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

November 24, 2021

To:

City of Longmont
350 Kimbark Street
Longmont, CO 80501

Attn: Dr. Jane Turner

Re: Longmont Regional Air Quality Study – Year 2021 Quarter 3 Report

Dear Dr. Turner,

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

Longmont Air Quality Study

Executive Summary

This report summarizes the data and preliminary findings from the Longmont Air Quality Study during July through September 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 July - September, i.e. Quarter 3 (Q3), 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 (BRZ), and the Broomfield Soaring Eagle Park (BSE) and Broomfield North Pecos (BNP) sites.

The ozone National Ambient Air Quality Standard (NAAQS) (8-hour average >70 ppb) was exceeded on 24 days at LUR and on 25 days at LMA during Q3. The hot, dry weather that occurred during July and August were conducive to enhanced ozone formation that resulted in these multiple exceedances of the NAAQS.

There were two periods of exceedances of the PM 2.5 NAAQS this quarter, in early August (August 1st and 2nd and August 8th and 9th) when the air quality was very poor along the Front Range because of wildfire smoke.

Table of Contents

1. Project Scope and Goals

No changes from Q2, 2021 report.

2. Overview of the Monitoring Program

No major changes from Q2, 2021 report.

3. Air Quality Monitoring Study Updates

No changes from Q2, 2021 report.

A new password-protected diagnostics website was implemented for real-time display of instrument operational data, for Boulder A.I.R. staff to identify and promptly address instrument and station outages.

4. Data Quality Assurance/Quality Control Process

The Colorado Department of Public Health & Environment (CDPHE) conducted an audit of the nitrogen oxides monitoring, PM analyzer, and the ozone analyzer at LUR on October 8th. All systems passed the audit and fall within the state regulatory guidelines. While the audit was conducted in Q4, we are providing it here with the Q3 report for faster dissemination. The audit reports are included in Supplements D. All monitoring passed the federal regulatory requirements. A more in depth discussion of the audit results will be presented in the Q4 report.

5. Website Development

During Q3 there were 4862 visits to the Longmont Air Quality Now website.

6. Data Archiving

No changes from Q2, 2021 report.

7. Data for Quarter 3, 2021

The data that were recorded in Q3, 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 Q3 ozone records for LMA and LUR are presented in Figures SA8 and SA9 for LMA and SB8 and SB9 for LUR. Hot, dry, and smoky summer days all played a role in affecting air quality in Longmont. July was the 9th warmest on record and August was the 3rd warmest on record (NWS July and August monthly climate summaries for Denver). The abundant sunshine and below normal precipitation throughout the summer were conducive to the formation of ozone. Other meteorological factors were at play throughout Q3:

- A Denver Cyclone formed on at least three days (7/12, 9/1, and 9/14). The Denver Cyclone causes a convergence of winds north of Denver that can allow pollutants to accumulate due to lack of horizontal transport out of the region. There were ozone exceedances at LMA and LUR on one of these days (7/12).
- The hot, cloud-free days allowed for weak upslope (easterly) winds to form along the Front Range throughout the summer, and these weak easterlies will transport pollutants toward the foothills where they become trapped, another mechanism for allowing ozone to accumulate and possibly reach 8-hr NAAQS exceedance values.
- From July 21 - 28 (at least) a high-pressure dome dominated over the Four Corners region, bringing stagnant conditions (i.e., light winds) to the Front Range, again allowing ozone and other pollutants to accumulate. Many of these days were ozone exceedance days at LMA and LUR.
- A nighttime gust front passed through the region after midnight on 7/10, mixing ozone and particulate matter downward to the surface, leading to an increase in both. Ozone at LUR had an extraordinary increase in ozone of ~35 ppb between midnight and 0200 MST, as the gust front passed through. The increase was less dramatic at LUR since the ozone had not dropped as low before the gust front, but there was an ~12 ppb increase in ozone with this gust front passage.
- There were fewer thunderstorms to cleanse the air of pollutants.

At LUR, there were 24 days with exceedances of the 70 ppb NAAQS for 8-hour ozone, with 16 of those occurring in July (an 8-hour average of 71 ppb or greater is used to assess the exceedances). There were several multi-day streaks in ozone exceedances at LUR, including a 7-day streak from July 24th to July 30th. LMA had 25 days that exceeded the 70 ppb NAAQS for 8-hour ozone, including a 5-day streak of exceedances from July 24th to July 28th. With the decreasing amount of daylight hours throughout the quarter (see the solar radiation time series in Figure SA5), maximum 8-hour ozone decreased from late July through late September.

Figure 1 presents a statistical analysis of the full Q3 ozone data, comparing the Longmont data with observations from Boulder Reservoir (BRZ) and Broomfield Soaring Eagle Park (BSE). As seen in previous quarters, slightly less ozone was measured at LUR than at the other stations. More NO_X was measured at LUR than at BRZ and BSE (Figure 14). The higher NO_x levels at LUR cause more ozone depletion at night, resulting in overall lower ozone at night and in the early morning at the LUR station. This lower ozone morning starting value can, under calm air circulation conditions, result in an overall delayed ozone production at LUR and slightly lower ozone afternoon maximum values.

CO_2

The full Q3 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. Mean CO_2 decreased throughout the quarter at LMA. More CO_2 was measured at LMA and LUR than at BSE. The wind speed/wind direction analyses are shown in Figure 3. The results from the wind direction/speed analyses comparing Q3 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 Q3 2020 and Q3 2021. The increase in CO_2 mean values between Q3 2020 and Q3 2021 was 4.4 ppm, larger than the global increase in CO_2 between August 2020 and August 2021 of approximately 2.62 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 Q3 methane records are available in Figures SA7 and SB7 for LMA and LUR, respectively. In the statistical comparisons among the stations, LUR measured the most methane in each month of Q3 (Figure 6). Median and 95th percentile values of methane also continued to be greatest at LUR. LMA methane measurements were closer to BSE and BRZ measurements. Wind rose and heat map analyses are shown in Figure 7. Note the enhanced values of methane seen at higher wind speeds to the north-northeast in the LMA methane heat map and to the north-northwest in the LUR heatmap. A detailed analysis of wind speed and wind direction for these two stations indicated that each of these "hot spots" occurred within minutes of each other on July 10th, between 12:00 and 12:30 local time and were likely from a source to the north of both stations. The peak at LMA occurred when the wind shifted from north-northwest to the north-northeast. There is a similar signature in the CO_2 heat map plots (Figure 3) and analysis indicates these CO_2 peaks were coincident with the methane peaks. This event is the same one mentioned in the ozone section – there was a gust front passage that brought a change of airmass and vertical mixing that caused an increase of ozone at the same time.

The Q3 2020 versus Q3 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 18.9 ppb between Q3 2020 and Q3 2021 at LMA, when interpreted against the approximately 15 ppb increase in the global methane background between July 2020 and July 2021, indicates a greater increase between quarters at LMA than seen globally, although the difference was consistent with the Q2 difference of 18.8 ppb. Mean values and all percentile values of methane increased from Q3 2020 to Q3 2021.

VOCs

The full Q3 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 – September 2021. These graphs show declines in the oil and gas tracers ethane and benzene relative to March 2020. Excluding some short-lived spikes in January and February 2021, observations of ethane and benzene have stayed low compared to March 2020. Acetylene values peaked in the colder months and there was a large spike at the end of Q3. This spike of 17.7 ppb occurred at ~1800 MDT, coincident with an abrupt wind shift from northeasterly to northwesterly winds.

The statistical comparison of the VOCs is plotted in Figure 10. In Q3, LUR instrumentation did not necessarily measure the most VOCs relative to the other stations, in contrast to previous quarters. LUR measurements of ethane were the most among the stations for the quarter, however. For propane, it depended upon the metric – more propane was measured at LUR as indicated by mean values, but BSE measurements had higher median values of propane. The least amount of propane was measured at BRZ. The BNP VOC analyses are skewed by large spikes that occurred in VOCs during the latter half of September when new drilling began at a Broomfield drilling site to the northwest of the BNP station. Figure 11 and Table 1 show the comparison of Q3 2020 statistics for ethane and benzene compared to those of 2021. For ethane, the mean value, percentile values, and the maximum value were all less in 2021. The minimum value was greater than that of 2020 (Table 1). For benzene, the Q3 mean value was equal to the Q2 mean value. The 95th percentile and max value were lower than in 2020.

Wind speed/wind direction dependence results of ethane, propane, acetylene, and benzene are shown in Figure 12. Compared to Q2 2021 analyses, the heat map transport patterns are similar. In the case of propane, the amounts detected were lower.

The analysis of VOCs signatures, using VOC/VOC ratio values, are shown in Figure 13.

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. The time series data do show less NO and NO_x in July. LUR measurements had much higher 95th percentile values for NO and NO_x in August and September than the other stations, in addition to higher mean values. Dependency of NO and NO_x on wind direction and wind speed is presented in Figure 15. In contrast to previous quarters, there were higher values of NO and NO_x detected at higher wind speeds to the northwest and the southeast.

Particulate Matter (PM)

PM10 and PM2.5 LUR Q3 monitoring results are presented in Figures SB19 and SB20. The 24-hour averaged PM2.5 data are available in Figure SB21. There were two periods of exceedances of the PM 2.5 NAAQS this quarter, in early August (August 1st and 2nd and August 8th and 9th) when the air quality was very poor along the Front Range because of wildfire smoke. The statistical comparison of LUR data with BSE data is presented in Figure 16. August had greater amounts of particulate matter than the other two months because of the wildfire smoke in the region. Overall, measured PM2.5 values were much higher in Q3 than in Q2, at both stations. For PM 10, the means and medians were greater in Q3 than in Q2.

Elevated PM2.5 recordings were to a significant extent associated with the occurrence of wildfire smoke, which then makes the PM2.5 measurements a good indicator or tracer of wildfire smoke conditions. We utilized this dependency to conduct a preliminary investigation of the correlations between hourly-averaged PM2.5 and hourly-averaged benzene, toluene, acetylene, and NO_x, as well as ozone, with the goal to better understand potential enhancements of these pollutants due to the wildfire smoke transport into the Front Range. Figure 17 shows these correlations in scatter-plot graphs. The analysis was conducted for the August 1-9 window, when the area was most heavily impacted by smoke with a resulting large reduction in visibility. Please recall that the PM2.5 NAAQS for 24-hour averaged recordings is 35 $\mu g\ m^{-3}$.

Results of the orthogonal linear regression analysis (which minimizes errors both in the x and y variables) show a clear positive correlation between benzene and PM2.5. 64% of the variance (dependency) of benzene was associated with PM2.5, showing that the smoke was the main source of benzene during this time window. Acetylene was more weakly correlated with PM2.5, with a 34% association with the wildfire smoke. For toluene, only 29% of its concentration could be traced to the smoke occurrence. NO_x did not appear to be correlated with PM 2.5 amounts.

For ozone, hourly averages of all of the Q3 data were considered, and data points were color coded by time of day. Highest ozone values occurred during midday to late afternoon, plotted in the brownish colors. These data show a wide scatter, with high ozone values occurring over a wide range of PM2.5. However, the majority of dots representing ozone > 70 ppb occurred with PM2.5 values < 35 $\mu g\ m^{-3}$. Under the cleanest conditions, with PM2.5 levels below 5 $\mu g\ m^{-3}$, ozone levels were more moderate. Most of the highest ozone levels were seen when PM 2.5 values were between 5-30 $\mu g\ m^{-3}$, with just a very few exceptions. At the very highest PM2.5 loading, ozone levels were again more moderate (< 70 ppb). For PM2.5 > 40 $\mu g\ m^{-3}$, all ozone recordings were below 60 ppb.

These results show that there was no clear correlation between the severity of wildfire smoke and ozone. It actually appears that ozone production is suppressed during the most severe wildfire pollution conditions, resulting in relatively moderate ozone concentrations when the smoke conditions are the worst. Possible explanations for this behavior may be lower ozone production rates due to less available solar irradiance from the light blocking by the smoke particulates and/or destruction of ozone on the abundant aerosol particles.

Tables

Table 1:
Comparison of the statistics of CO_2 and methane data (5-min averages) at LMA and ethane and benzene at LUR during Q3 of 2020 and Q3 of 2021. "Abs Diff" is the 2021 value minus the 2020 value.

Species	stat	2020	2021	Abs Diff	% Diff
CO_2	count	131745	131055	-690	0.00
(ppm)	mean	427.7	432.1	4.4	1.0
	std	20.2	23.8	3.7	18.2
	min	393.6	391.1	-2.6	0.7
	5%	407.2	409.0	1.8	0.4
	25%	411.9	413.9	1.9	0.5
	50%	421.7	423.9	2.1	0.5
	75%	438.5	444.4	5.9	1.3
	95%	468.4	479.3	11.0	2.3
	max	587.3	644.6	57.4	9.8
CH_4	count	131745	131055	-690	0.00
(ppb)	mean	2007	2026	19	0.9
	std	69	69	0	0.6
	min	1882	1905	23	1.2
	5%	1913	1943	30	1.6
	25%	1958	1980	22	1.1
	50%	1998	2014	16	0.8
	75%	2043	2057	15	0.7
	95%	2130	2144	14	0.6
	max	2714	2968	254	9.3
Ethane	count	1825	2115	290	15.76
(ppb)	mean	7.60	6.47	-1.13	0.16
	std	8.22	4.60	-3.62	52.58
	min	0.19	0.64	0.45	6.18
	5%	1.75	1.72	-0.03	17.72
	25%	3.64	3.49	-0.15	19.62
	50%	6.11	5.43	-0.68	16.85
	75%	9.60	8.08	-1.52	6.95
	95%	17.08	14.58	-2.51	0.52
	max	260.10	42.94	-217.16	68.71
Benzene	count	1825	2115	290	15.89
(ppb)	mean	0.13	0.13	0.00	1.67
	std	0.13	0.10	-0.03	25.64
	min	0.01	0.01	0.00	5.41
	5%	0.03	0.04	0.01	35.51
	25%	0.05	0.07	0.01	26.54
	50%	0.09	0.10	0.01	16.30
	75%	0.16	0.17	0.01	8.20
	95%	0.36	0.31	-0.05	14.01
	max	1.83	1.53	-0.30	16.37

Figures

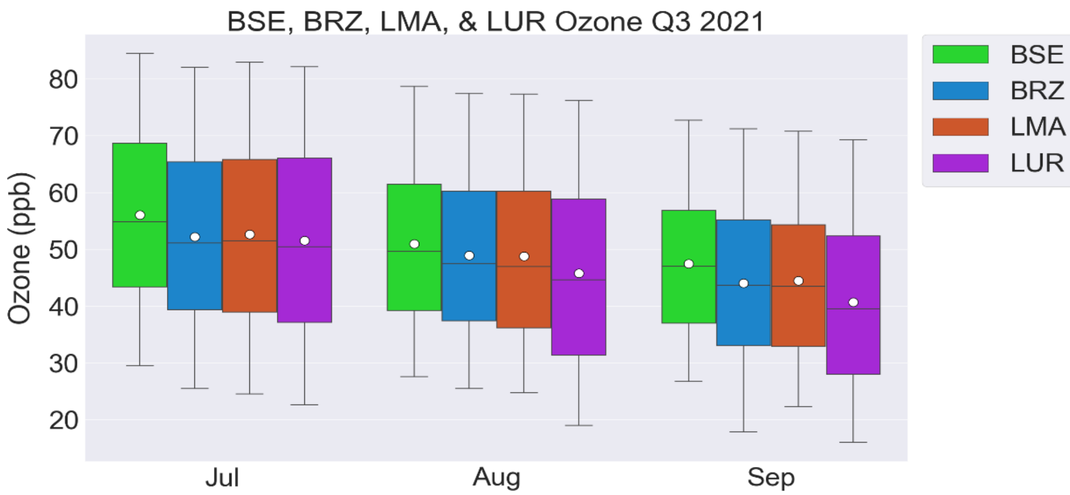


Figure 1:
Comparison of the ozone distribution at BSE, BRZ, LMA, and LUR during July – September 2021. These box whisker plots show the median value as the center line, the 25-75 percentile distribution as the colored boxes, and the 5-percentile and 95-percentile values as the whiskers. The white dot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

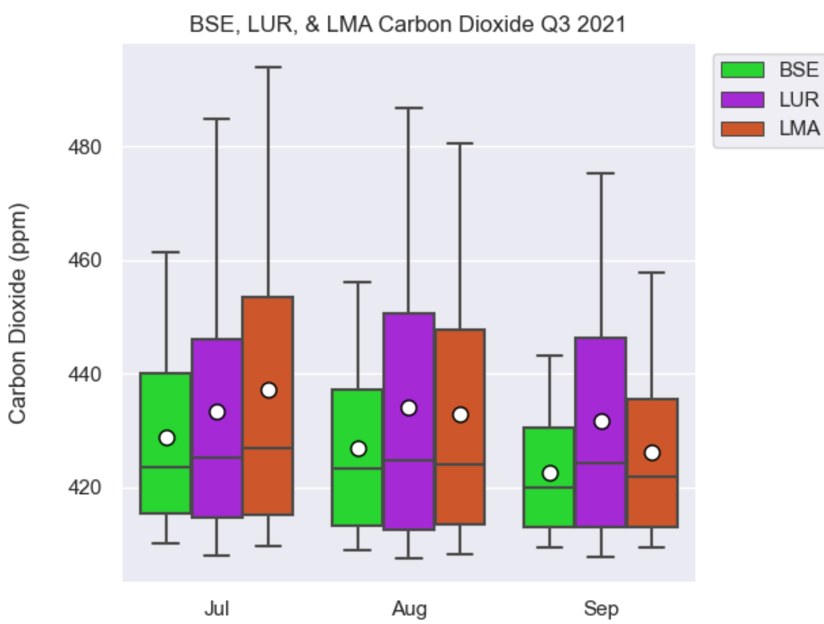


Figure 2:
Comparison of the CO_2 distribution at LMA, LUR, and BSE during July – September 2021. See Figure 1 for explanation of the box whisker plot format.

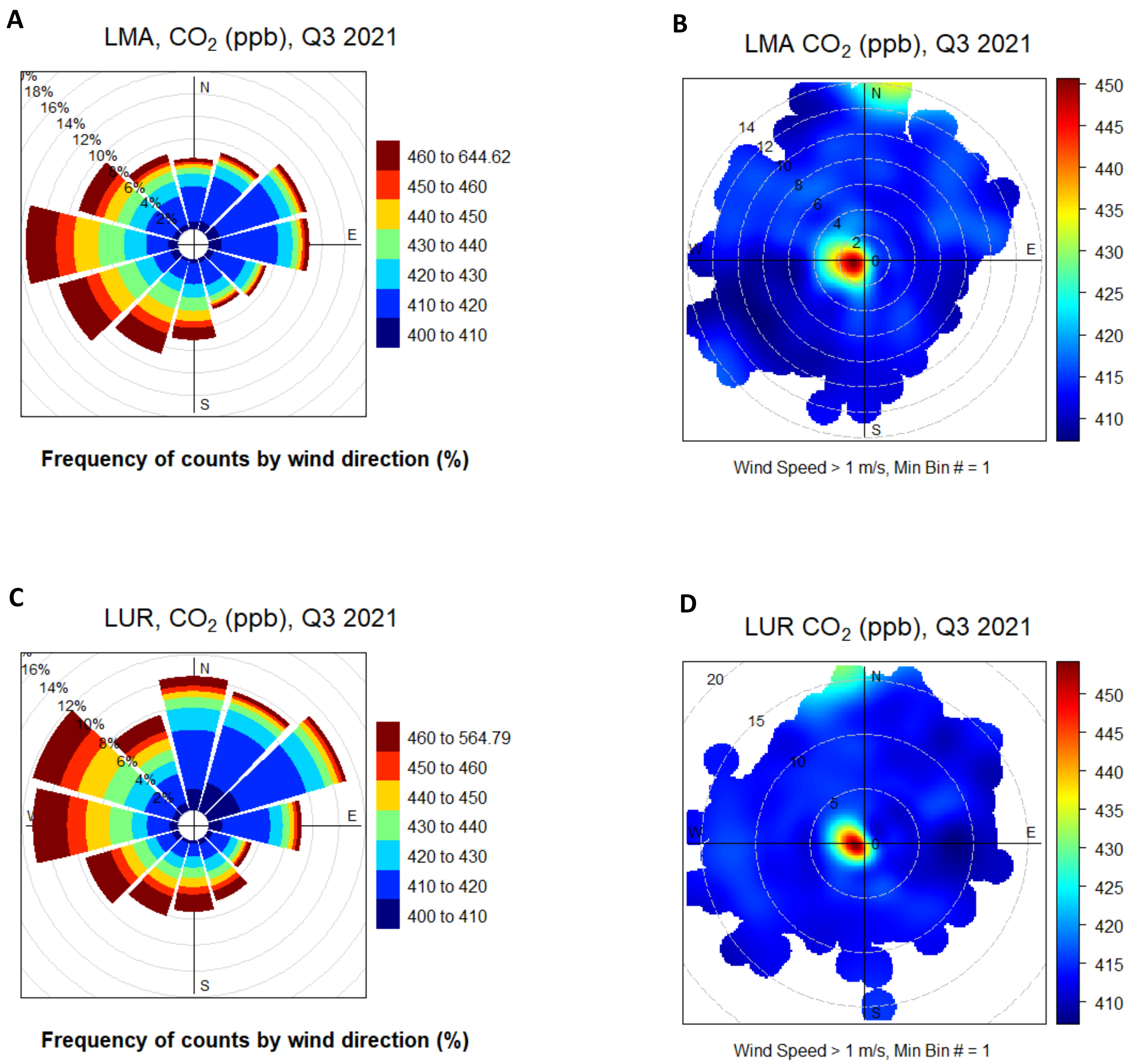


Figure 3:
Wind rose (left) and wind heat map analysis showing the dependency of CO_2 mole fractions at LMA (top, A, B) and LUR (bottom, C, D) during July – September 2021. The LUR site is east of the City of Longmont. These analyses suggests that the city is the primary source for enhanced CO_2 observed 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).

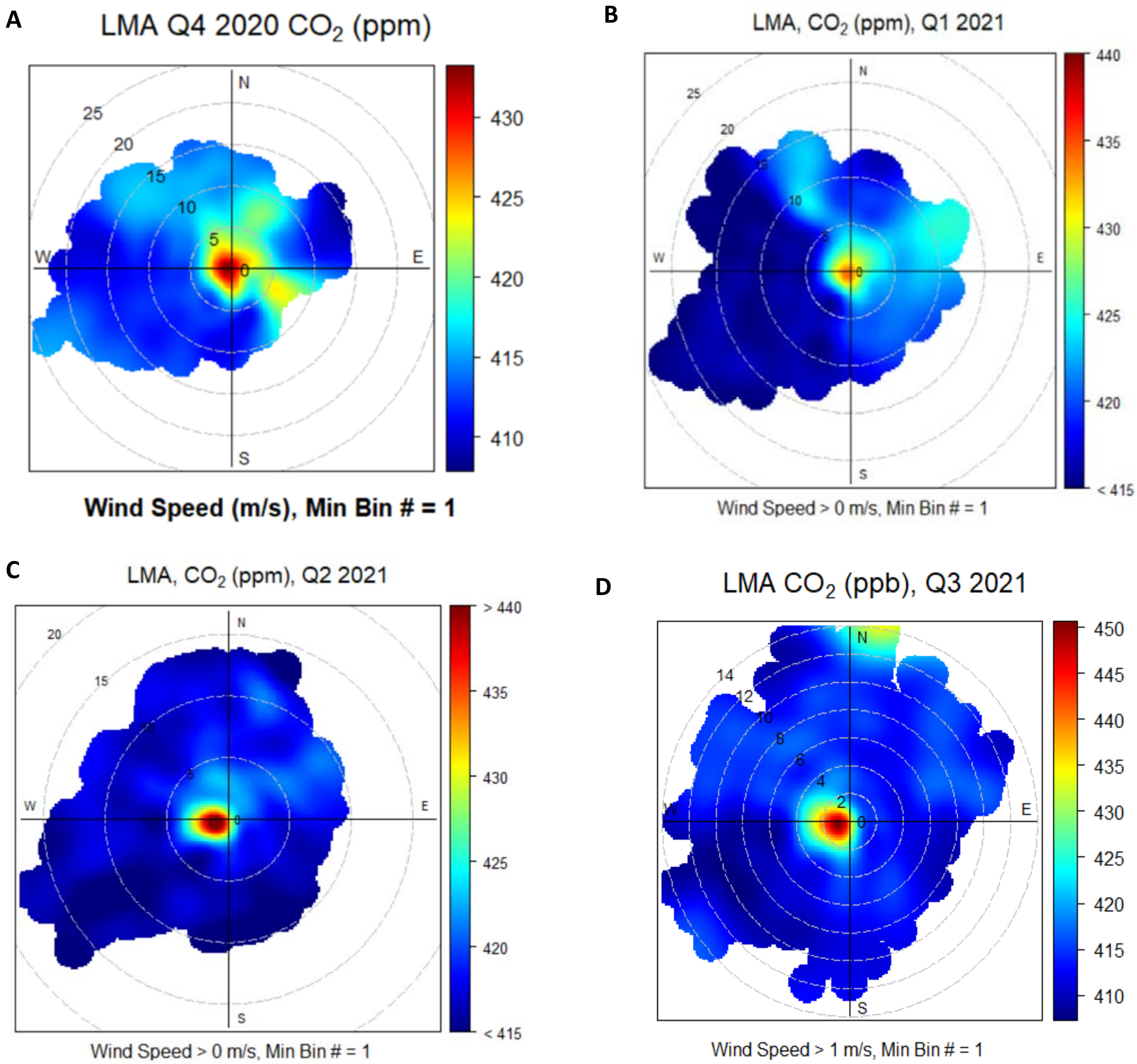


Figure 4:
Comparison of the wind speed/wind direction to observed CO_2 at LMA from Q4 2020 to Q3 of 2021. There is a consistent pattern with a relatively strong source to the west of the station throughout the year.

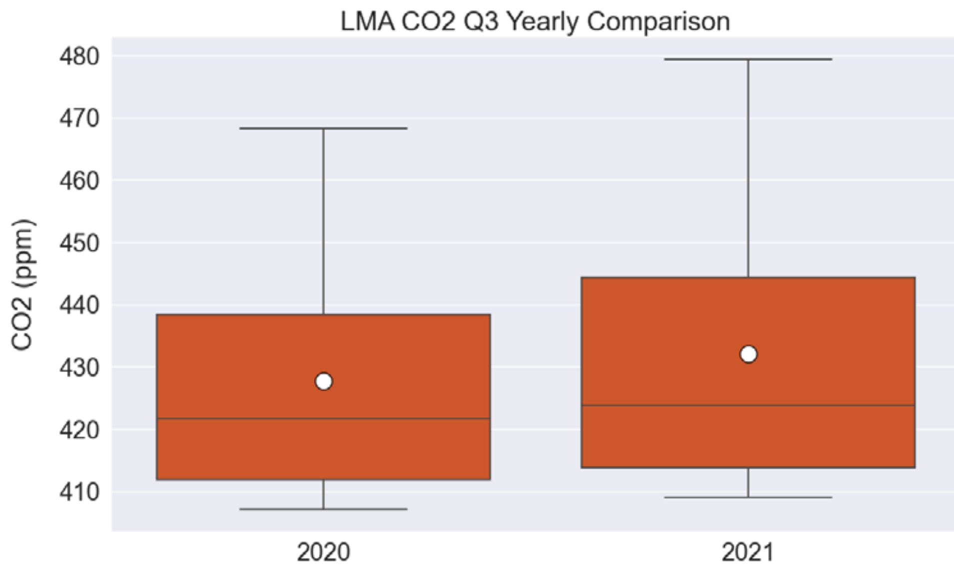


Figure 5:
Comparison of the CO_2 distribution at LMA during Q3 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The mean, median, and highest percentile values were all larger in 2021 than in 2020 (see Table 1 for the numerical values).

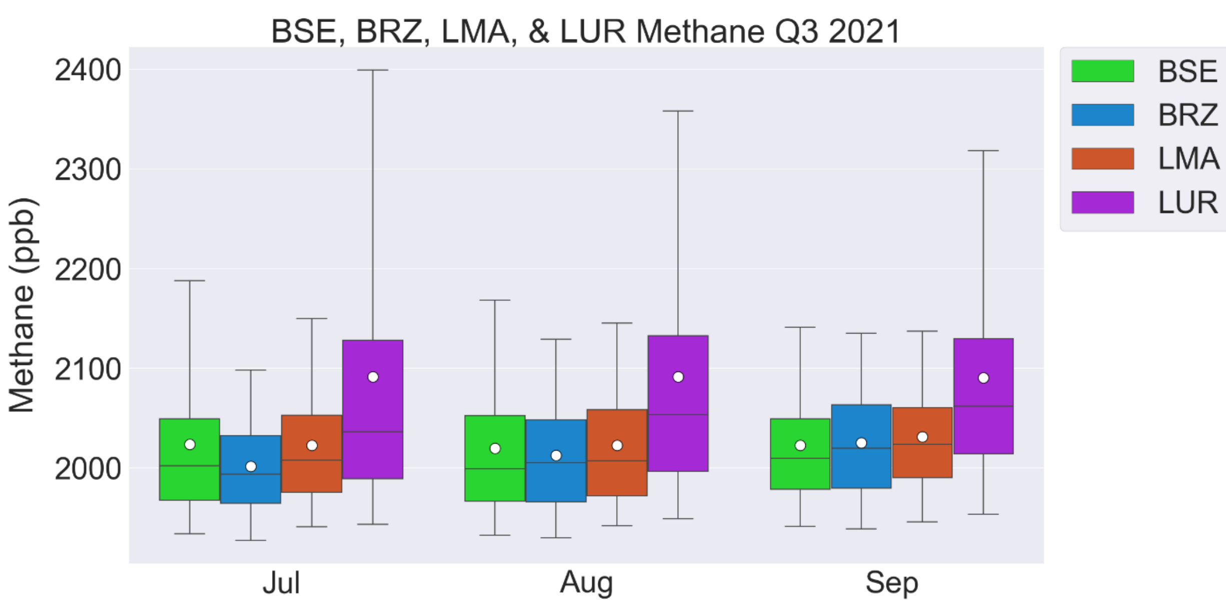


Figure 6:
Comparison of the methane distribution at BSE, BRZ, LMA, and LUR during July – September 2021. See Figure 1 for explanation of the box whisker plot format. Between the two Longmont sites, LUR has higher absolute values and variance.

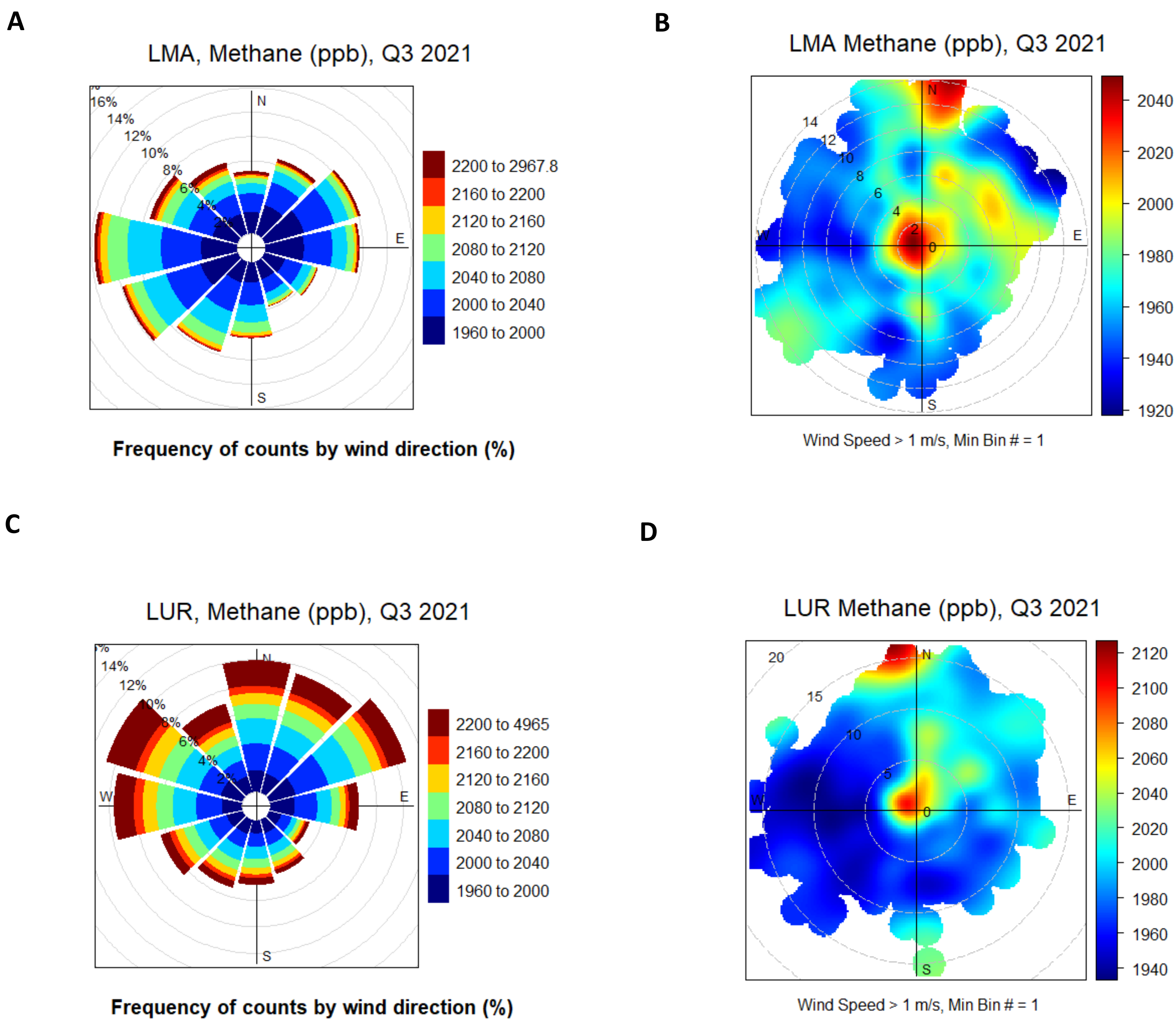


Figure 7:
Wind rose (left) and wind heat map analysis showing the dependency of CH_4 mole fractions at LMA (top, A, B) and LUR (bottom, C, D) during July – September 2021.

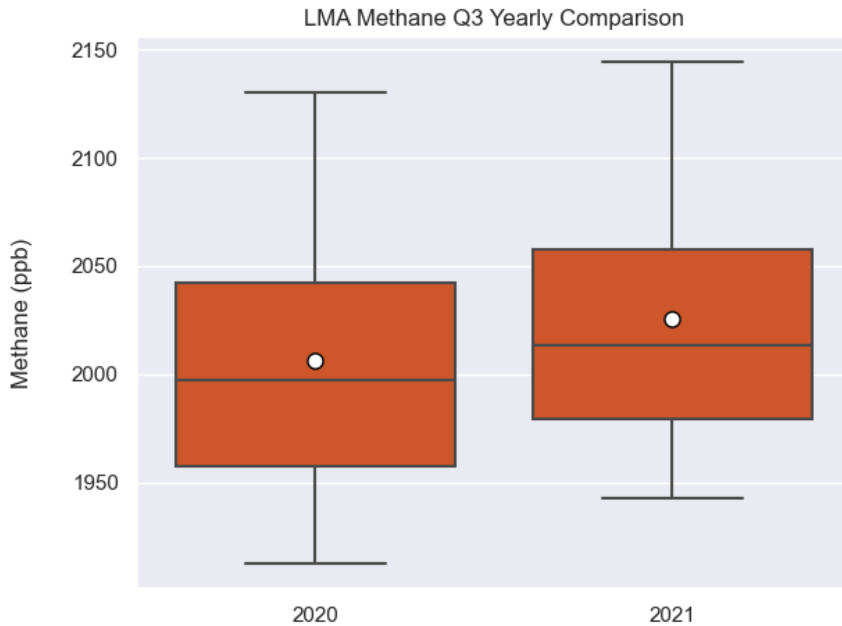


Figure 8:
Comparison of the methane distribution at LMA during Q3 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions are presented in Table 1. The mean, median, and percentile values were all larger in 2021 than in 2020.

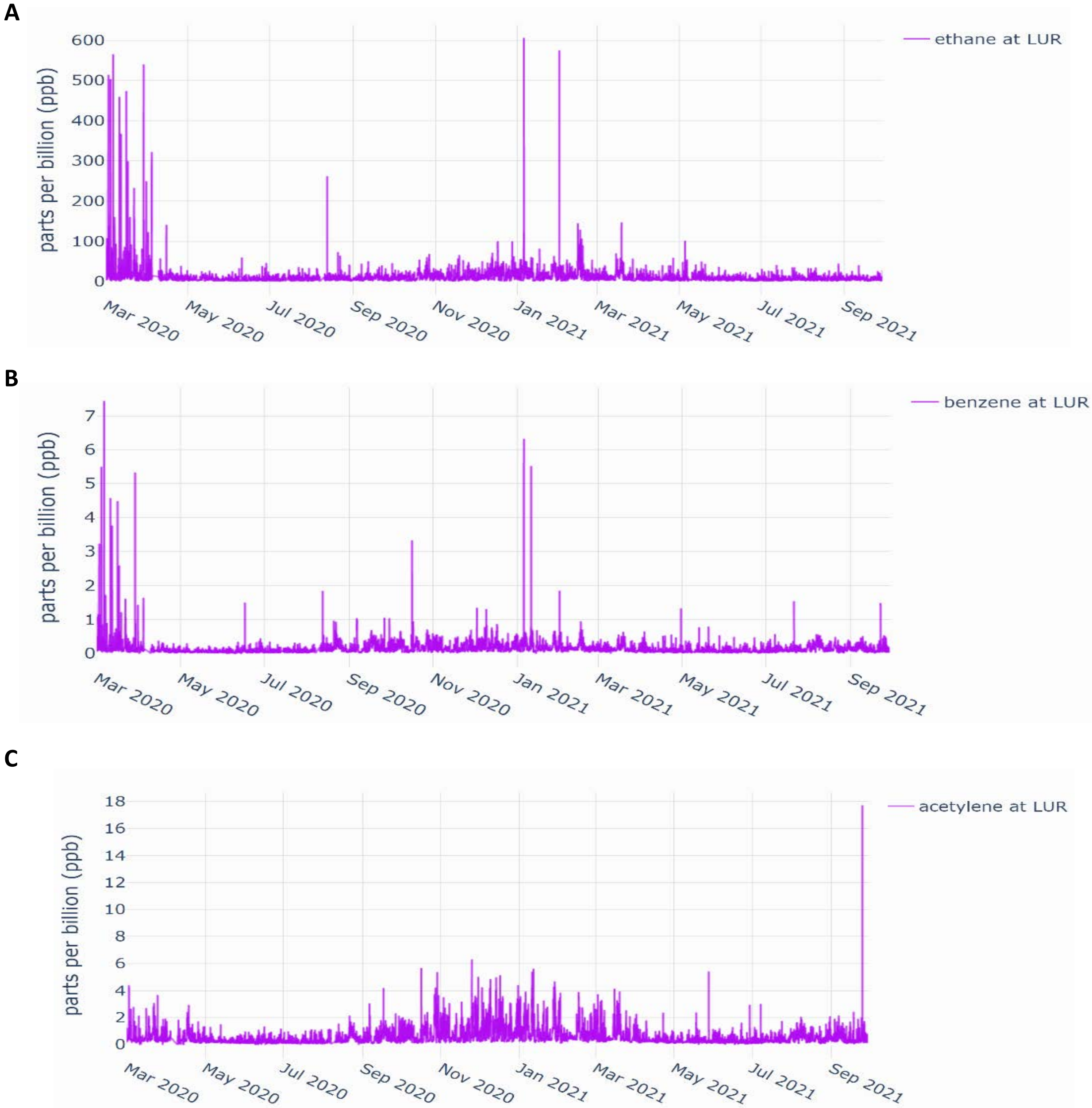


Figure 9:
Ethane (A, top), benzene (B, middle), and acetylene (C, bottom) at LUR between March 1, 2020 and September 30, 2021. Lower frequency and lower maximum values of concentration spikes during the summer are observed for all three compounds. These summer minima are mostly caused by the stronger 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 was a decline in the source strength for ethane and benzene from the earliest measurements, but this trend appears to have leveled off.

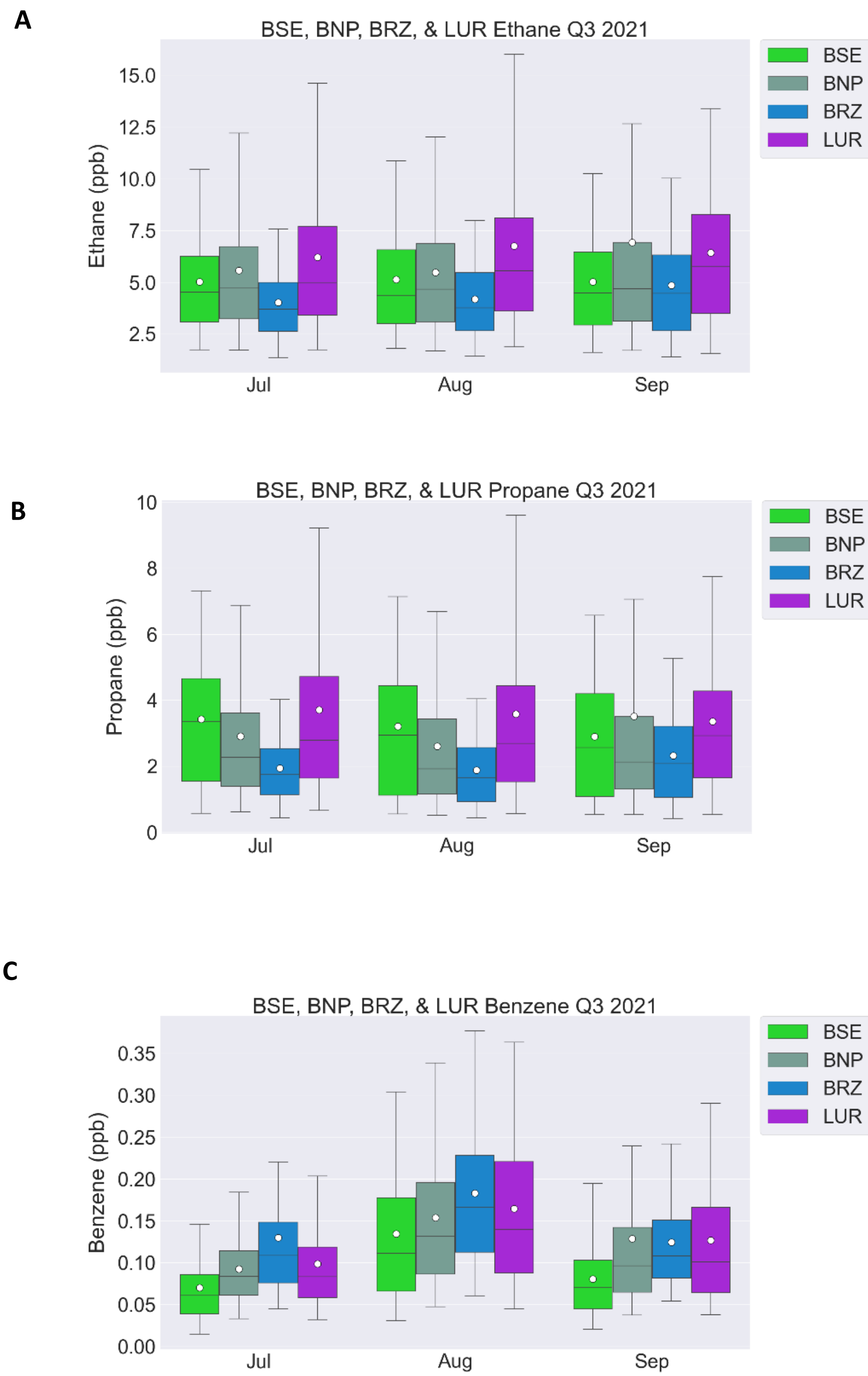


Figure 10:
Comparison of the distribution of ethane (A), propane (B), and benzene (C) at BRZ, BNP, BSE, and LUR during Q3. See Figure 1 for explanation of the box whisker plot formats. LUR tended to have the highest 95th percentiles, with the exception of benzene at BRZ in July and August.

A

B

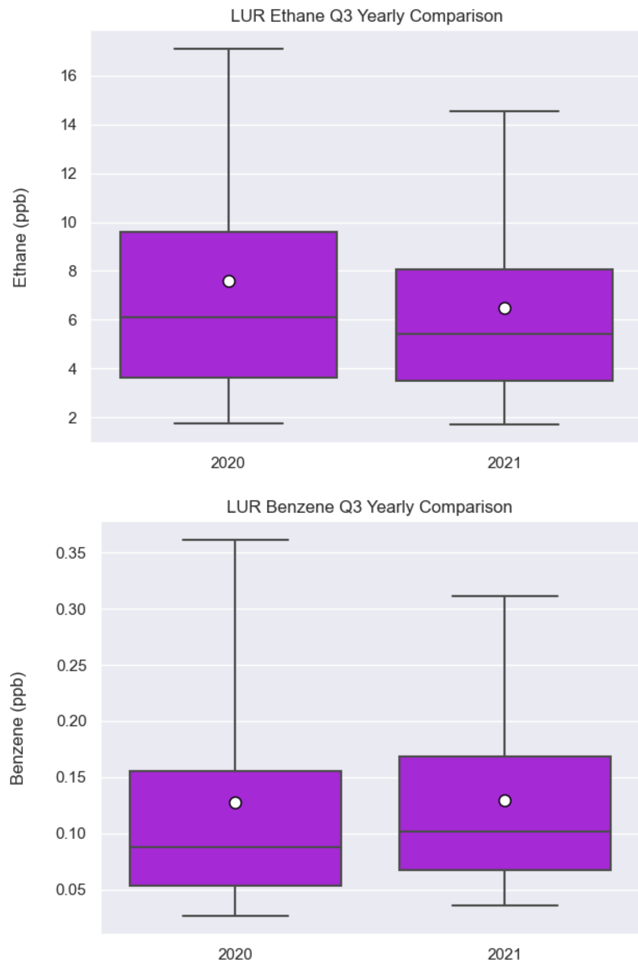


Figure 11:
Comparison of the ethane distribution (top, A) and the benzene distribution (bottom, B) at LUR during Q3 of 2020 and 2021. See Figure 1 for explanation of the box whisker plot format. The numerical values for the statistical distributions are presented in Table 1. The mean and median values were higher in 2021. 95th percentile values were smaller for benzene in 2021 than in 2020.

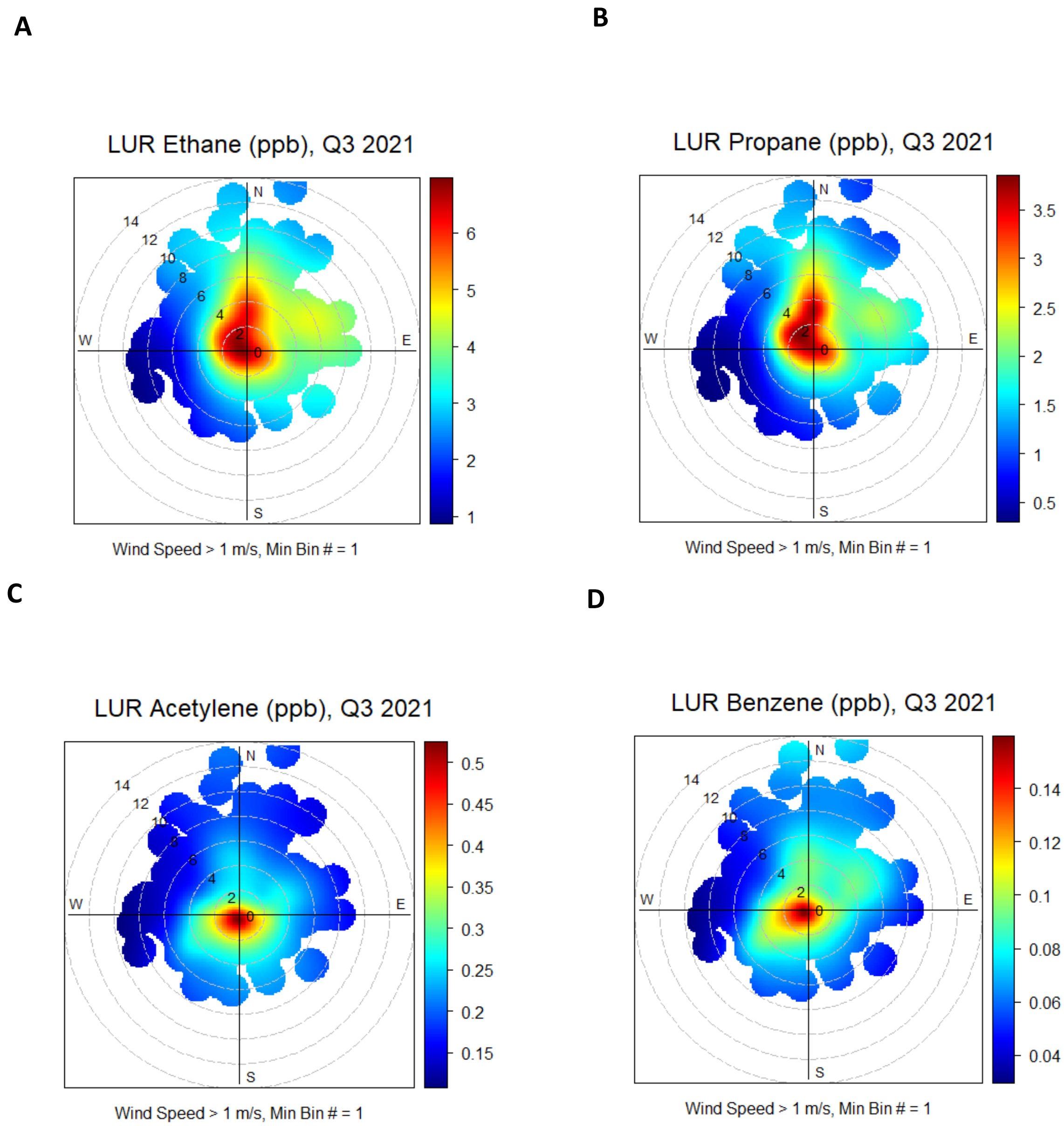


Figure 12:
Comparison of ethane (A), propane (B), acetylene (C), and benzene (D) occurrences as a function of wind speed and direction at LUR during Q3 2021.

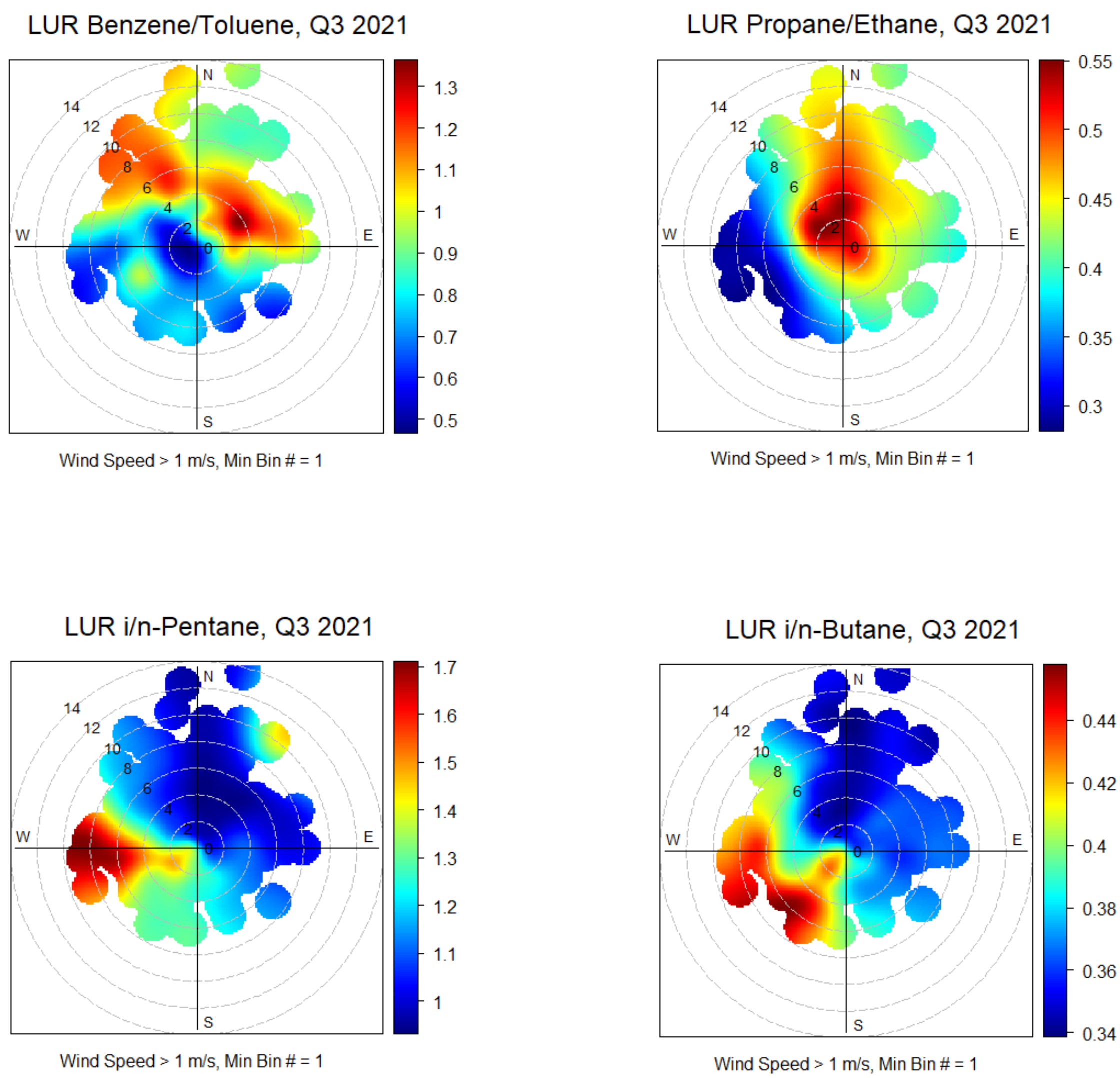
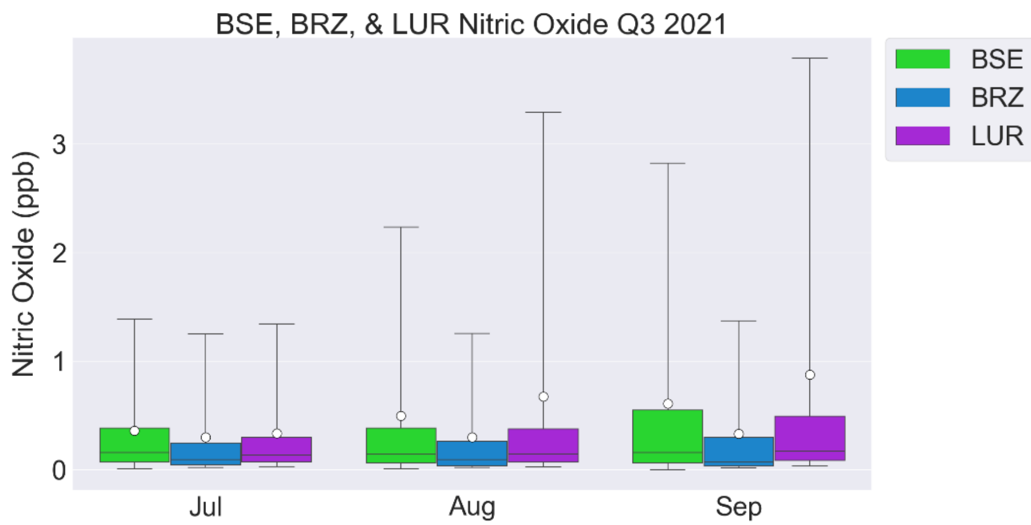


Figure 13:
Ratios of selected VOC pairs as a function of wind direction and wind speed during Q3. These analyses show clear differences in the chemical signatures in air transported from different directions to the monitoring station.

A



B

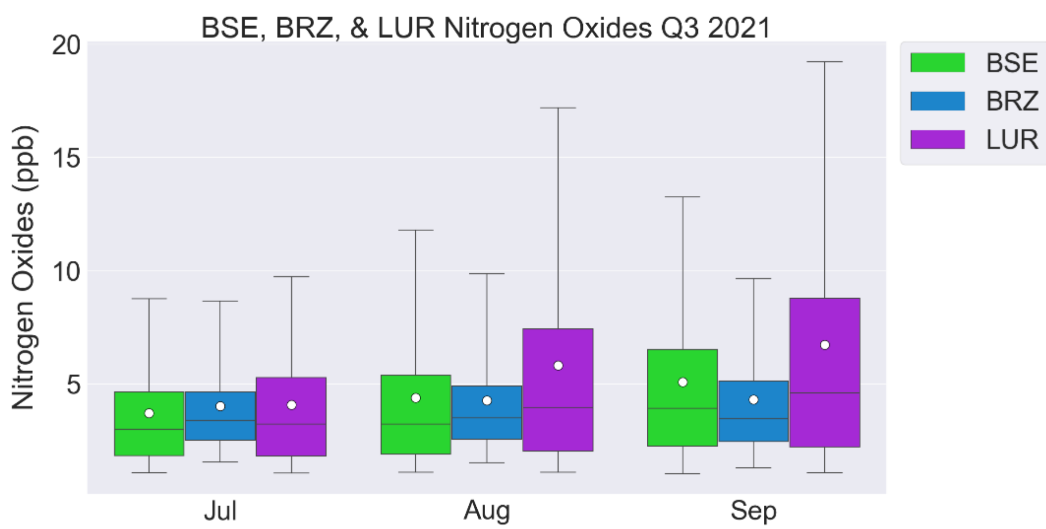


Figure 14:
Comparison of nitric oxide (A) and nitrogen oxides (B) at BSE, BRZ, and LUR during July – September 2021. See Figure 1 for explanation of the box whisker plot formats.

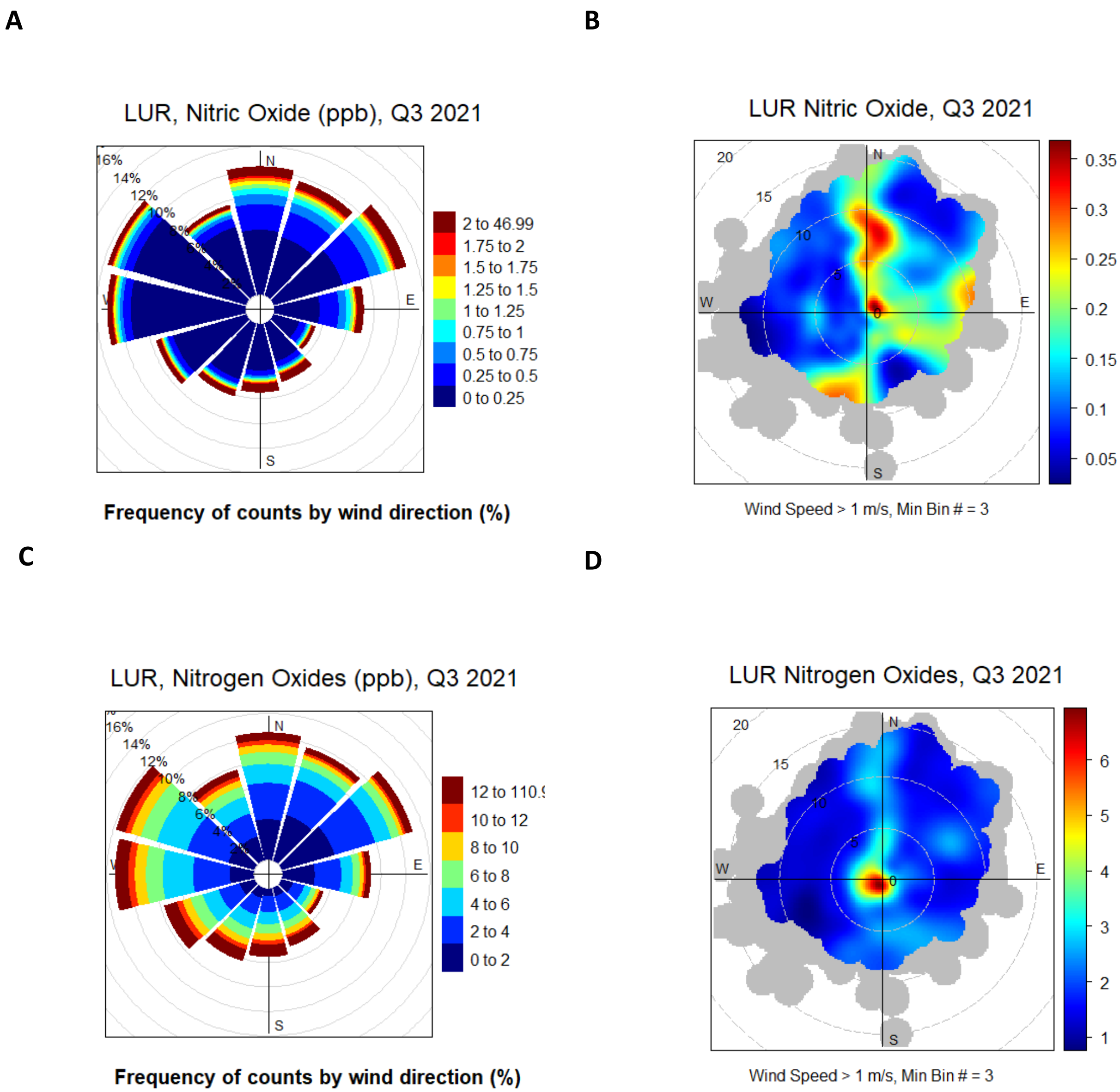
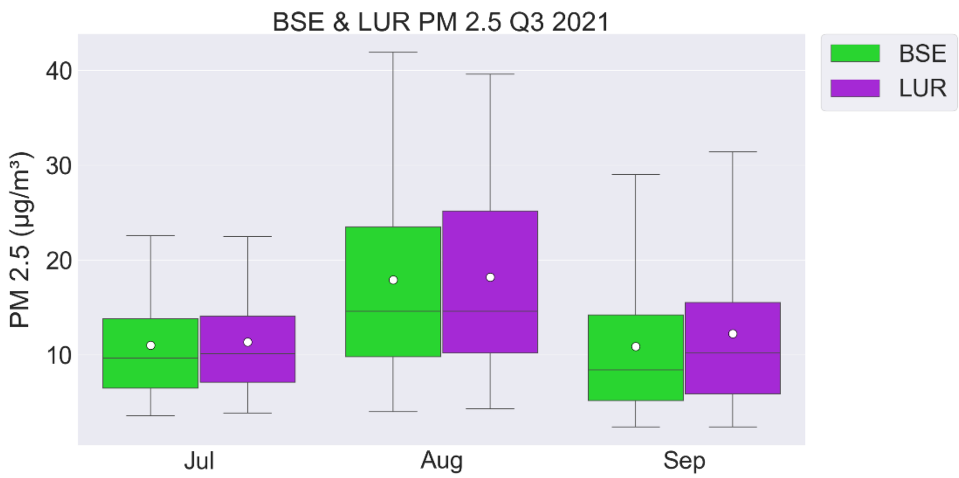


Figure 15:
Dependence of nitric oxide (A, B) and nitrogen oxides (C, D) as a function of wind speed and direction at LUR during July – September 2021. As seen in the prior data, the City of Longmont, located to the west, appears to be the strongest upwind source for NO_2.

A



B

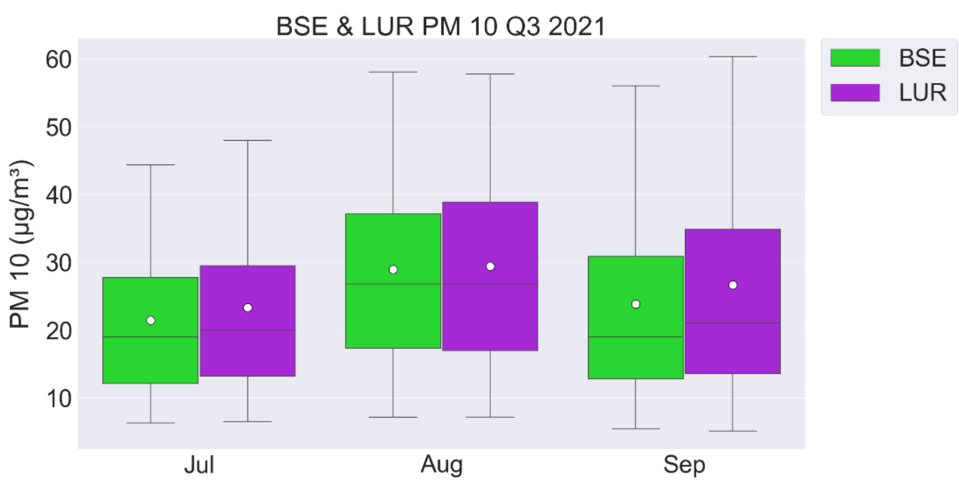


Figure 16:
Comparison of PM 2.5 (A) and PM 10 (B) at LUR and BSE during July - September 2021. See Figure 1 for explanation of the box whisker plot formats. Wildfire smoke was pervasive along the Front Range during August.

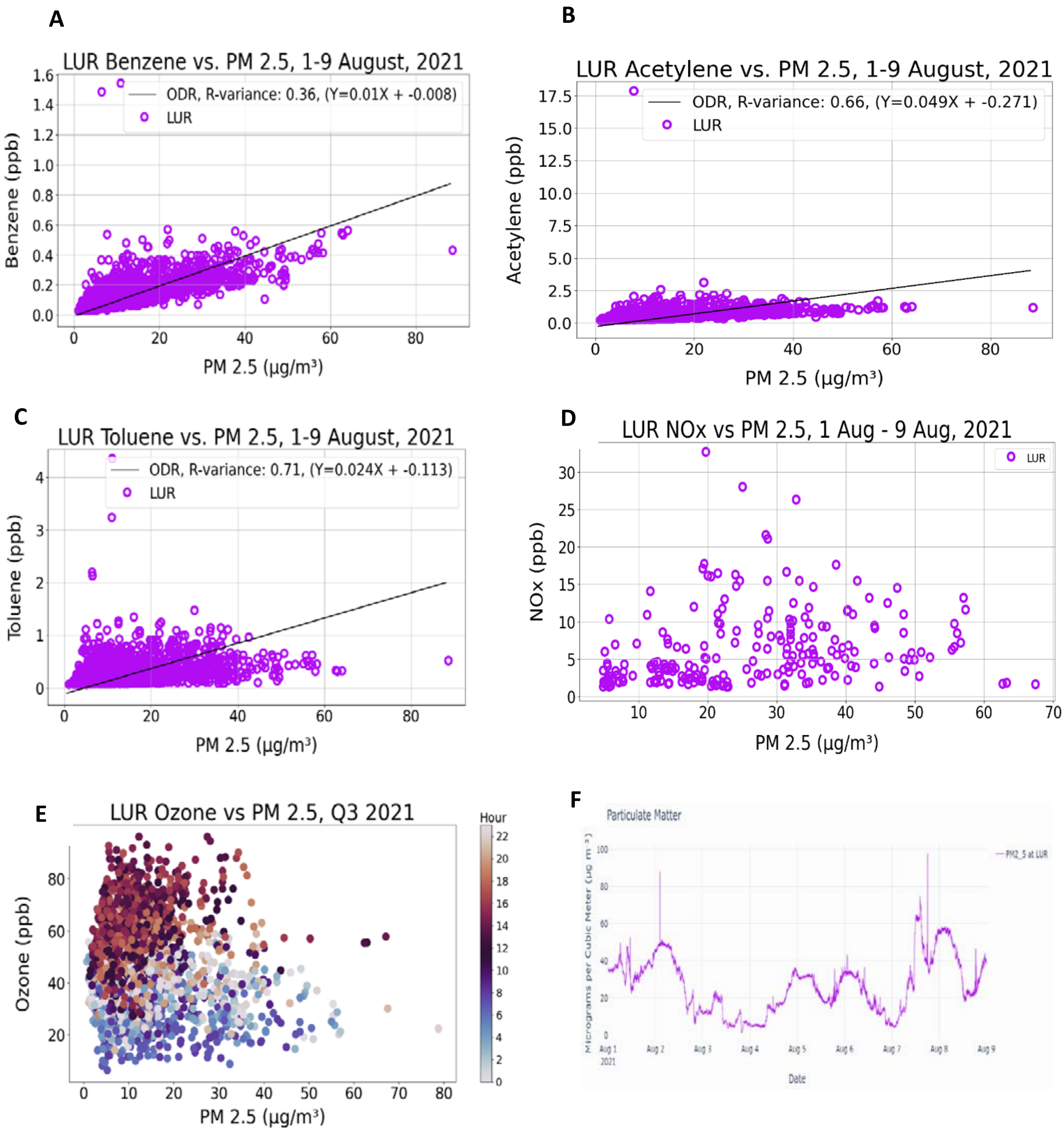


Figure 17:
Scatter plots for benzene (A), acetylene (B), toluene (C) and NOx (D) vs. PM 2.5 at LUR for August 1st – 9th, 2021, when wildfire smoke was pervasive along the Front Range. The lines on the VOC plots indicate the orthogonal linear regression (ODR) fit, which accounts for errors in both the x and y variables. For ozone (E), hourly-averaged values for all of Q3 were plotted. The time series of PM 2.5 measured at LUR during this period is shown in (F) for reference.

Supplement A

Time Series Graphs of Preliminary LMA Data Q3, 2021.

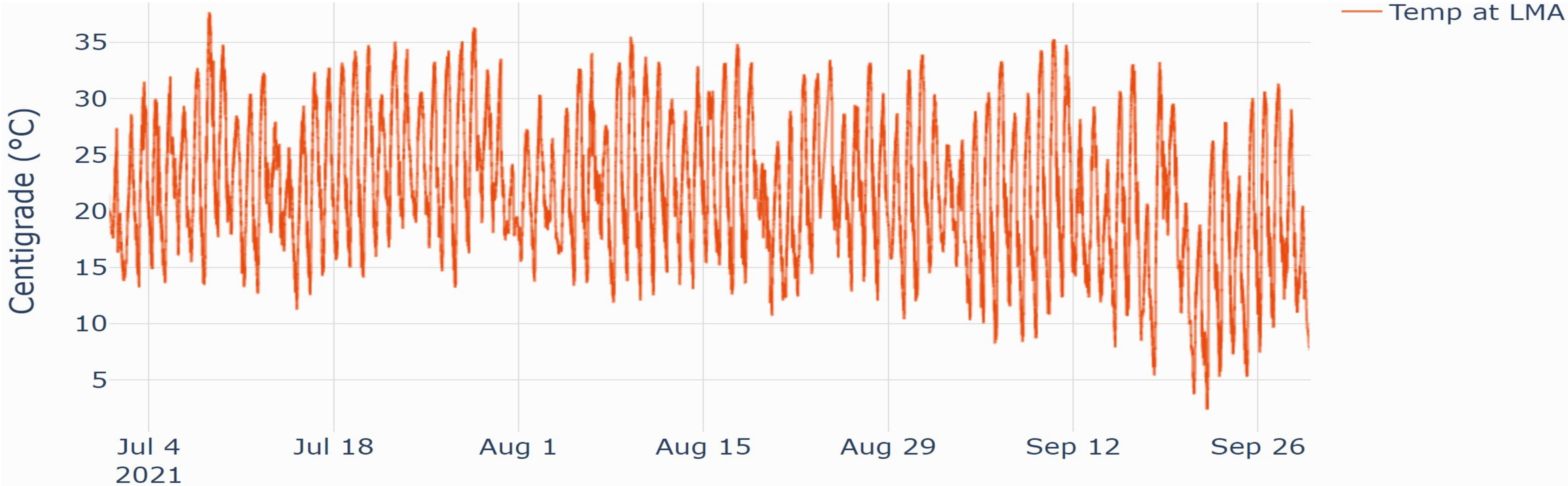


Figure SA1:
LMA temperature record Q3, 2021.

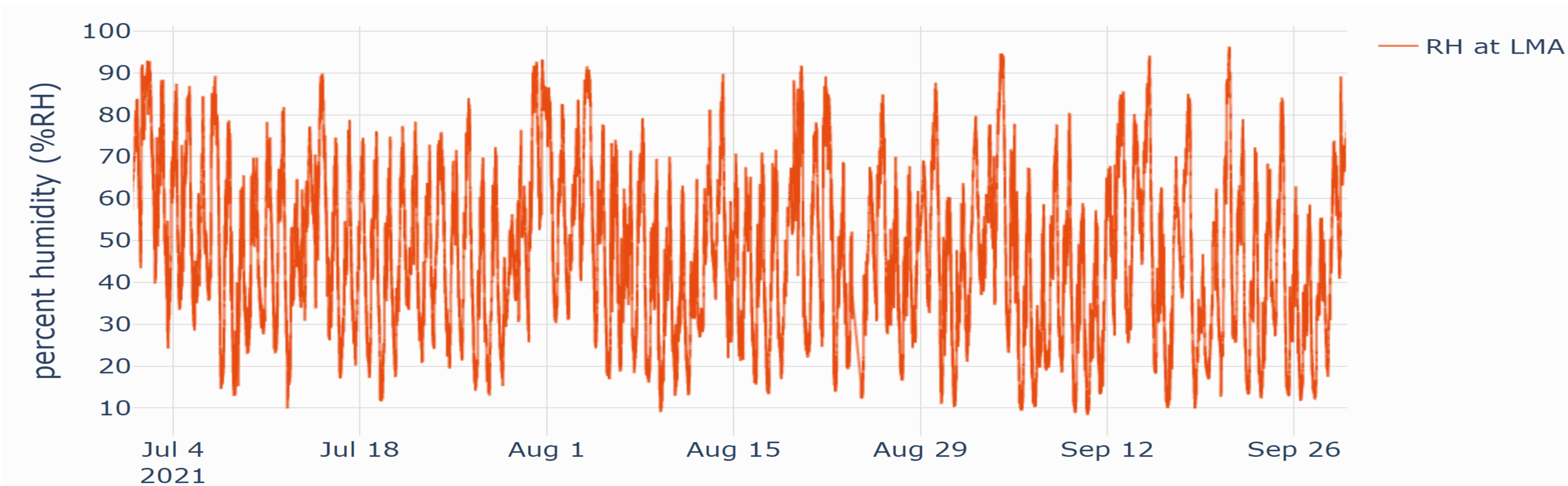


Figure SA2:
LMA relative humidity record Q3, 2021.

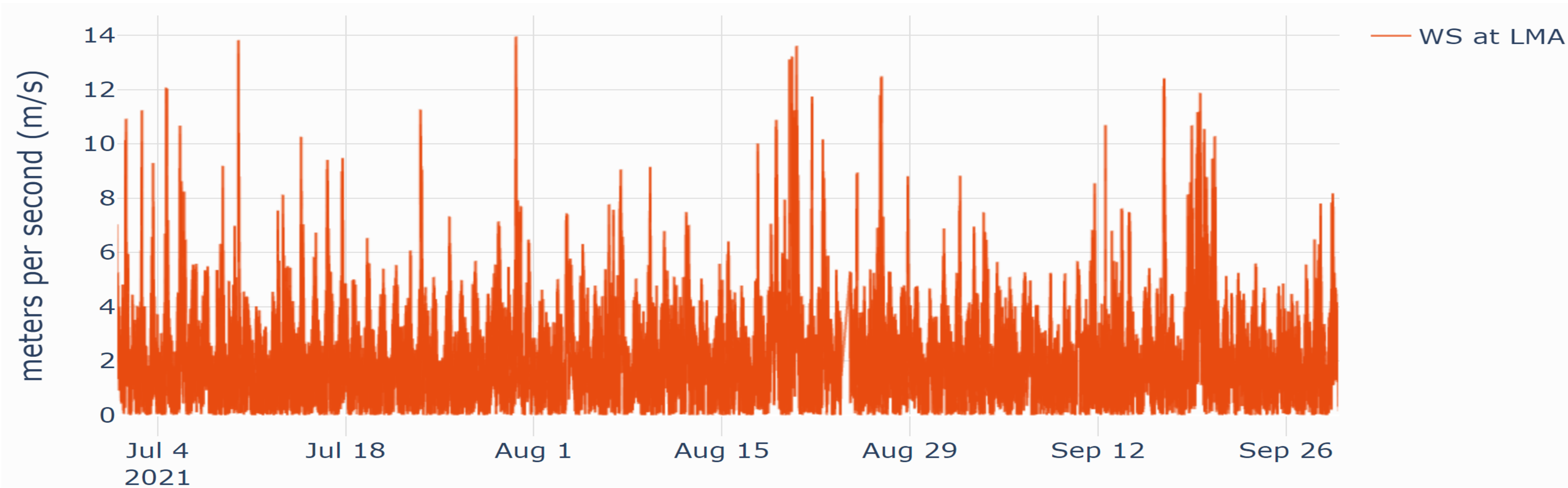


Figure SA3:
LMA wind speed record Q3, 2021.

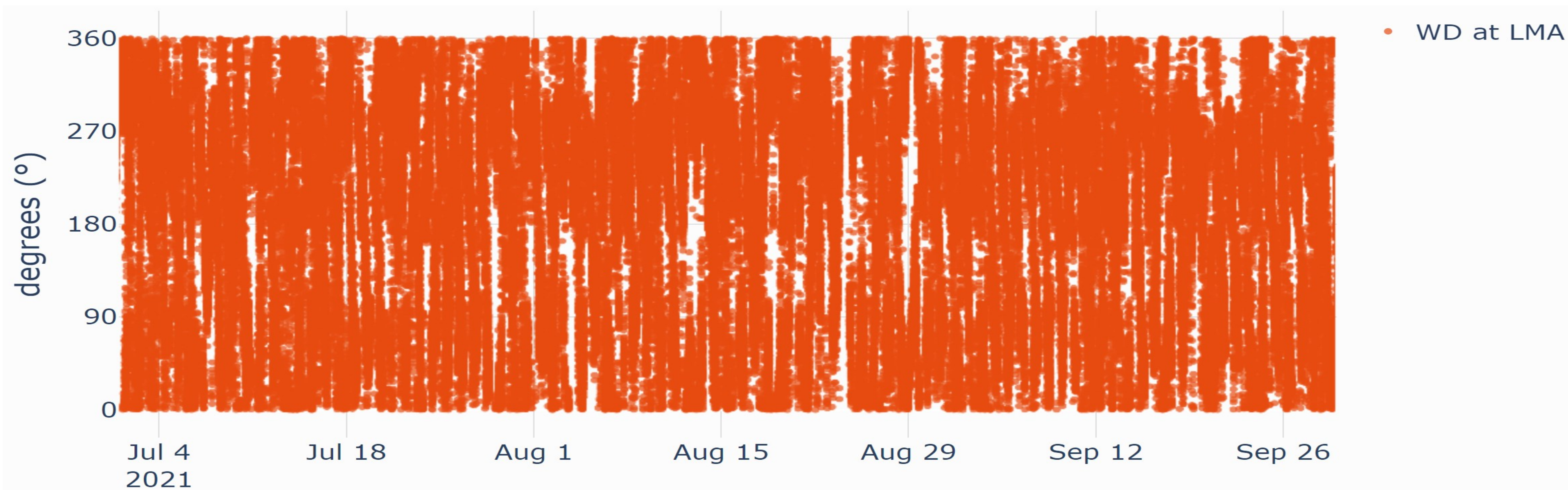


Figure SA4:
LMA wind direction record Q3, 2021.

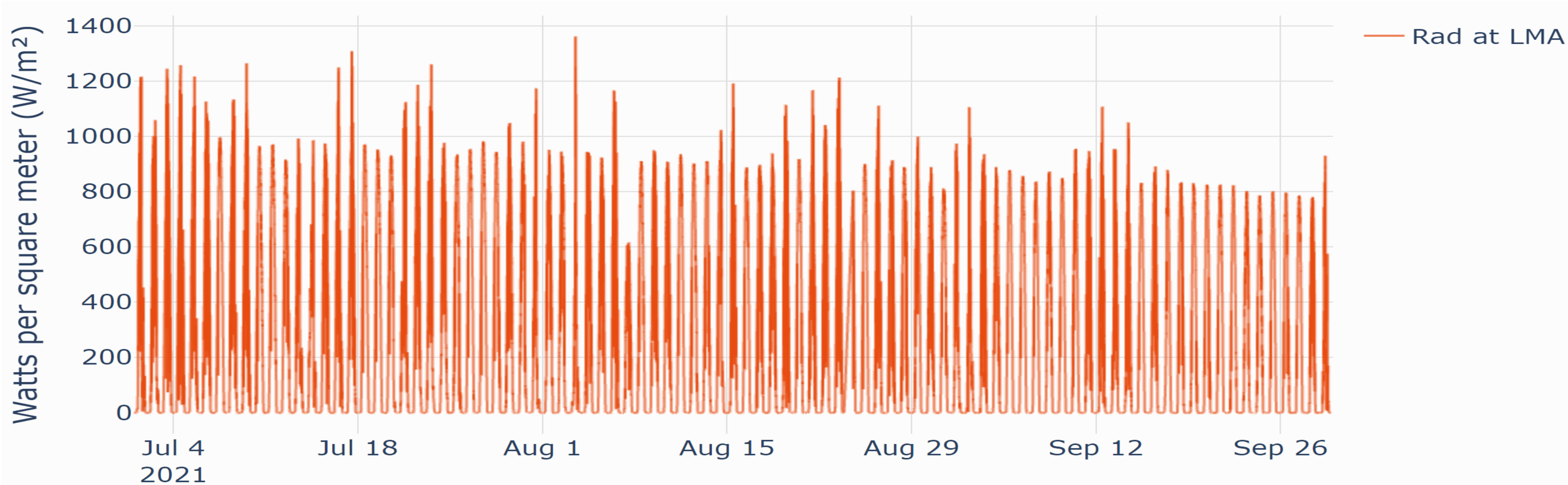


Figure SA5:
LMA solar radiation record Q3, 2021.

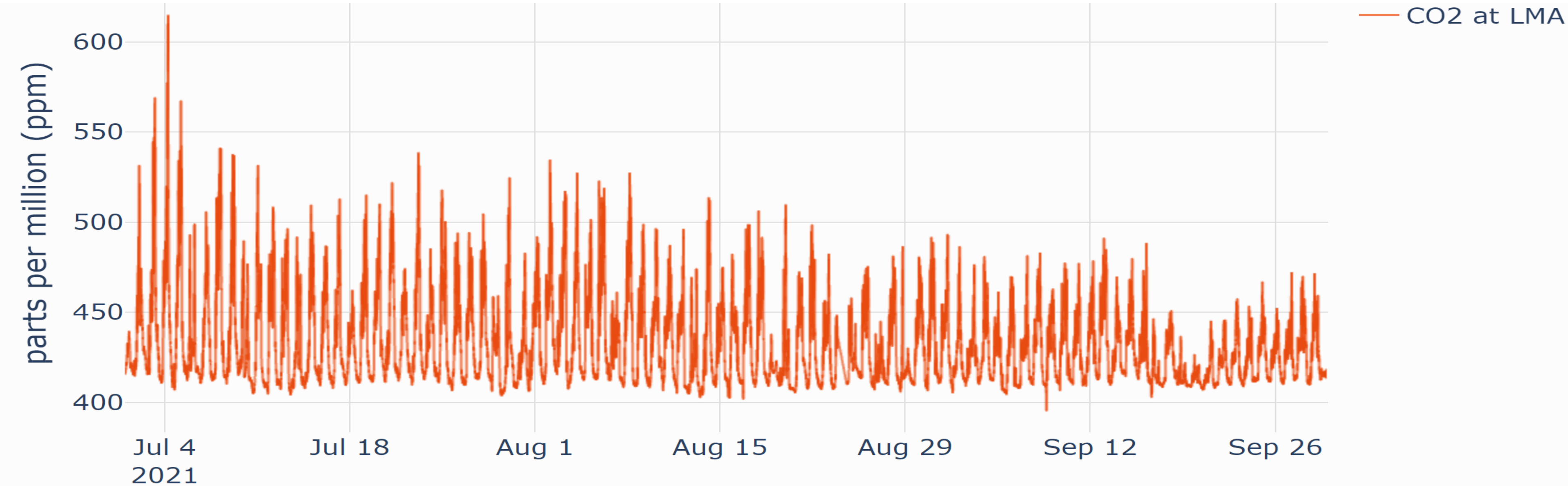


Figure SA6:
LMA CO_2 record Q3, 2021.

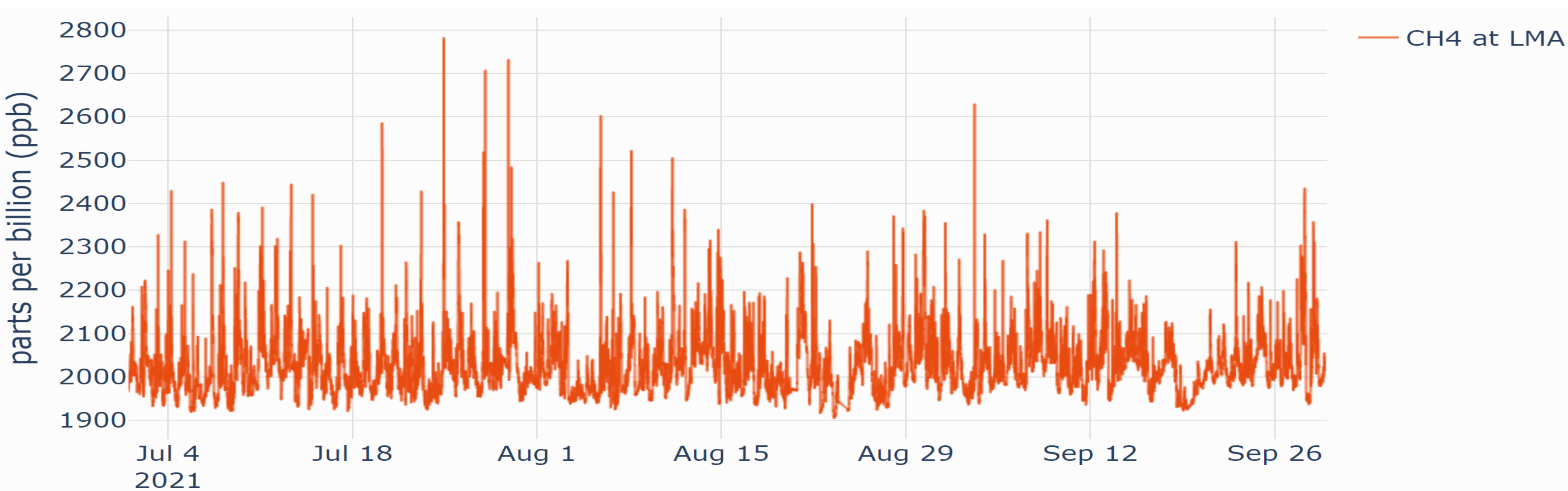


Figure SA7:
LMA methane record Q3, 2021.

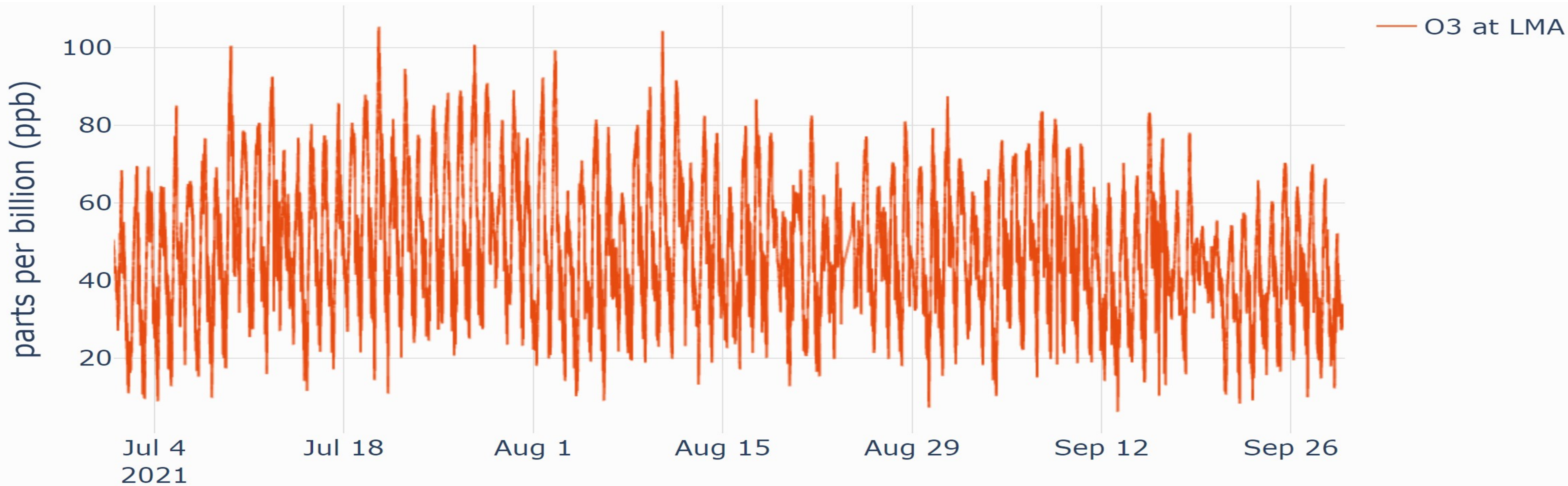


Figure SA8:
LMA ozone record Q3, 2021.

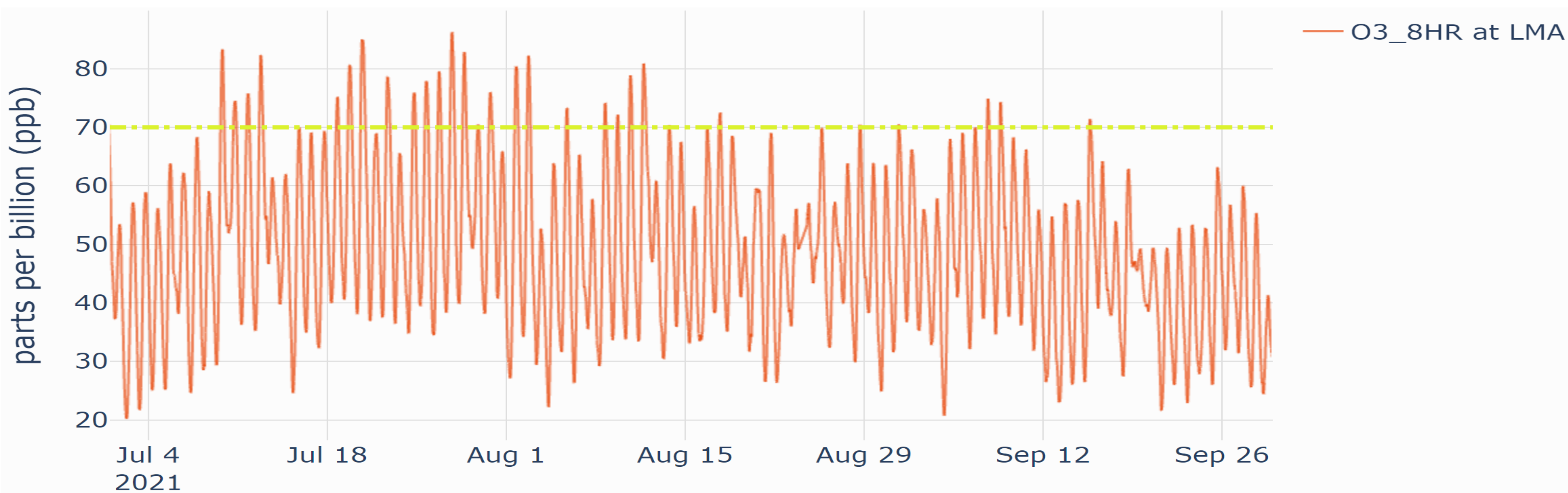


Figure SA9:
LMA 8-hour averaged ozone Q3, 2021.

Supplement B

Time Series Graphs of Preliminary LUR Data Q3, 2021.

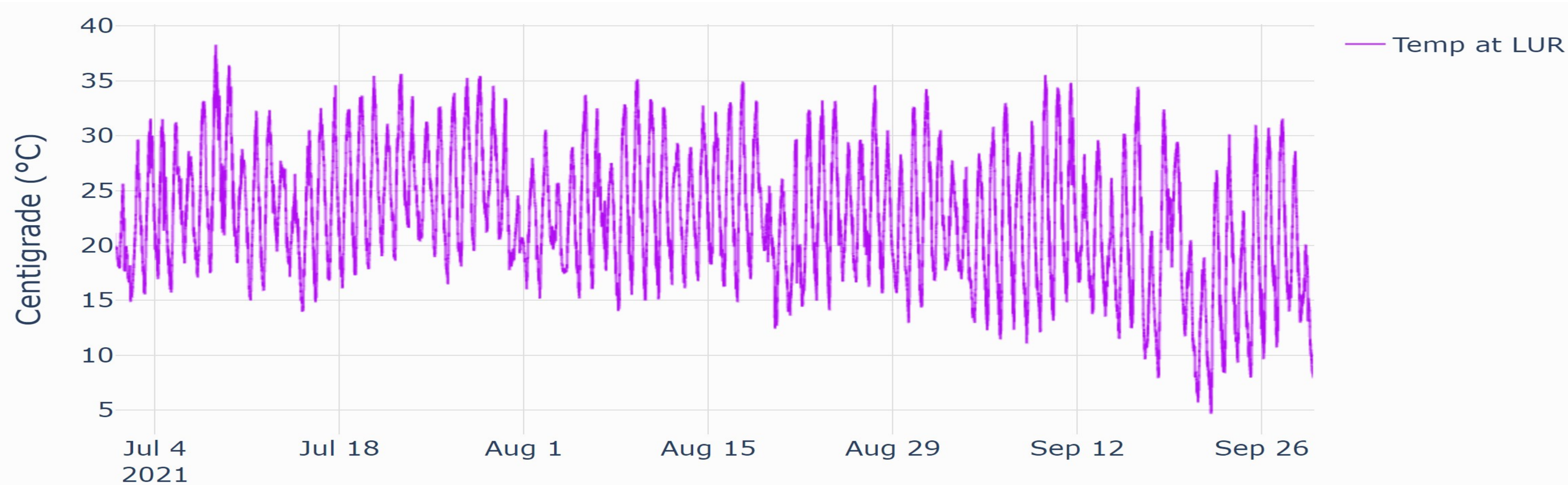


Figure SB1:
LUR temperature record Q3, 2021.

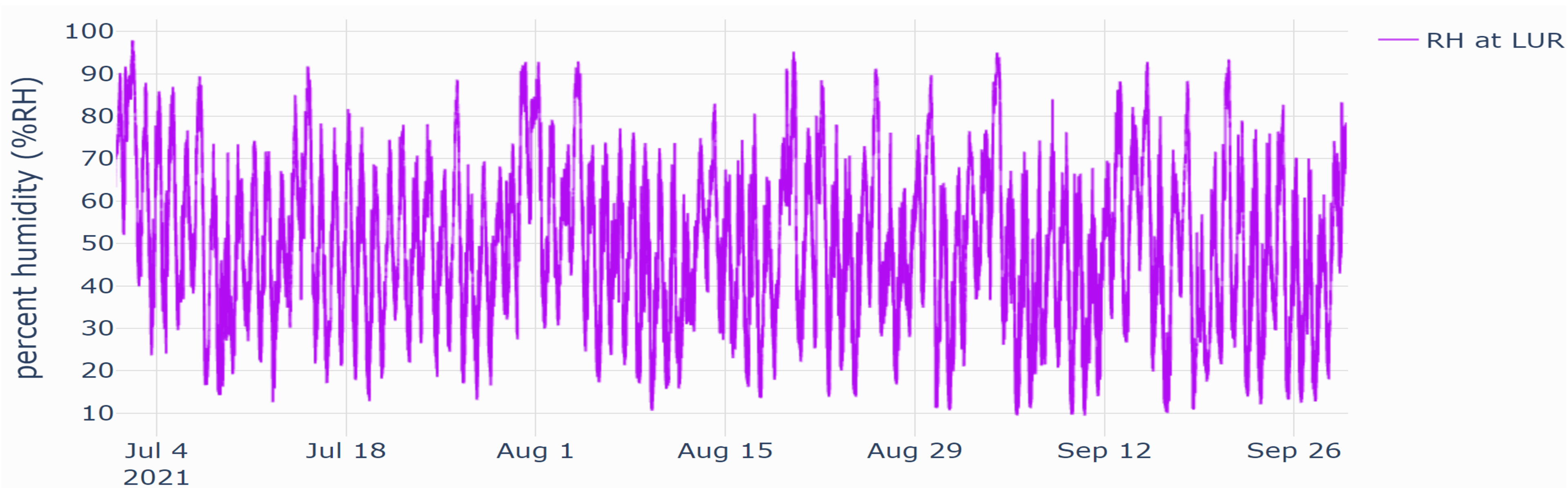


Figure SB2:
LUR relative humidity record Q3, 2021.

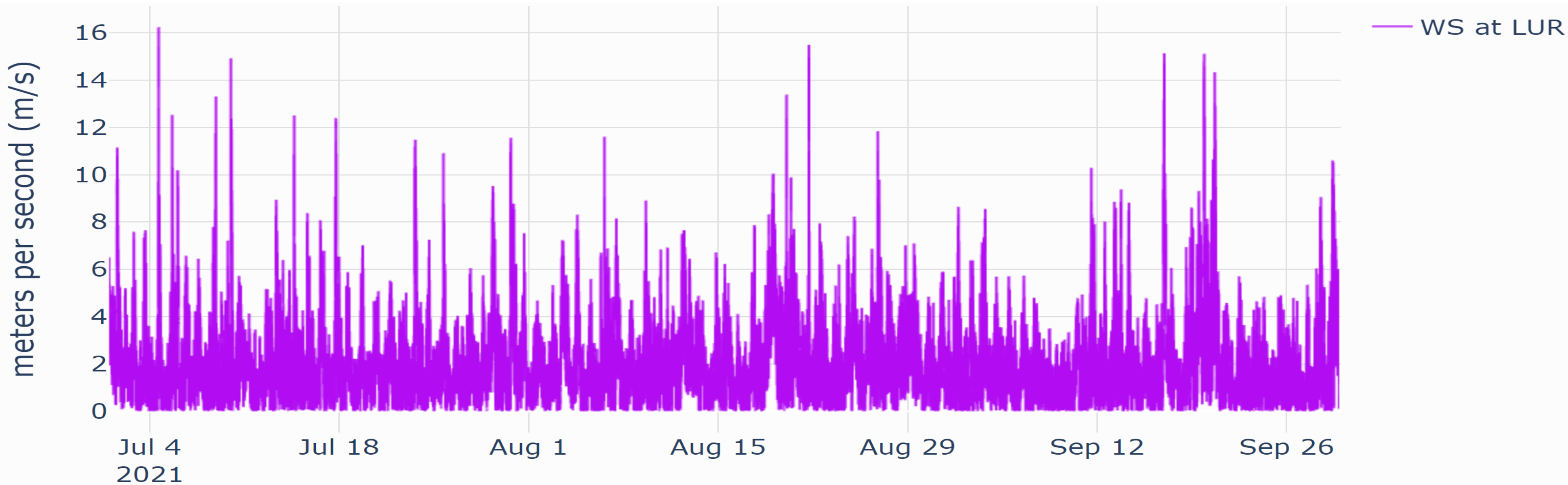


Figure SB3:
LUR wind speed record Q3, 2021.

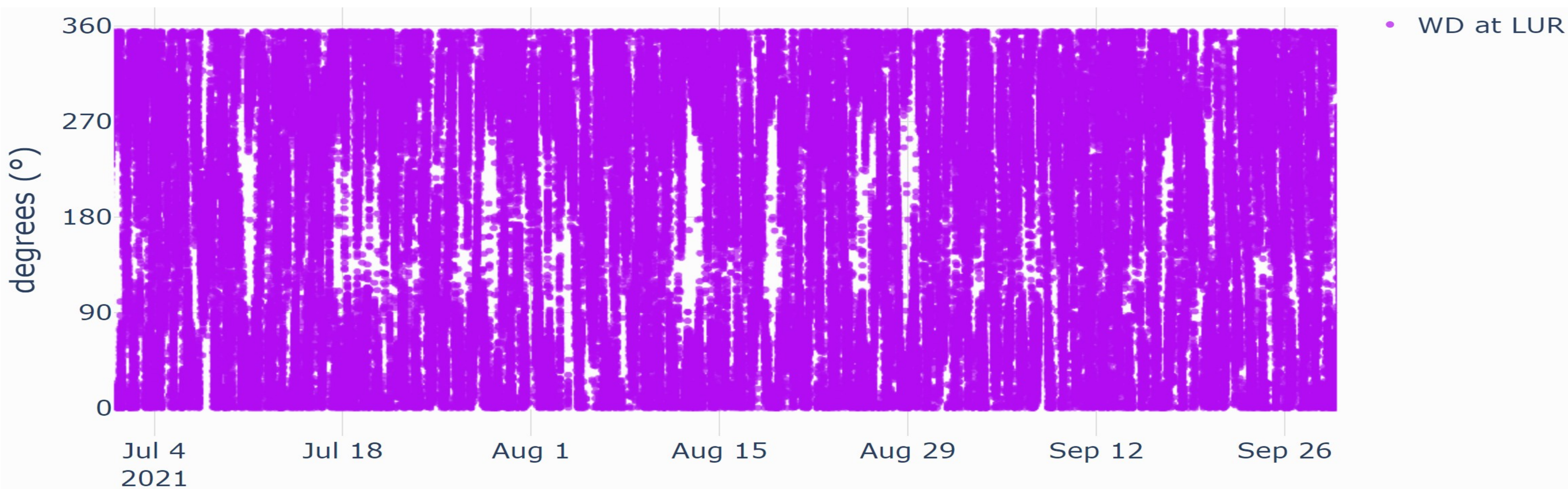


Figure SB4:
LUR wind direction record Q3, 2021.

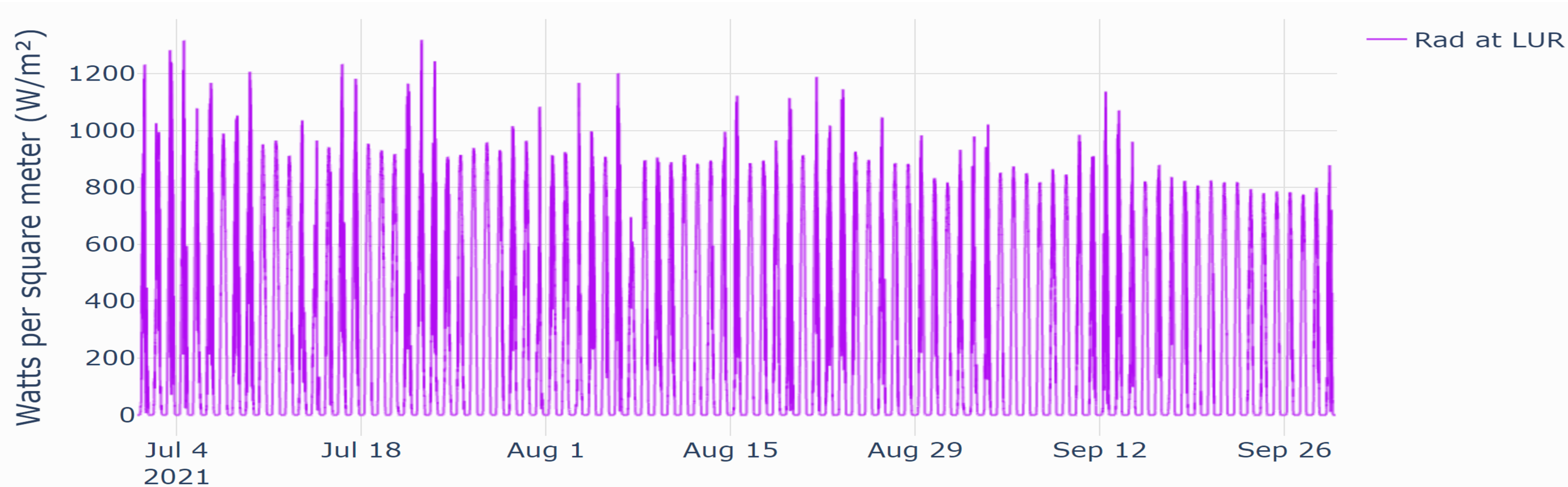


Figure SB5:
LUR solar radiation record Q3, 2021.

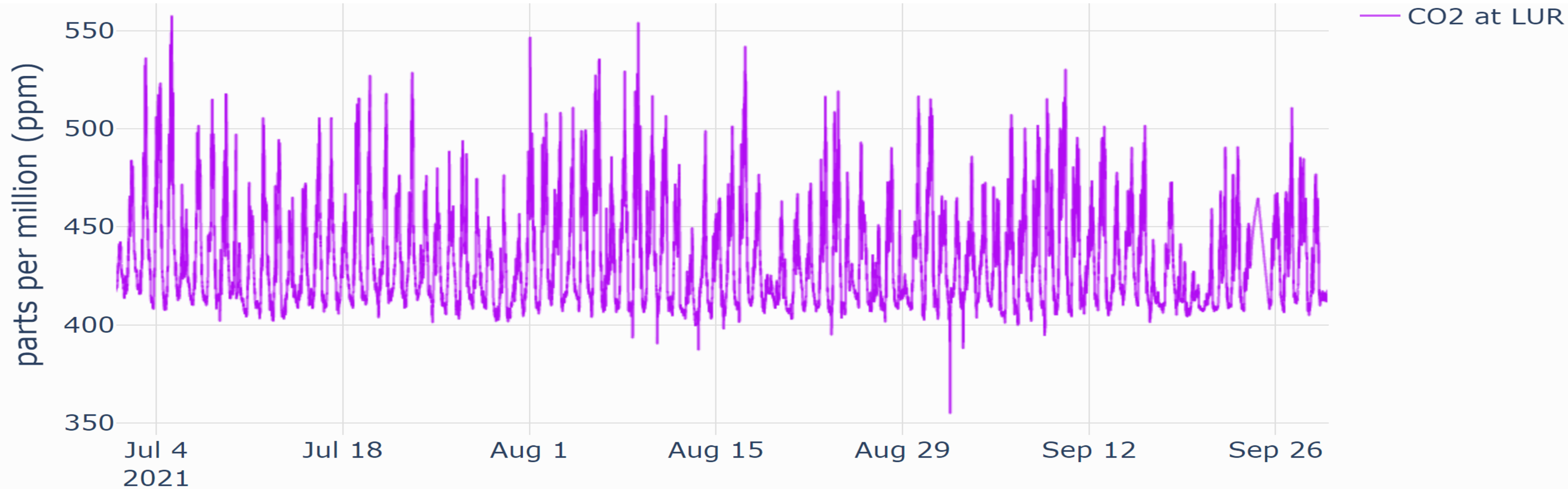


Figure SB6:
LUR CO_2 record Q3, 2021.

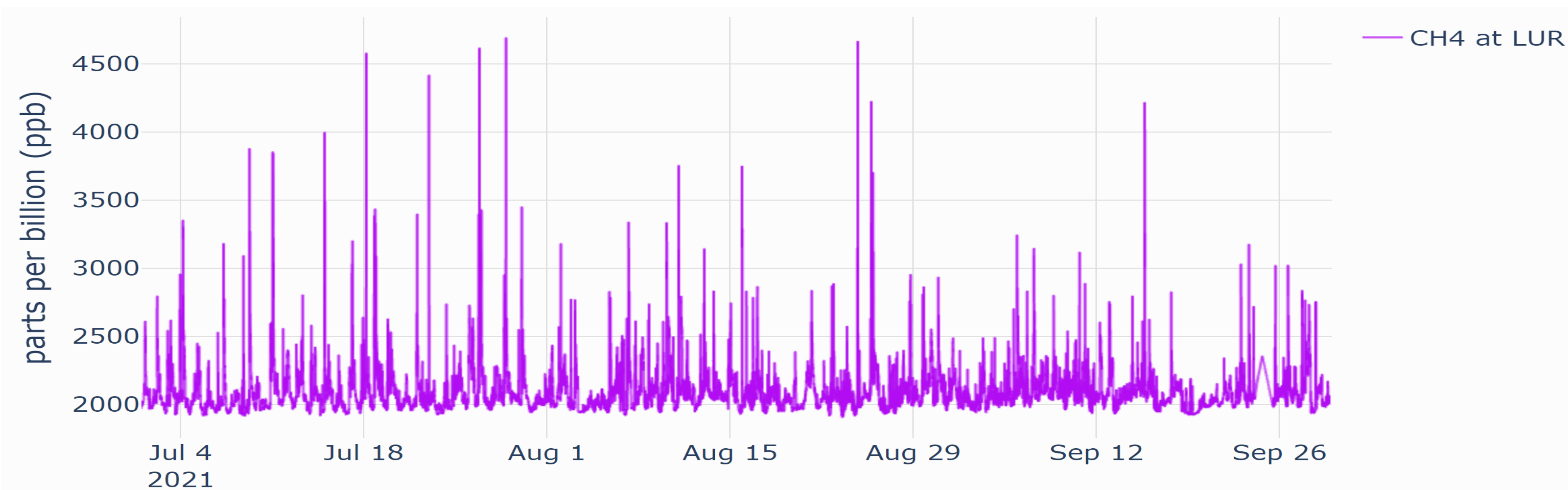


Figure SB7:
LUR methane record Q3, 2021.

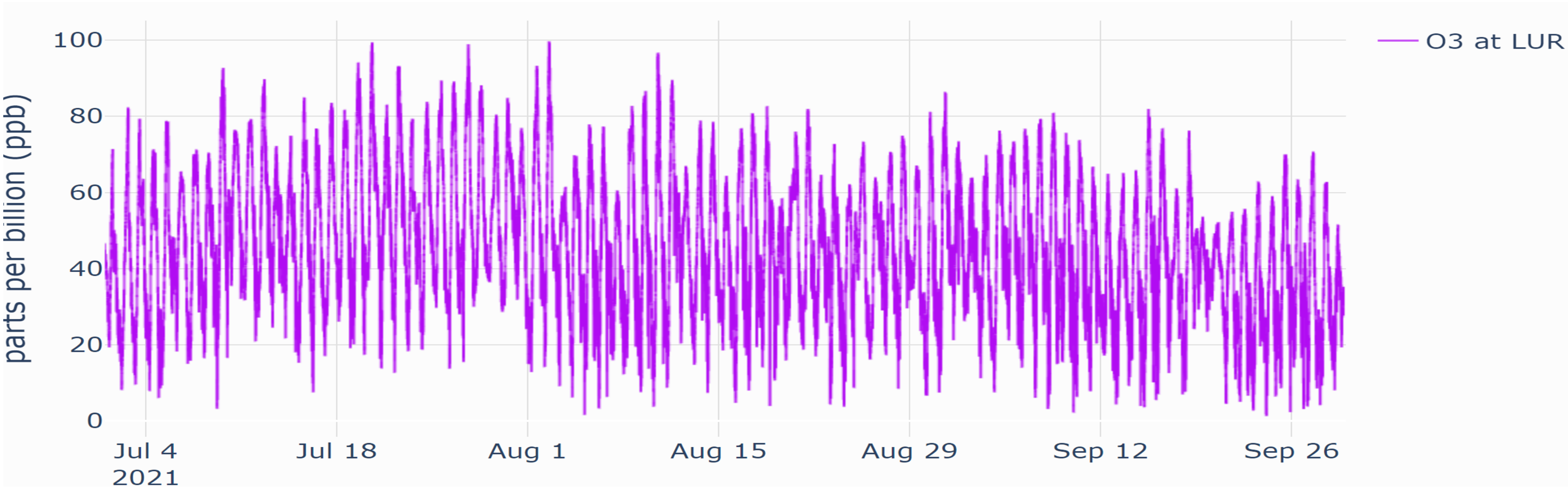


Figure SB8:
LUR hourly ozone record Q3, 2021.

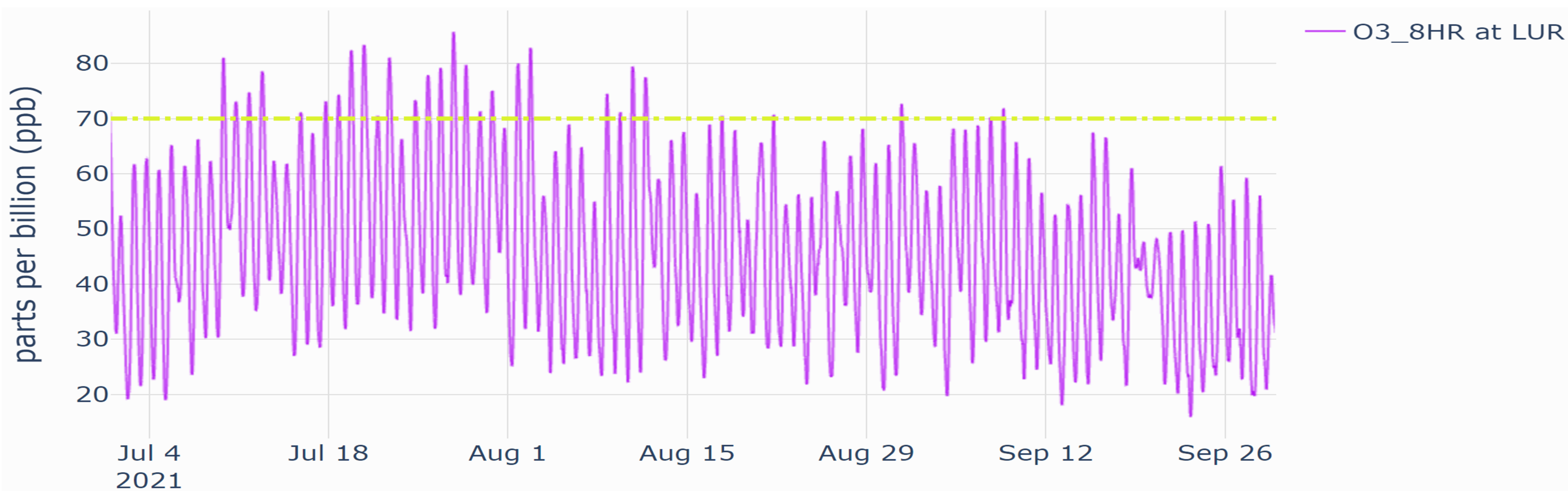


Figure SB9:
LUR 8-hour averaged ozone record Q3, 2021.

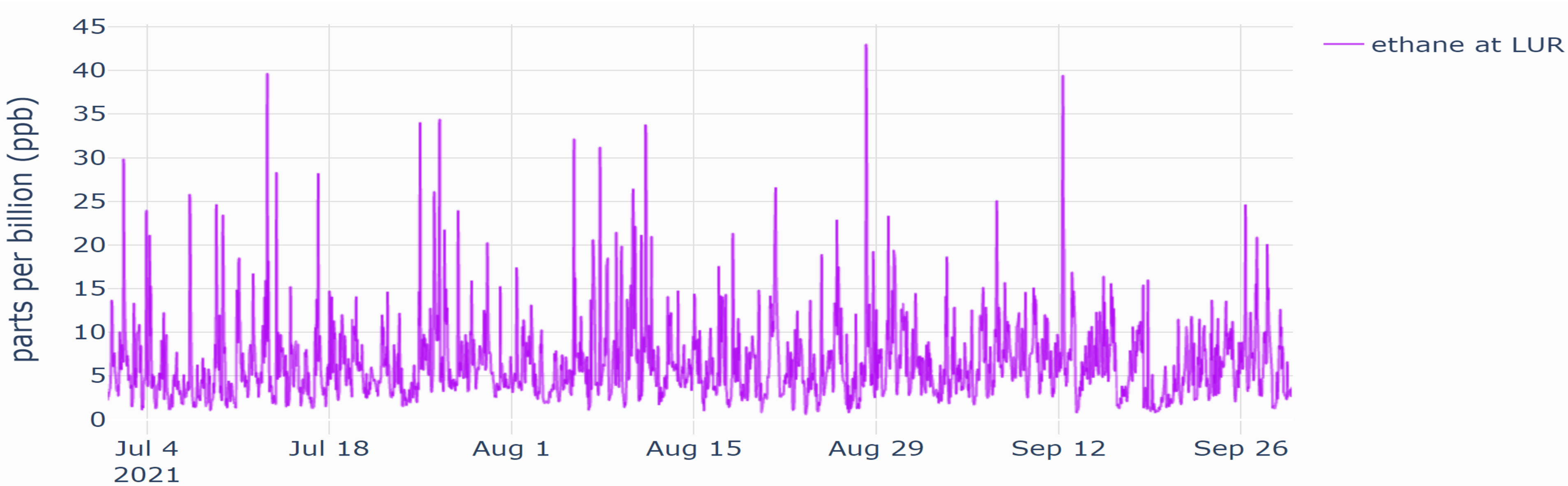


Figure SB10:
LUR ethane record Q3, 2021.

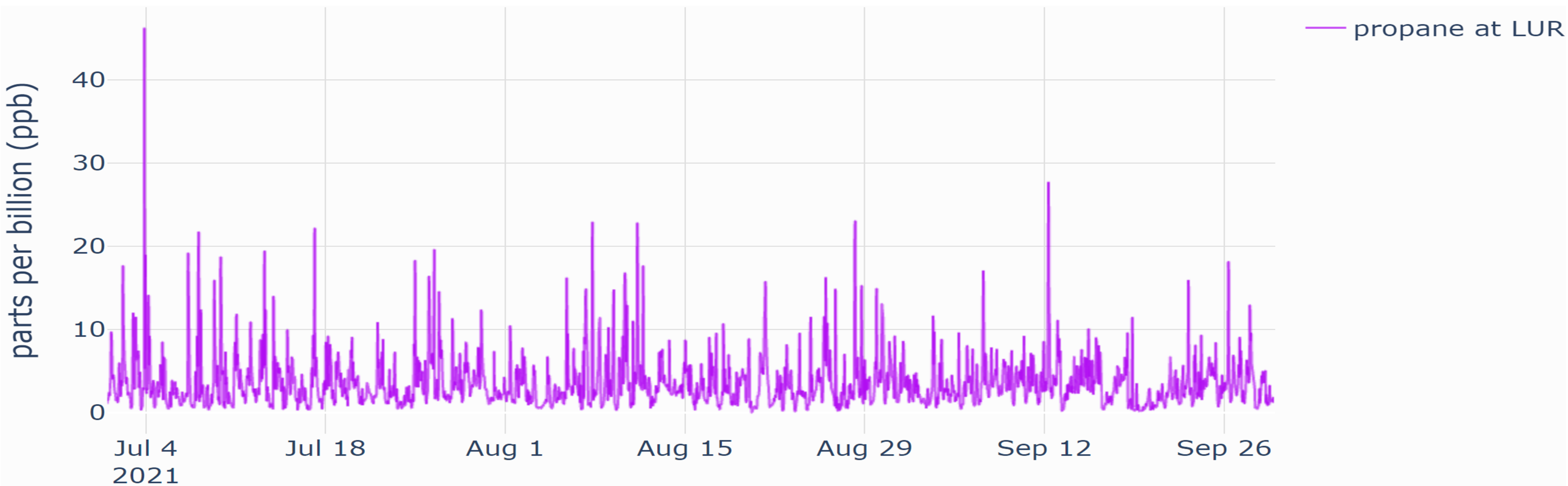


Figure SB11:
LUR propane record Q3, 2021.

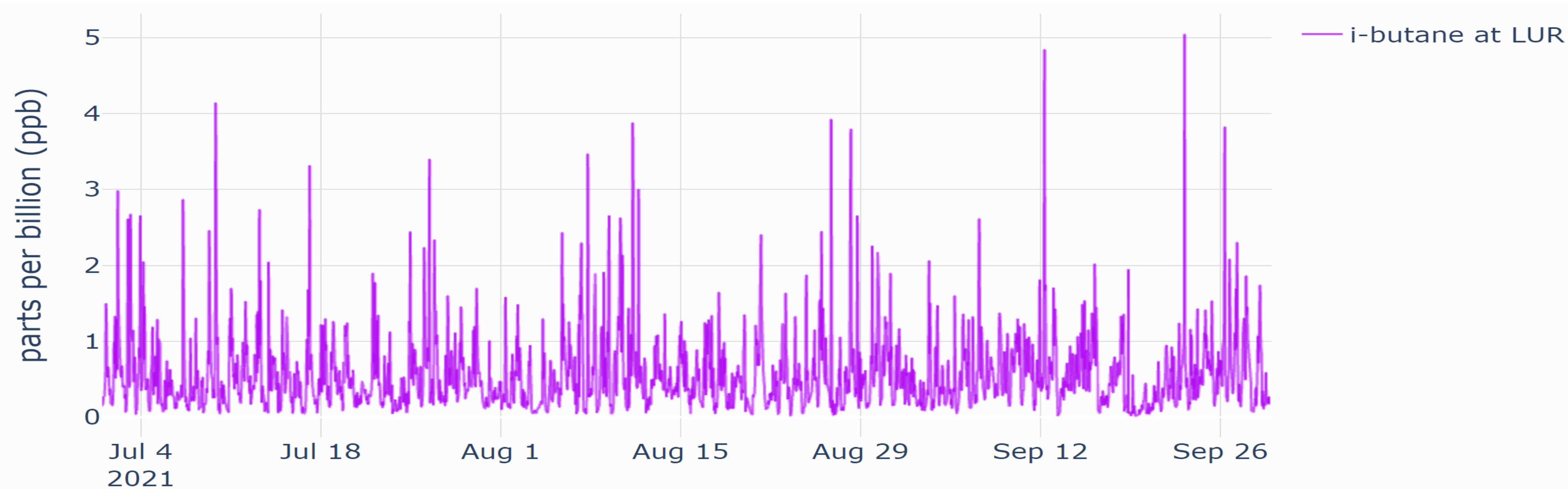


Figure SB12:
LUR i-butane record Q3, 2021.

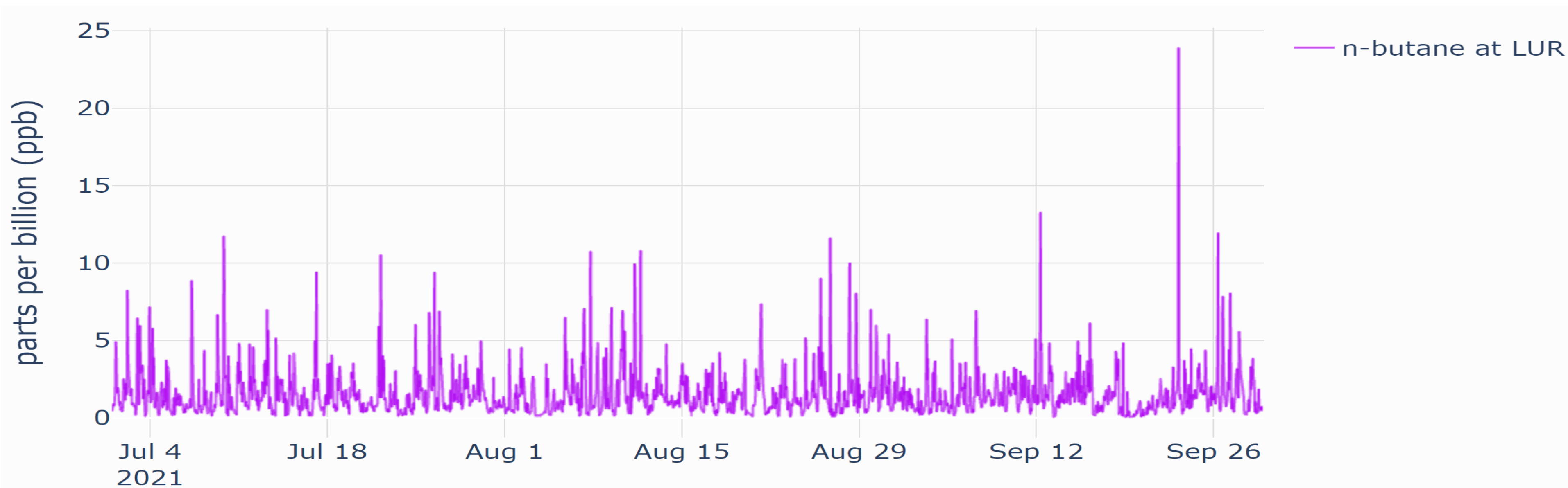


Figure SB13:
LUR n-butane record Q3, 2021.

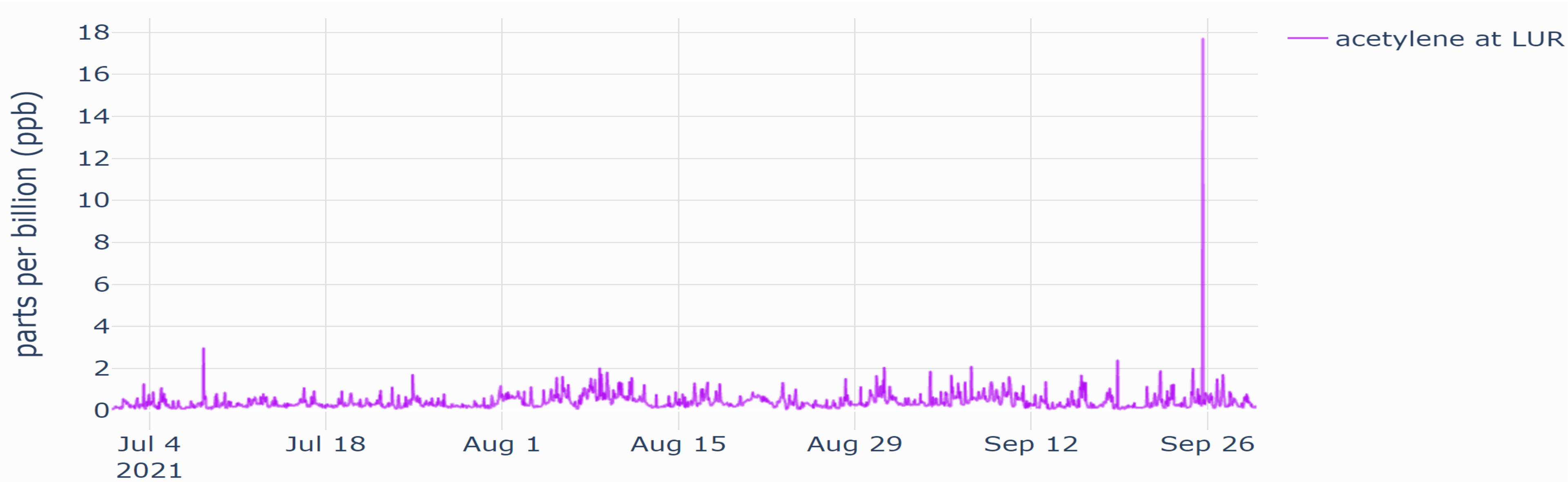


Figure SB14:
LUR acetylene record Q3, 2021.

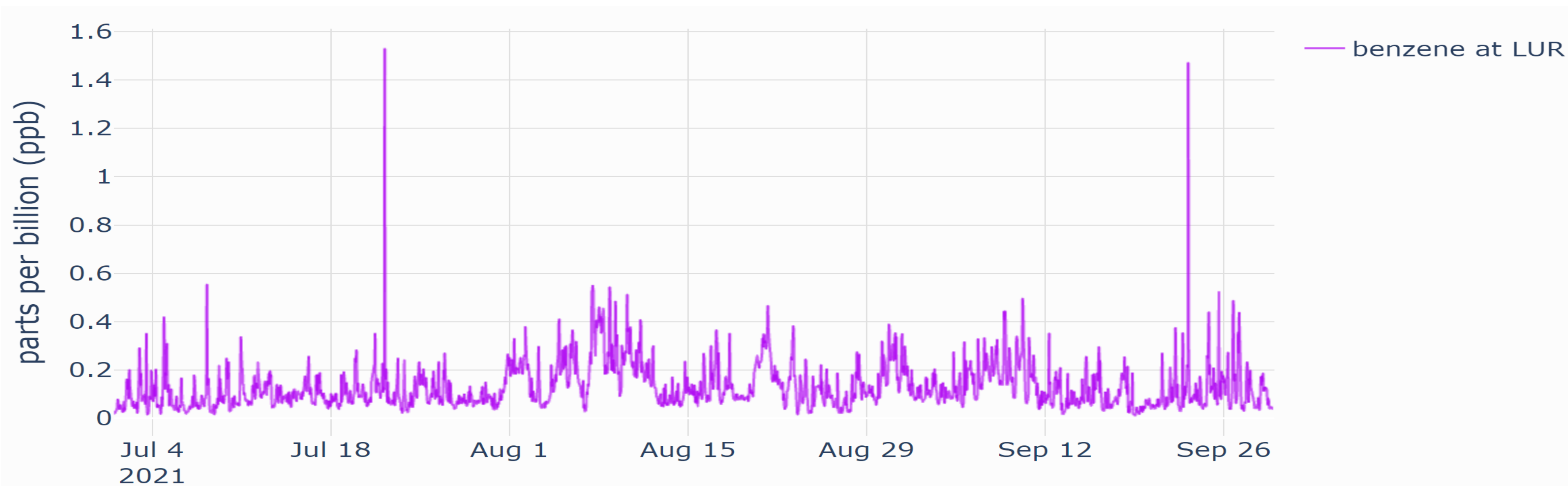


Figure SB15:
LUR benzene record Q3, 2021.

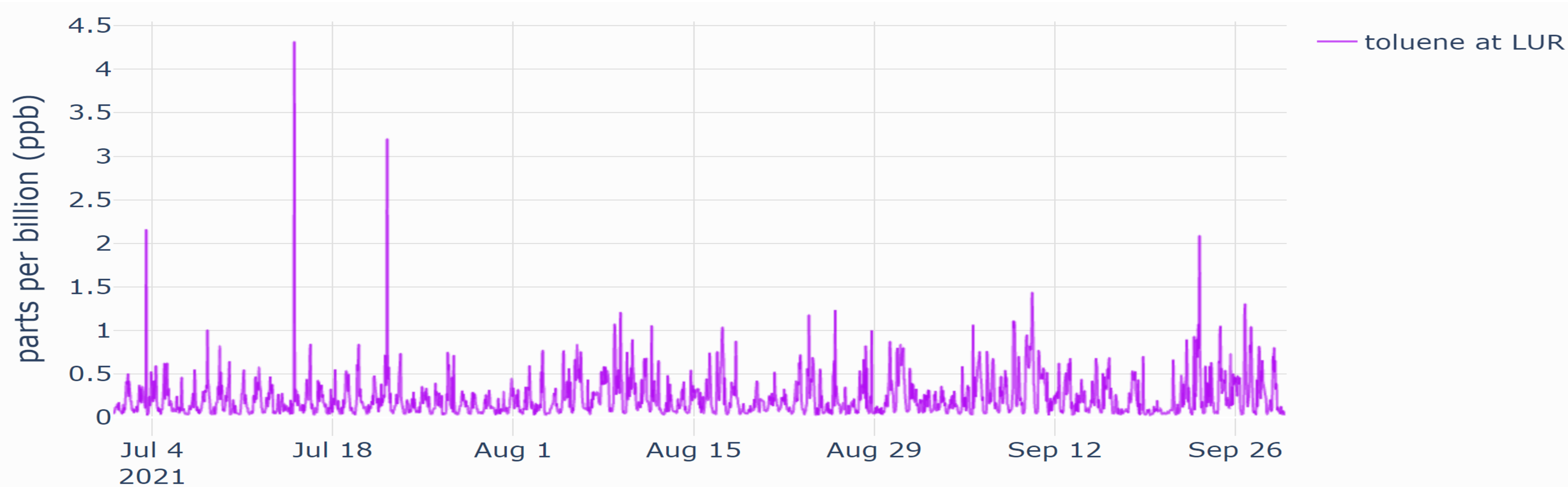


Figure SB16:
LUR toluene record Q3, 2021.

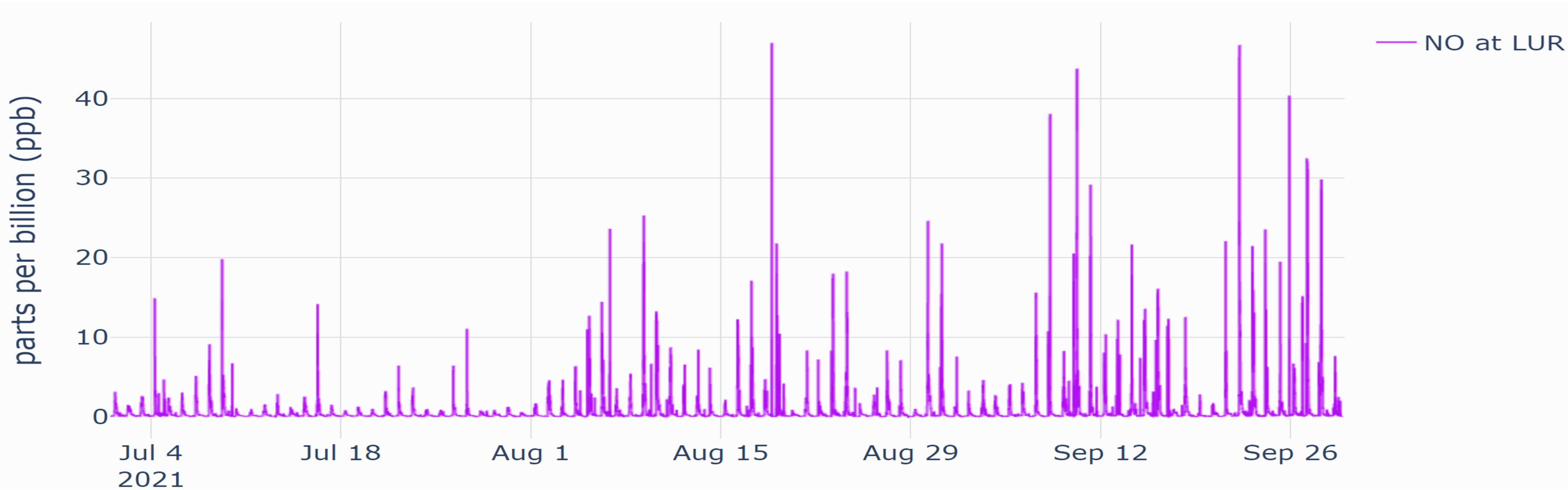


Figure SB17:
LUR NO record Q3, 2021.

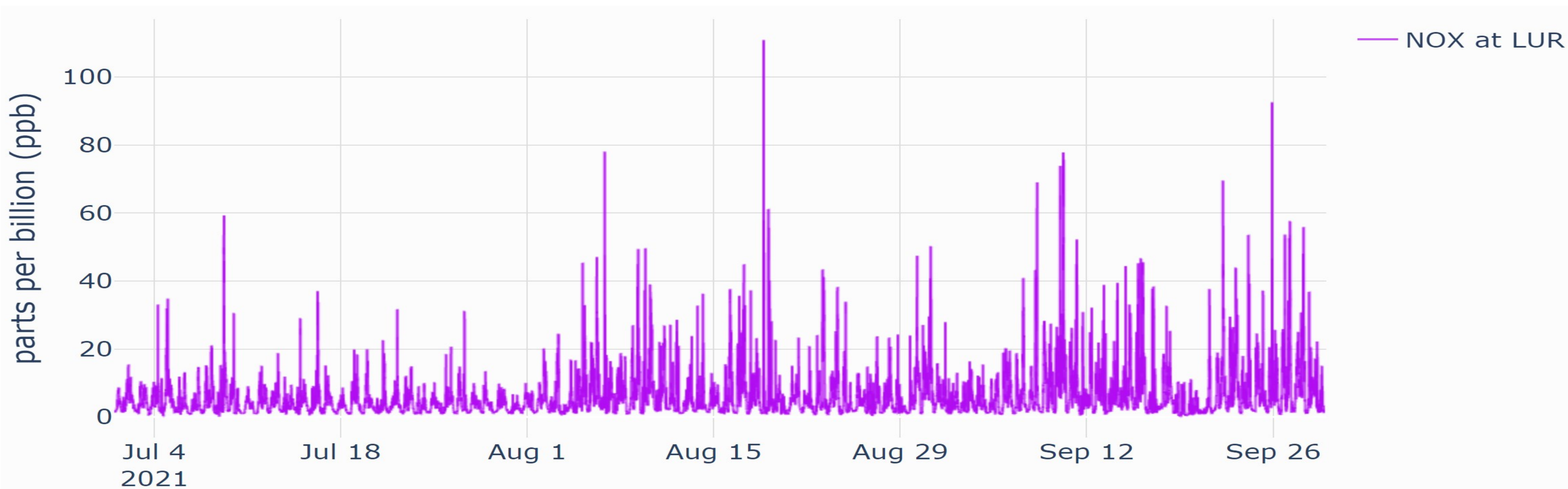


Figure SB18:
LUR NOx record Q3, 2021.

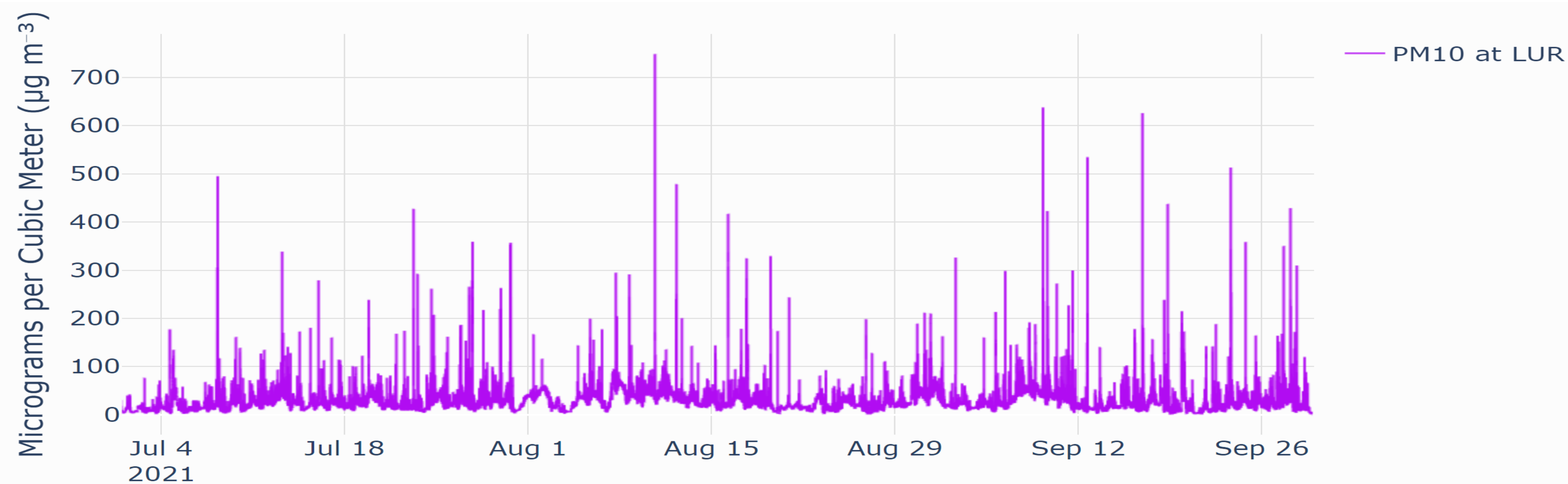


Figure SB19:
LUR PM 10 record Q3, 2021.

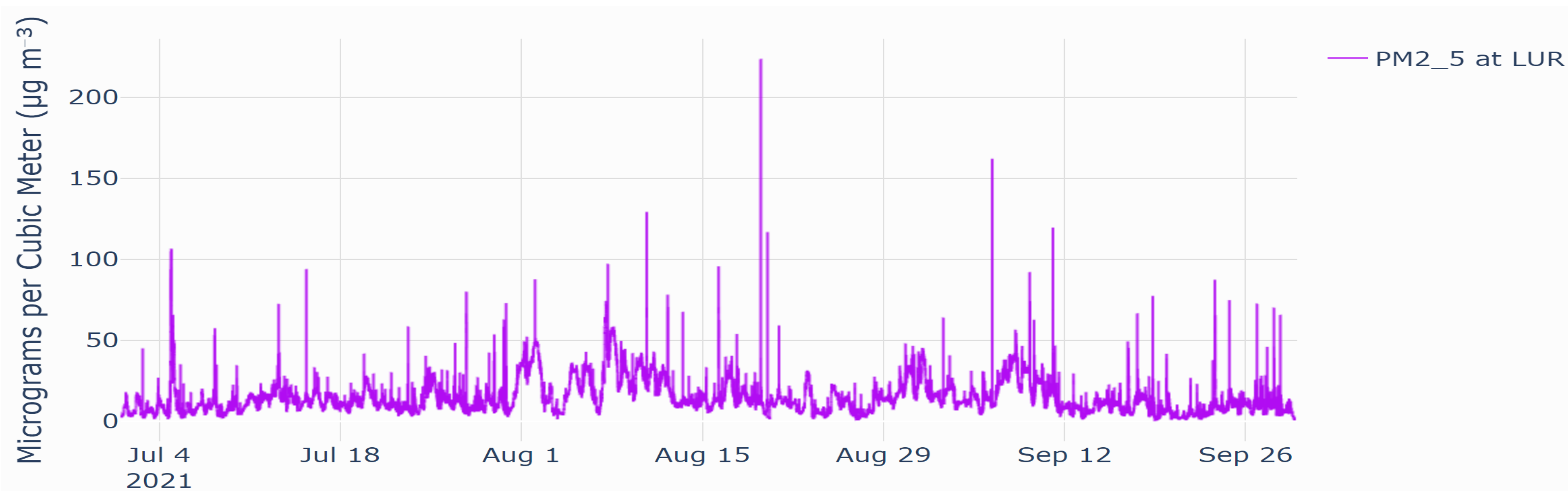


Figure SB20:
LUR PM 2.5 record Q3, 2021.

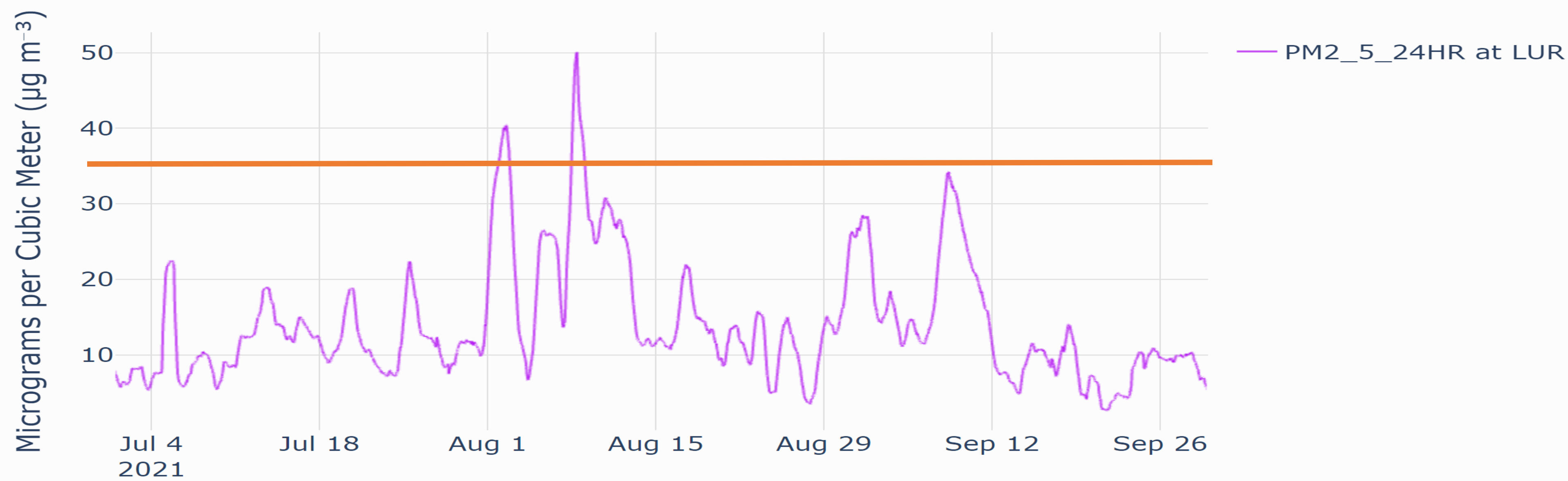


Figure SB21:
LUR PM 2.5 24-hour averages record Q3, 2021 Horizontal orange line indicates the NAAQS 24-hour limit for PM 2.5 of 35 $\mu g/m^3$.

Supplement C

Time Series Graphs of Preliminary LMA & LUR combined Data Q3, 2021.

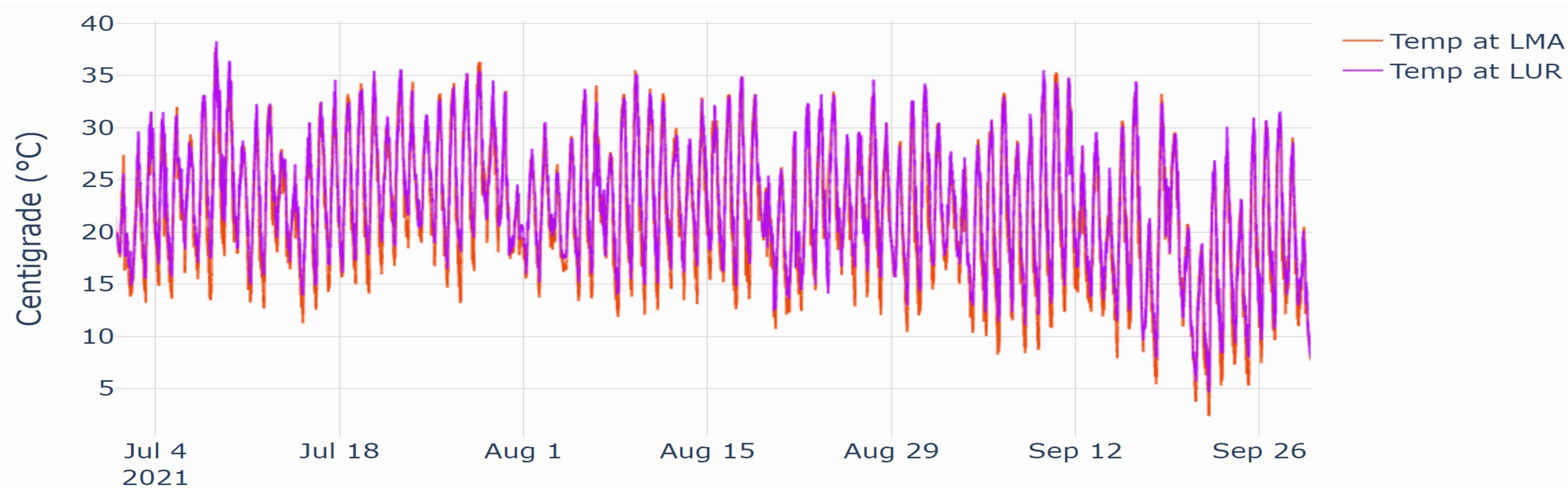


Figure SC1:
LMA & LUR combined temperature record Q3, 2021.

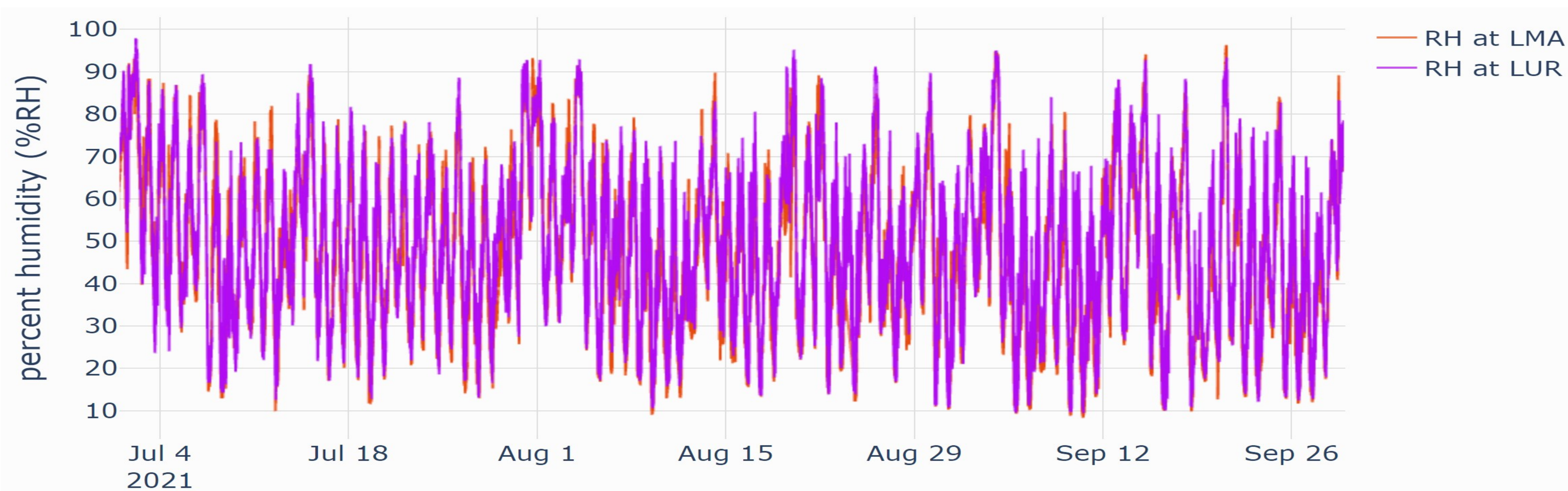


Figure SC2:
LMA & LUR combined relative humidity record Q3, 2021.

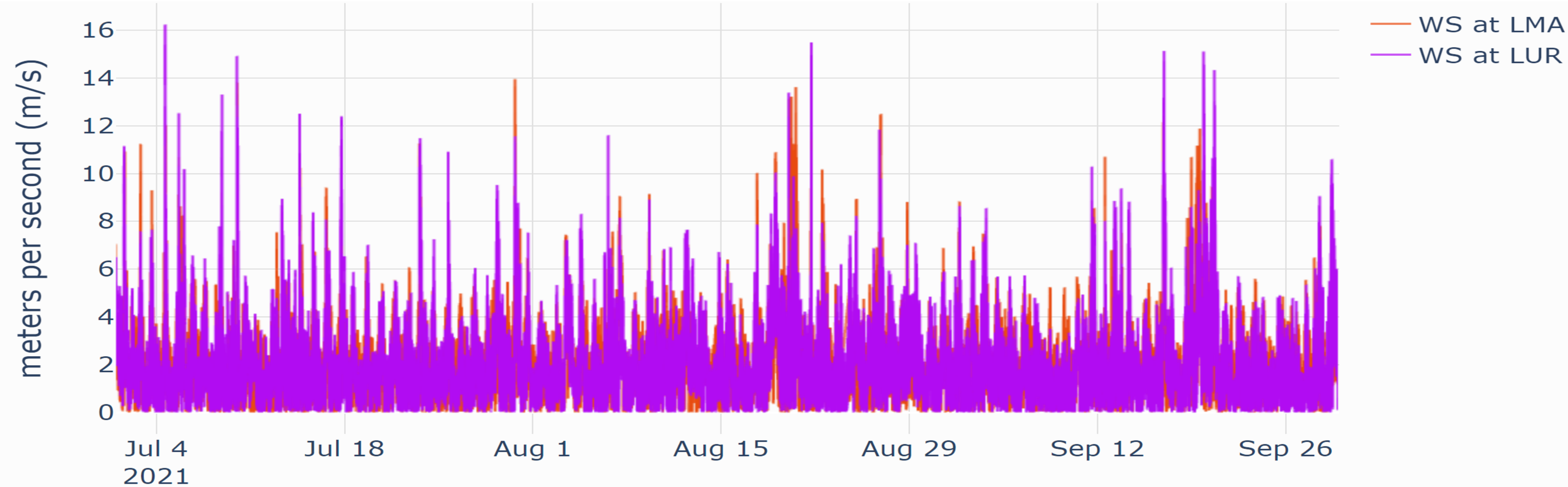


Figure SC3:
LMA & LUR combined wind speed record Q3, 2021.

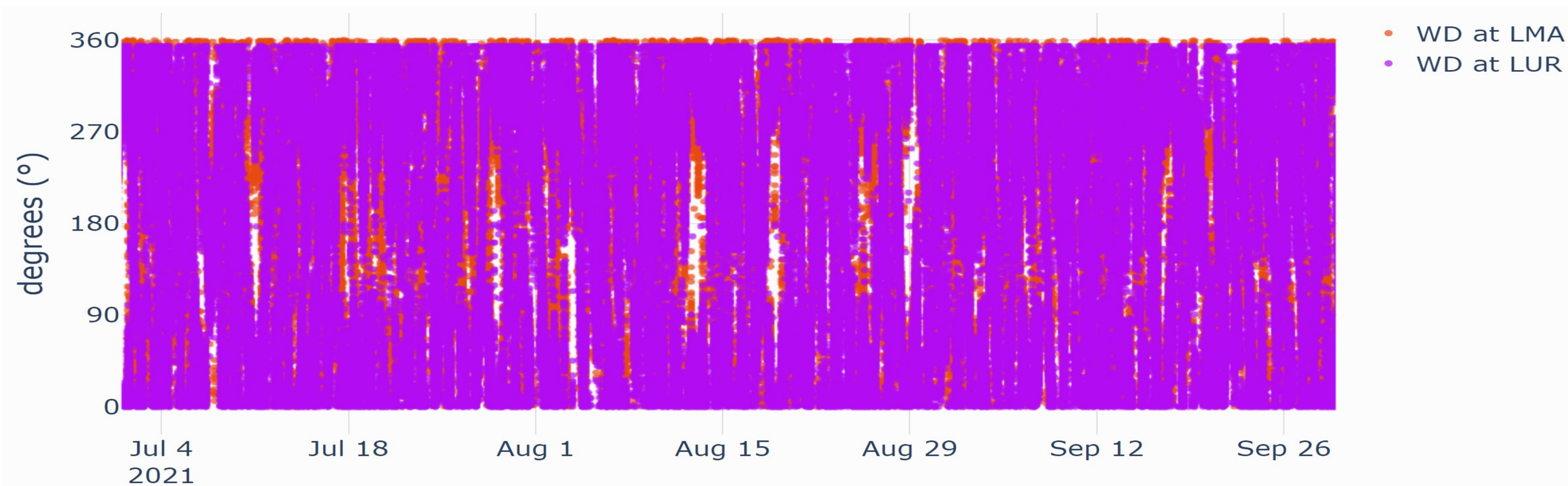


Figure SC4:
LMA & LUR combined wind direction record Q3, 2021.

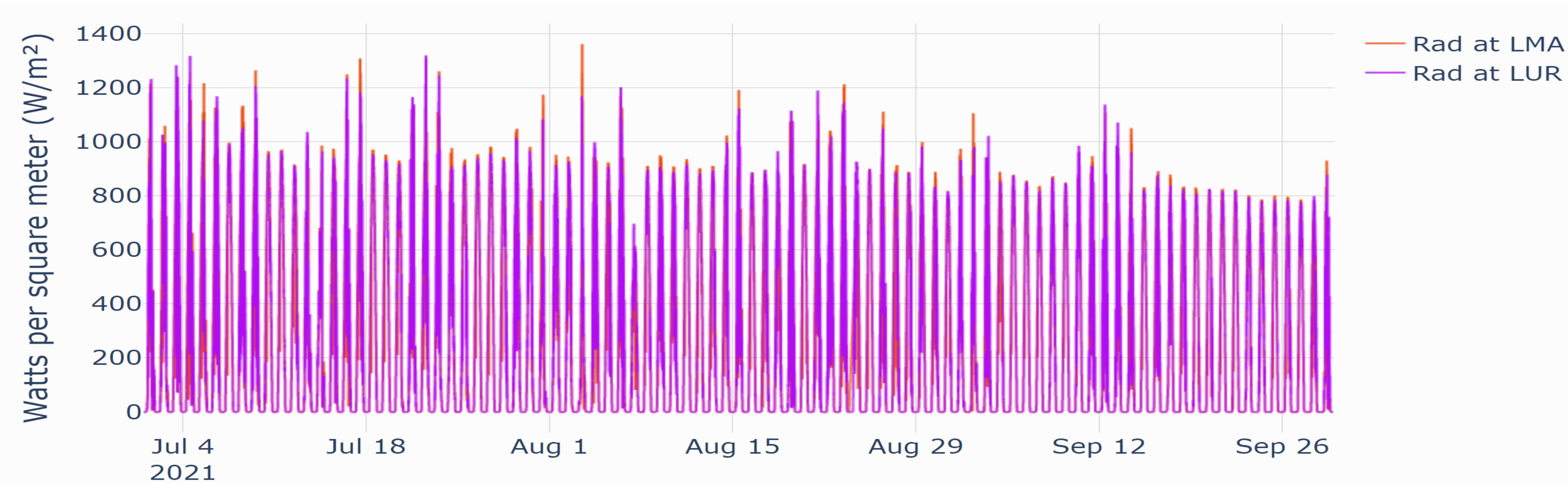


Figure SC5:
LMA & LUR combined solar radiation record Q3, 2021.

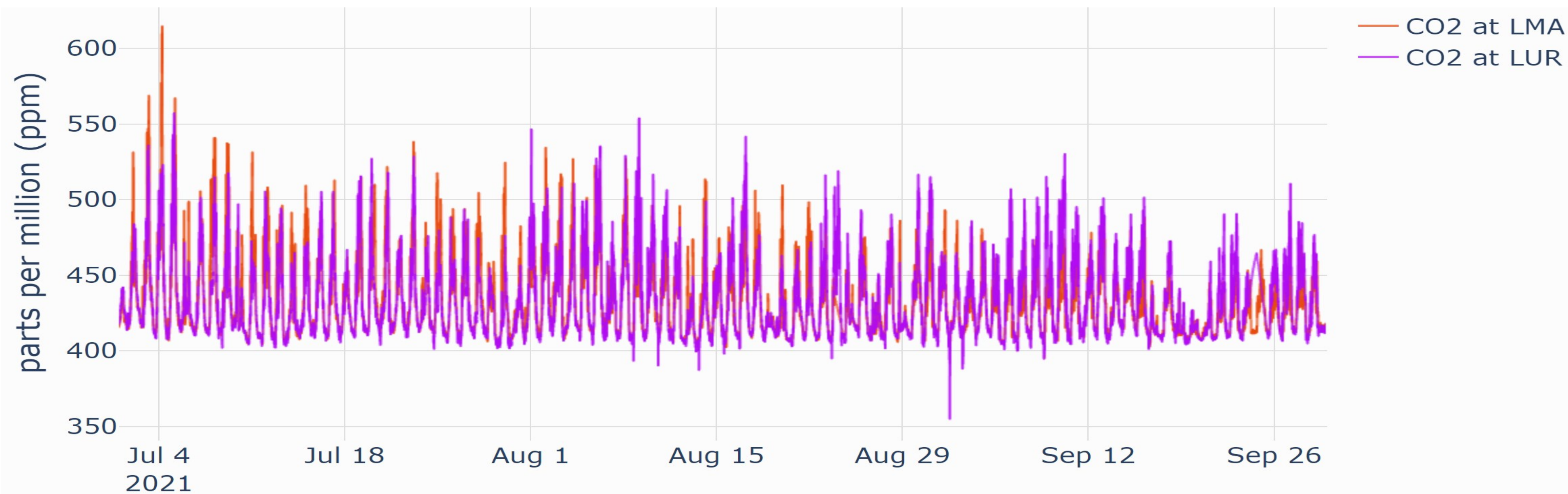


Figure SC6:
LMA & LUR combined CO_2 record Q3, 2021.

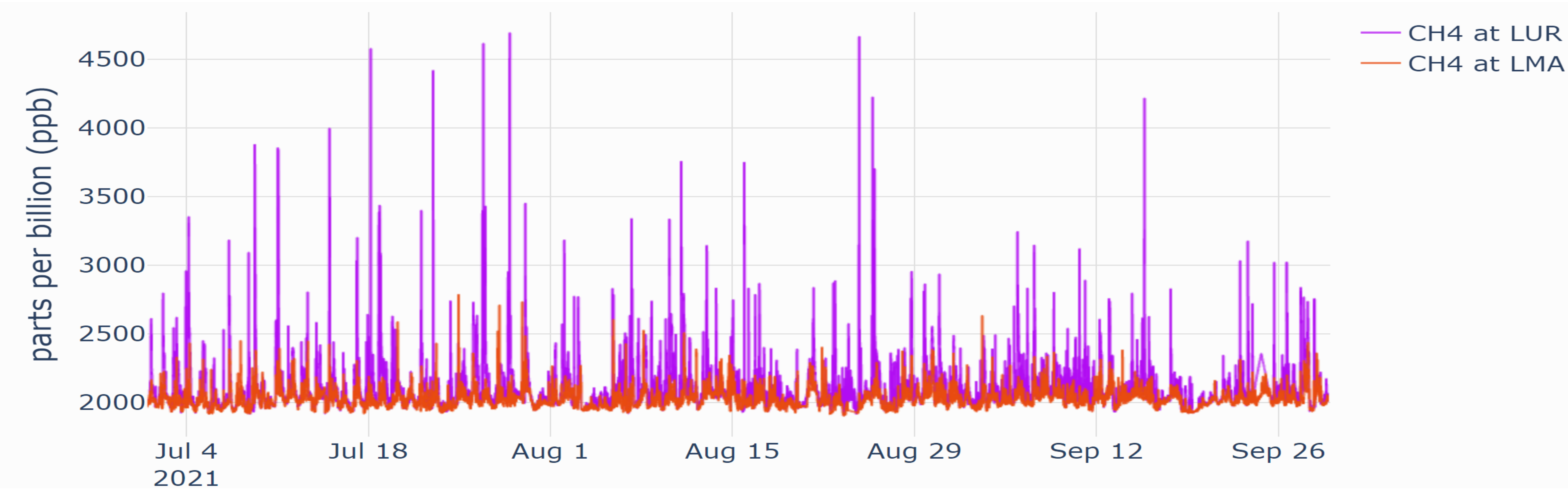


Figure SC7:
LMA & LUR combined methane record Q3, 2021.

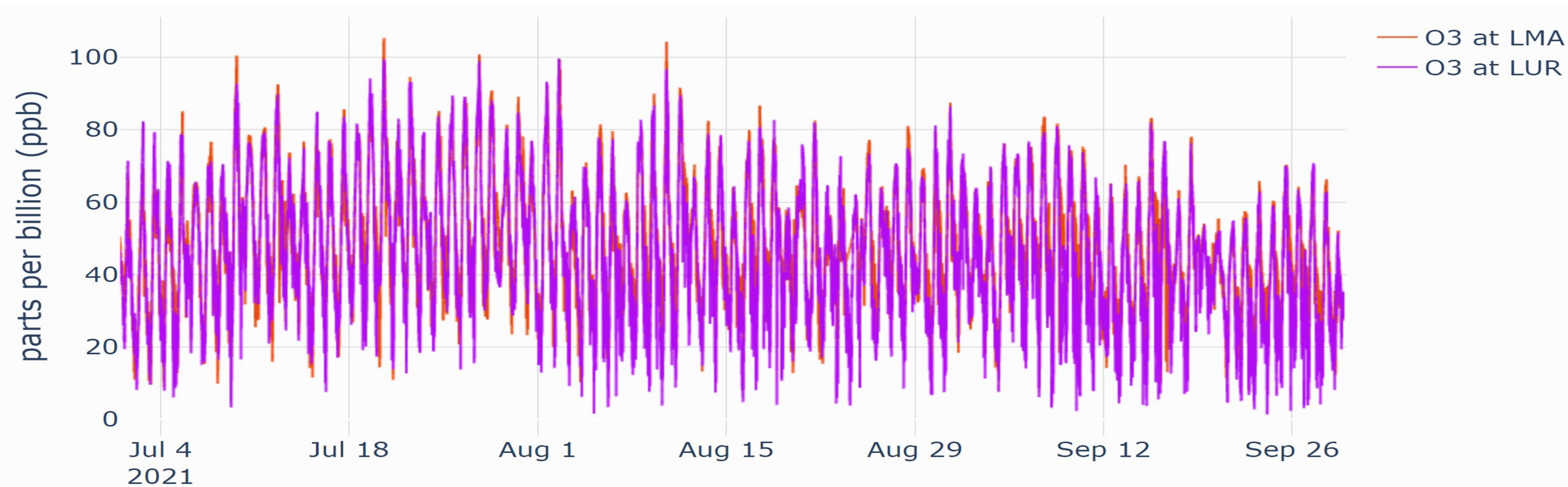


Figure SC8:
LMA & LUR combined hourly ozone record Q3, 2021.

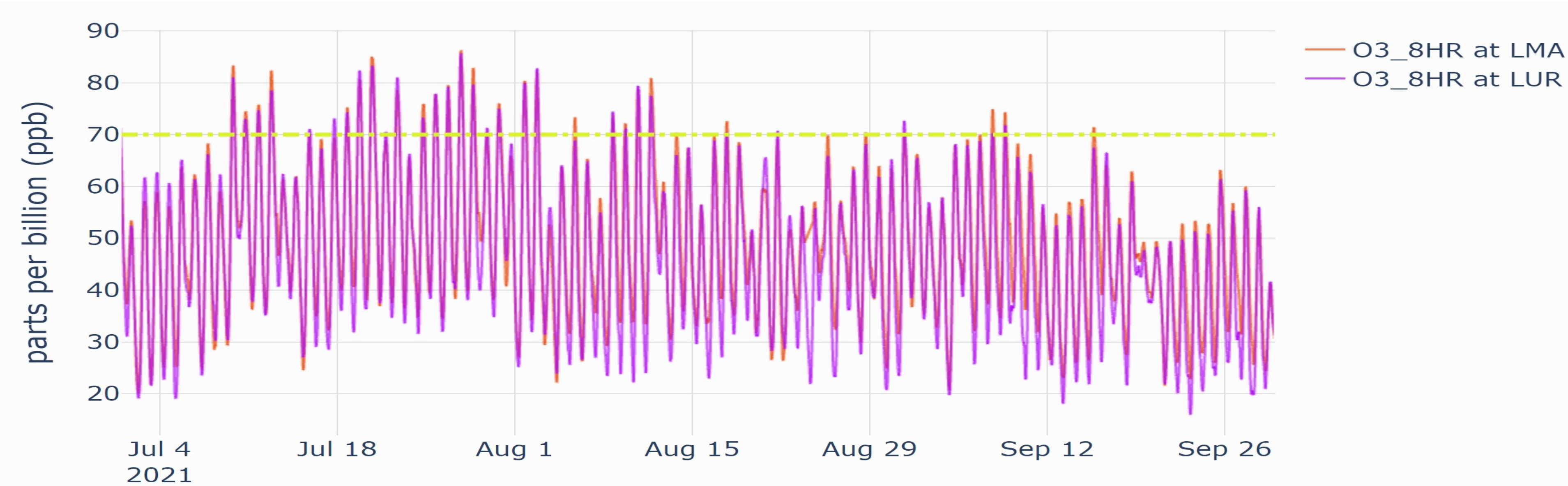


Figure SC9:
LMA & LUR combined 8-hour ozone record Q3, 2021.

Supplement D

CDPHE Audit of the LUR NO2 analyzer, PM analyzer, and the ozone analyzer

Lo-Vol / Continuous PM Analyzer Audit

COLORADO
Air Pollution Control Division
Department of Public Health & Environment

Site	888888888				
Site Name	Union Reservoir-Longmont				
Method	GRIMM EDM Model 180 with naphion dryer - Laser Light Scattering				
Parameter	88101	POC	1	Method Code	195
Auditor	Clyde	Audit Date	10/8/2021	Audit Time	1:37
Serial #					
FTS	YL897				
Cal. Date	1/13/2021	Slope	0.0265	Intercept	0.0190

	Ambient Pressure			Ambient Temperature		
	(mm Hg)	(atm)	(inches Hg)	(Farenheit)	(Celsius)	(Kelvin)
Audit Standard		0.8362	25		24.7	297.9
Sampler		0.8241	25		25.6	298.8

Leack Check Verification ☑ *Upload to AQS?* ☐

Flow Rate Verification

Assessment Number	Audit Set Point (lpm)	Sampler Flow (lpm)	Audit Flow (lpm)	Delta H2O	Temp. (C)	Audit Rel. Error (%)	Design Rel. Error (%)
1	1.20	1.20	1.20	5.530	24.7	0.4%	0.4%

Audit Results

Pressure		**Temperature**		**Audit Flow**		**Design Flow**	
-0.012	PASS	0.9	PASS	0.4%	PASS	0.4%	PASS
+/- 0.013 atm		*+/- 2 degrees C*		*+/- 4%*		*+/- 5%*	

Comments

Boulder Air Union Reservoir site. Operator flow meter measured 1.19 lpm during time of audit.

Ozone Analyzer Audit

COLORADO
Air Pollution Control Division
Department of Public Health & Environment

Site	888888888				
Site Name	Union Reservoir-Longmont				
Monitor	44201				
POC	1	Method Code	53	AQS Units	7 (ppm)
Auditor	Clyde	Initial O3	31.2	Calibrator SN	161
Audit Type	Performance	Time Offline	11:15	Cal. Slope	0.998659
Audit Date	10/8/2021	Final O3	44.9	Cal. Intercept	1.19397E-04
Audit Time	11:00	Time Online	1:16		
Station Temp.	24.2	Audit Temp.	23.7		

Analyzer Information

Serial #	64432-344	Slope	0.998	Intercept	-0.3	Full Scale	500

Do you want to zero correct the analyzer? ☐

Upload to AQS? ☐

Audit Set Point	Conc. Out (ppm)	DAS Value (ppm)	Zero Corr. (ppm)	% Relative Error	Display Value (ppm)	% Relative Error
Pre-Audit Precision and Span Evaluation						
Zero						
Span						
Precision						

Raw Audit Data

	1	2	3	4	5	6	7	8	9	10	Average
Zero											
Standard	-0.0005	0.0005	0.0006	0.0004	0.0003	0.0004	0.0000	0.0000	-0.0001	0.0001	0.0002
Analyzer	0.0011	0.0009	0.0005	0.0007	0.0008	0.0012	0.0011	0.0005	0.0007	0.0007	0.0008
Level 5											
Standard	0.1297	0.1299	0.1299	0.1299	0.1302	0.1306	0.1299	0.1297	0.1300	0.1300	0.1300
Analyzer	0.1264	0.1267	0.1262	0.1265	0.1268	0.1267	0.1269	0.1270	0.1269	0.1270	0.1267
Level 4											
Standard	0.0750	0.0749	0.0751	0.0753	0.0750	0.0747	0.0751	0.0748	0.0749	0.0747	0.0750
Analyzer	0.0733	0.0734	0.0737	0.0735	0.0732	0.0731	0.0729	0.0725	0.0732	0.0731	0.0732
Level 3											
Standard	0.0353	0.0351	0.0351	0.0352	0.0351	0.0350	0.0350	0.0350	0.0345	0.0345	0.0350
Analyzer	0.0342	0.0340	0.0341	0.0346	0.0346	0.0337	0.0336	0.0331	0.0328	0.0335	0.0338
Level 2											
Standard	0.0157	0.0143	0.0145	0.0147	0.0149	0.0154	0.0155	0.0153	0.0154	0.0155	0.0151
Analyzer	0.0147	0.0142	0.0149	0.0154	0.0152	0.0152	0.0152	0.0147	0.0144	0.0143	0.0148
Level 1											
Standard											
Analyzer											

Audit Summary				
Audit Set Point	Conc. Out (ppm)	DAS Value (ppm)	Zero Corr. (ppm)	% Relative Error
Zero	0.0001	0.0008		
Level 5	0.1300	0.1267	0.1267	-2.6%
Level 4	0.0749	0.0732	0.0732	-2.3%
Level 3	0.0349	0.0338	0.0338	-3.1%
Level 2	0.0150	0.0148	0.0148	-1.3%
Level 1				

Audit Results

DAS Results

Zero	PASS
Level 5	PASS
Level 4	PASS
Level 3	PASS
Level 2	PASS
Level 1	

Internal Temp.

Station	PASS
Audit	PASS
Difference	PASS

Regression Results

Slope	0.972101
Intercept	0.000255
R-Squared	0.999961

Comments

Union Reservoir Boulder Air site. Back of the analyzer audit conducted. Analyzer readings taken from display.

Nitrogen Dioxide Analyzer Audit

COLORADO
Air Pollution Control Division
Department of Public Health & Environment

Site	888888888				
Site Name	Union Reservoir - Longmont				
Monitor	42602				
POC	1	Method Code	599	AQS Units	8 (ppb)
Auditor	Clyde	Initial NO2	10	Calibrator SN	76-S
Audit Type	Performance	Time Offline	10:30	Zero Air SN	698
Audit Date	10/8/2021	Final NO2		Station Temp.	24.2
Audit Time	10:30	Time Online	2:45	Audit Temp.	23.7

Analyzer Information

Serial #	149	Slope	1.049	Intercept	-0.1	Full Scale	200

Do you want to zero correct the analyzer? ☐

Upload to AQS? ☐

Pre-Audit Precision and Span Evaluation

Audit Set Point	NO Conc. Out (ppb)	NO Display Value (ppb)	NO Zero Corr. (ppb)	NO % Relative Error	NO2 Display Value (ppb)	NOx Display Value (ppb)	NOx % Relative Error
Zero	0.000	0.064			-0.006	0.059	
Span	160.000	158.800	158.800	-0.7%	-0.100	158.600	-0.9%
Precision							

Audit Calibrator Flow Rates

Audit Set Point	Target (ppb)	Cylinder	Source NO (ppm)	Source NOx (ppm)	Dilution Flow (l/min)	Cal. Flow (l/min)	NO Conc. Out (ppb)	NOx Conc. Out (ppb)	NO Indicated (ppb)
Zero	0.000				4.5000	0.0000	0.000	0.000	0.000
Level 6	250.000	FF22545	10.43	10.53	4.2030	0.1062	257.047	259.511	257.000
Level 5	150.000	FF22545	10.43	10.53	4.2500	0.0630	152.351	153.812	152.000
Level 4	75.000	FF22545	10.43	10.53	5.2660	0.0392	77.067	77.806	77.000
Level 3	15.000	FF22545	10.43	10.53	5.8040	0.0087	15.611	15.760	15.000
Level 2									
Level 1									

Nitric Oxide (NO) Audit Data

Audit Set Point	NO Display Value (ppb)	NO Zero Corr. (ppb)	NO % Relative Error	NO2 Display Value (ppb)	NOx Display Value (ppb)	NOx % Relative Error
Zero	0.001			-0.010	-0.013	
Level 6	250.372	250.372	-2.6%	11.231	261.645	0.8%
Level 5	149.625	149.625	-1.8%	6.476	156.101	1.5%
Level 4	75.863	75.863	-1.6%	2.672	78.476	0.9%
Level 3	14.740	14.740	-5.6%	0.283	15.024	-4.7%
Level 2						
Level 1						

Regression Results

NO

Slope	0.975912
Intercept	0.123897
R-Squared	0.99996

NOx

Slope	1.011020
Intercept	-0.24847
R-Squared	0.999969

NO Results

Zero	PASS
Level 6	PASS
Level 5	PASS
Level 4	PASS
Level 3	PASS
Level 2	
Level 1	

Gas-Phase Titration Data

Audit Set Point	Ozone Conc. Out (ppb)	NO Indicated (ppb)	NO Remaining (ppb)	NOx Indicated (ppb)	NOx Remaining (ppb)	NO2 Indicated (ppb)	NO2 Actual (ppb)
Level 6	170.000	83.860	85.803	266.790	264.128	182.930	173.236
Level 5	70.000	83.759	85.699	157.975	156.499	74.216	68.946
Level 4	15.000	61.732	63.129	78.482	77.872	16.750	14.738
Level 3	4.000	11.106	11.253	15.125	15.206	4.019	3.853
Level 2							
Level 1							

NO2 Relative Error

Level 6	5.6%
Level 5	7.6%
Level 4	13.7%
Level 3	4.3%
Level 2	
Level 1	

NO Conv. Efficiency

Level 6	97.1%
Level 5	97.4%
Level 4	100.0%
Level 3	97.5%
Level 2	
Level 1	

Internal Temp.

Station	PASS
Audit	PASS
Difference	PASS

Regression Results

Slope	1.053092
Intercept	0.824484
R-Squared	0.999918

Comments

Back of the analyzer audit done. DAS readings taken from display of analyzer. Boulder Air, City of Longmont Union Reservoir site.