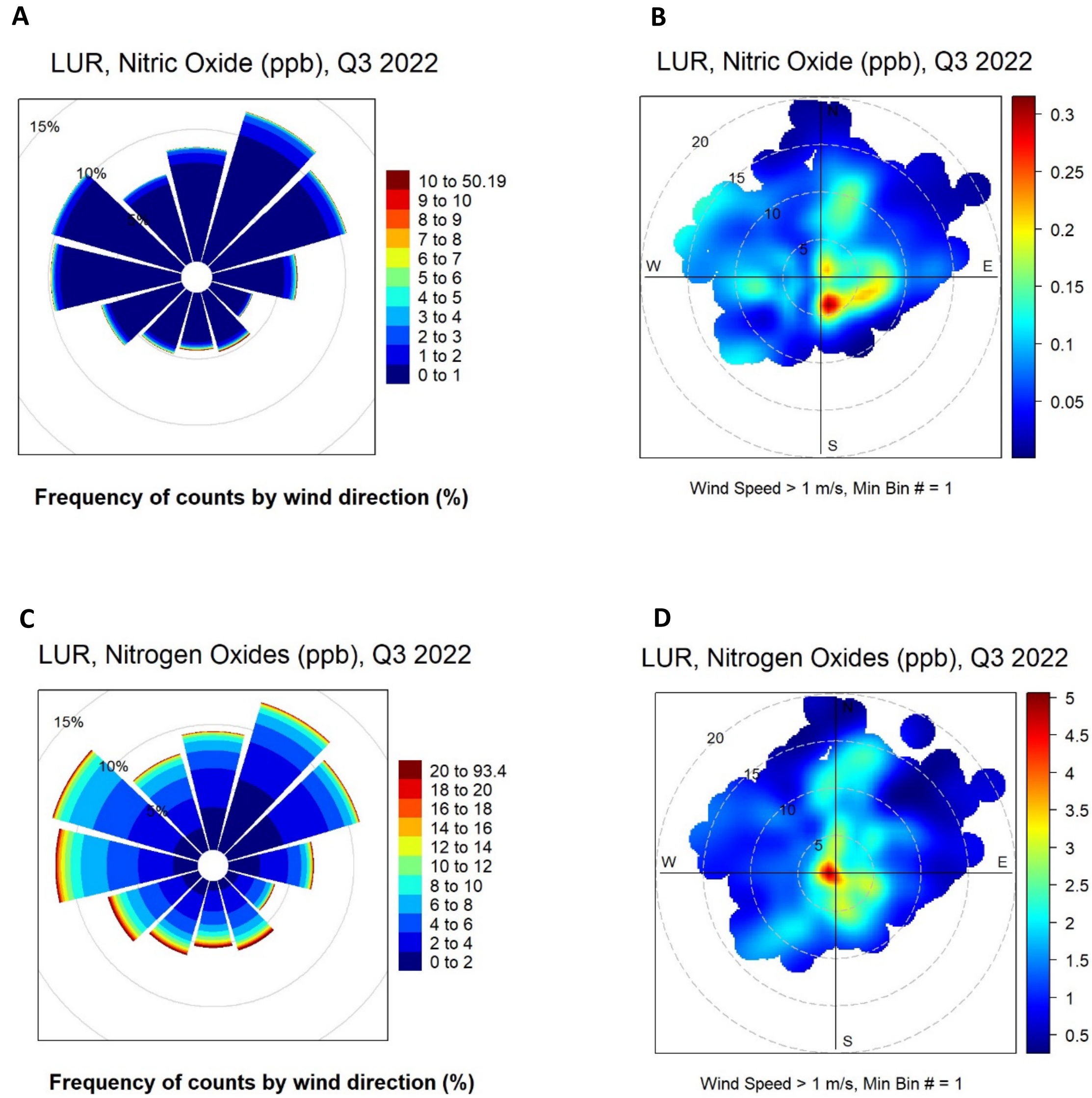
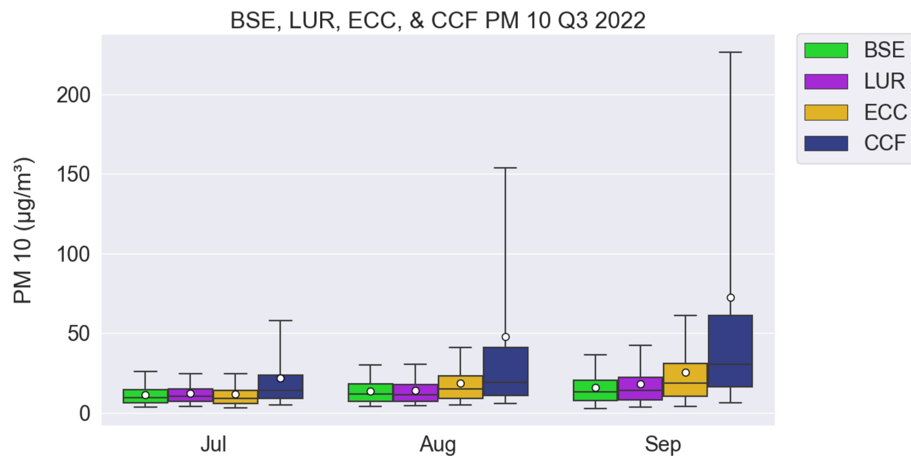



**Figure 15:**
Dependence of nitric oxide (A, B) and nitrogen oxides (C, D) as a function of wind speed and direction at LUR during July – September 2022. As seen in the prior data, the City of Longmont, located to the west, appears to be the strongest upwind source for $NO_x$.

**A**




**B**

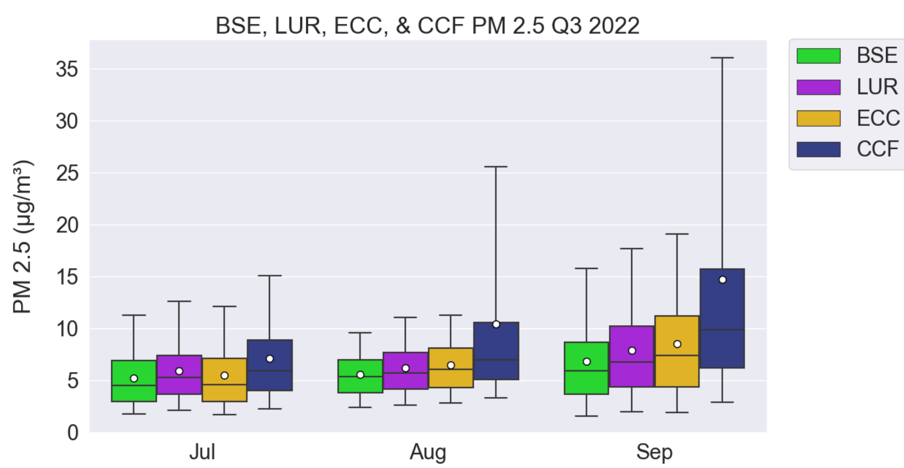



**Figure 16:**
Comparison of PM 10 (A, top) and PM 2.5 (B, bottom) at BSE, LUR, ECC, and CCF during July – September 2022. See Figure 1 for explanation of the box whisker plot format.