ATMOSPHERE INNOVATION RESEARCH
BOULDER AIR

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August 30, 2024

To:

City of Longmont
350 Kimbark Street
Longmont, CO 80501

Attn: Dr. Jane Turner

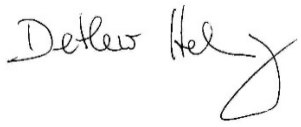
Re: Longmont Regional Air Quality Study – Year 2024 Quarters 1 and 2 Report

Dear Dr. Turner,

Please find included with this letter the January - June (Quarters 1 and 2) 2024 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,

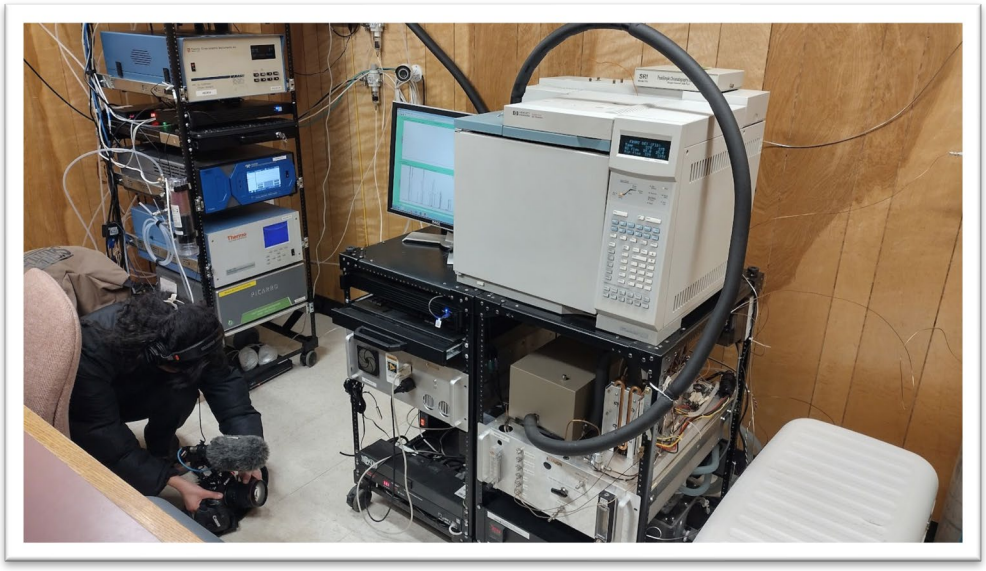


Detlev Helmig

Boulder AIR LLC

2024 Quarters 1 and 2 (January - June) Report

Longmont Air Quality Study



PBS NOVA reporter Lizzy Mulvey visits LUR to film a story about air quality –
Photos by Detlev Helmig

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 January - June, i.e., Quarters 1 and 2 (Q1 and Q2), 2024. 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) and the Erie Community Center (ECC). The Broomfield Soaring Eagle Park (BSE) and Broomfield North Pecos (BNP) monitoring stations were not operational from January 1, 2024 – April 30, 2024, and therefore there are no comparisons with Broomfield measurements in this report.

There were no PM 2.5 NAAQS exceedances at LUR during Q1 or Q2, 2024. There were two days when the ozone NAAQS was exceeded at a Longmont monitoring site during this period. The ozone NAAQS was exceeded at LLG on June 17 from 18:00 to 20:00 MST and on June 26 from 15:00 to 18:00 MST. The maximum 8-hr average ozone value measured at LLG was 73.0 ppb between 16:00 – 17:00 MST on June 26. The ozone NAAQS was exceeded at LUR on June 26 between 14:00 – 19:00 MST, with a maximum value of 76.1 ppb between 16:00 and 17:00 MST.

A tropospheric fold transported high-ozone air, greater than 90 ppb, to the Front Range for a brief period on May 6, 2024. The highest value measured at a Boulder A.I.R. station during this event was 100 ppb at LLG at approximately 05:30 MST. This event was relatively short, with the 8-hour ozone surrounding this event not exceeding the ozone NAAQS.

There were two high VOC events of note at LUR during Q1 of 2024. On March 21, 2024, benzene reached a maximum of 2.89 ppb. There were additional VOC peaks during the same sampling period, but not for ethane. There were also no methane peaks at the same time, indicating that this plume was not due to a natural gas release, but likely caused by a liquid raw hydrocarbon mixture. On March 24, 2024, there were large peaks in VOCs, including an ethane peak of 254 ppb. With additional peaks in other VOCs and methane measured at the same time, this was likely an oil and gas plume. In both cases, back trajectory analysis indicated transport from the northeast. Details can be found in Supplements D and E.

A new data analysis technique was applied for investigating changes in concentrations over time (trends) for CO_2, methane, ethane, and benzene.

Dr. Detlev Helmig was interviewed by a journalist from PBS NOVA for a recording about air quality. Some of the footage was shot at LUR.

Video: Colorado Voices | Commerce City air pollution | PBS (https://www.pbs.org/video/nova-s5rdte/)

Web story: Community-led air monitoring in Commerce City reveals gaps in environmental regulation | Rocky Mountain PBS (rmpbs.org) (https://www.rmpbs.org/blogs/rocky-mountain-pbs/commerce-city-air-pollution)

Drs. Jane Turner and Detlev Helmig visited the CDPHE particulate matter monitoring site on Kimbark Street in April 2024.

Table of Contents

1. Project Scope and Goals

No changes from the Q4, 2023 report.

2. Overview of the Monitoring Program

No major changes from the Q4, 2023 report.

3. Air Quality Monitoring Study Updates

A door alarm system was installed on the entry door at both Longmont stations during Q1 2024. When a door is opened without prior disabling of the alarm, the alarm triggers a strobe light at the station as well as sending a text alert to Jacques Hueber, Kat Potter, and Woody Daly (JH, KP, RWD) who work with Boulder A.I.R. This door sensor system can be remotely disabled by JH, KP, or RWD prior to opening the door for routine station visits by Boulder A.I.R. staff.

4. Data Quality Assurance/Quality Control Process

Longmont Union Reservoir (LUR)

Picarro (CO_2 and methane)
The two NOAA certified calibration standards were submitted in April for analysis and recertification by the Boulder NOAA Global Monitoring Laboratory. The recertified standards were returned to the monitoring station in June. The results showed no drift in the NOAA cylinders since the original calibration in 2019.

A sample air drying system was installed for the Picarro on May 10, 2024, using Nafion tubing with a counterpurge air flow dried with Drierite. This was installed because at high ambient humidity, issues with water accumulation in the sampling line had been noticed in previous summer CO_2 measurements. The Nafion drying system is commonly used and recommended with the Picarro instrument in more humid environments. This new system is reducing water vapor to ~0.08% in the air sampling stream across a wide range of ambient sample moisture levels and was tested to have negligible retention of CO_2 and methane.

The 6-month linearity check was performed on June 18, 2024.

The Picarro pump was serviced on June 25, 2024.

GRIMM (PM)
The previous GRIMM instrument with SN 18B19007 was removed and replaced with a new analyzer, SN 18B20037, on March 8, 2024. From the regular testing with the particulate standard, it was determined that the older instrument's performance was deteriorating.

The new GRIMM had the 6-month maintenance and testing on May 14, 2024, and passed all system tests, and 2.5 µm and 1.0 µm standard tests.

Wind vane
The 6-month testing of the RM Young wind vane occurred on February 19, 2024. A crack was found in the propeller and the propeller was replaced. The wind vane passed all wind direction and speed tests, using the same procedures and equipment as for a CDPHE audit.

Ozone
Quarterly calibration checks through the tower inlet were performed on March 11, 2024 and June 5, 2024.

NO_x
NO_x quarterly calibrations were done on March 21, 2024, and June 25, 2024. Small adjustments were made to the zero and span settings.

Lykins Gulch (LLG)

Picarro (CO_2 and methane)
The two NOAA certified compressed air standards were submitted in April for analysis and recertification by NOAA. The recertified standards were returned to the monitoring station in June. The results showed no drift in the two target gas mole fractions since the original calibration in 2019.

A sample air drying system was installed for the Picarro on May 15, 2024, using Nafion tubing with a counterpurge air flow dried with Drierite. This was installed because potential issues with water in the sampling line had been noticed in previous summer CO_2 measurements. The Nafion drying system is commonly used and recommended with the Picarro instrument for this reason in more humid environments. This new system has reduced water vapor to a residual moisture level ~0.08% at the range of typically encountered ambient humidity. It was tested to have negligible effects on CO_2 and methane monitoring results.

The 6-month linearity check was performed on June 13, 2024.

Wind vane
The 6-month testing of the RM Young wind vane occurred on February 20, 2024. The wind vane passed all wind direction and speed tests, using the same procedures and equipment as a CDPHE audit.

Ozone
The ozone calibrator pump was serviced, and the ozone monitor pump and air compressor were replaced on January 19, 2024.

Quarterly calibration checks through the tower inlet were performed on March 11, 2024, and June 5, 2024.

The temperature inside both the LLG and LUR monitoring stations has remained stable throughout the record warm temperatures that occurred during Q2 2024 thanks to the HVAC and insulation improvements made during Q4 2023, eliminating data outages caused by extreme heat in the shelters.

Revisiting of CO_2 data

For atmospheric trace gases with high variability in their mole fractions, as observed along the Front Range, longer time records and application of sophisticated trend analysis tools are required for an accurate trend analysis. Recently, Boulder A.I.R. CO_2 data have undergone another round of extensive quality control. During the summer, particularly at LUR, the Picarro instrument has occasionally exhibited unusual behavior, recording abnormally low CO_2 mole fractions, likely due to moisture in the inlet line. Since the exact cause of this issue could not be pinpointed from the data, we employed a non-linear machine learning algorithm to correct the data. This algorithm was trained on meteorological data, methane levels, and CO_2 data, using a subset of low CO_2 values as a target to identify similar occurrences across the dataset. Each year from 2020 to 2023 was analyzed separately to account for annual variations in CO_2 behavior. Timestamps flagged by the model as having likely erroneous low CO_2 values were subsequently removed from the dataset. The percentage of data removed from the LUR CO_2 dataset by the machine learning algorithm for the years 2020 through 2023 was approximately 4.5%, 6%, 2%, and 1.4%, respectively. For LMA and LLG data, which do not exhibit this phenomenon as frequently, the data were largely unchanged, with only a very few extremely low CO_2 values, e.g., < 400 ppm, removed. So far, in 2024, anomalously low CO_2 values have not been recorded at LLG or LUR.

5. Website Development

During Q1 and Q2 2024, there were 4242 visits to the *Longmont Air Quality Now* website. Since May 2020, there have been 38163 website visits to the Longmont website (as of June 30, 2024) in total. Data from the Longmont air monitoring sites are also included for data comparisons with up to five other monitoring programs on the *AirLive* Combined Data Graphs website (https://www.bouldair.com/NoCo-FrontRange.htm), which has received 15632 visits since the website first came online.

6. Data Archiving

LUR VOC data and meteorology data for 2020 were accepted into the EPA's Ambient Monitoring Archive (AMA) for the Hazardous Air Pollutants (HAPs) and are now publicly posted and available at this link: https://www.epa.gov/amtic/amtic-ambient-monitoring-archive-haps.

LUR VOC data and meteorology data for 2021 and 2022 were submitted to the EPA's Ambient Monitoring Archive (AMA) for the Hazardous Air Pollutants (HAPs) on December 29, 2023. (https://www.epa.gov/amtic/amtic-ambient-monitoring-archive-haps) The data are currently under review and have not yet been confirmed as publicly posted.

LUR 2020 – 2023 PM data were submitted to the EBAS archive on July 12, 2024. They have been accepted into the EBAS archive and are available at this link: https://ebas-data.nilu.no/. Note that the EBAS archive only stores hourly averages of the data.

LUR ozone data from 2019 through 2023 were submitted to the EBAS archive on August 20, 2024 (https://ebas-data.nilu.no/). The data are currently under review.

7. Data for Quarters 1 and 2, 2024

The data that were recorded in Q1 and Q2, 2024, 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 was ~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.

The Broomfield Soaring Eagle Park (BSE) and Broomfield North Pecos (BNP) monitoring stations were not operational from January 1, 2024 – April 30, 2024, and therefore there are no comparisons with Broomfield measurements in this report.

8. Boulder A.I.R. Presentations

During Q1 and Q2, 2024, there were four Boulder A.I.R. presentations in which Longmont monitoring results were included:

Jan. 4, 2024; EPA Denver; “Commerce City, the most polluted ZIP Code in the U.S.?”

Apr. 10, 2024; HEI Energy NMED Briefing, “Assessing source contributions to air quality and noise in unconventional oil shale plays”

Apr. 25, 2024; HEI Annual Conference; “Air Quality trends in Texas and Colorado as associated with Unconventional Oil and Gas Development (UOGD)”

June 17, 2024; UC Riverside Air Sensors; “Commerce City, the most polluted ZIP Code in the U.S.?”

Boulder A.I.R.’s Dr. Helmig was interviewed for an air pollution story with PBS NOVA. Some footage was taken at the LUR monitoring site.

Video: Colorado Voices | Commerce City air pollution | PBS (https://www.pbs.org/video/nova-s5rdte/)

Web story: Community-led air monitoring in Commerce City reveals gaps in environmental regulation | Rocky Mountain PBS (rmpbs.org) (https://www.rmpbs.org/blogs/rocky-mountain-pbs/commerce-city-air-pollution)

9. Selected Data Examples and Preliminary Interpretations

Ozone

The full Q1 and Q2, 2024 ozone records for LLG are presented in Figures SA15 – SA18, and in Figures SB15 – SB18 for LUR. There were two days during Q2 2024 when the 8-hr averages of one-minute ozone data exceeded the 8-hour National Ambient Air Quality Standard (NAAQS) for ozone of 70 ppb (we use ≥71.0 ppb as the lower limit to determine the times of exceedances). The NAAQS was exceeded at LLG

on June 17 from 18:00 to 20:00 MST and on June 26 from 15:00 to 18:00 MST. The maximum 8-hr average ozone value of Q2 measured at LLG was 73.0 ppb between 16:00 – 17:00 MST on June 26. The NAAQS was exceeded at LUR on June 26 between 14:00 – 19:00 MST, with a maximum value of 76.1 ppb between 16:00 and 17:00 MST.

On May 6, a tropospheric fold occurred during a mountain-wave windstorm, which transported high-ozone air from the higher layers of the atmosphere to the surface along the Front Range of Colorado, raising the surface ozone values to greater than 70 ppb from approximately 4:00 – 8:00 MST. The maximum one-minute ozone value measured during this event among the four Boulder A.I.R. stations that were measuring ozone at this time was 100 ppb at LLG at 5:31 MST. The highest ozone value measured at LUR during this event was 97 ppb at 05:44 MST. Because this ozone event was relatively short lived, lasting about four hours, the high ozone values were not sustained for long enough to raise the 8-hour ozone average above the 8-hour NAAQS.

Figure 1 presents a statistical analysis of the full Q1 (Figure 1A) and Q2 (Figure 1B) one-minute resolution ozone data from the Longmont stations, compared to data from the Erie Community Center (ECC). The increase in the number of daylight hours during Q1 resulted in an increase in ozone measured at each station from month to month. In Q2, the mean monthly ozone values were not as variable as seen in Q1 and there were no big differences in ozone measurements among the three stations during Q2. The 5th percentile values tended to be higher at LLG than at the other stations during both quarters.

CO_2

The full Q1 and Q2, 2024 CO_2 records are available in Figures SA11 and SA12 for LLG and SB11 and SB12 for LUR. The statistical comparison of the one-minute resolution monitoring data is presented in Figure 2. During Q1 2024 (Figure 2A), the mean values of measured CO_2 at LUR were greater than the mean values measured at LLG. The higher CO_2 values measured in January and February, relative to March – June, are a function of the suppressed vertical mixing that occurs in the colder months. In Q2 (Figure 2B) there was less variability among the monthly mean CO_2 measurements.

The wind dependency plots for LLG and LUR CO_2 shown in Figures 3 and 4 were similar to results from previous quarters. Each site appears to have its strongest source of CO_2 to the west of the station.

Table 1 provides comparisons of CO_2 data at LUR between Q1 2023 and Q1 2024 to investigate year-to-year changes. There was a decrease in CO_2 mean values between Q1 2023 and Q1 2024 at LUR of -1.7 ppm, in contrast to the average at MLO CO_2 increase between February 2023 and February 2024, of 2.9 ppm (data obtained from NOAA Global Monitoring Laboratory (GML) - Carbon Cycle Greenhouse Gases (noaa.gov)). The average at MLO represents the Northern Hemisphere background conditions at approximately 20° latitude.

Table 2 shows this same comparison for Q2 2023 and Q2 2024. The Q2 2023/2024 comparison at LUR shows there was also a decrease in the mean CO_2 measurement, with a decrease of -0.1 ppm between the two years. The increase in the Northern Hemisphere background average CO_2 (measured in April of each year) was 3.0 ppm. In both quarterly comparisons, at least 116,000 individual 1-min data points were considered in the comparison.

With the improved data set (see Section 4), we introduce a trend analysis of LUR CO_2 data to this quarterly report (Figure 5). A trend analysis shows the change in concentrations over time, using linear regression analysis to quantify the overall increase or decrease with time. Similar to the methane trend analyses included in previous quarterly reports, we used a NOAA trend analysis tool where seasonal

components in the data are removed with residuals then investigated for changes over time. The LUR data are plotted along with the NOAA Mauna Loa Observatory (MLO) data, from January 2020 through the end time of the most recent MLO data file. (The availability of the MLO data lags behind that of the Boulder A.I.R. data.) MLO is located on the Mauna Loa volcano on the Big Island of Hawaii, where air from the free troposphere, free from local pollution sources and vegetation, can be measured. The time period covered in this trend analysis is relatively short; therefore, it should be considered preliminary until additional years of data are included in the future.

The LUR CO_2 data presented in Figure 5 show the seasonal pattern of higher CO_2 data measured in the winter in Colorado, whereas at MLO the peak CO_2 is measured in the spring. The minimum CO_2 measurements at LUR occur in the spring to summer, whereas the minimum values at MLO are measured in the fall. It is interesting that the minimum CO_2 values measured at LUR are well below the minima at MLO, despite the average being 21 ppm higher at LUR. This is likely due to the presence of vegetation near LUR, as plants use CO_2 for photosynthesis during the growing season, which removes a fraction of CO_2 from the atmosphere. Over the four-and-a-half-year period analyzed, the slope of the linear regression lines for both monitoring sites were nearly the same, with the LUR slope slightly higher than the MLO slope (2.401 ppm/yr vs. 2.347 ppm/yr, respectively). While the mean CO_2 from each site, from the time period plotted, differed by 21 ppm, the rate of increase over this period was nearly the same. With the LUR data trending upward at a higher rate than at MLO (i.e., MLO and LUR trend lines are diverging), these trend analyses point toward a slightly higher rate of CO_2 increase in Longmont than in the hemispheric background. This also points toward regionally increasing CO_2 emissions, which is not in line with the City of Longmont's climate sustainability goal of reducing CO_2 by 66% from a 2016 baseline measurement by 2030. If CO_2 sources had become weaker over time, the linear regression lines for LUR and MLO would be expected to converge.

This trend analysis result also shows that the drop in CO_2 in 2024 versus the prior year during the same quarters was most likely driven by a difference in weather conditions during these comparison years, and not due to a drop in emissions. Most likely, more frequent higher wind days in 2024 compared to 2023 caused stronger dilution of local air with lower-CO_2 background air, resulting in overall lower quarterly mean values. The average wind speed at LUR during Q1 2023 and Q1 2024 was nearly the same (2.60 vs 2.63 m/s, respectively). There was a bigger difference between Q2 2023 and Q2 2024, which had mean wind speeds of 2.60 vs 2.86 m/s, respectively. For a regional perspective, NCAR reanalysis comparisons between the quarters (not shown) also indicated higher winds in northeast Colorado in Q2 2024 compared to Q2 2023. The differences in mean values shown in Tables 1 and 2 indicate drops in all species shown (CO_2, methane, ethane, and benzene) between the 2023 and 2024 quarters, further suggesting that this difference was caused by meteorology rather than across the board reductions in emissions.

Methane

The full Q1 and Q2, 2024 methane records are available in Figures SA13 and SA14 for LLG and SB13 and SB14 for LUR. Methane exceeded 5000 ppb at LUR two times during Q2 2024 (6205.8 ppb on June 21 at 02:10 MST and 5640.9 ppb on June 27 at 01:00 MST). There were no times during Q2 2024 when methane exceeded 5000 ppb at LLG, or at either station during Q1 2024. All methane data for the analyses discussed in the report are the 1-minute averaged data.

The statistical analysis of the full Q1 and Q2 methane data is shown in Figure 6. Considering the mean and median values, higher methane was measured at LUR than at LLG throughout the two quarters, consistent with previous observations, which likely is an indication for stronger methane emission

sources near LUR than at LLG. With increasing vertical mixing occurring with the approaching onset of spring and warmer temperatures, methane measurements decreased from month to month during Q1 at all stations due to more rigorous dilution as a result of the increase in vertical mixing.

Wind rose and heat map analyses for LLG and LUR methane data are shown in Figures 7 and 8. As in previous quarters, methane was transported to LLG mainly from the east to northeast of the station. The analysis for LUR methane data indicated consistent transport from the northeast.

Table 1 shows the numerical values of the comparison between Q1 2023 and Q1 2024 methane measurements at LUR. The mean values between the datasets showed a local decrease of 56 ppb in Q1 2024 compared to Q1 2023. The Northern Hemisphere background mean methane value for January 2023 compared to that of January 2024 showed an increase of 9 ppb (obtained from NOAA Global Monitoring Laboratory (GML) - Carbon Cycle Greenhouse Gases (noaa.gov)). For the Q2 comparison (Table 2) the local change in the mean methane was a decrease of -12 ppb while the Northern Hemisphere background difference was an increase of 11 ppb (mean values obtained in March of each year).

Figure 9A provides preliminary LUR versus BRZ and MLO methane time series and trend analyses for hourly-averaged data. This comparison is sensitive to the relatively few high methane occurrences, and the regression slope (trend) results vary depending on what fraction of high values are included or, alternatively, excluded as outliers. The methane trend in the LUR data according to these calculations is an increase of 14.30 ppb yr^{-1} compared to a value of 13.43 ppb yr^{-1} for MLO. As a test, we eliminated the top 1% of the full record of the LUR methane measurements for comparison to the complete LUR data set (Figure 9B). This resulted in a higher LUR trend result of 15.45 ppb yr^{-1}.

For both analyses, the LUR methane trend was higher at LUR than the MLO Northern Hemisphere background data, which implies that regional methane emissions would have increased at a higher rate at LUR than over the globe as a whole. These differences are relatively small, however, and within the uncertainty range of the determination. More sensitivity studies of this type of analysis are ongoing to statistically solidify this finding.

VOCs

The full Q1 and Q2, 2024 LUR records for six selected VOCs are available in Figures SB19–SB32. Figure 10 presents a 52-month record of ethane, propane/ethane ratio, benzene, and acetylene from March 2020 – June 2024, measured at LUR. Ethane, benzene, and acetylene all show increases in winter and lower amounts in summer (Figures 10A, 10C, and 10D).

The details of a large peak in VOCs, particularly benzene, are shown in Supplement D. During the 9:00 – 9:10 MST VOC sampling period on March 21, 2024, the benzene measurement was 2.89 ppb, approximately 29 times the average for March 2024 and more than 3 times the alert level of 0.9 ppb. Pentanes and butanes also peaked during this benzene event; however, methane and ethane measurements were not notably elevated, as is typical of natural gas venting or leaks. This suggests that the source was likely a liquid raw hydrocarbon mixture (oil) rather than volatile natural gas. The back trajectory calculated from LUR winds during the 30-minute period ending at the end of the VOC sampling window indicated transport across Union Reservoir, mostly from the northeast of the LUR monitoring station.

Supplement E includes details for an event that occurred on March 24. VOCs measured during the 8:00 – 8:10 MST sampling period included an ethane peak of 254 ppb, approximately 30 times the March 2024 average value. Benzene, propane, toluene, pentanes, and butanes also had higher than normal peaks. Methane also peaked; the highest peaks were just below 3100 ppb. These increases in both VOCs and

methane indicated this plume was likely associated with oil and gas operations. The back trajectory calculated from LUR winds during the 60-minute period ending at the end of the VOC sampling window again indicated air transport from the from the northeast, over the reservoir from the general direction of the Hergenreder well pad.

The statistical comparison of selected VOCs is plotted in Figures 11 and 12. Throughout Q1 and Q2, more ethane was measured at LUR than at ECC and BRZ during most months (according to mean values). Mean values of propane were higher at LUR compared to BRZ and ECC in every month. 95th percentile values of propane were higher at LUR than at the other stations. Mean and 95th percentile benzene values at ECC outpaced those of LUR and BRZ throughout both quarters. The lower VOC mean values in Q2 compared to Q1 are likely again because of the enhanced vertical mixing (and therefore increased dilution of pollutants) that occurs as the atmosphere warms up in the spring.

The Q1 and Q2 2024 versus 2023 comparisons for ethane and benzene indicated lower mean values in the 2024 quarters compared to the 2023 quarters (Tables 1 and 2). In Figure 13, we show trend plots for both ethane and benzene. There are two sets of plots for each species. In 13A and 13C, we show the trend in the data from February 1, 2020 (the start of the VOC data record at LUR) until June 30, 2024. The linear regression slopes were -1.59 ppb/yr for ethane and -0.018 ppb/yr for benzene. When the VOC measurements first began at LUR in early 2020, it became immediately apparent that measured ethane and benzene mole fractions were highly variable and overall high in their concentrations. Shortly after this was brought to the attention of the public in a March 2020 Longmont City Council meeting, a sharp decline in measured mole fractions occurred. We therefore performed the same trend analysis for a time period starting on April 1, 2020 (13B and 13D), eliminating this initial period of high ethane and benzene, to see if there was still a downward trend detected in these species. Over this shorter time period, the linear regression slopes were -1.48 ppb/yr and -0.017 ppb/yr for ethane and benzene, respectively. These slope values were only slightly different and remained negative in these cases, indicating that the implied downward trend in the measurements was relatively robust. Since ethane is a selective oil and gas tracer, this finding points towards a gradual decrease in observed natural gas plumes and concentrations at LUR, possibly caused by decreasing rate of upwind natural gas emissions.

Wind speed/wind direction dependence results for ethane, propane, acetylene, and benzene at LUR are shown in Figures 14 and 15. The ethane and propane figures indicate a source to the north and northeast of LUR, consistent with recent previous quarters. The higher values of acetylene are transported to LUR from the west, under low wind speed conditions. However, there appears to be some transport from the northeast also. The results for benzene are similar.

Further analyses of VOC signatures, using VOC/VOC ratio values, are shown in Figures 16 and 17. Similar to previous quarters, the lower i/n-pentane values clearly show that air associated with oil and gas production containing relatively higher amounts of n-pentane (resulting in lower i/n-pentane ratio values) to the north and northeast of LUR was transported to LUR (yielding ratio values < 1.0). Plots of the other VOC/VOC ratios are consistent between quarters.

Nitrogen Oxides (NO, NO_x)

The Q1 and Q2 LUR record for nitric oxide (NO) is available in Figures SB33 and SB34, and the record for total nitrogen oxides (NO_x) in Figures SB35 and SB36. Figures 18 and 19 show the statistical analyses for NO (A) and NO_x (B). More NO_x was measured at LUR than at BRZ (indicated by the mean values), with much higher 95th percentile values, every month of Q1 and Q2, 2024, often by a factor of 2-3. The large

95th percentile values indicated large peaks in NO_x were measured at LUR. The 1-hour NAAQS for NO_2 is defined as the 98th percentile of the 1-hour daily maximum mole fraction, averaged over 3 years, exceeding 100 ppb. There is also an annual mean NAAQS for NO_2 of 53 ppb. The hourly-averaged NO_2 results shown in Figures 18C and 19C have mean and maximum values (listed in the figure annotations) indicating that NO_2 measured at LUR did not approach the NAAQS threshold levels during these quarters. Dependency of NO and NO_x on wind direction and wind speed is presented in Figures 20 and 21.

Particulate Matter (PM)

PM 10 and PM 2.5 LUR Q1 and Q2, 2024 monitoring results are presented in Figures SB37 – SB40. The 24-hour averaged PM 2.5 data are available in Figures SB41 and SB42. There was some regional smoke in the area in mid-June, slightly elevating the June PM measurements relative to the other months. There were no exceedances of the NAAQS PM 2.5 24-hour average (35 µg/m^3) in either quarter. Time series of PM 10 data are shown in Figure 22 and PM 2.5 data are shown in Figure 23, including 24-hour averages. Time series data for PM 10 and PM 2.5 are shown in Figures 24 and 25.

In Supplement F, we show a comparison of PM 2.5 data between the Longmont CDPHE station (located on top of the Municipal Building on Kimbark Street) and the measurements from LUR. When CDPHE compared the 98th percentile values of all of their PM 2.5 monitors, the 3-year average of these percentiles was highest at the Kimbark Street monitor, raising questions about the representativeness of these measurements. The comparisons shown in Supplement F between the 24-hour averages of CDPHE data from the downtown location and the LUR data compare well in 2022 and 2023 for the mean and median values of these averages. In 2021, the mean and median values for the 24-hour averages were greater at Kimbark Street than at LUR. In two of the years, the 98th percentile values in the CDPHE data occurred on days with abundant wildfire smoke along the Front Range (August 7, 2021 and May 22, 2023). The conditions leading to high PM 2.5 measurements on December 31, 2022 (the day of the 98th percentile measurement for that year) were less clear. It does not appear that there was wildfire smoke on that day on the Front Range.

In an effort to further understand the CDPHE PM 2.5 measurements on Kimbark Street, Drs. Jane Turner and Detlev Helmig met CDPHE staff and visited the CDPHE monitoring site on Kimbark Street in April 2024 (Figure 26).

10. Summary

There were no PM 2.5 NAAQS exceedances at LUR during Q1 or Q2, 2024. However, there were two days when the ozone NAAQS was exceeded. The NAAQS standard was exceeded at LLG on June 17 from 18:00 to 20:00 MST and on June 26, 2024 from 15:00 to 18:00 MST. The maximum 8-hr average ozone value at LLG was 73.0 ppb between 16:00 – 17:00 MST on June 26. The NAAQS standard was exceeded at LUR on June 26 between 14:00 – 19:00 MST, with a maximum value of 76.1 ppb between 16:00 and 17:00 MST.

An event occurred when air from the upper troposphere was transported high ozone to the surface, greater than 90 ppb, to the Front Range for a brief period on May 6. The highest value measured at a Boulder A.I.R. station during this event was 100 ppb at LLG at approximately 05:30 MST.

There were two high VOC events of note at LUR during Q1 of 2024. On March 21 benzene reached a maximum of 2.89 ppb. There were additional VOC peaks during the same sampling period, but not for ethane. There were also no methane peaks at the same time, indicating that this plume was likely not

natural gas related, but rather caused by a liquid raw hydrocarbon mixture. On March 24, there were large peaks in VOCs, including an ethane peak of 254 ppb. With additional peaks in other VOCs and methane measured at the same time, this was likely a natural gas/oil plume. In both cases, back trajectory analyses indicated transport from the northeast. Details can be found in Supplements D and E.

Preliminary trend analyses indicate that LUR is subjected to regionally increasing emissions of CO_2 and methane, whereas there appears to be a gradual decline in observed concentrations of benzene and of the natural gas tracer ethane.

Dr. Detlev Helmig was interviewed by a journalist from PBS NOVA for a program about air quality monitoring. Some of the footage was recorded at LUR.

Video: Colorado Voices | Commerce City air pollution | PBS (https://www.pbs.org/video/nova-s5rdte/)

Web story: Community-led air monitoring in Commerce City reveals gaps in environmental regulation | Rocky Mountain PBS (rmpbs.org) (https://www.rmpbs.org/blogs/rocky-mountain-pbs/commerce-city-air-pollution)

Drs. Jane Turner and Detlev Helmig met with CDPHE staff and visited the CDPHE particulate matter monitoring site on Kimbark Street in April 2024.

Tables

Table 1: Comparison of the statistics of CO_2 and methane (CH_4) one-minute data, and ethane and benzene data (sampled over a 10-min period once every hour) at LUR during Q1 of 2023 and Q1 of 2024. "Diff" is the 2024 value minus the 2023 value. "% Diff" shows the relative change between the two years. The "Local/NH" column shows the relative ratio of the change seen in the Longmont data compared to the Northern Hemisphere average background change.

Species	Stat	Q1 2023	Q1 2024	Diff	% Diff	Local/NH
CO_2	count	126168	129102	2934	2.3	
(ppm)	mean	449.2	447.5	-1.7	-0.4	-0.6
	std	29.4	27.1	-2.3	-7.9	
	min	419.0	422.0	3.0	0.7	
	5%	422.1	424.9	2.7	0.6	
	25%	427.3	429.8	2.5	0.6	
	50%	437.3	436.9	-0.4	-0.1	-0.1
	75%	463.8	455.3	-8.4	-1.8	
	95%	510.5	503.9	-6.6	-1.3	
	max	621.9	669.5	47.6	7.7	
	NH mean	419.9	422.9	2.9	0.0	
CH_4	count	126168	129102	2934	2.3	
(ppb)	mean	2209	2153	-56	-2.5	-6.2
	std	249	159	-90	-36.0	
	min	1963	1963	0	0.0	
	5%	1995	1995	0	0.0	
	25%	2054	2043	-11	-0.5	
	50%	2148	2106	-42	-2.0	-4.7
	75%	2315	2214	-101	-4.4	
	95%	2596	2475	-121	-4.7	
	max	24722	4942	-19781	-80.0	
	NH mean	1922	1931	9.0	0.0	
Ethane	count	1774	2094	320	18.0	
(ppb)	mean	17.3	11.2	-6.1	-35.4	
	std	17.9	11.3	-6.5	-36.6	
	min	1.3	1.0	-0.3	-23.0	
	5%	2.1	1.9	-0.2	-9.6	
	25%	5.5	4.2	-1.3	-23.1	
	50%	12.1	8.1	-4.0	-33.2	
	75%	23.6	14.6	-9.0	-38.0	
	95%	47.2	30.4	-16.8	-35.6	
	max	316	254	-62	-19.7	
Benzene	count	1774	2094	320	18.0	
(ppb)	mean	0.185	0.136	-0.049	-26.5	
	std	0.145	0.127	-0.018	-12.4	
	min	0.024	0.018	-0.007	-27.6	
	5%	0.046	0.038	-0.008	-17.8	
	25%	0.080	0.067	-0.013	-16.4	
	50%	0.131	0.100	-0.031	-23.5	
	75%	0.259	0.169	-0.090	-34.7	
	95%	0.484	0.346	-0.138	-28.5	
	max	1.059	2.884	1.825	172.3	

Table 2: As in Table 1, except for Q2 of 2023 and Q2 of 2024.

Species	Stat	Q2 2023	Q2 2024	Diff	% Diff	Local/NH
CO_2	count	116097	129018	12921	11.1	
(ppm)	mean	435.6	435.5	-0.1	0.0	0.0
	std	18.2	16.1	-2.0	-11.2	
	min	402.1	404.5	2.4	0.6	
	5%	417.6	420.9	3.3	0.8	
	25%	423.6	424.7	1.2	0.3	
	50%	429.2	430.0	0.7	0.2	0.2
	75%	441.8	440.8	-1.1	-0.2	
	95%	475.3	469.8	-5.5	-1.2	
	max	564.1	562.1	-2.0	-0.4	
	NH mean	420.5	423.5	3.0	0.0	
CH_4	count	116097	129018	12921	11.1	
(ppb)	mean	2079	2067	-12	-0.6	-1.1
	std	125	109	-15	-12.2	
	min	1948	1944	-4	-0.2	
	5%	1979	1975	-5	-0.2	
	25%	2011	2008	-3	-0.2	
	50%	2049	2040	-9	-0.4	-0.8
	75%	2107	2097	-11	-0.5	
	95%	2281	2230	-51	-2.2	
	max	8612	6206	-2406	-27.9	
	NH mean	1919.7	1930.8	11	0.0	
Ethane	count	1897	2085	188	9.9	
(ppb)	mean	6.4	4.5	-1.9	-29.7	
	std	9.7	5.2	-4.5	-46.3	
	min	1.1	0.6	-0.5	-46.9	
	5%	1.6	1.2	-0.5	-27.5	
	25%	3.1	2.1	-1.0	-32.4	
	50%	4.9	3.5	-1.4	-28.1	
	75%	7.7	5.6	-2.1	-27.3	
	95%	15	10	-5	-32.3	
	max	348	145	-203	-58.3	
Benzene	count	1897	2085	188	9.9	
(ppb)	mean	0.070	0.054	-0.016	-22.4	
	std	0.108	0.035	-0.074	-67.9	
	min	0.004	0.004	0.000	-0.7	
	5%	0.012	0.019	0.007	59.1	
	25%	0.028	0.030	0.002	7.2	
	50%	0.047	0.046	-0.001	-1.7	
	75%	0.081	0.067	-0.014	-17.4	
	95%	0.174	0.121	-0.054	-30.7	
	max	3.221	0.265	-2.956	-91.8	

Figures

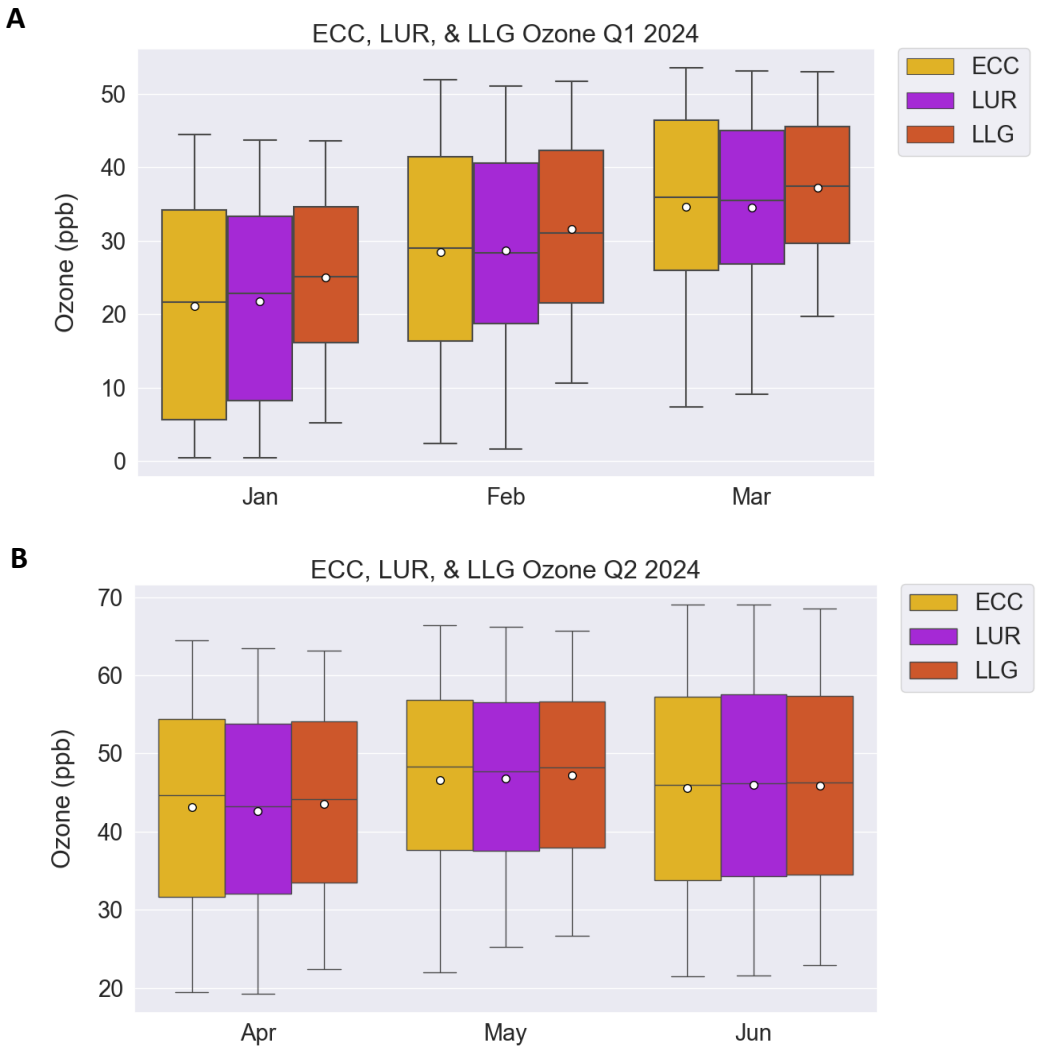


Figure 1:
Comparison of the ozone distribution at ECC, LUR, and LLG, during (A) January - March 2024 and (B) April – June 2024. These box whisker plots show the median value as the center line, the 25-75 percentile distribution as the colored boxes, and the 5-percentile and 95-percentile values as the whiskers. The white dot on each box illustrates the mean value at each site.

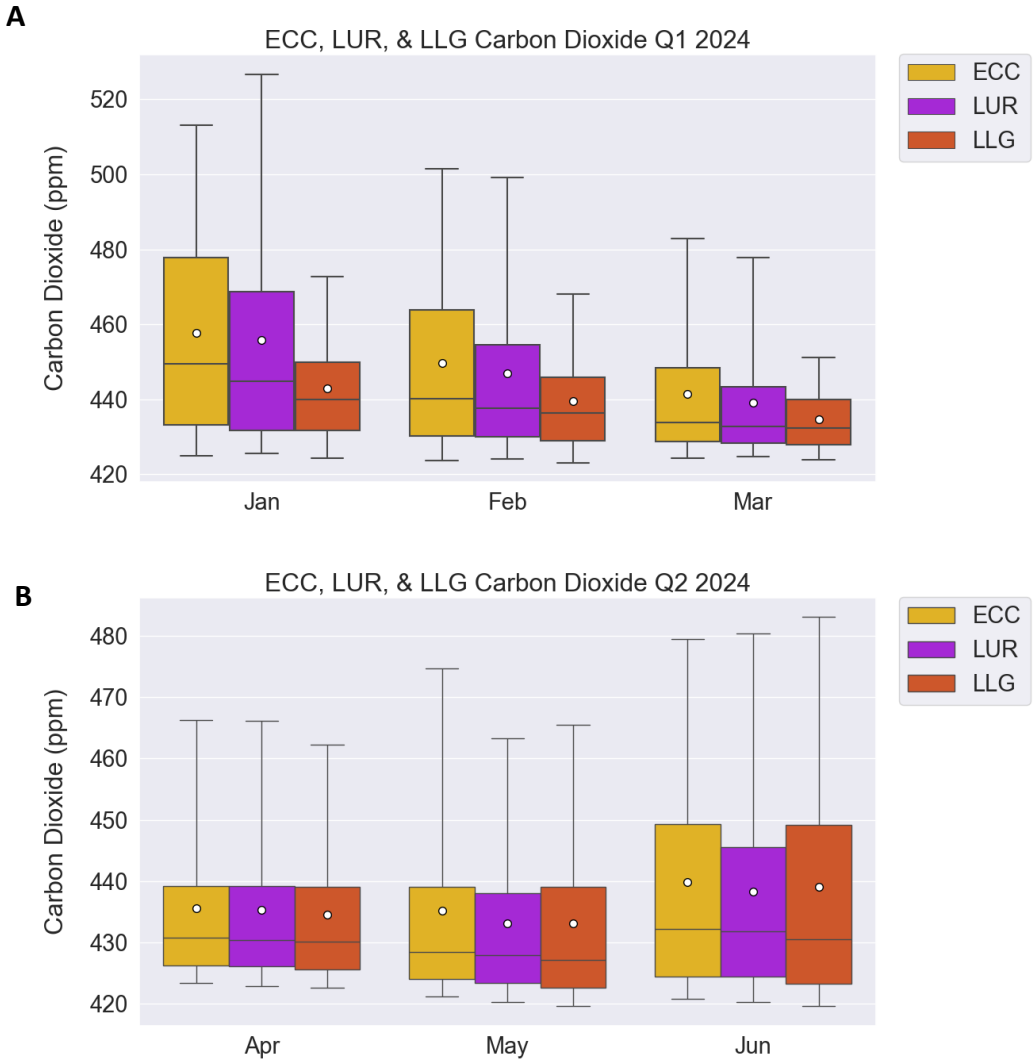


Figure 2:
Comparison of the CO_2 distribution at ECC, LUR, and LLG, during (A) January - March 2024, (B) April – June 2024. See Figure 1 for explanation of the box whisker plot format.

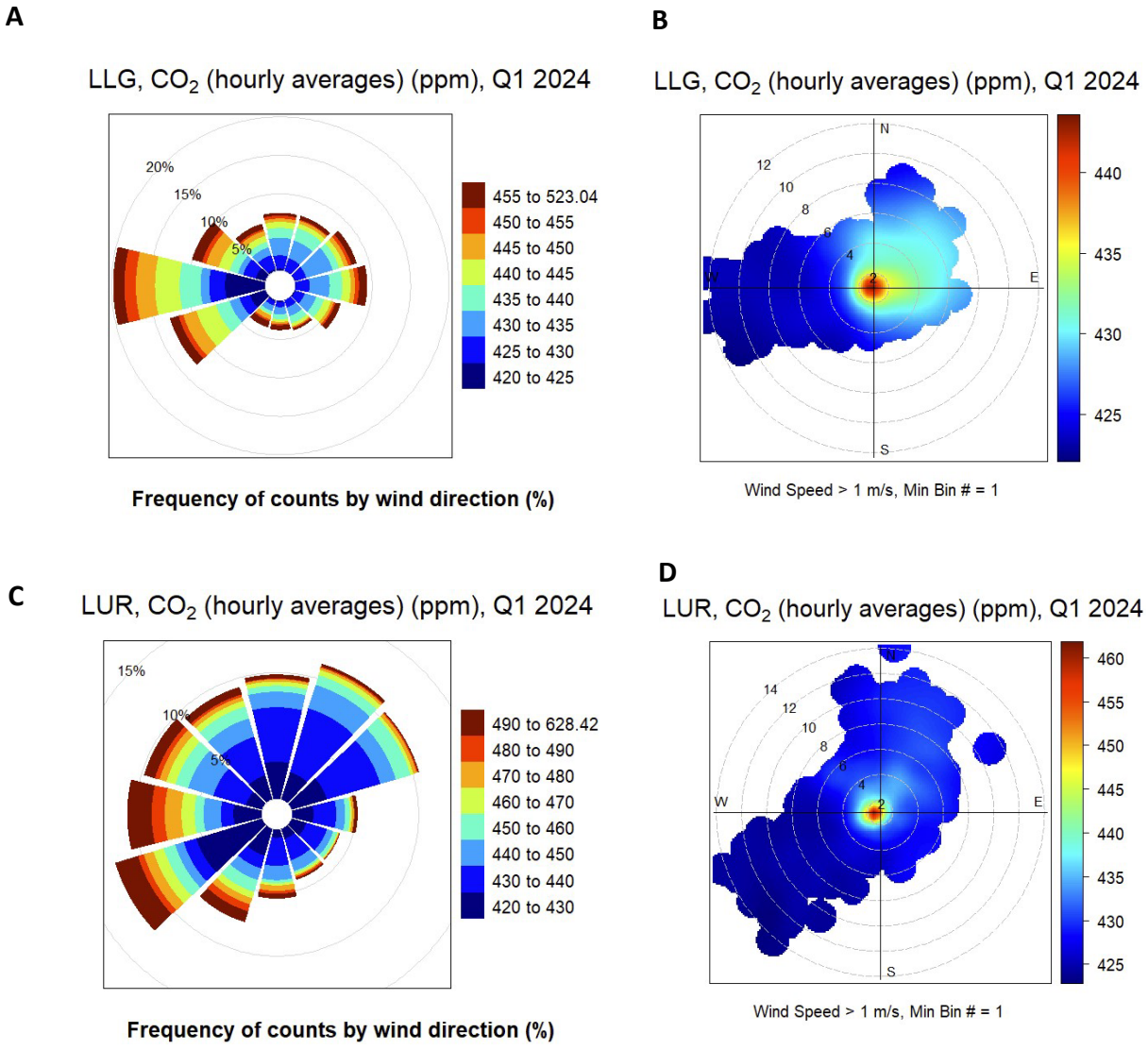
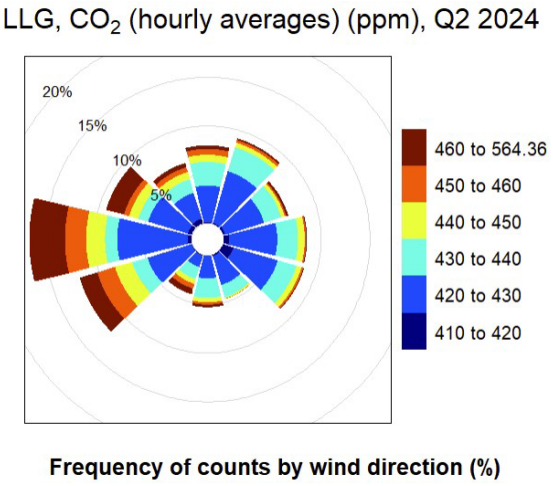
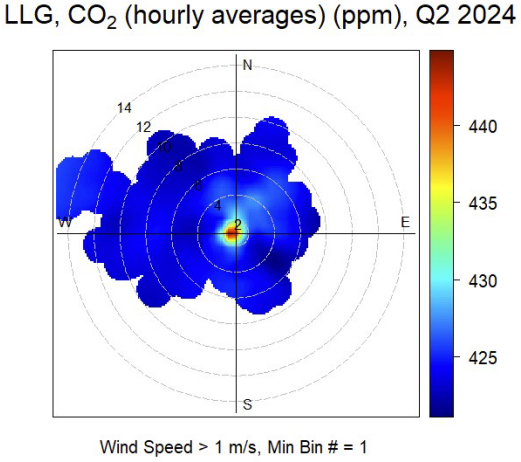


Figure 3:
Wind rose (left) and wind heat map analysis (right) showing the dependency of CO_2 mole fractions at (A, B) LLG and (C, D) LUR during January - March 2024. The LUR site is east of the City of Longmont. These analyses suggest that the city is the primary source for enhanced CO_2 observed at LUR.

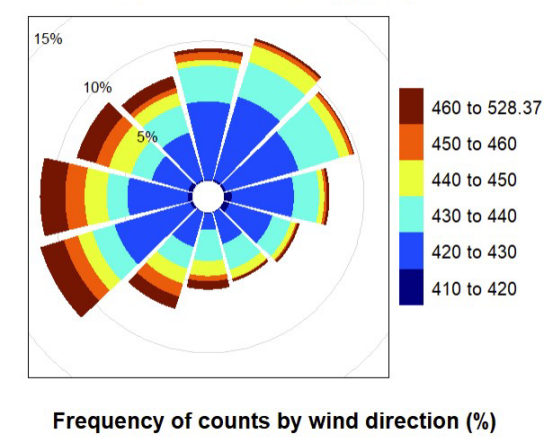
A



B



C



D

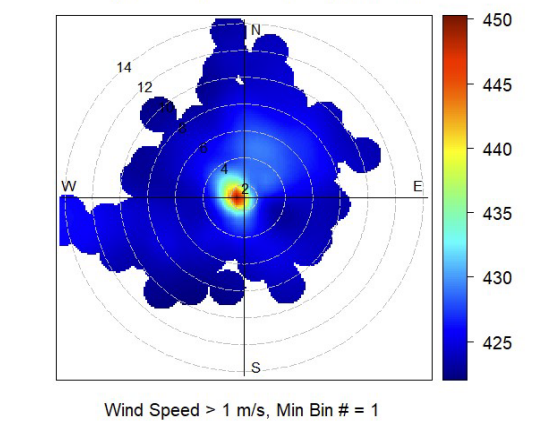


Figure 4:
As in Figure 3, except for April - June 2024.

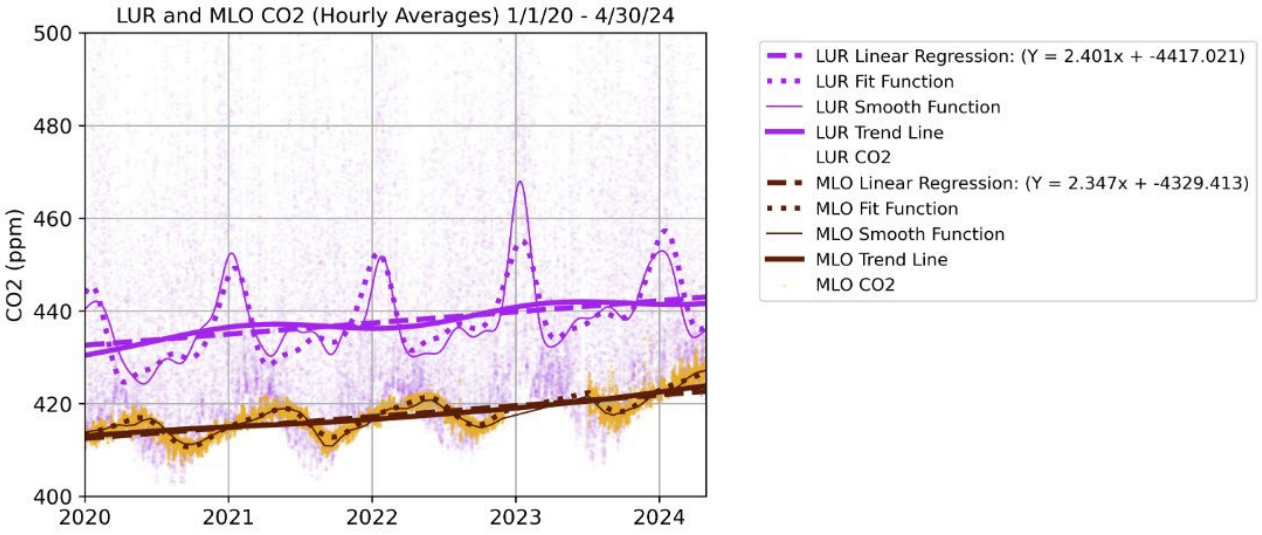


Figure 5:
Comparison of the CO_2 trend between LUR (purple) and the Mauna Loa Observatory (MLO, orange) hourly-averaged CO_2 data. (Note there is a gap in the MLO dataset due to the Mauna Loa volcano eruption that temporarily interrupted measurements at the observatory from December 2022 to July 2023.). The fit functions, smooth functions, and trend lines were computed using the NOAA curve fitting code (Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases (noaa.gov, https://gml.noaa.gov/ccgg/mbl/crvfit/crvfit.html). The trend in CO_2 (increase of CO_2 per year) is reflected by the slope values of the linear regression results that are given in the legend.

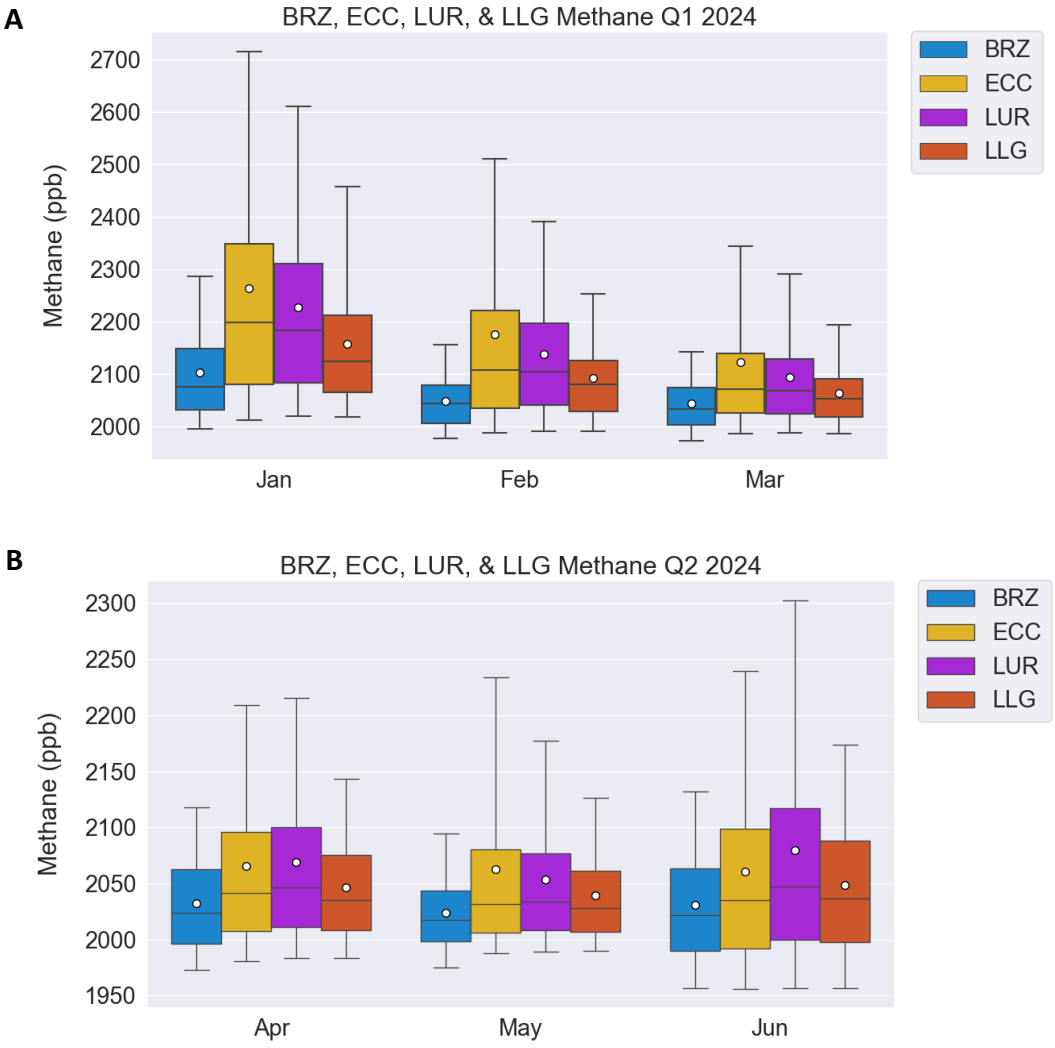
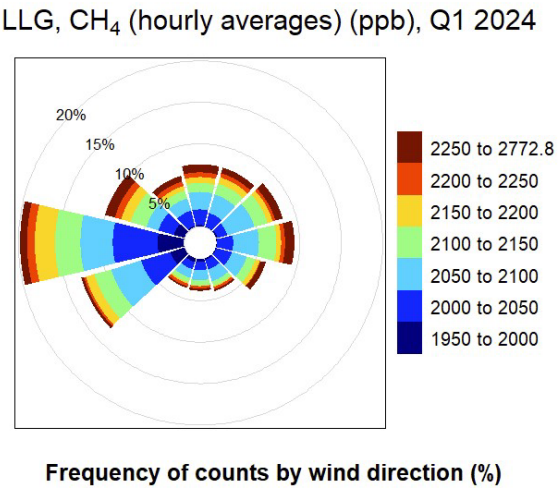
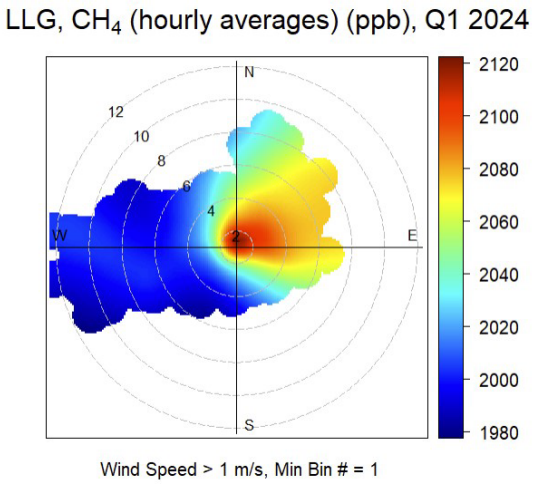


Figure 6:
Comparison of the methane distribution at BRZ, ECC, LUR, and LLG, during (A) January - March 2024 and (B) April – June 2024. See Figure 1 for explanation of the box whisker plot format. Between the two Longmont sites, LUR has higher absolute values and variance.

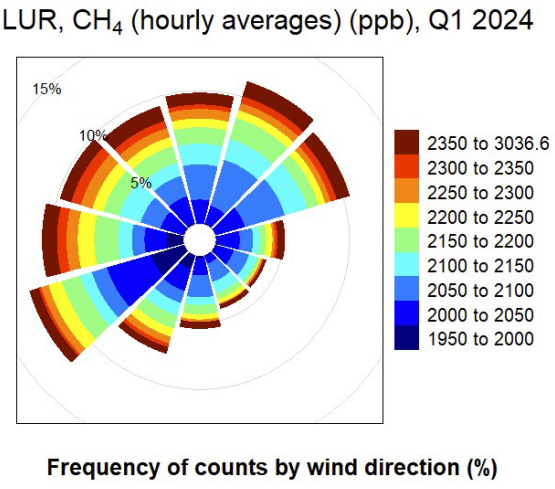
A



B



C



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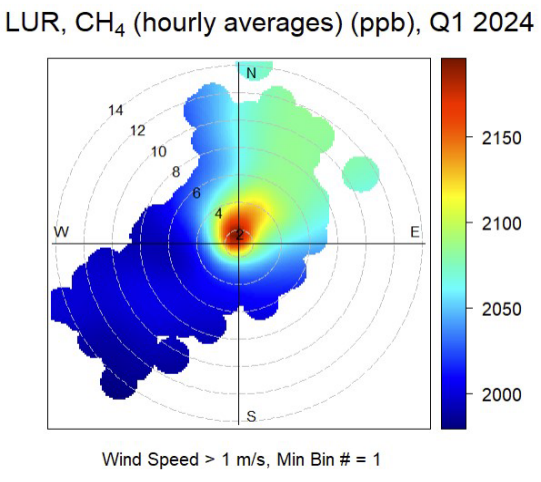
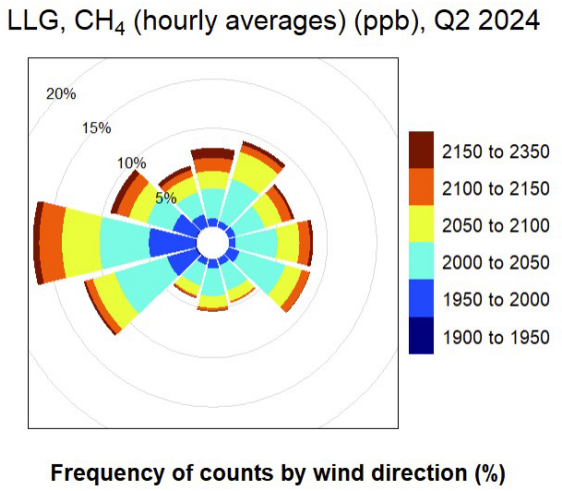
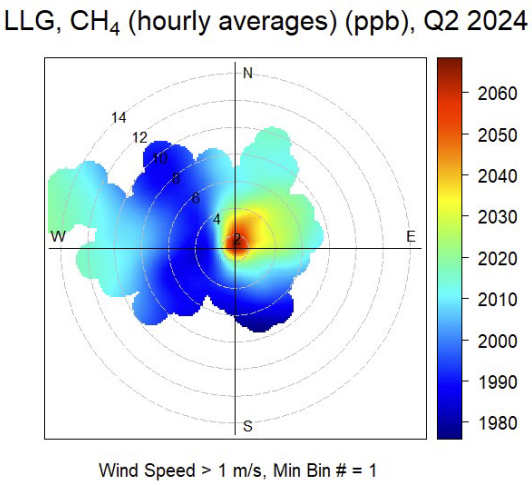


Figure 7:
Wind rose (left) and wind heat map analysis (right) showing the dependency of methane (CH_4) mole fractions at (A, B) LLG and (C, D) LUR during January - March 2024.

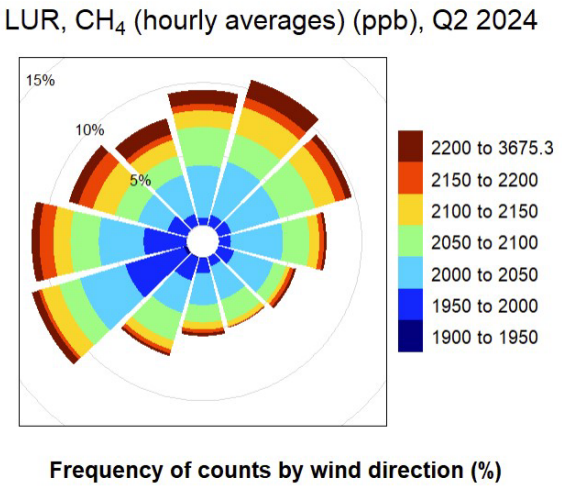
A



B



C



D

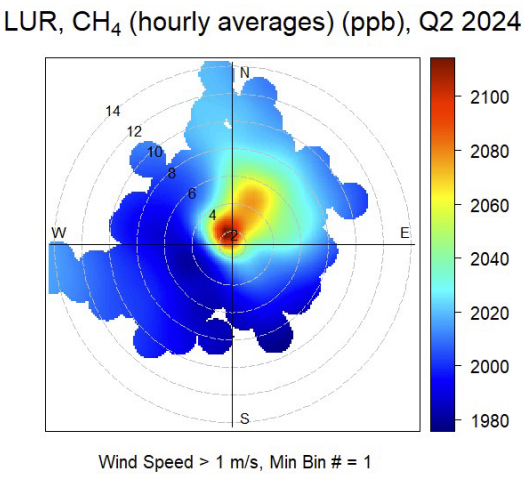
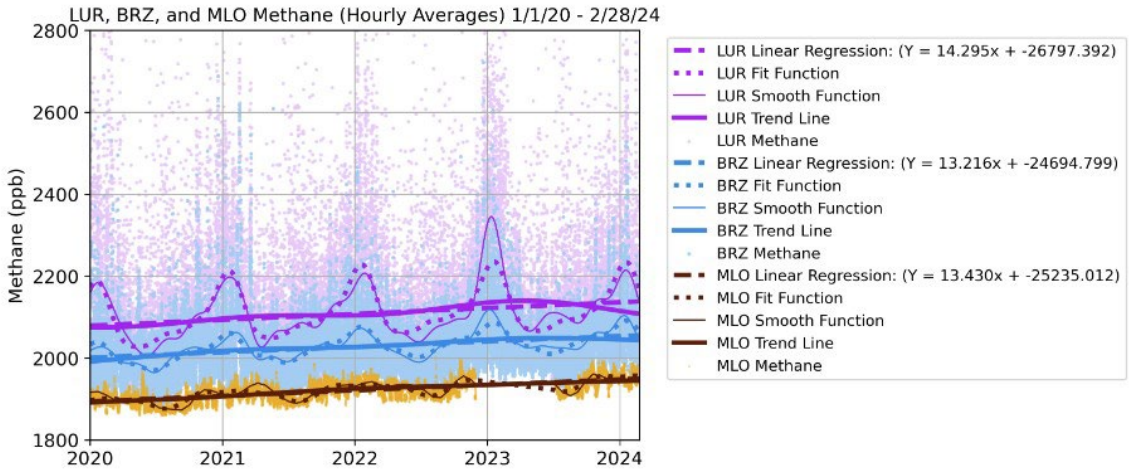


Figure 8:
As in Figure 7, except for April - June 2024.

A



B

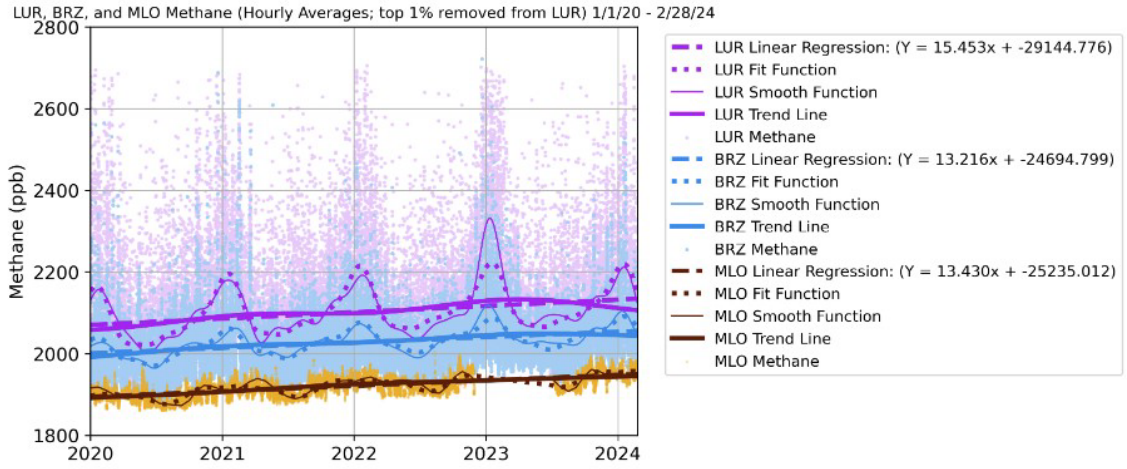


Figure 9:
Comparison of the methane trend between LUR (purple), BRZ (blue), and MLO (orange). (Note there is a gap in the MLO dataset due to the Mauna Loa volcano eruption that temporarily interrupted measurements at the observatory from December 2022 to July 2023.) This analysis uses hourly-averaged data. Figure 10A considers all data, whereas in Figure 10B, the highest 1% of LUR data were removed. This was done to test the effect of large pollution spikes on the LUR methane slope estimate given that there were a large number of methane spikes at the beginning of 2020, relative to later years. The fit functions, smooth functions, and trend lines were computed using the NOAA curve fitting code (Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases (noaa.gov, https://gml.noaa.gov/ccgg/mbl/crvfit/crvfit.html). The trend in methane (increase of methane per year) is reflected by the slope values of the linear regression results that are given in the legend.

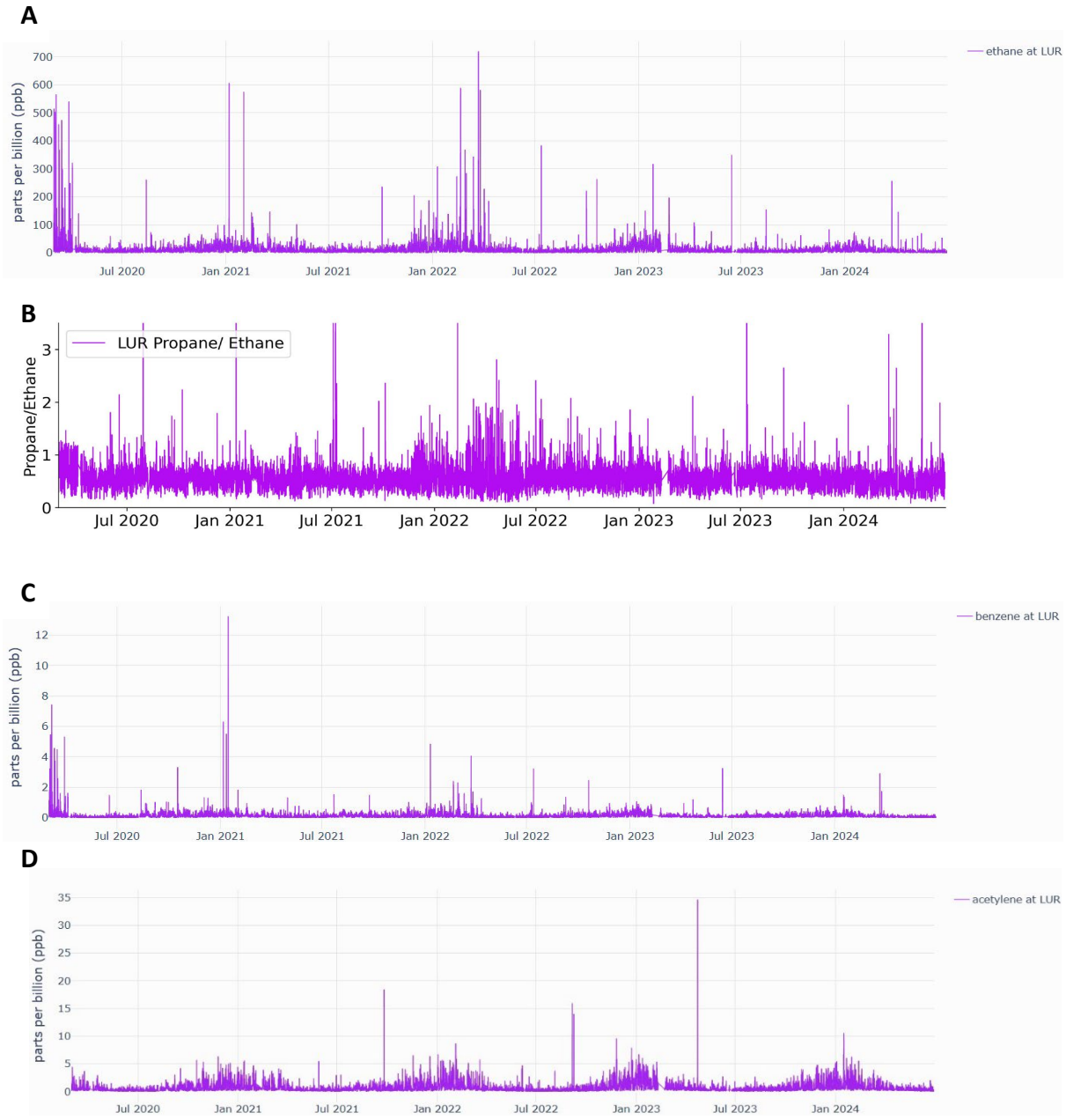


Figure 10:
Time series analyses of (A) ethane, (B) propane/ethane ratio, (C) benzene, and (D) acetylene at LUR between March 1, 2020, and June 30, 2024. Lower frequency and lower maximum values of concentration spikes during the summer are observed for all compounds. These summer minima are mostly caused 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.

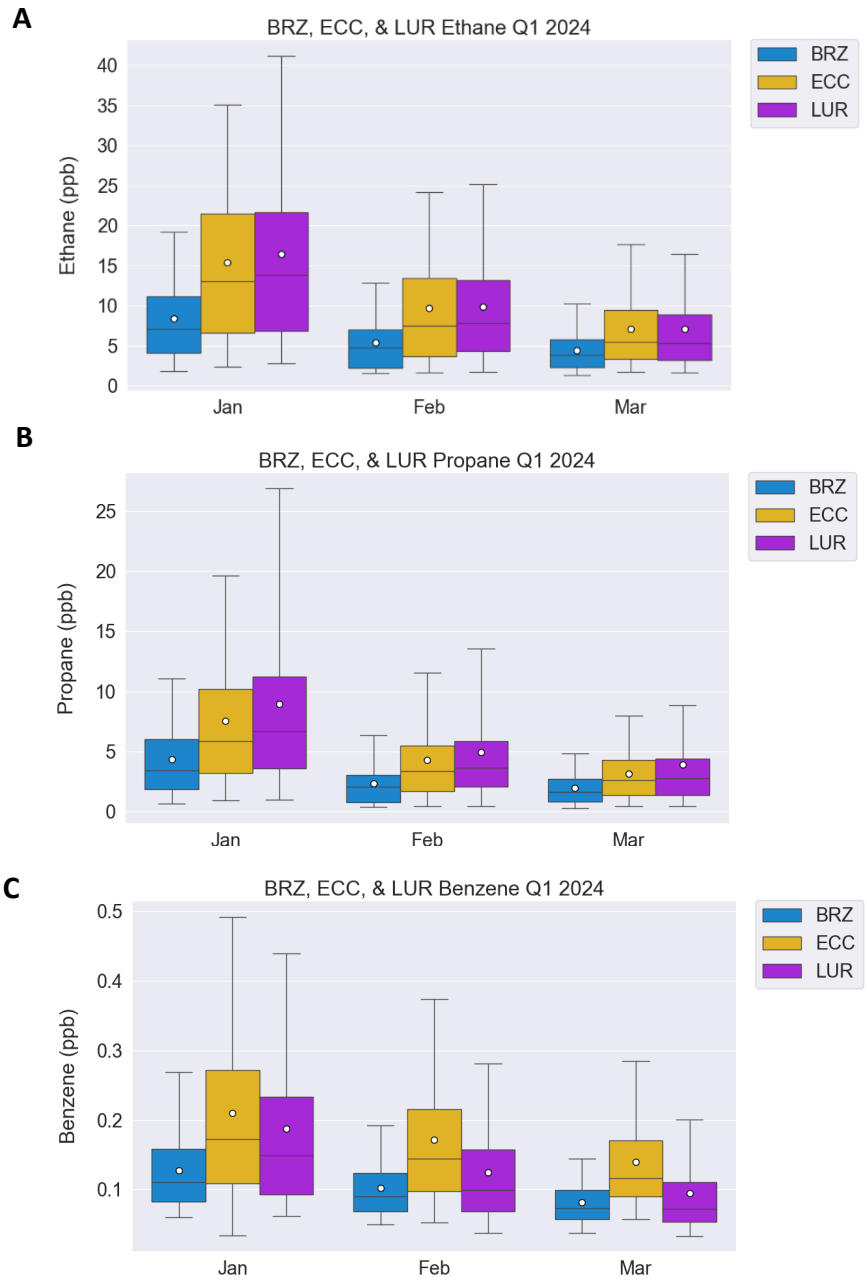


Figure 11:
Comparison of the distribution of (A) ethane, (B) propane, and (C) benzene at BRZ, ECC, and LUR during Q1, 2024. See Figure 1 for explanation of the box whisker plot format.

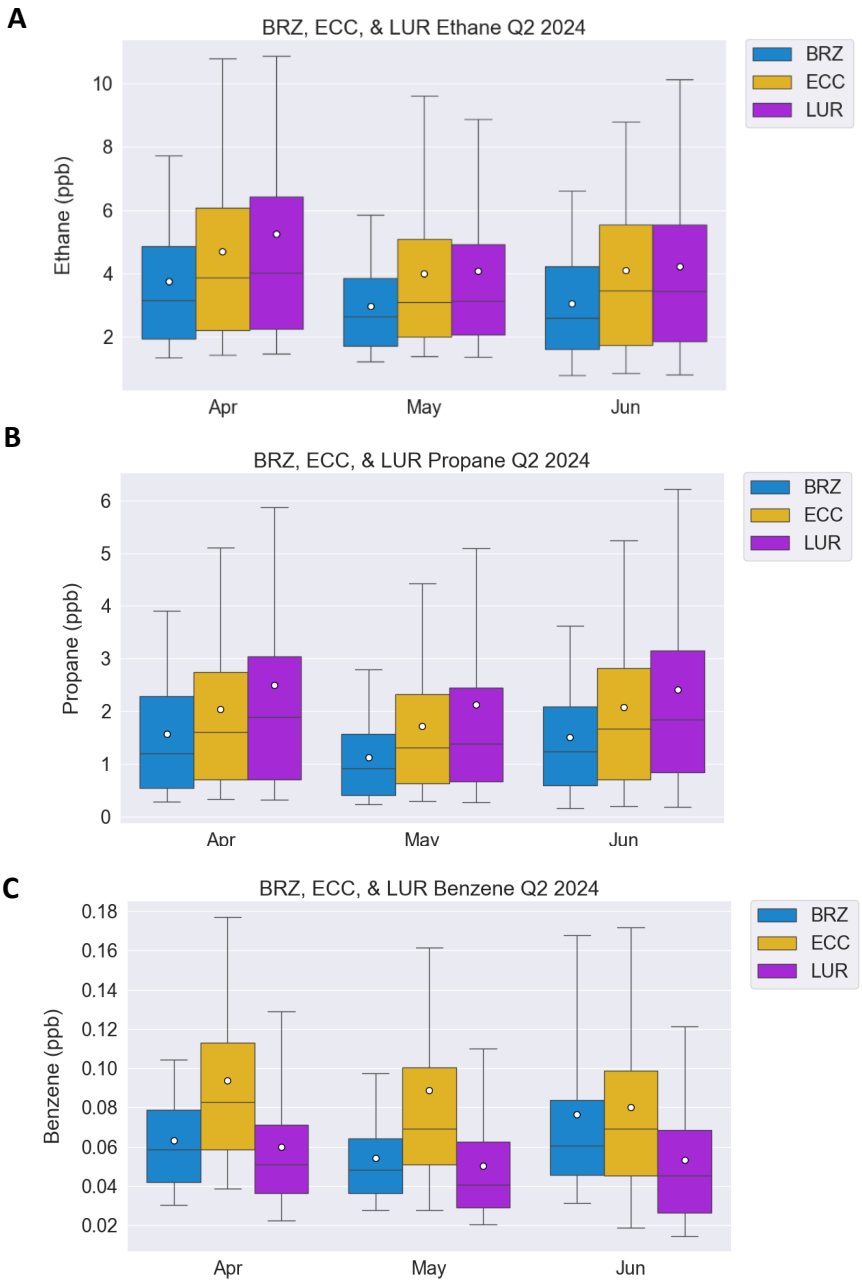


Figure 12:
As in Figure 11, except for Q2, 2024.

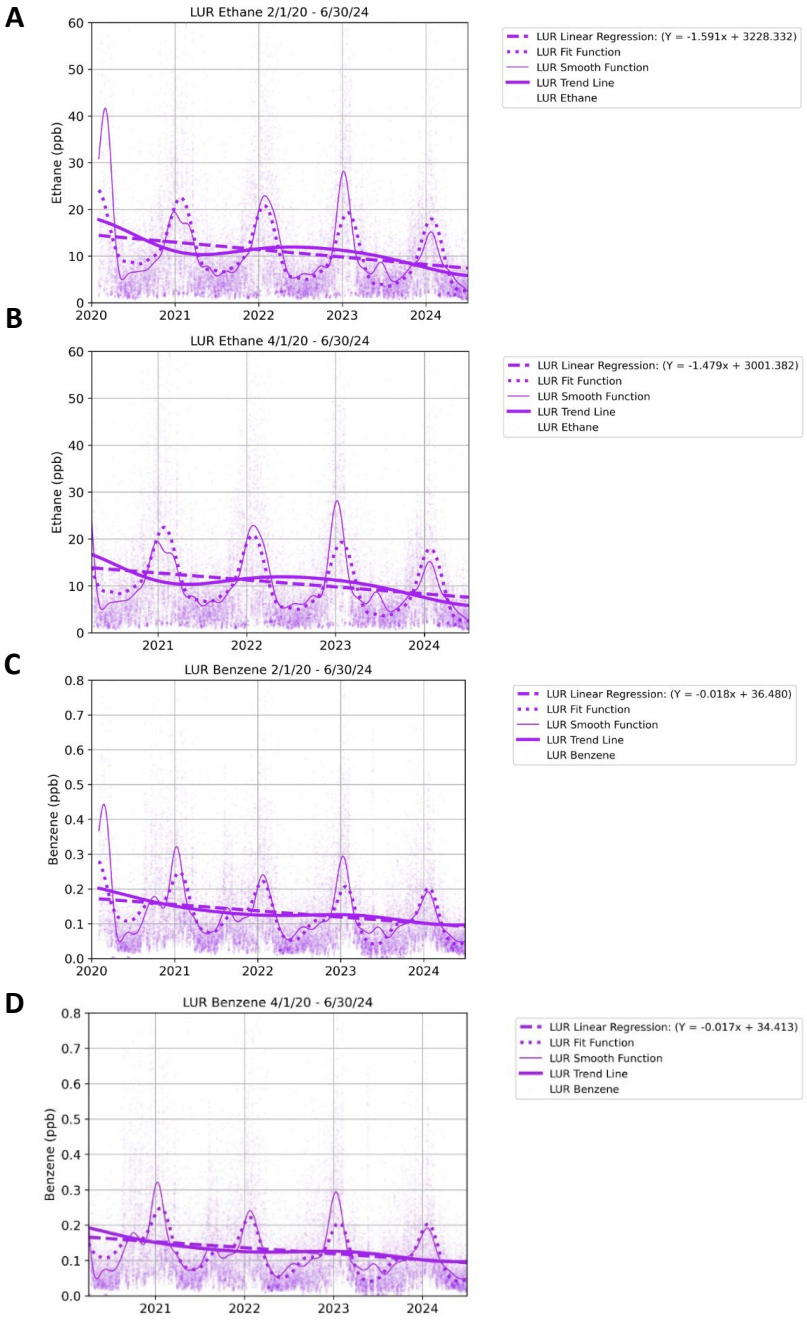


Figure 13:
Trend analyses for LUR (A,B) ethane, and (C,D) benzene. The analyses for February 1, 2020 – June 30, 2024 are shown in (A) and (C). A second analysis was performed from April 1, 2020 – June 30, 2024 (B and D) to confirm that these species were declining over time after the high values found in the initial monitoring were removed from the time series. In all cases, the analyses indicated an overall downward trend in these pollutants.

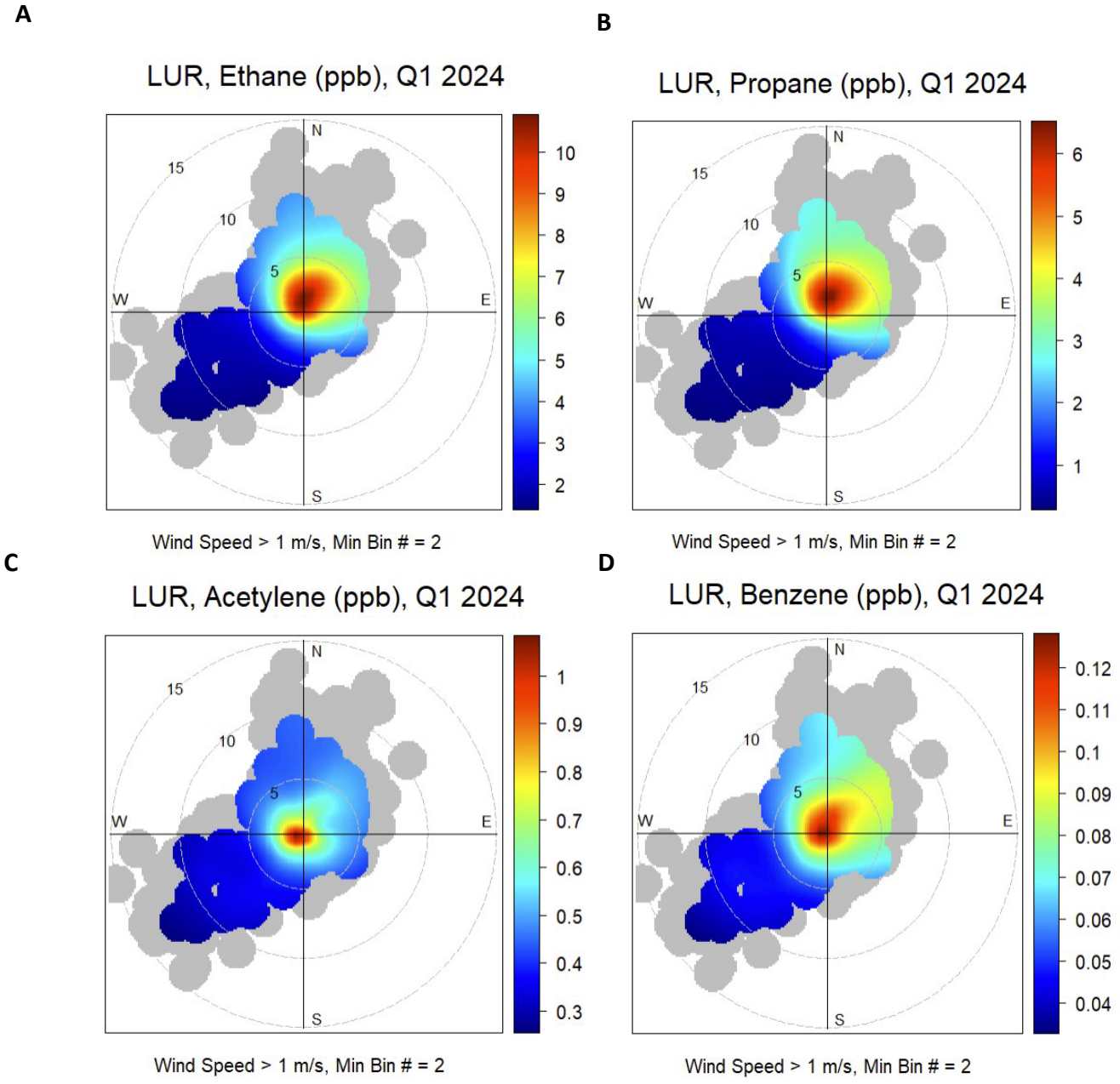


Figure 14:
Comparison of (A) ethane, (B) propane, (C) acetylene, and (D) benzene occurrences as a function of wind speed and direction at LUR during Q1 2024.

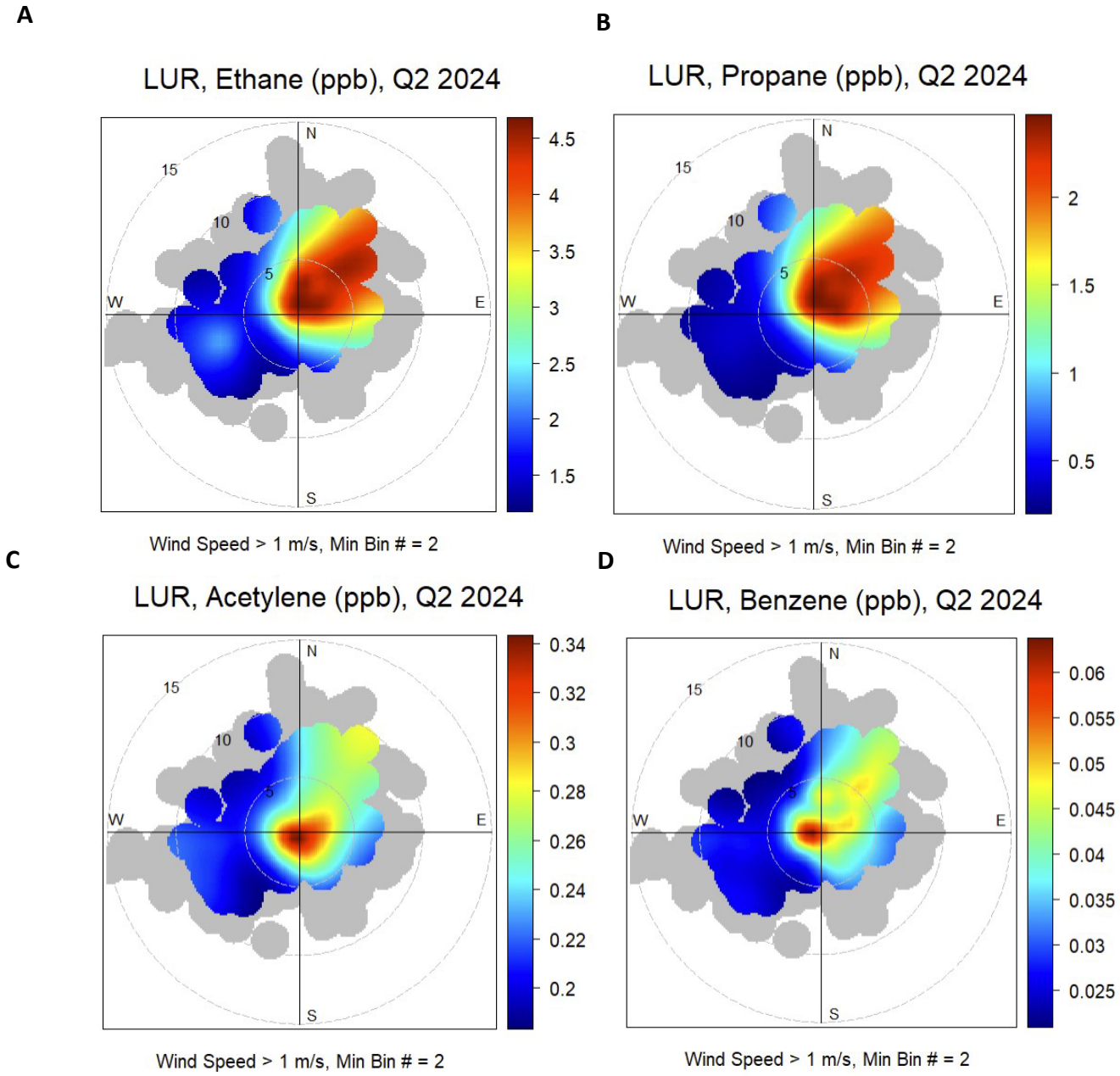


Figure 15:
As in Figure 14, except for Q2, 2024.

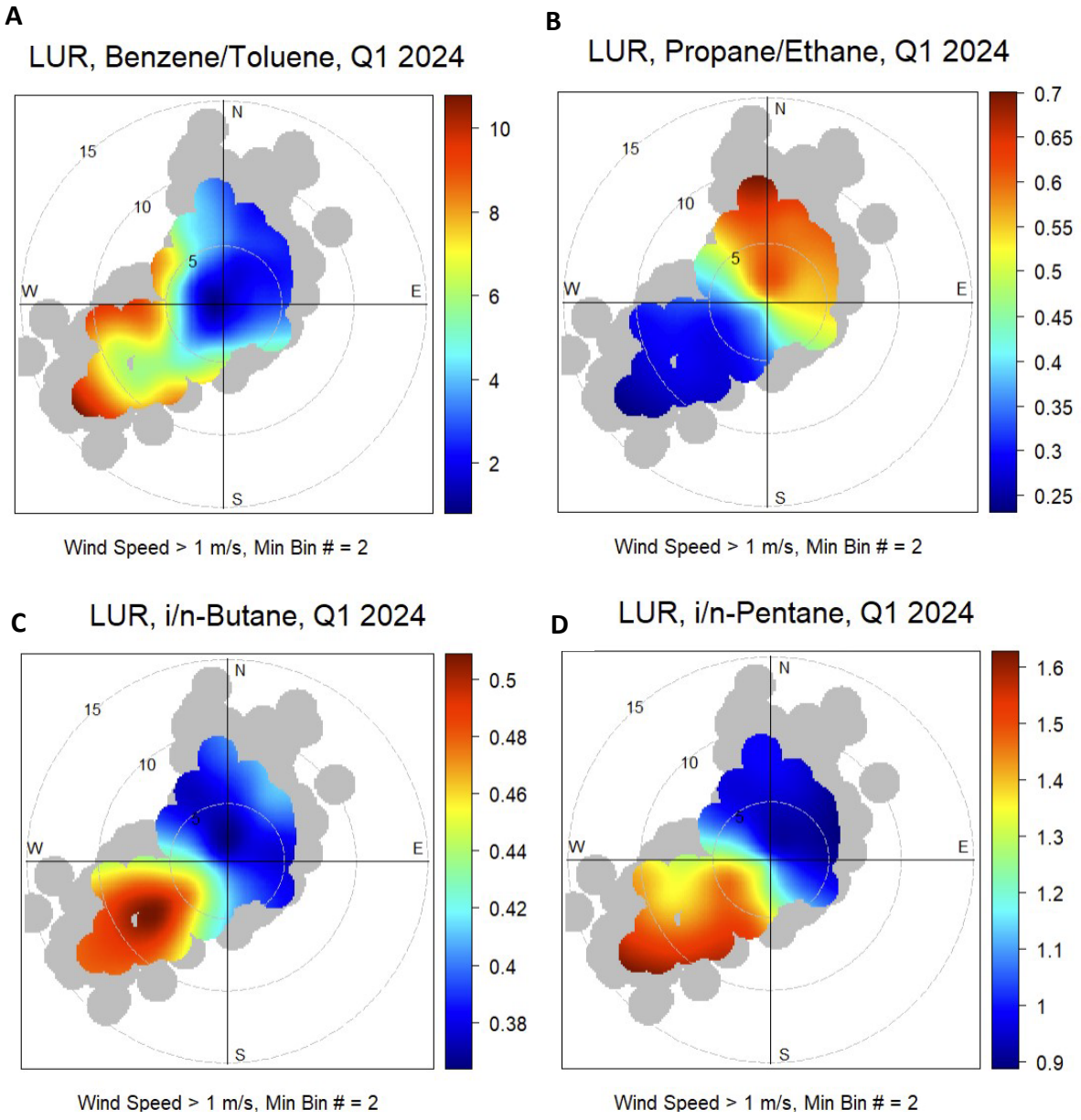


Figure 16:
Ratios of selected VOC pairs as a function of wind direction and wind speed during Q1, 2024. These analyses show clear differences in the chemical signatures in air transported from different directions to the monitoring station.

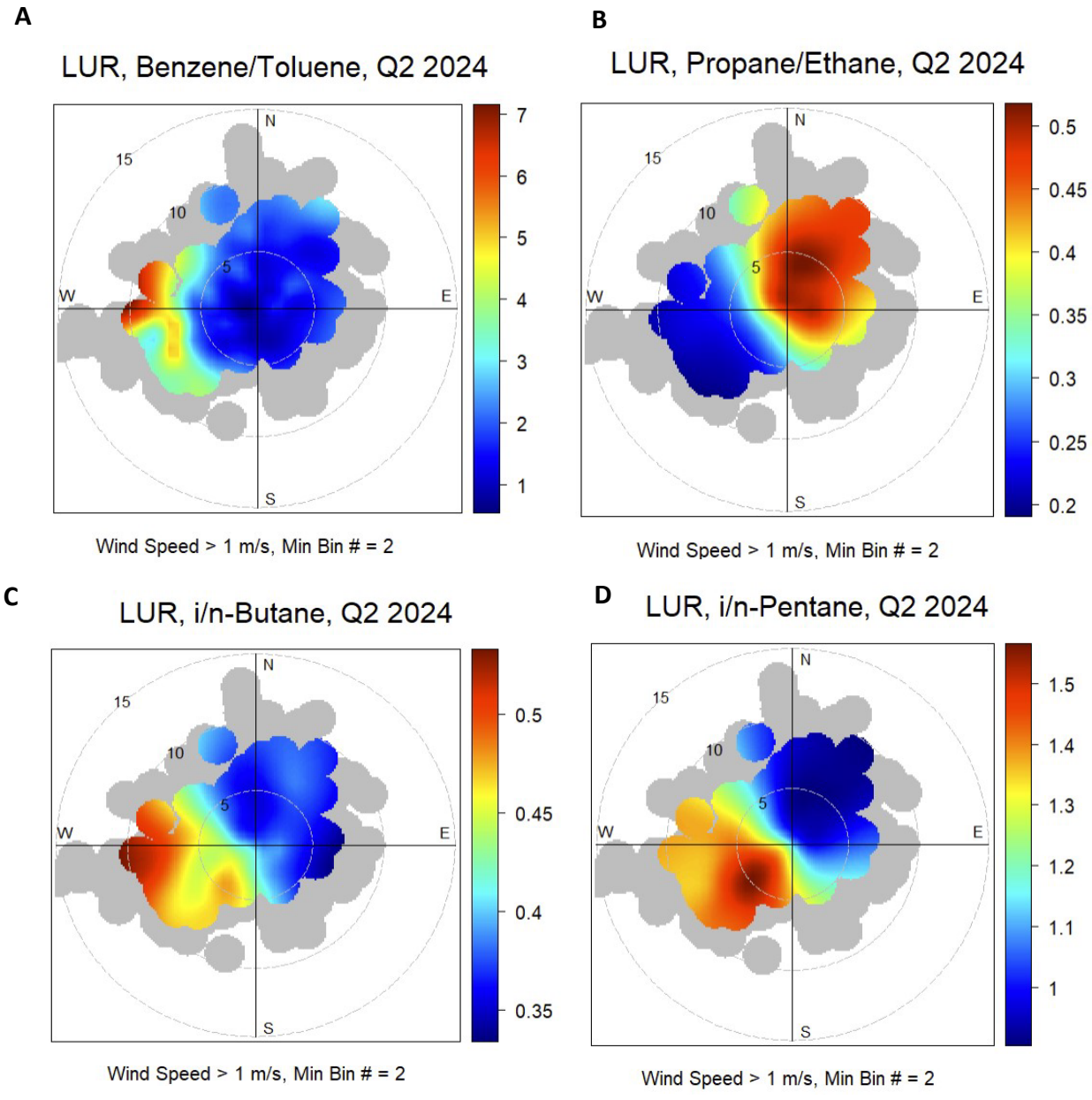


Figure 17:
As in Figure 16, except for Q2, 2024.

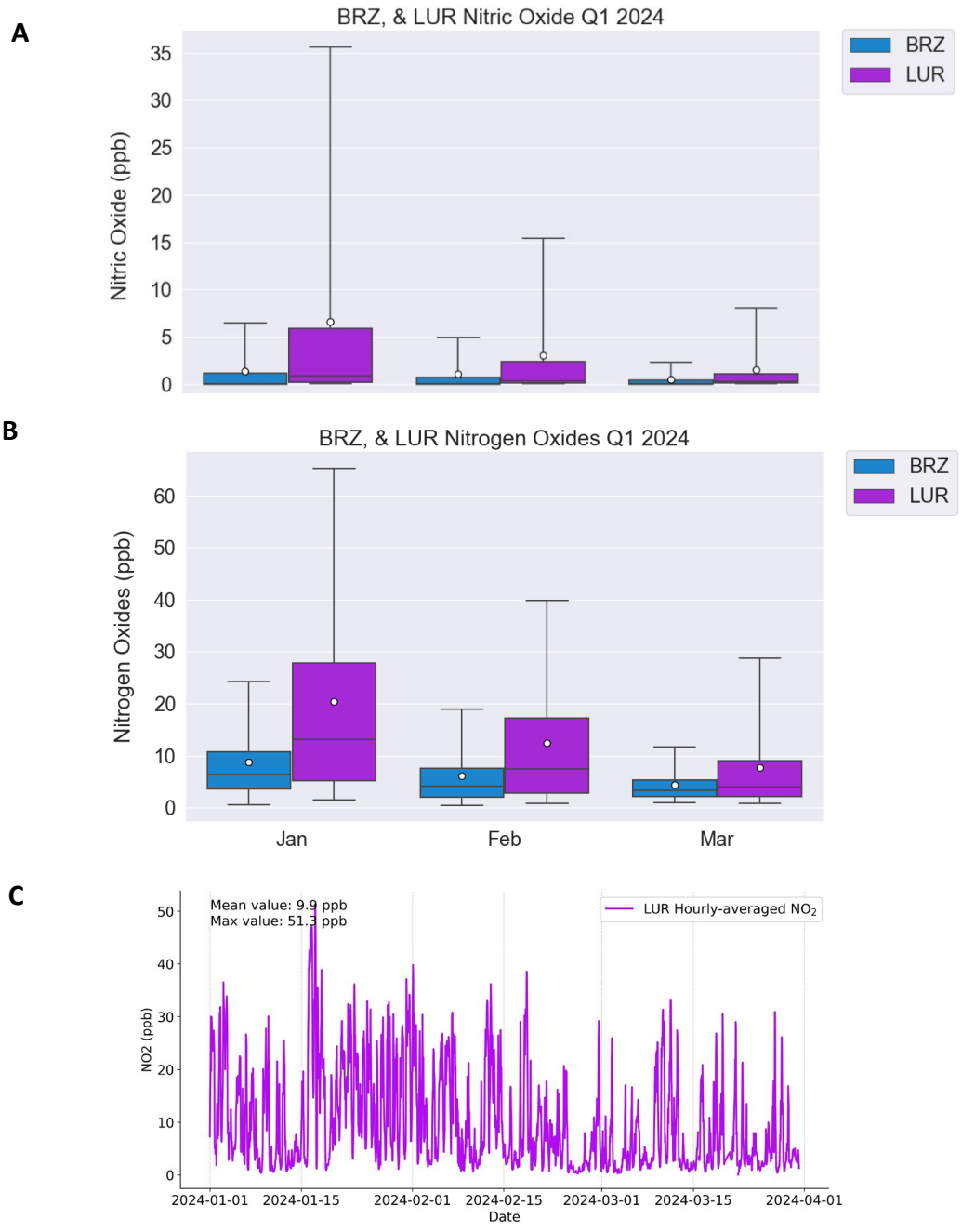


Figure 18:
Comparison of (A) nitric oxide and (B) nitrogen oxides at BRZ and LUR during January - March 2024. See Figure 1 for explanation of the box whisker plot format. (C) LUR hourly-averaged NO_2 for Q1 2024.

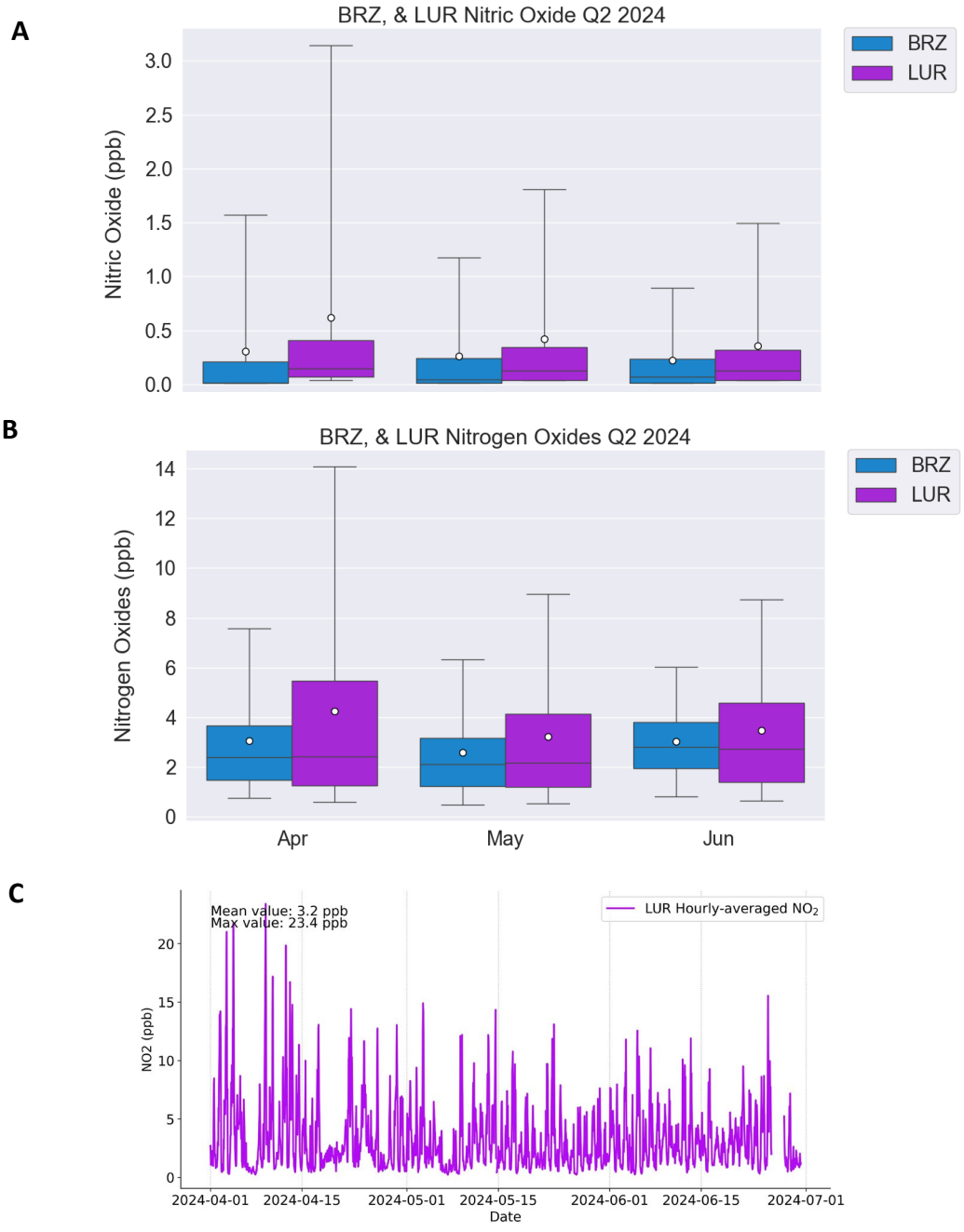


Figure 19:
As in Figure 18, except for Q2, 2024.

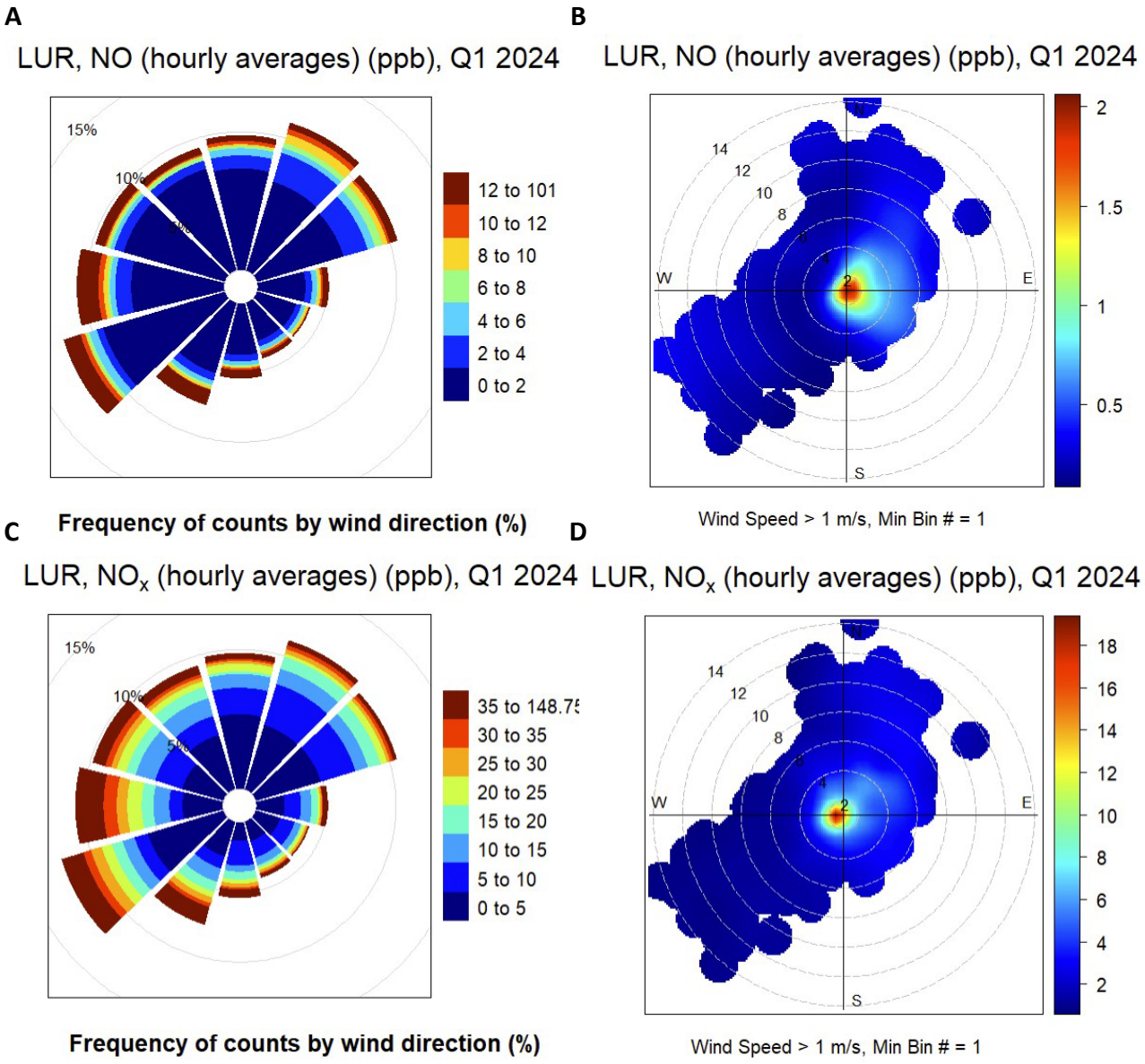


Figure 20:
Dependence of (A, B) nitric oxide and (C, D) nitrogen oxides as a function of wind speed and direction at LUR during January - March 2024. As seen in the prior data, the City of Longmont, located to the west of LUR, appears to be the strongest upwind source for NO_x.

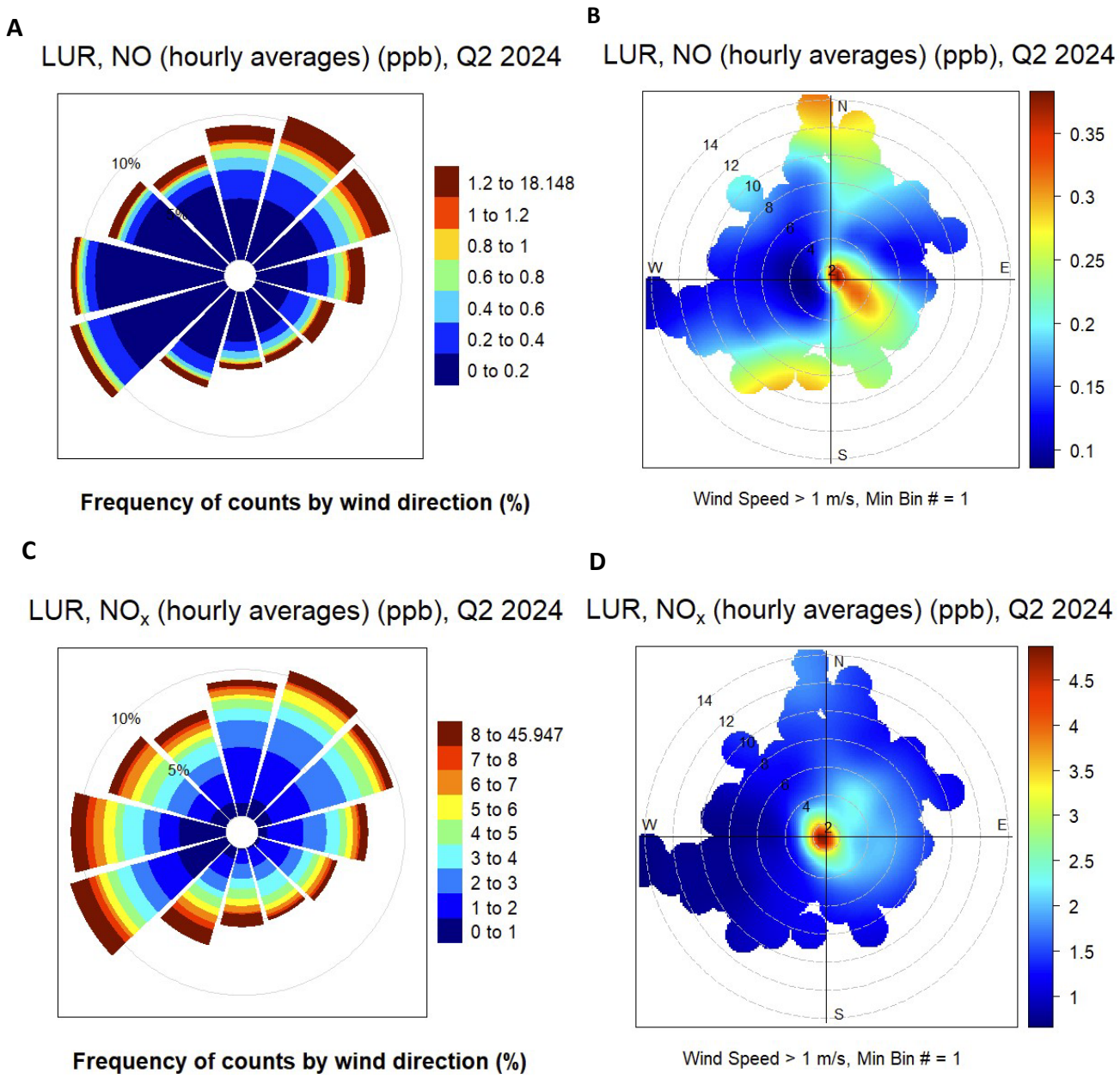
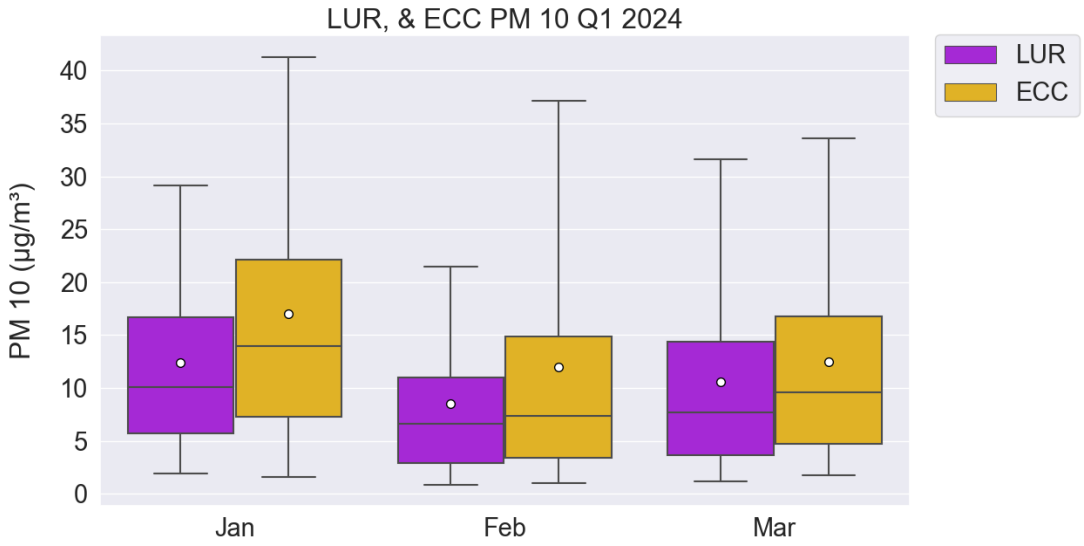


Figure 21:
As in Figure 20, except for Q2, 2024.

A



B

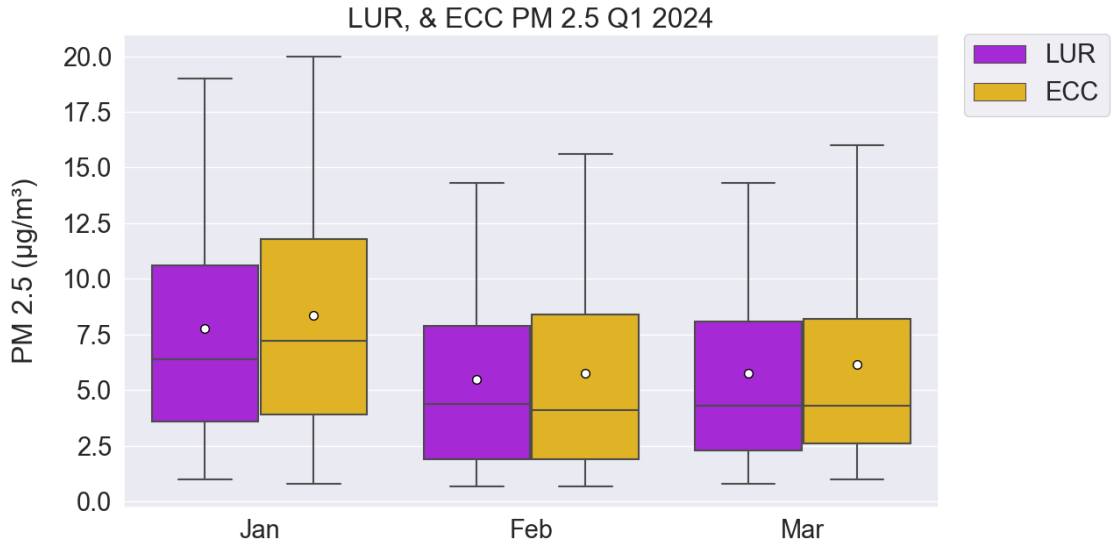
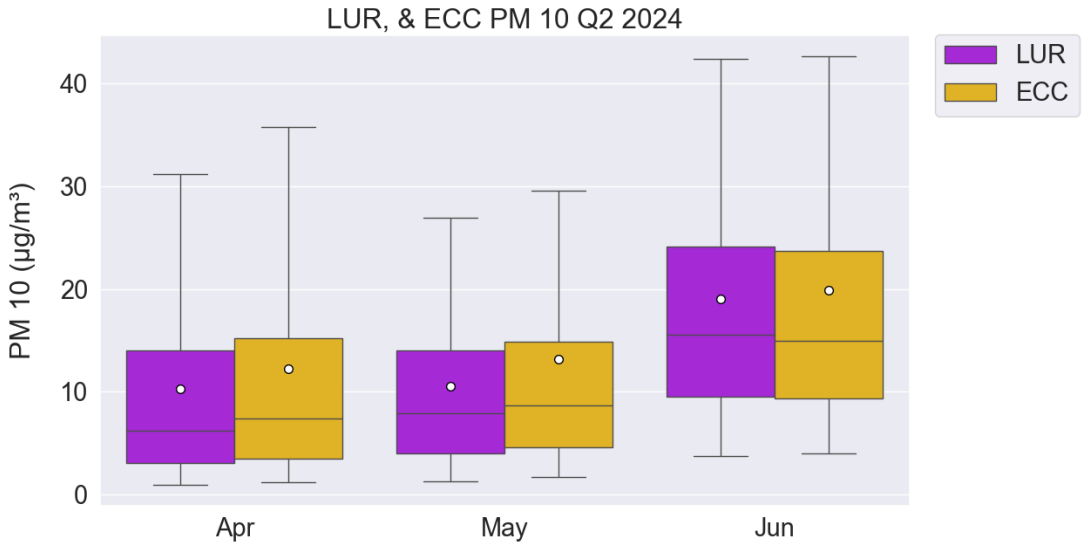


Figure 22:
Comparison of (A) PM 10 and (B) PM 2.5 at LUR and ECC, during January - March 2024. See Figure 1 for explanation of the box whisker plot format.

A



B

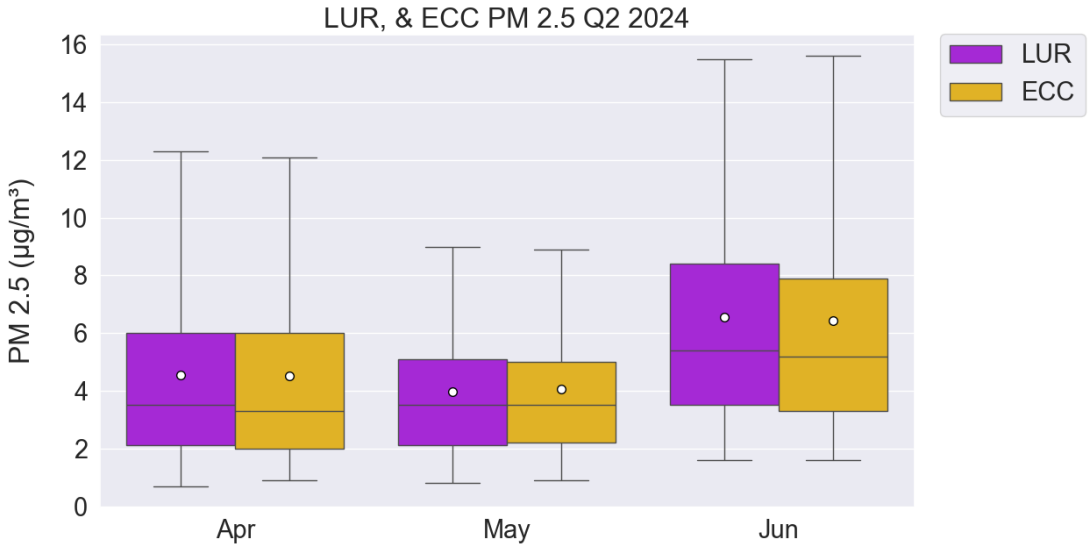
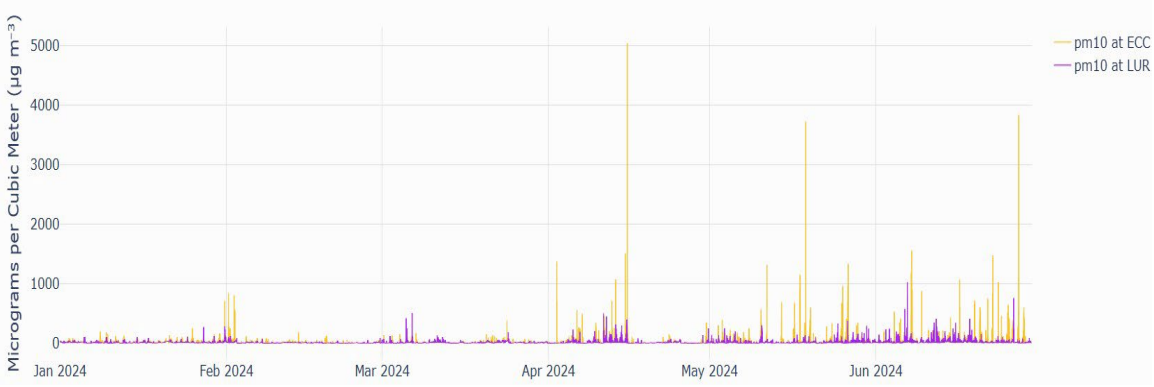


Figure 23:
As in Figure 22, except for April – June, 2024.

A



B

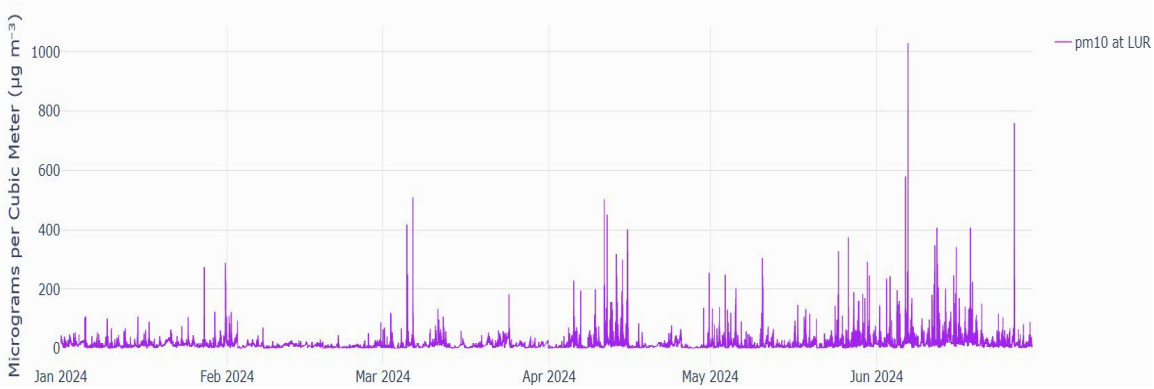


Figure 24:
Full Q1 and Q2, 2024 record of PM 10 for (A) select stations and (B) LUR only.

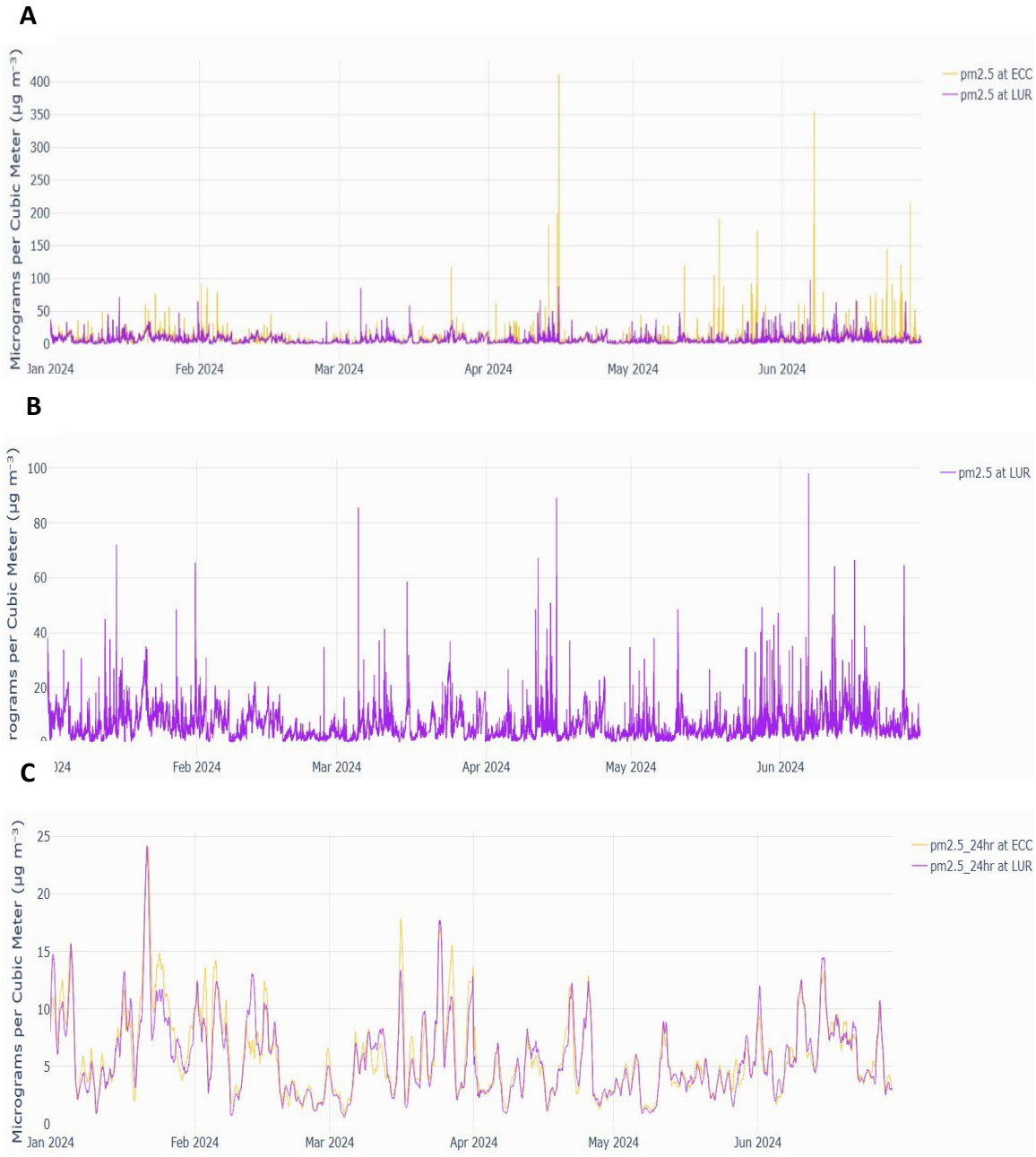


Figure 25:
Full Q1 and Q2, 2024 record of PM 2.5 for (A) select stations, (B) LUR only, and (C) PM 2.5 24-hour averages, compared to ECC.

Figure 26:
CDPHE particulate matter monitor at the Longmont Municipal Building (April 2024).