Boulder Atmosphere Innovation Research

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August 16, 2021

To:

City of Longmont
350 Kimbark Street
Longmont, CO 80501

Attn: Dr. Jane Turner

Re: Longmont Regional Air Quality Study – Year 2021 Quarter 2 Report

Dear Dr. Turner,

Please find included with this letter the April – June (Quarter 2) 2021 report for our work on the Longmont Air Quality Study. The monitoring data and data interpretations are presented.

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

Sincerely,

Detlev Helmig

Boulder AIR LLC

2021 Quarter 2 (April – June) Report

Longmont Air Quality Study

Executive Summary

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

This report includes graphical analyses of all data acquired at the Longmont Municipal Airport (LMA) and Longmont Union Reservoir (LUR) during April-June, i.e. Quarter 2 (Q2), 2021. In addition, data comparisons and analyses of selected events that resulted in enhanced concentrations are presented. LMA and LUR data are compared with each other and also with concurrent observations from the Boulder Reservoir and the Broomfield Soaring Eagle Park, Livingston and North Pecos sites.

The ozone National Ambient Air Quality Standard (NAAQS) (8-hour average >70 ppb) was exceeded eight times during Q2, inclusive, at several stations along the Front Range, including LMA and LUR. After a quiet April and May, the hot, dry weather in June led to high hourly ozone values and exceedances of the NAAQS at LMA or LUR on 8 days in June, 2021 (June 7, 8, 10, 12, 13, 14, 15, 17). On June 13, LMA was the only station in the Boulder A.I.R. network to exceed the NAAQS. The same was true for LUR on June 7 and June 17.

The NAAQS for fine particulate matter, PM_2.5, was not exceeded this quarter. In general, lower concentrations of many species were measured in Q2 compared to Q1, likely due to enhanced vertical mixing as winter weather, with strong temperature inversions that reduce vertical mixing, gave way to spring and summer weather.

Table of Contents

1. Project Scope and Goals

No changes from Q1, 2021 report.

2. Overview of the Monitoring Program

No major changes from Q1, 2021 report.

3. Air Quality Monitoring Study Updates

No changes from Q1, 2021 report.

4. Data Quality Assurance/Quality Control Process

Ozone monitor calibration checks: The ozone monitors are going through an automated zero and span check every day against an ozone calibrator. The span check is setup at 80 ppb. Another daily check at 50 ppb is performed as well.

During this quarter, all zero checks at LUR and LMA were below the 3 ppb limit and all span checks were within 3% of the 80 ppb target.

On 06/18/2021, the monitor at LMA (49C#13) passed the quarterly multipoint calibration against the ozone calibrator (49C#20) with an offset of 0.4 ppb (upper limit 3 ppb, lower limit -3 ppb) and a slope of 0.993 (upper limit 1.03, lower limit 0.97). Linearity was excellent as well with an R^2 of 1.0000. The calibrator in use (49C#20) was certified by the EPA as a level 2 standard on 05/20/2021. A calibration graph is shown in Figure 20a.

On 06/20/2021, the monitor at LUR (49C#12) passed the quarterly multipoint calibration against the ozone calibrator (49C#20) with an offset of 0.5 ppb (upper limit 3 ppb, lower limit -3 ppb) and a slope of 0.999 (upper limit 1.03, lower limit 0.97). Linearity was excellent as well with an R^2 of 1.0000. The calibrator in use (49C#20) was certified by the EPA as a level 2 standard on 05/20/2021. A calibration graph is shown in Figure 20b.

Ozone monitor maintenance: During this quarter, the inlet filter for the ozone monitor sampling line at both sites was changed on 05/06/2021 and 06/22/2021. The filter is changed every 2 months. No other maintenance on the instruments was necessary during this quarter.

5. Website Development

During Q2 there were 1672 visits to the Longmont Air Quality Now website.

- We transitioned to a new graphing package that allows the user to hover over a curve and view the curve values at specific points in time.
- We added an i/n-pentane ratio graph and combined certain other curves to support analysis (NO and NOx, fine particles and total particles, ethane and propane, butane isomers and acetylene, benzene and toluene), all at LUR.
- The website layout was changed to improve users' ability to view the data graphs on mobile devices.

6. Data Archiving

No changes from Q1, 2021 report.

7. Data for Quarter 2, 2021

The data that were recorded in Q2, 2021, are included in this report in graphical time series format in Supplement A (LMA) 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 both sites are shown together in a set of time series graphs. These graphs are presented to highlight similarities and differences between the two locations.

8. Selected Data Examples and Preliminary Interpretations

Ozone

The full Q2 ozone records for LMA and LUR are presented in Figures SA8 and SA9 for LMA and SB8 and SB9 for LUR. Through April and May, the hourly ozone values tended to range between 20 and 60 ppb. Hot, dry, summertime conditions in June led to high hourly ozone values, including exceedances of the 70 ppb 8-hr ozone NAAQS at LMA or LUR on 8 days in June, 2021 (June 7, 8, 10, 12, 13, 14, 15, 17). On June 13, LMA was the only station in the Boulder A.I.R. network to exceed the NAAQS. The same was true for LUR on June 7 and June 17. More information about these high ozone days is presented in Section 9.

Figure 1 presents a statistical analysis of the full Q2 ozone data, comparing the Longmont data with observations from Boulder Reservoir (BRZ) and Broomfield Soaring Eagle Park (BSE). As seen in previous quarters, LUR had slightly less ozone than the other stations.

CO_2

The full Q2 CO_2 records are available in Figures SA6 and SB6 for LMA and LUR, respectively. The statistical comparison of the monitoring data is presented in Figure 2. The wind speed/wind direction analyses are shown in Figure 3. There was more CO_2 in the second half of the quarter at LMA and LUR. Also, there was more variability and higher extremes in May and June at both Longmont stations, compared to BSE. The means and medians were in a similar range as in Q1 2021 (between 420 and 440 ppb). The results from the wind direction/speed analyses comparing Q2 2021 to the previous three quarters (Figure 4) show that there is still a strong source of CO_2 to the west of LMA.

Figure 5 and Table 1 provide comparisons of CO_2 data at LUR between Q2 2020 and Q2 2021. The increase in CO_2 mean values between Q2 2020 and Q2 2021 was 3.9 ppm, larger than the global increase in CO_2 between April 2020 and April 2021 of approximately 2.9 ppm. Over 130,000 individual 5-min annual data points were considered in the comparison. In 2021, CO_2 mean values and all percentile values were larger than in 2020. As always, there could have been differences in meteorology during these two years that drove the differences in observed concentrations of atmospheric trace gases.

Methane

The full Q2 methane records are available in Figures SA7 and SB7 for LMA and LUR, respectively. In the statistical comparisons among the stations, the pattern seen in Q1 was retained with BRZ having the least amount of methane, LUR the most, and BSE the second highest amounts (Figure 6). Median and 95th percentile values of methane were greatest at LUR. Wind rose and heat map analyses are shown in Figure 7. Heat map plots for both sites show a source to the NNE at higher wind speeds not seen in Q1 2021.

The Q2 2020 versus Q2 2021 comparison of methane at LMA is presented in Figure 8. Numerical results of this analysis are included in Table 1. The increase in mean methane values of 18.8 ppb between Q2 2020 and Q2 2021 at LMA, when interpreted against the approximately 13 ppb increase in the global methane background between March 2020 and March 2021, indicates a greater increase between quarters at LMA than seen globally in March. Mean values and all percentile values of methane, except for the 95th percentile, increased from Q2 2020 to Q2 2021.

VOCs

The full Q2 LUR records for six selected VOCs are available in Figures SB10–SB16. Figure 9 presents a 16-month record of ethane, benzene, and acetylene from March 2020 – June 2021. These graphs show continued declines in the oil and gas tracers ethane and benzene relative to March 2020. Excluding some short-lived spikes in January and February 2021, the winter/spring/early summer observations of ethane and benzene have stayed relatively low, especially in March 2021 vs March 2020. Acetylene values peaked in the colder months.

The statistical comparison of the VOCs plotted in Figure 10 shows again how VOCs are overall higher at LUR in comparison to the other sites, as in the previous quarters, with the exception of benzene in June. Figure 11 and Table 1 show the comparison of Q2 2020 statistics for ethane and benzene compared to those of 2021. The mean values of ethane and benzene were nearly the same in 2021 as in 2020 (Table 1).

Wind speed/wind direction dependence results of ethane, propane, acetylene, and benzene are shown in Figure 12. Compared to Q1 2021 analyses, the heat map transport patterns are similar, but the amounts detected were much lower. These lower amounts are likely a result of more vertical mixing (which drives dilution of surface air by cleaner air that is mixed in from aloft) that occurs with higher temperatures in spring and summer.

The analysis of VOCs signatures, using VOC/VOC ratio values, are shown in Figure 13. At LUR a high benzene/toluene signature source appeared in the NE quadrant that was not seen in Q1 2021. For propane/ethane at LUR, the pattern in Q2 was also similar to that of Q1. The i/n- pentane ratio was also similar to Q1, but the i/n-butane ratio showed a clearer definition of a high signature value to the SW of LUR.

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. The time series data do not show much change in NO and NO_x over the course of Q2 after an initial drop-off in April. Thus, statistical analysis for NO &NOx (Figure 14) shows more variability in April. During each Q2 month, LUR measured the most NO_x among the stations. Overall, the amounts of NO and NO_x measured in Q2 was less than what was measured in Q1, again, likely a result of more vertical mixing in Q2. Dependency of NO and NO_x on wind direction and wind speed is presented in Figure 15. The resulting patterns are similar to what was seen in Q1.

Particulate Matter (PM)

PM10 and PM2.5 LUR Q1 monitoring results are presented in Figures SB19 and SB20. The 24-hour averaged PM2.5 data are available in Figure SB21 – there were no exceedances of the PM 2.5 NAAQS this quarter. The statistical comparison of LUR data with BSE data is presented in Figure 16. LUR had slightly larger median values of PM2.5 than BSE.

9. June High Ozone Days

Accumulation of ozone precursors and hot dry weather from June 7th to June 17th promoted ozone production that led to exceedances of the 70 ppb 8-hr ozone NAAQS on 8 days in June, 2021 (June 7, 8, 10, 12, 13, 14, 15, 17). On June 13, LMA was the only station in the Boulder A.I.R. network to exceed the NAAQS. The same was true for LUR on June 7 and June 17. BSE had the highest maximum ozone among the Boulder A.I.R. sensors on three of these days (June 10, 12, and 15, Figure 18 (top)). Temperature time series (Figure 18 (middle)) indicate how hot it was in the Denver metro area during this week in June. The temperature in Denver on June 15, 16, and 17 was equal to or above 100°F (38°C). Skies were clear on several of these days, as indicated by the solar radiation curves shown in Figure 18 (bottom). If the solar radiation curve is smooth, there were no clouds to interfere with the sunlight needed for photochemical production of ozone. A dome of high pressure over the Four Corners area caused these clear and stagnant conditions with periods of light winds (Figure 19), a known contributor to high ozone events in Colorado. Light winds reduce transport away from precursor sources, allowing ozone to accumulate as the abundant sunlight causes photochemical production of ozone. The high pressure, paired with light winds, also reduces upward vertical mixing, or transport, of ozone. Lastly, these meteorological conditions do not support sustained precipitation that will reduce ozone and its precursors, just thunderstorms that may have a temporary cleansing effect on air quality.

June 15th was particularly hot (temperature at least 100°F), with stagnant winds (< 4 m/s), and sunny skies, leading to the highest 8-hour ozone value of the period, at BSE, of almost 90 ppb. In Figure 20, we show ozone profiles taken by a research ozone profiling lidar stationed in Boulder, CO. This figure indicates that high ozone was not just at the surface, but existed in a deep layer, up to 1500 m above the surface later in the day. There are a couple of implications of having this deep layer of ozone. One is that if meteorological conditions cause easterly winds aloft, ozone well above the ground can be transported into the foothills, increasing surface ozone in mountain towns. The other implication is that at night, when the air near the surface becomes stable and ozone is removed by reaction with NO or deposition, the ozone that resides above this nighttime stable layer is unaffected by these processes, so remains aloft in light wind conditions and can be mixed downward to the surface the next day as heating and vertical mixing resume. The surface wind direction data in Figure 18 confirm the lidar profiling. During midday to late afternoon, surface winds on the high ozone days were mostly from the north to southeast. These flow conditions promote transport of VOCs-rich air that fuels efficient ozone production, largely originating from oil and gas emissions in Weld County, into the Front Range.

Table 1:
Comparison of the statistics of CO_2 and methane data (5-min averages) at LMA and ethane and benzene at LUR during Q2 of 2020 and Q2 of 2021. "Abs Diff" is the 2021 value minus the 2020 value. Data have been rounded to the 2nd decimal place.

Tables

Year		2020	2021	Abs Diff	% Diff
CH_4	count	130169	130289	120	0.09
(ppb)	mean	1991.8	2010.76	18.96	0.95
	std	61.69	55.62	-6.07	-9.84
	min	1886.2	1905.2	19	1.01
	5%	1912.6	1940.4	27.8	1.45
	25%	1950.7	1973.3	22.6	1.16
	50%	1980.9	2003.2	22.3	1.13
	75%	2020.9	2037.1	16.2	0.8
	95%	2109.1	2106.9	-2.2	-0.1
	max	3901.4	3323	-578.4	-14.83
CO_2	count	130169	130289	120	0.09
(ppm)	mean	427.14	431.14	4	0.94
	std	18.36	20.33	1.97	10.74
	min	390.33	393.79	3.46	0.89
	5%	409.5	412.3	2.8	0.68
	25%	414.03	418.12	4.09	0.99
	50%	420.97	424.27	3.3	0.78
	75%	435.18	436.66	1.48	0.34
	95%	463.53	474.08	10.55	2.28
	max	593.21	598.15	4.94	0.83
Ethane	count	1764	2042	278	15.76
(ppb)	mean	7.24	7.23	-0.01	-0.16
	std	13.02	6.18	-6.85	-52.58
	min	0.83	0.78	-0.05	-6.18
	5%	1.37	1.61	0.24	17.72
	25%	2.88	3.44	0.57	19.62
	50%	4.90	5.73	0.83	16.85
	75%	8.44	9.02	0.59	6.95
	95%	17.69	17.78	0.09	0.52
	max	320.20	100.20	-220.00	-68.71
Benzene	count	1764	2042	278	15.76
(ppb)	mean	0.07	0.08	0.01	11.19
	std	0.08	0.07	-0.01	-8.99
	min	0.00	0.01	0.01	0.00
	5%	0.02	0.02	0.00	11.21
	25%	0.04	0.04	0.01	17.84
	50%	0.06	0.06	0.01	9.68
	75%	0.09	0.10	0.01	7.56
	95%	0.17	0.20	0.03	17.80
	max	1.62	1.31	-0.31	-19.27

Figures

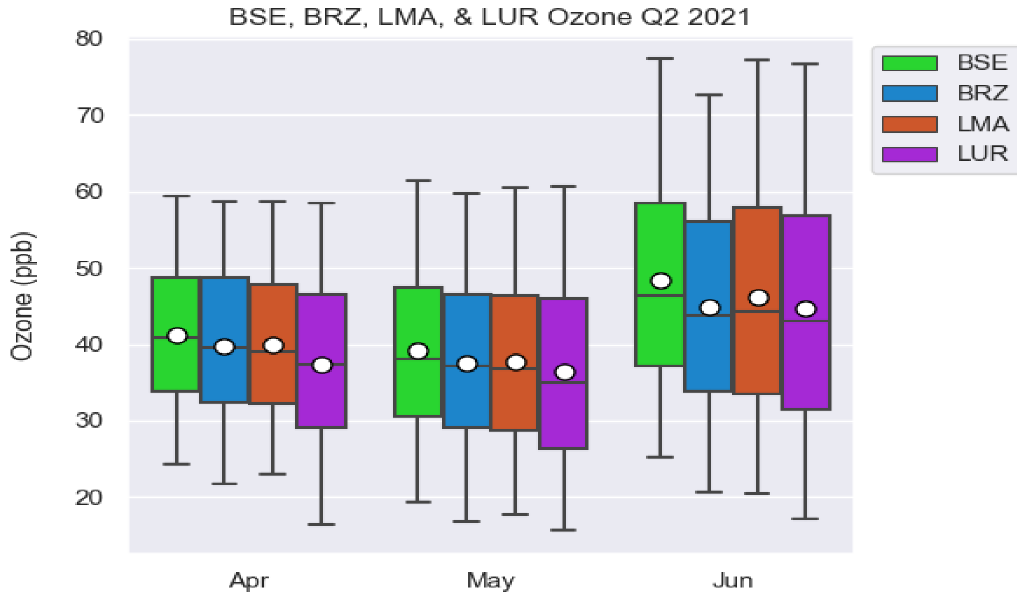


Figure 1:
Comparison of the ozone distribution at BSE, BRZ, LMA, and LUR during April – June 2021. These box whisker plots show the median value as the center line, the 25-75 percentile distribution as the colored boxes, and the 5-percentile and 95-percentile values as the whiskers. The white dot on each box illustrates the mean value at each site. Ozone at LUR showed the overall lowest percentile values.

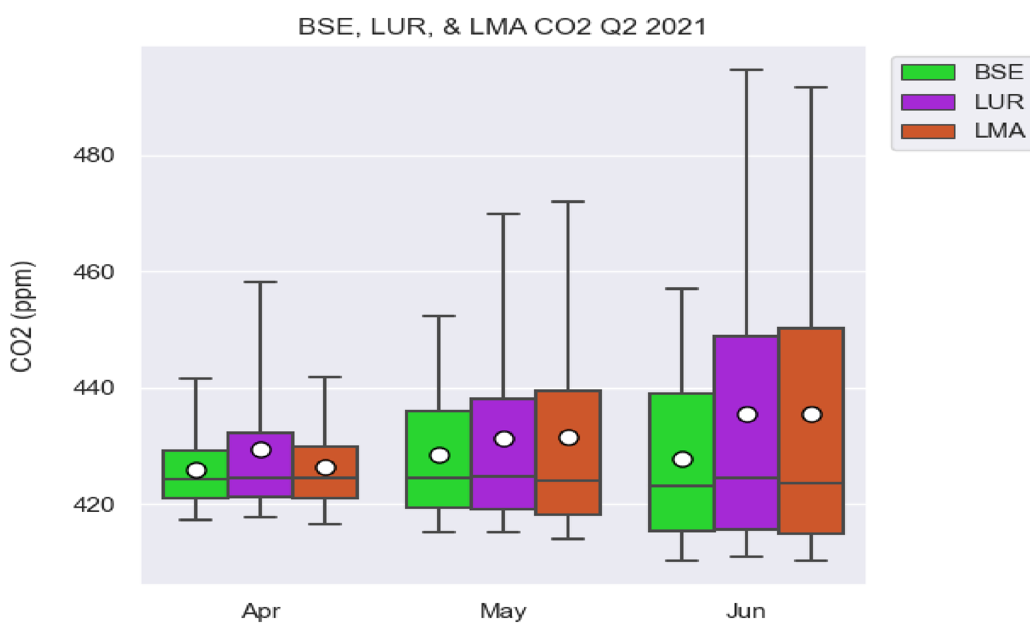


Figure 2:
Comparison of the CO_2 distribution at LMA, LUR, and BSE during April – June 2021. See Figure 1 for explanation of the box whisker plot format.

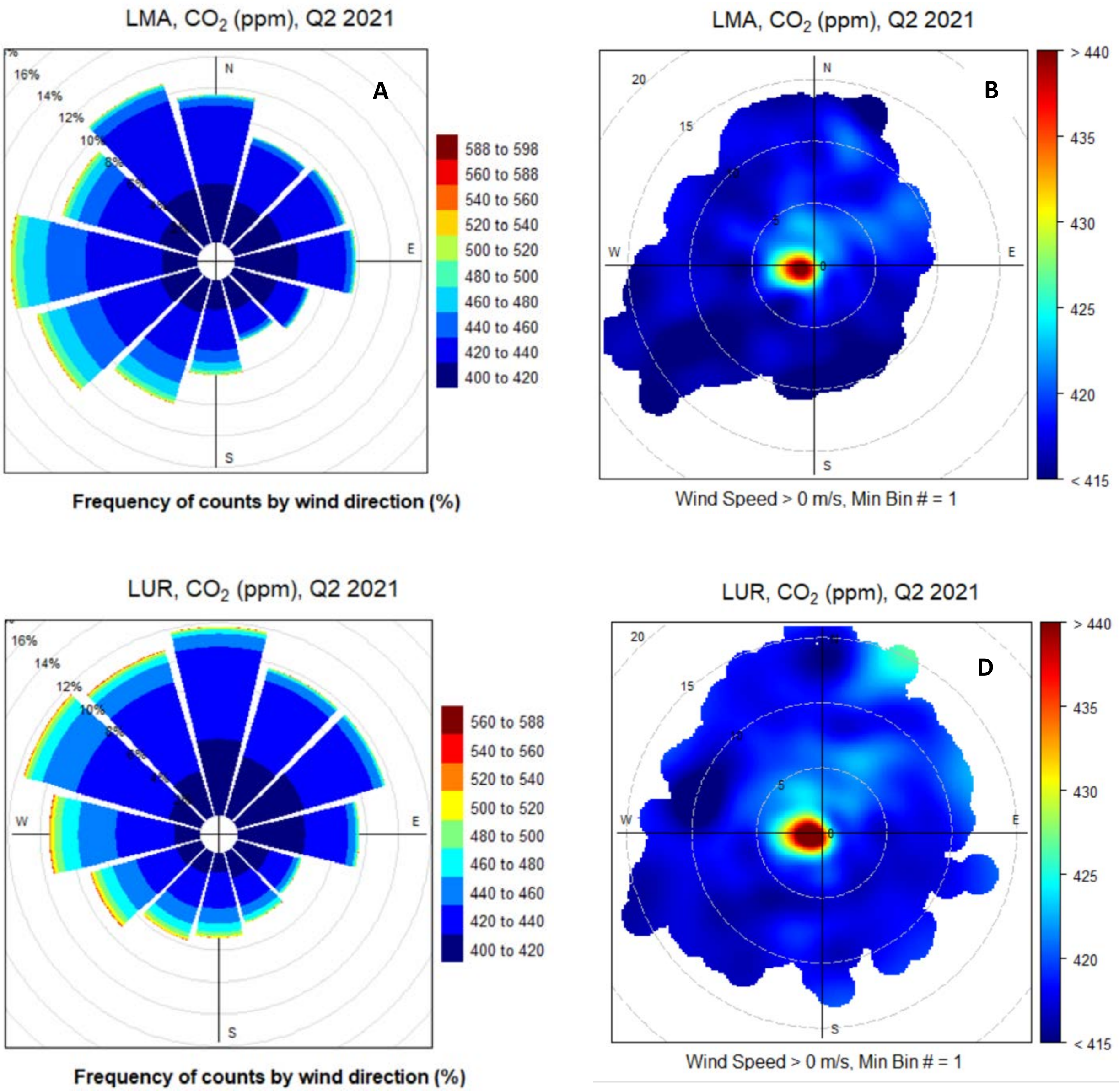


Figure 3:
Wind rose (left) and wind heat map analysis showing the dependency of CO_2 mole fractions at LMA (top, A, B) and LUR (bottom, C, D) during Apr – June 2021. The LUR site is east of the City of Longmont. These analyses suggests that the city is the primary source for enhanced CO_2 observed at LUR. These analyses also confirm the previously noted presence of a yet-to-be-identified CO_2 source to the west of LMA (see Figure 4).

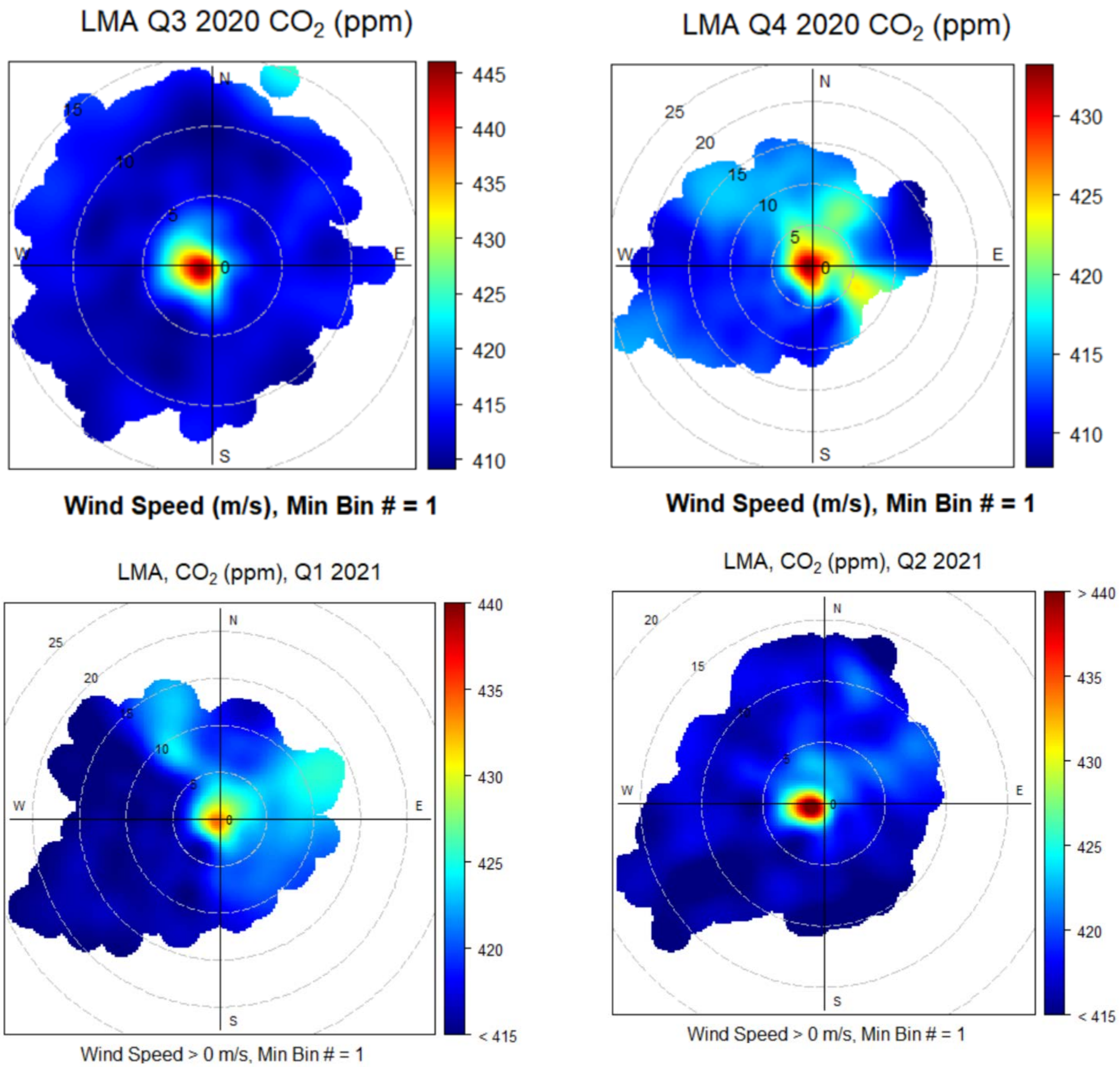


Figure 4:
Comparison of the wind speed/wind direction to observed CO_2 at LMA from Q3 2020 to Q2 of 2021. There is a consistent pattern with a relatively strong source to the west of the station throughout the year, with possibly additional sources emerging to the northwest and east of LMA.

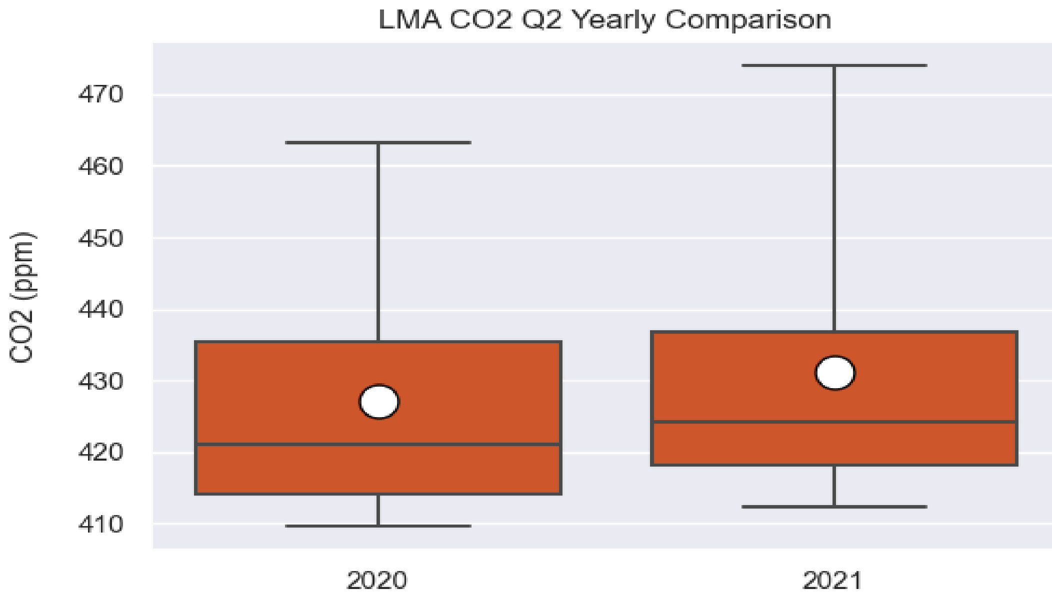


Figure 5:
Comparison of the CO_2 distribution at LMA during Q2 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The mean, median, and percentile values were all larger in 2021 than in 2020 (see Table 1 for the numerical values).

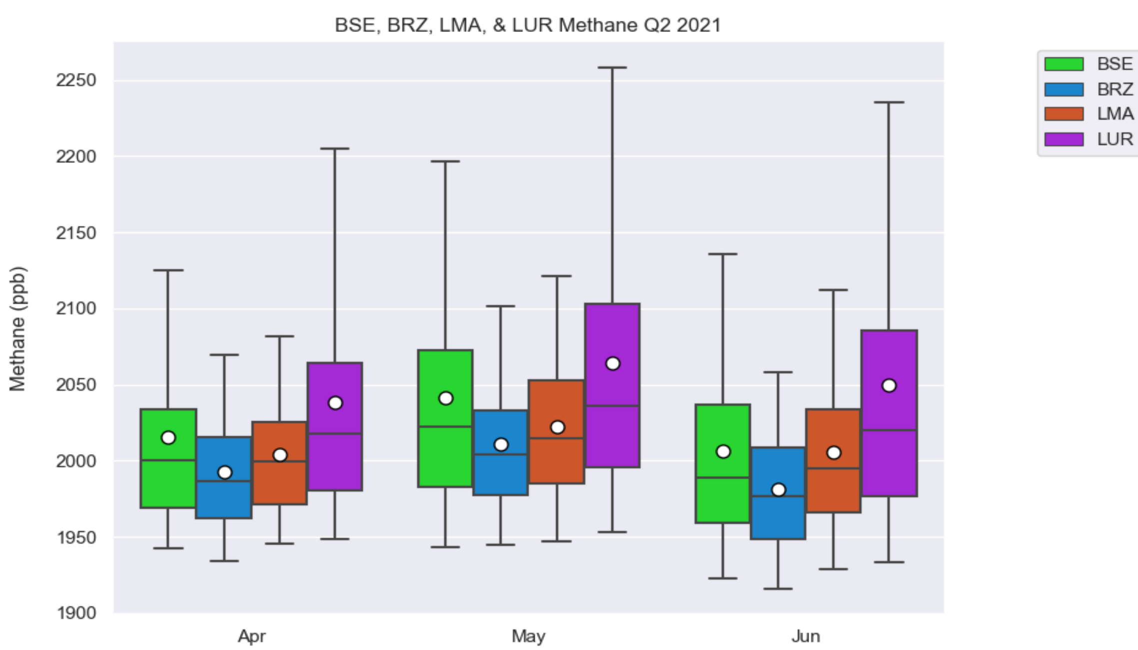


Figure 6:
Comparison of the methane distribution at BSE, BRZ, LMA, and LUR during Apr – June 2021. See Figure 1 for explanation of the box whisker plot format. Between the two Longmont sites, LUR has higher absolute values and variance.

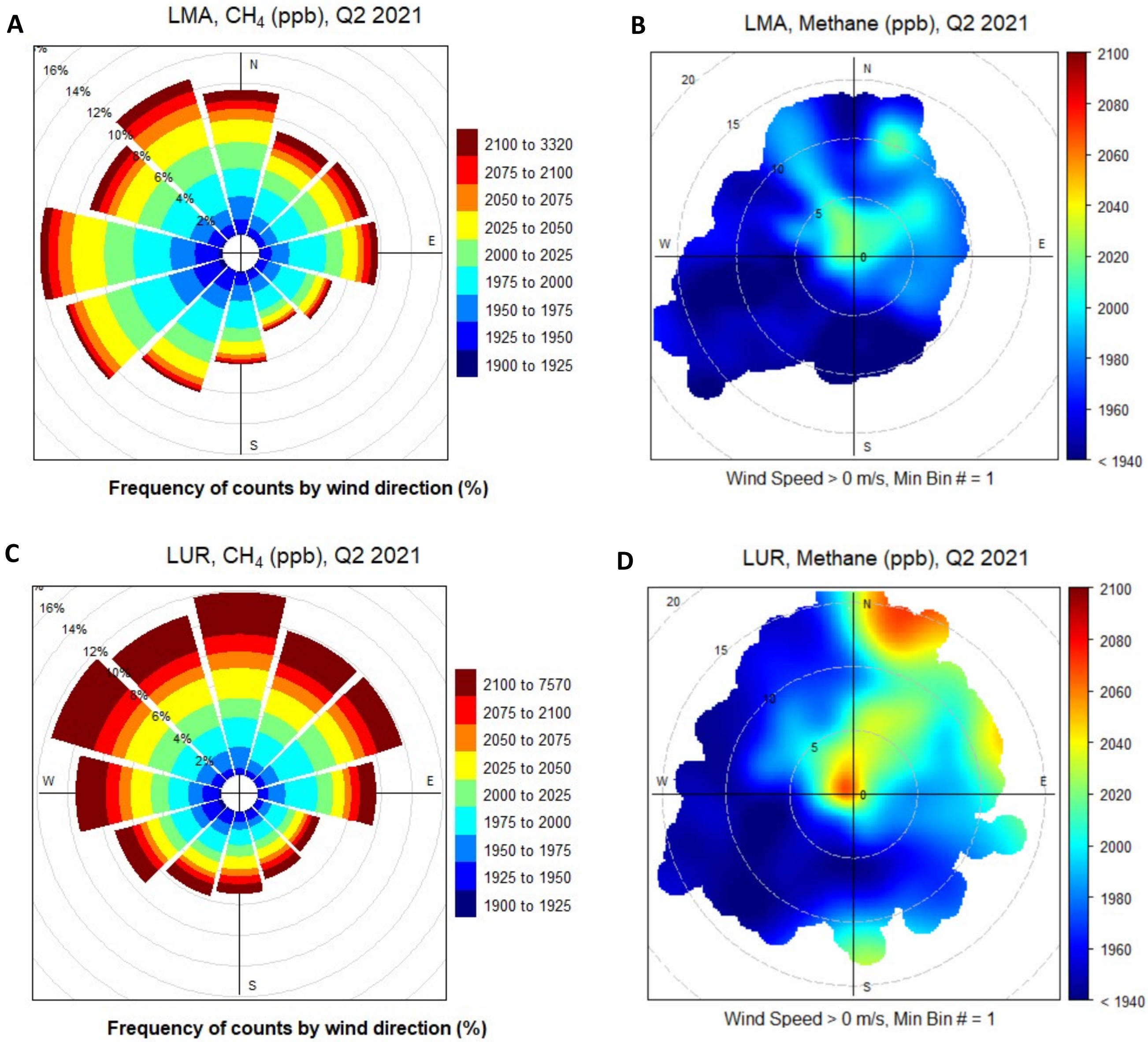


Figure 7:
Wind rose (left) and wind heat map analysis showing the dependency of CH_4 mole fractions at LMA (top, A, B) and LUR (bottom, C, D) during Apr – June 2021. Both sites show that transport of elevated methane mostly originates from the north to east sector.

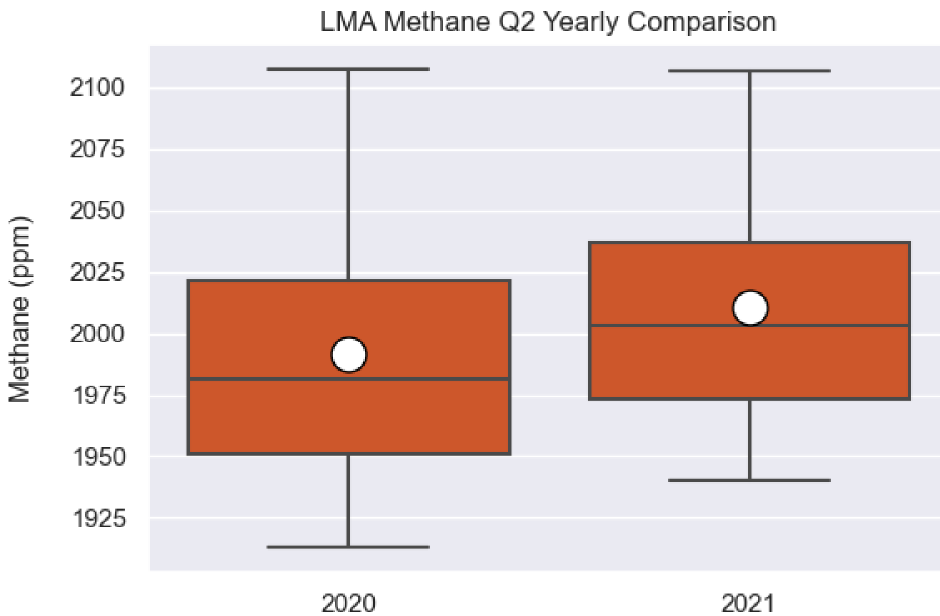
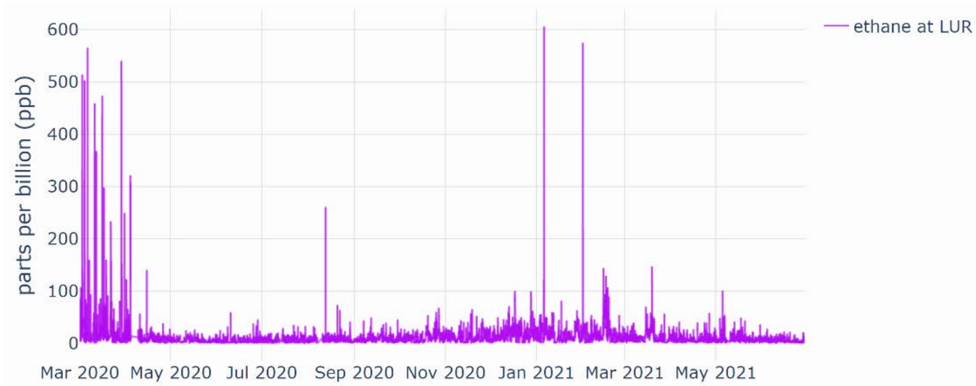


Figure 8:
Comparison of the methane distribution at LMA during Q2 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions are presented in Table 1. The mean, median, and lower percentile values were all larger in 2021 than in 2020.

A



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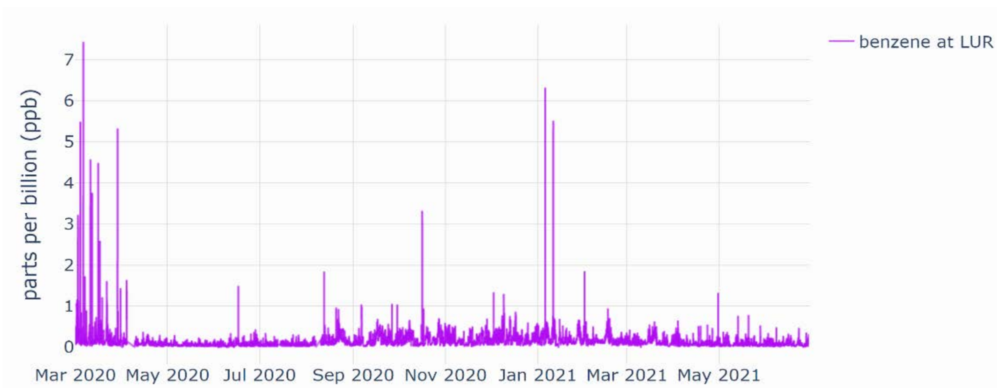

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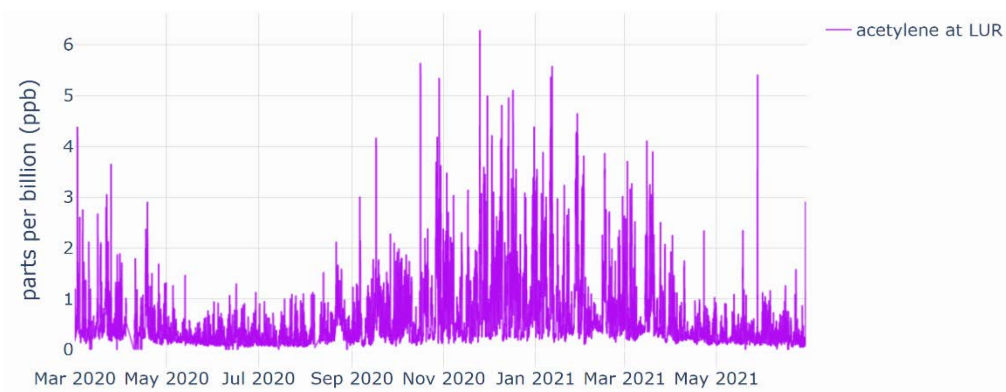


Figure 9:
Ethane (A, top), benzene (B, middle), and acetylene (C, bottom) at LUR between March 1, 2020 and June 30, 2021. Lower frequency and lower maximum values of concentration spikes during the summer are observed for all three compounds. These summer minima are mostly caused by the stronger mixing (dilution) of surface air from thermal convection. For acetylene, a compound that is mostly the result of combustion, similar peak patterns are observed for the spring, fall, and winter months. The behavior of the oil and gas tracer ethane is quite different. Here, occurrences of spikes were overall lower in the fall-winter, excluding the large spikes that occurred in January – February 2021. A similar pattern was observed for benzene. These time series suggest that there has been a continuing shift (decline) in the source strength for ethane and benzene.

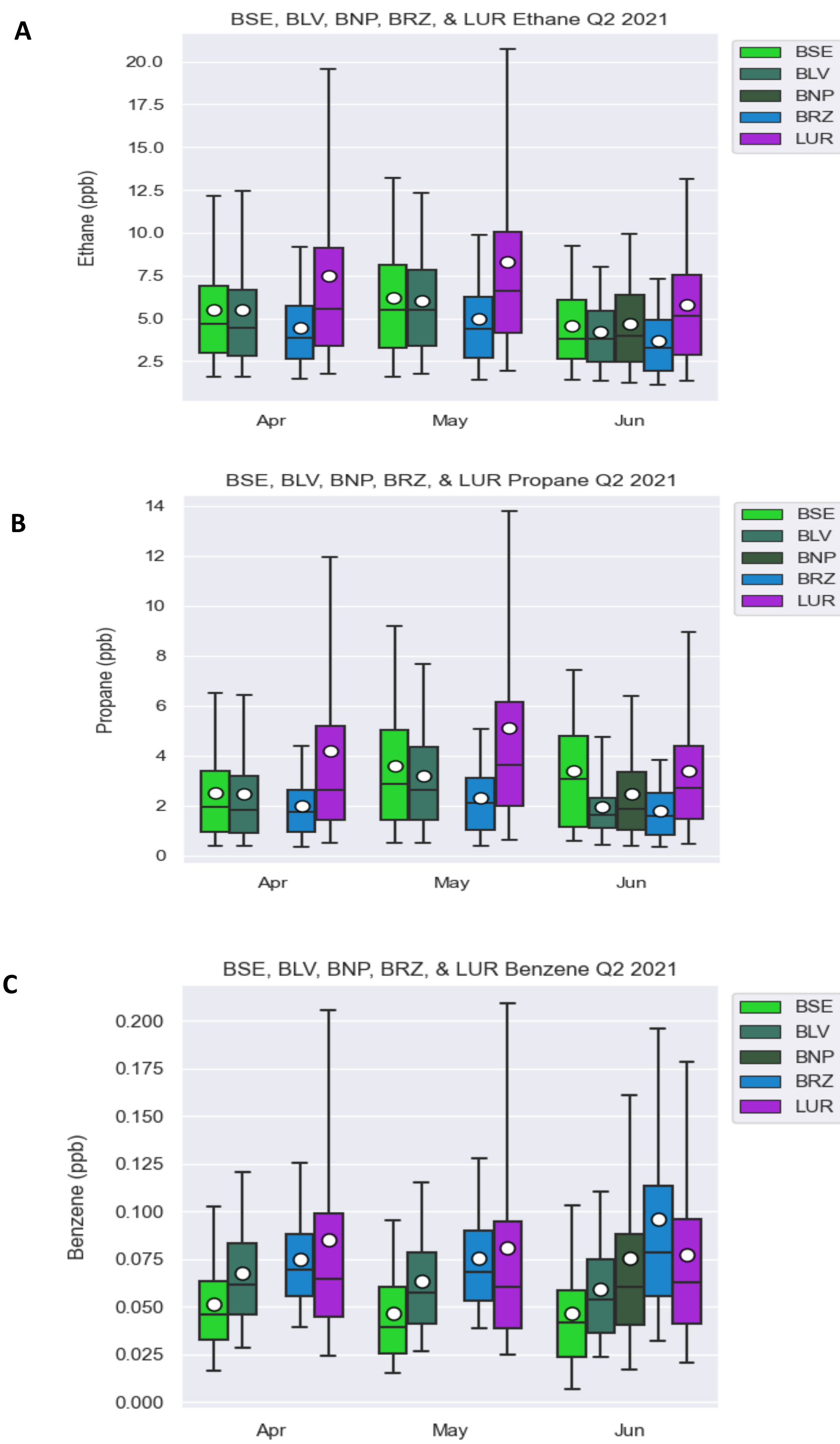
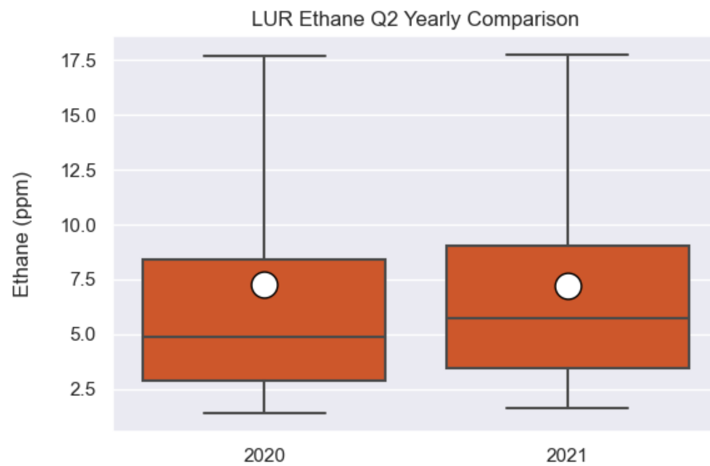


Figure 10:
Comparison of the distribution of ethane (A), propane (B), and benzene (C) at BRZ, BLV/BNP, BSE, and LUR during Q2. (Note that the Broomfield station BLV was moved to BNP on June 8/9. For this quarter, BNP data are shown in a darker green than used for BLV, to make the distinction between the two stations.) See Figure 1 for explanation of the box whisker plot formats. LUR tended to have the highest 95th percentiles, with the exception of benzene at BRZ in June. In all cases, measured amounts in Q2 2021 were less than what was measured in Q1 2021.

A



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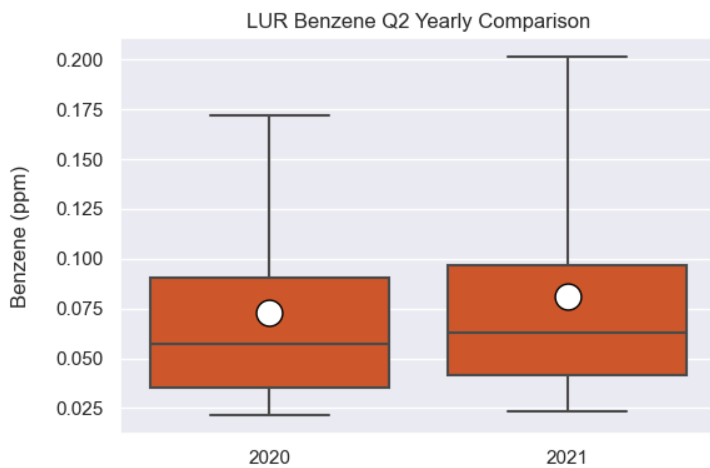


Figure 11:
Comparison of the ethane distribution (top, A) and the benzene distribution (bottom, B) at LUR during Q2 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions are presented in Table 1. The mean and median values were higher in 2021. 95th percentile values were larger for benzene in 2021 than in 2020.

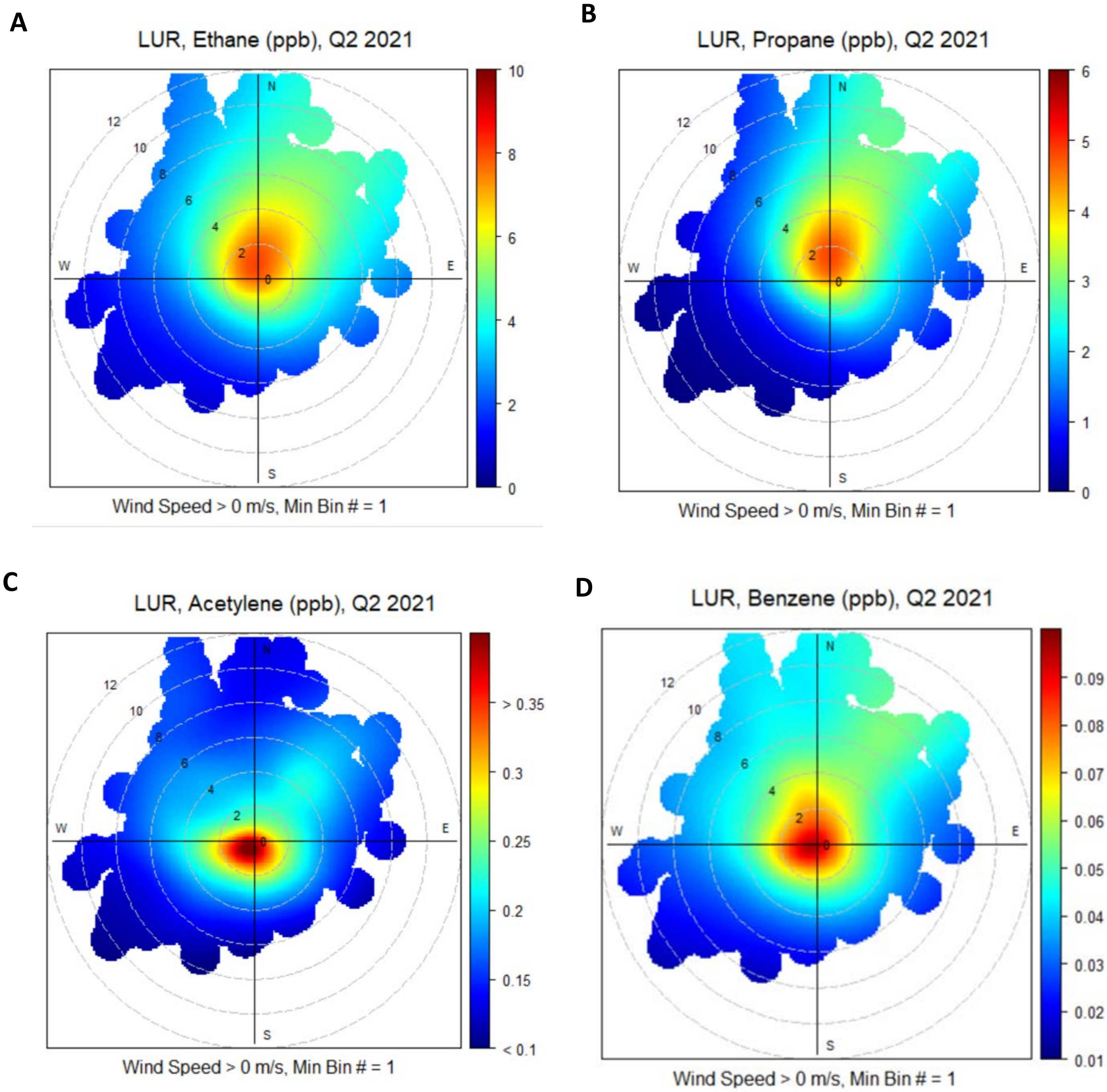


Figure 12:
Comparison of ethane (A), propane (B), acetylene (C), and benzene (D) occurrences as a function of wind speed and direction at LUR during Q2 2021.

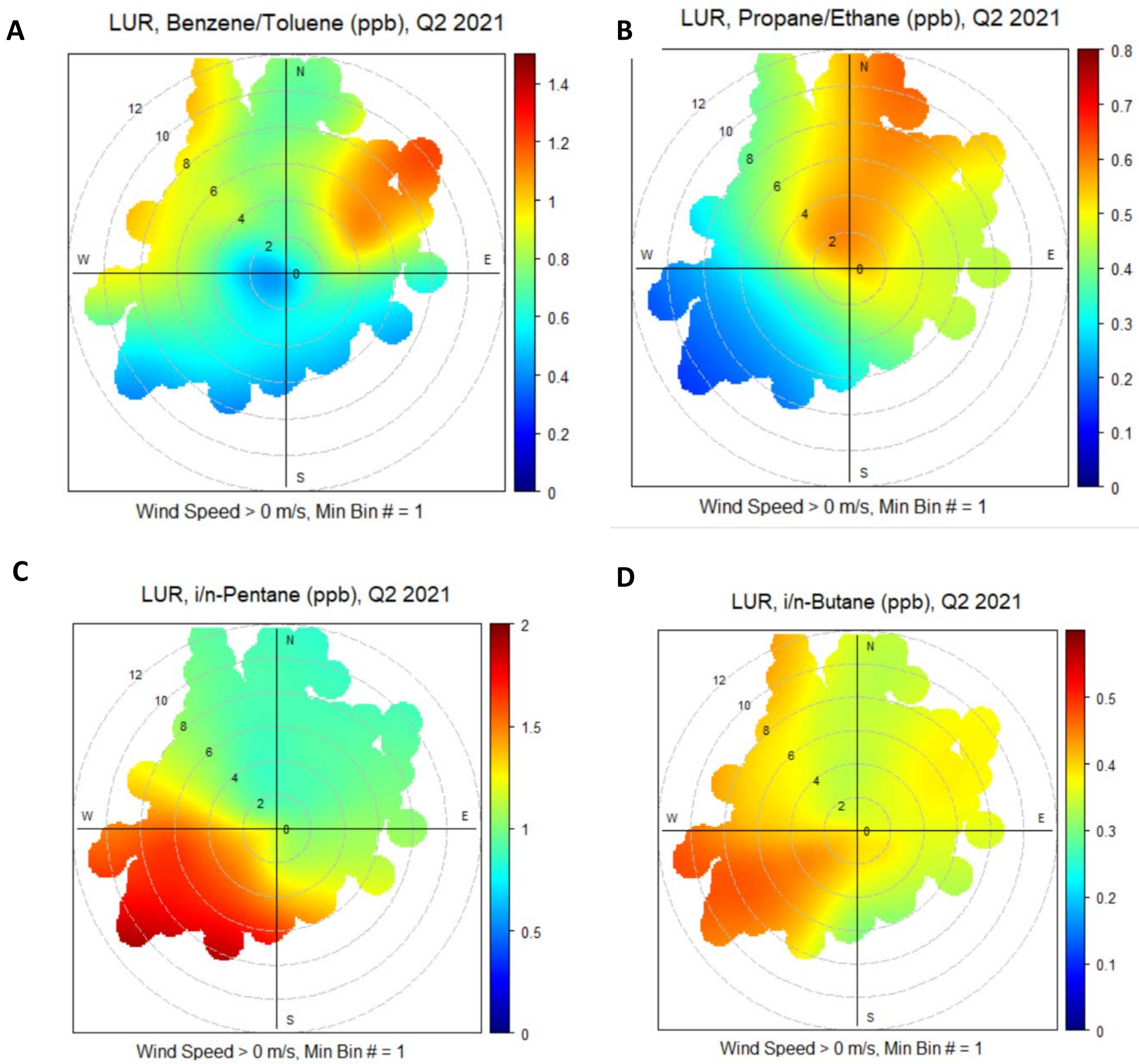
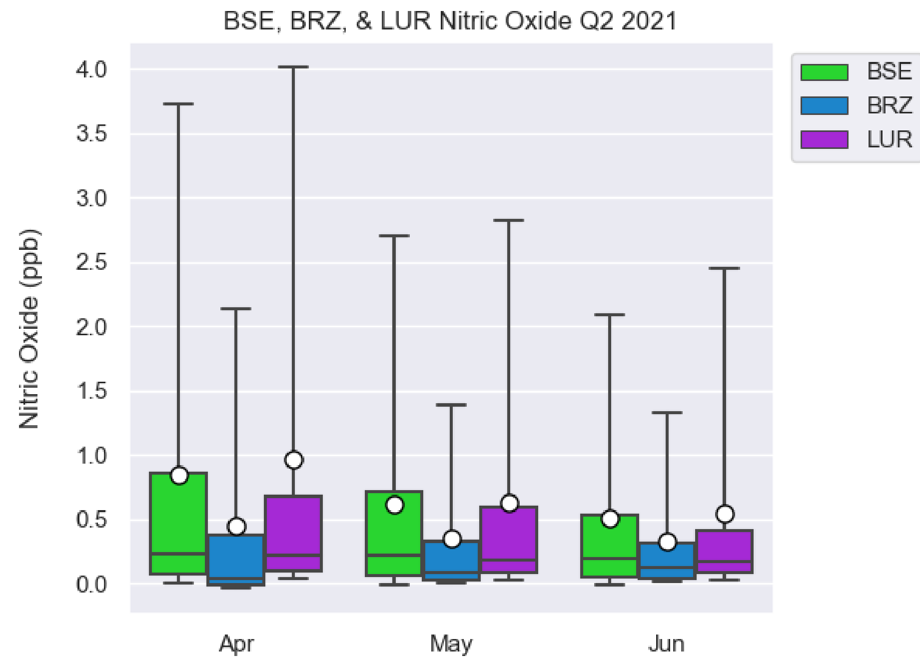


Figure 13:
Ratios of selected VOC pairs as a function of wind direction and wind speed during Q1. These analyses show clear differences in the chemical signatures in air transported from different directions to the monitoring station.

A



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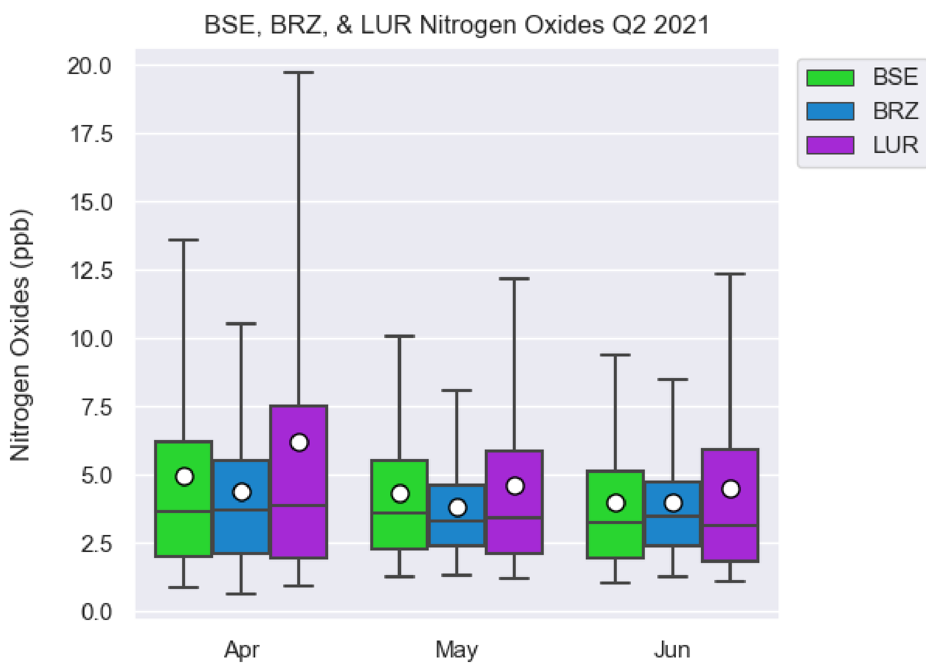


Figure 14:
Comparison of nitric oxide (A) and nitrogen oxides (B) at BSE, BRZ, and LUR during Apr – June 2021. See Figure 1 for explanation of the box whisker plot formats. While LUR continues to have the highest 95th percentile values among all the stations during all of the months, in a break from previous quarters, BSE had mean and median values of NO comparable to LUR during May and June. LUR continued to have higher mean values of nitrogen oxides relative to the other stations.

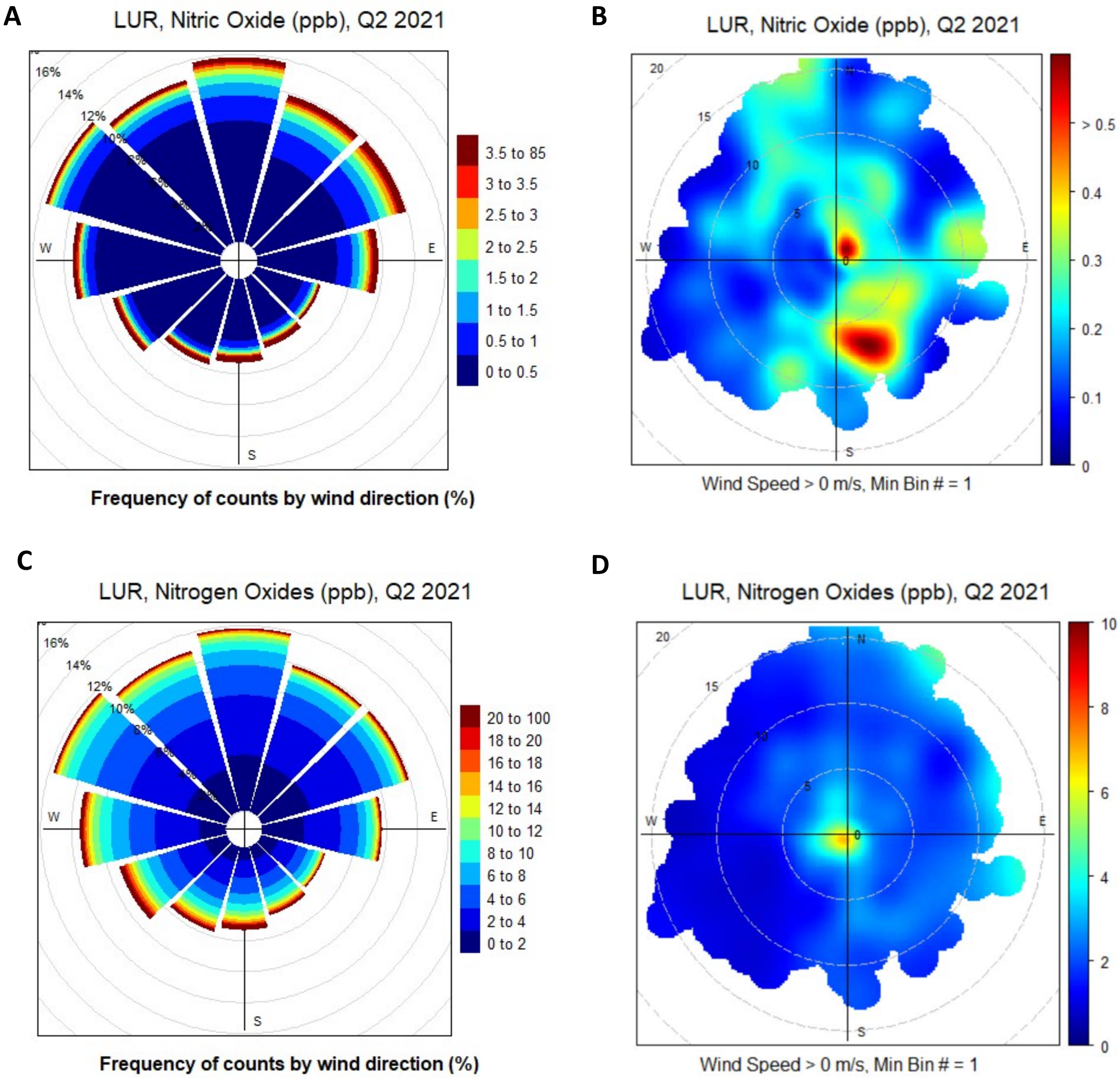
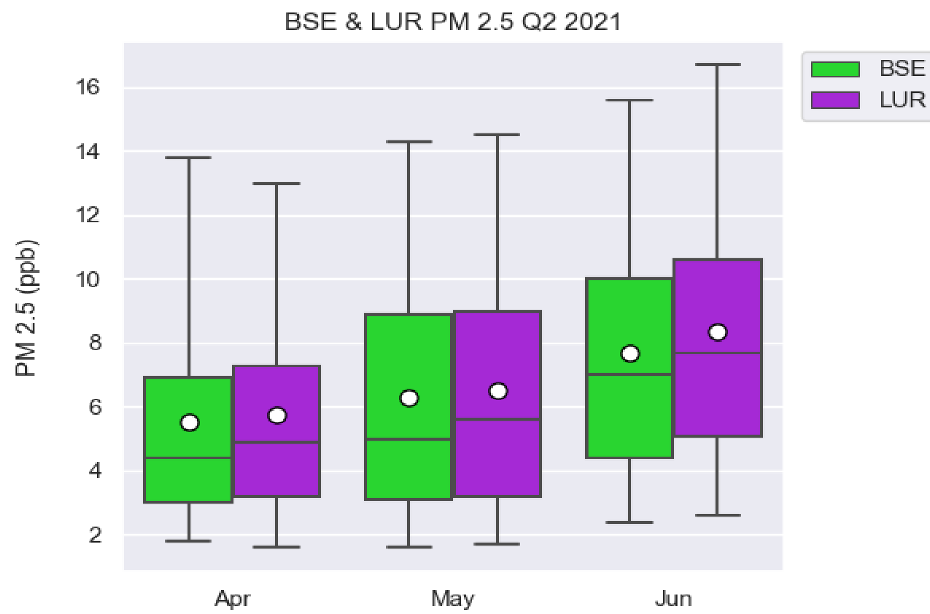


Figure 15:
Dependence of nitric oxide (A, B) and nitrogen oxides (C, D) as a function of wind speed and direction at LUR during Apr - June 2021. As seen in the prior data, the City of Longmont, located to the west, appears to be the strongest upwind source for NO_2.

A



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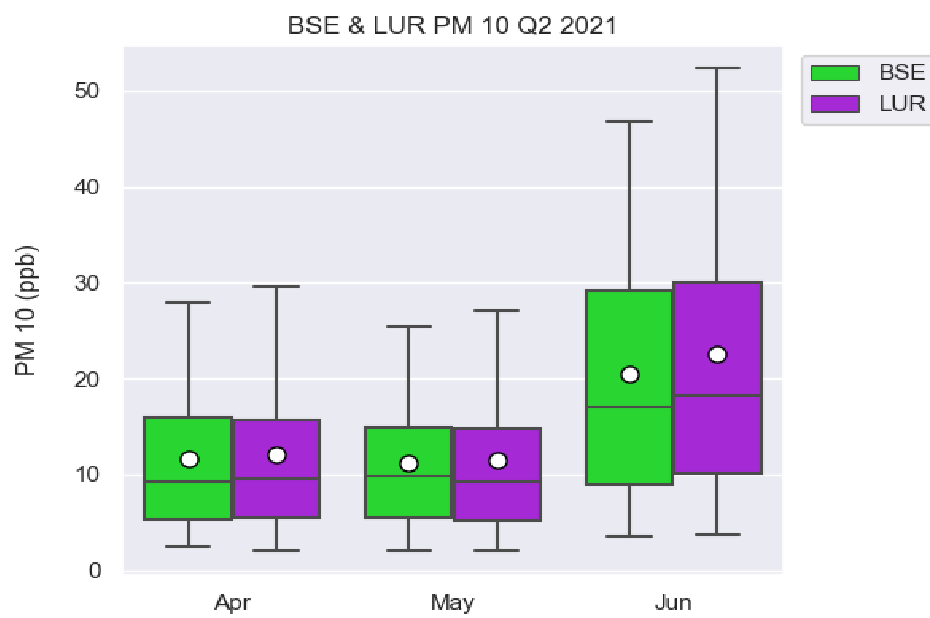


Figure 16:
Comparison of PM 2.5 (A) and PM 10 (B) at LUR and BSE during Apr - June 2021. See Figure 1 for explanation of the box whisker plot formats. LUR had higher median values for PM 2.5. The month of June had more variability in PM 10 than Apr and May.

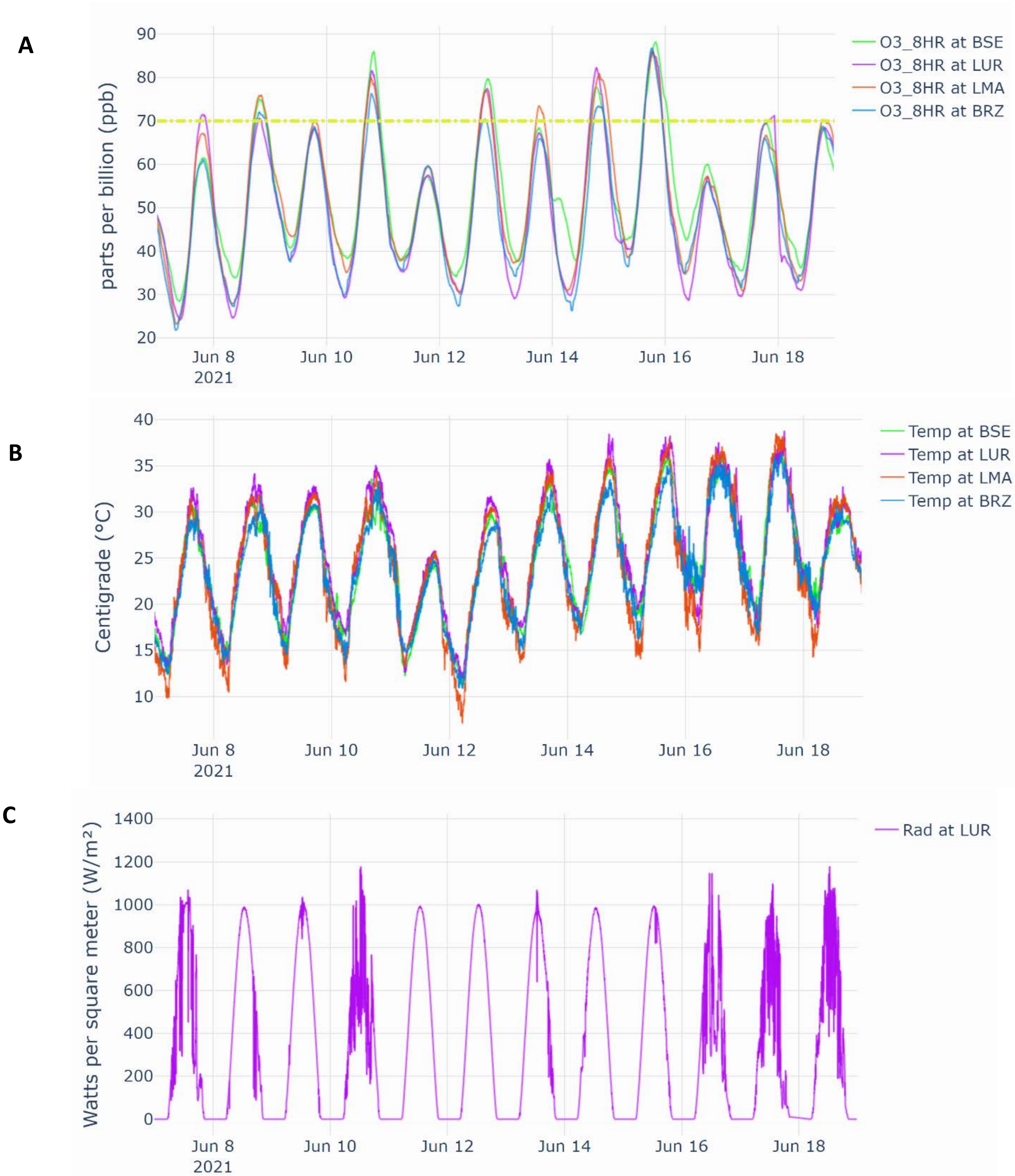


Figure 17:
Time series for June 7 – June 15. (A) 8-hour ozone (ppb) for BSE, LUR, LMA, and BRZ; (B) same as above, except for temperature (°C); (C) solar radiation (W/m^2) at LUR.

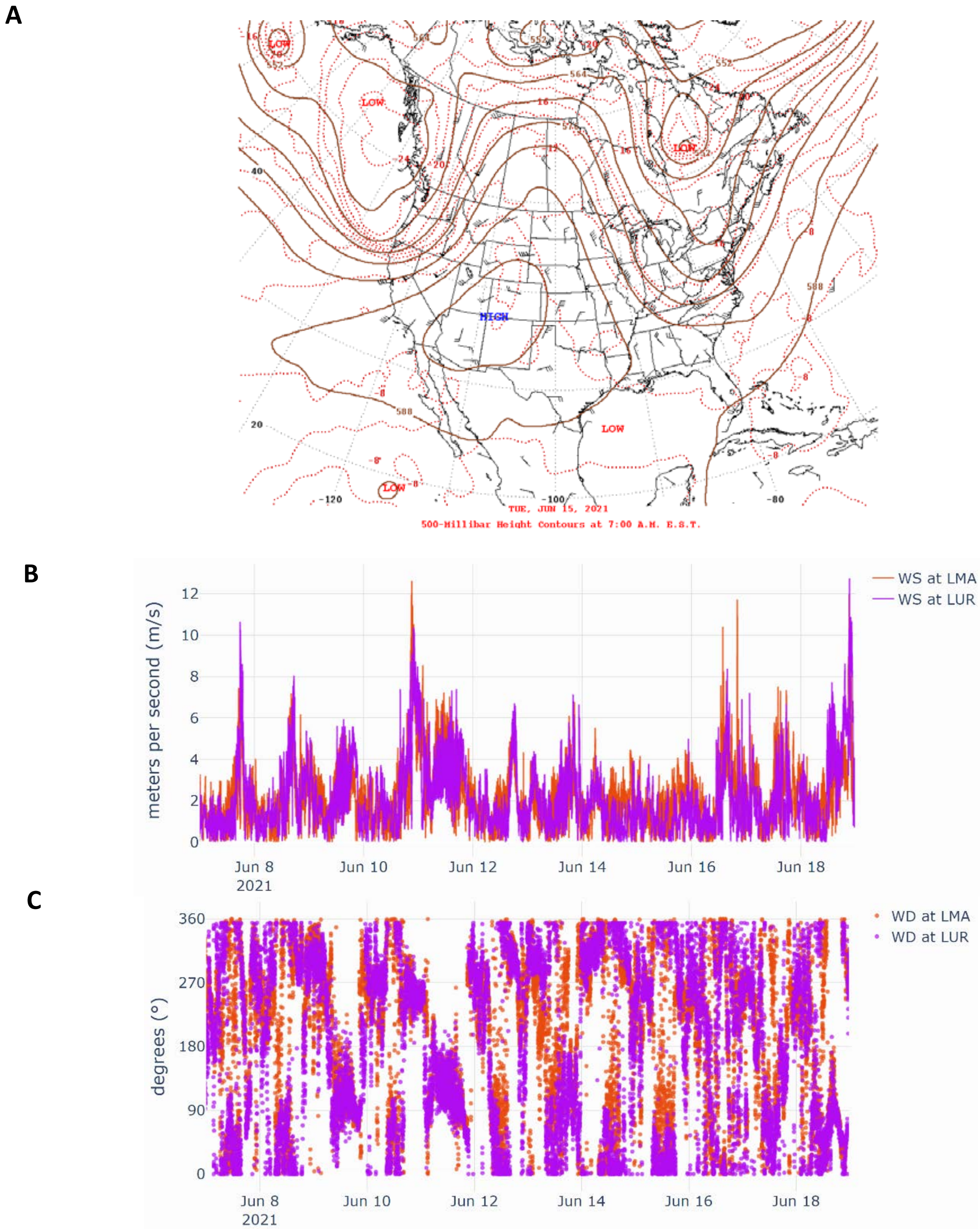


Figure 18:
(A) 500-mb height contours for the US; (B) wind speeds (m/s) at LMA and LUR; (C) wind direction at LMA and LUR.

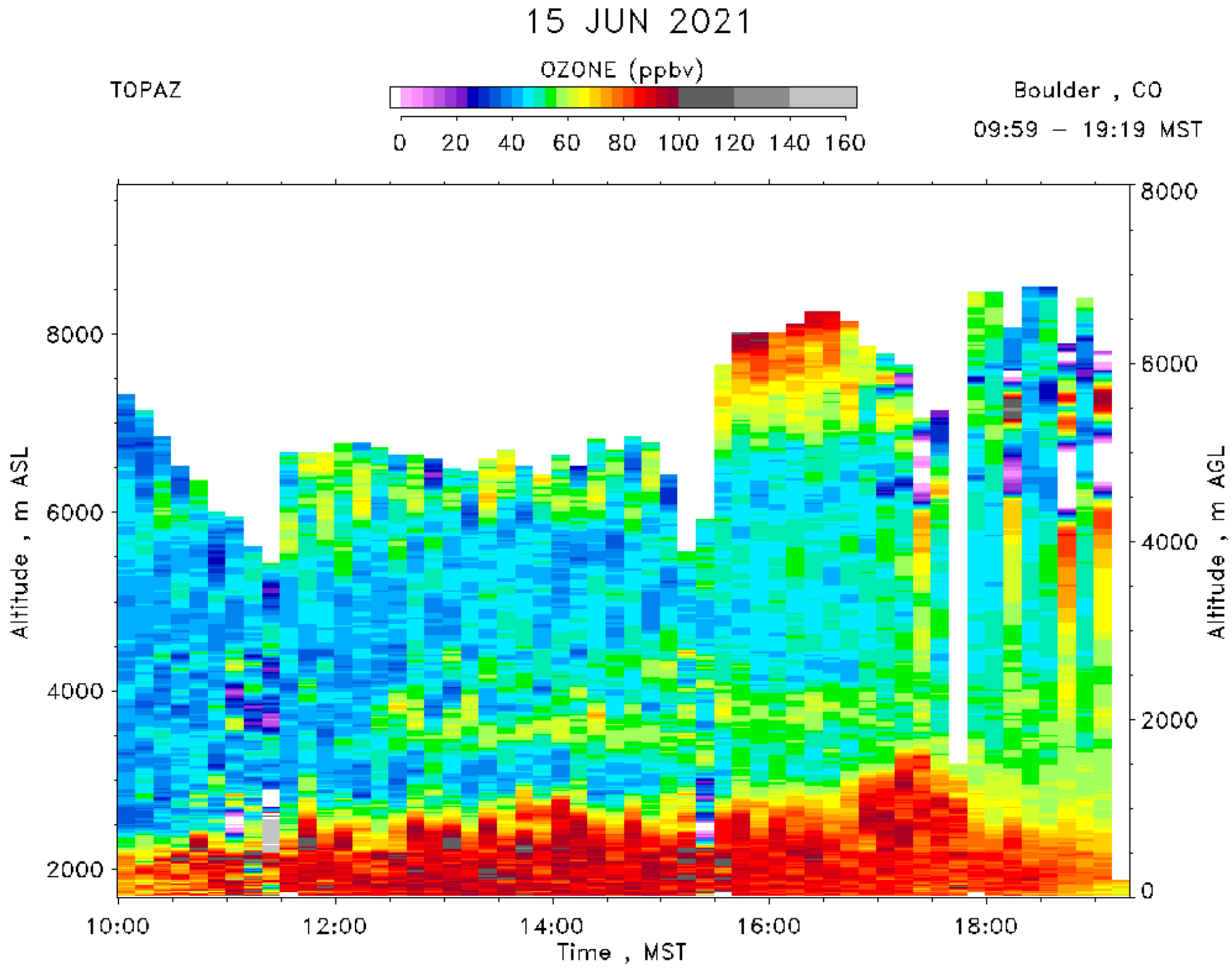
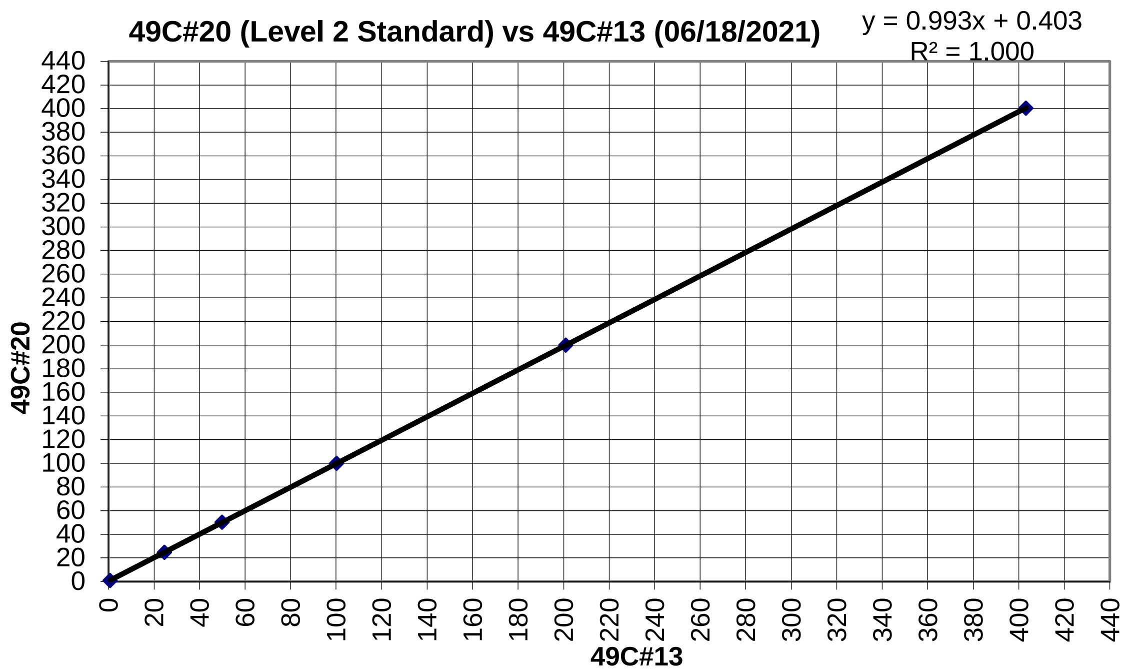


Figure 19:
Vertical profiles of ozone taken from an ozone profiling lidar stationed at the NOAA building at 325 Broadway in Boulder, for June 15, 2021. A deep layer of ozone, values ranging from 80 to 100 ppb, was measured throughout the day. Boulder 2018-2021 TOPAZ Data (noaa.gov). Contact: Dr. Christoph Senff (christoph.senff@noaa.gov)

A



B

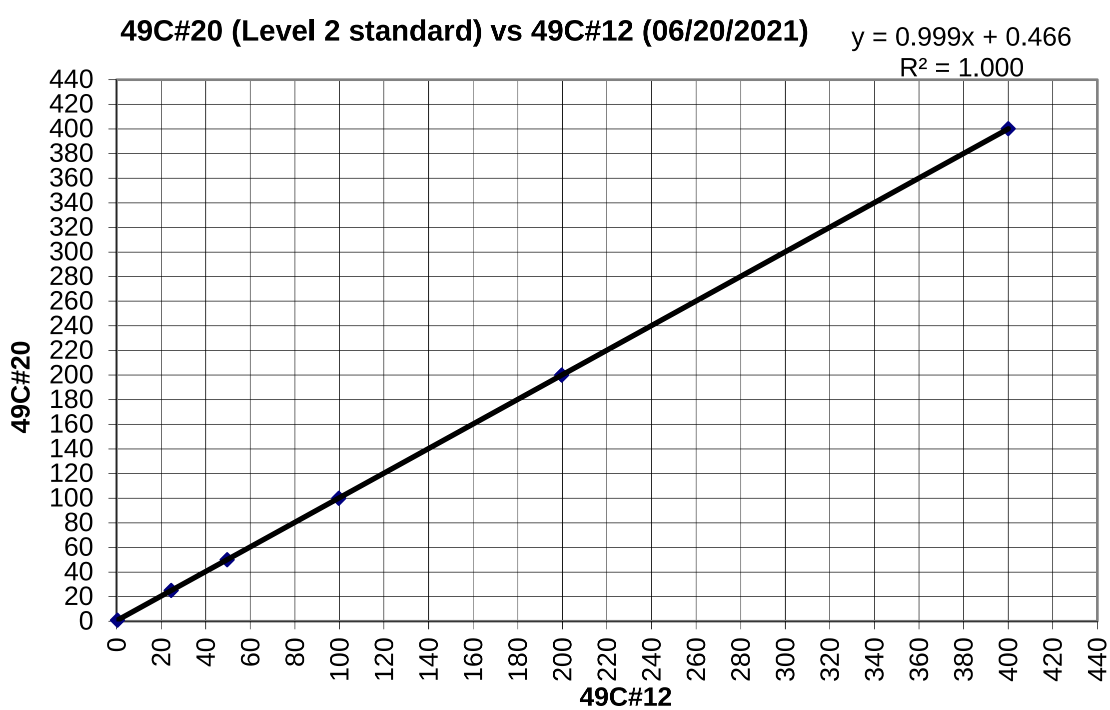


Figure 20:
Calibration graphs for the ozone monitors at LMA (A) and LUR (B) with the transfer reference standard results (49C#20) plotted against the respective station monitor.